018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Proposal of Solutions for the Decontamination and Recuperation of Water Resources in the Municipality of Cali (Cases study)

Due date of deliverable: January 31, 2011
Actual submission date: January 31, 2011

Start date of project: 1 February 2006 Duration: 60 months

Universidad del Valle

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	X
CO	Confidential, only for members of the consortium (including the Commission Services)	

Sustainable Water Improves Tomorrow's Cities' Health - SWITCH Project

Proposal of Solution for the Decontamination and Recuperation of Water Resources in the Municipality of Cali (Cases study)

Cali, January 2011

This document has been done by CINARA - Instituto de Investigación y Desarrollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico of Universidad del Valle in the framework of the "Sustainable Water Improves Tomorrow's Cities' Health" SWITCH project. This report has been done with the support of UNESCO-IHE and the institutions involved with the management of water resources, sanitation and environmental authorities at national, regional and local level.

The following people from Cinara Institute / Universidad del Valle took part in the development of this report

Alberto Galvis,	Sanitary Engineer MSc, SWITCH Project coordinator in Universidad del Valle
Melissa Herrera,	Sanitary Engineer, MSc
Kim Andersson,	Environmental Engineer, MSc
Carlos Martínez,	Civil Engineer MSc
Johnny Rojas,	Economist MSc.
Diana A. Zambrano,	Sanitary Engineer, MSc Student
Edda Cifuentes,	Topographical Engineer, MSc Student
María F. Jaramillo,	Agriculture Engineer, MSc Student
Luisa Fernanda Calderon,	Sanitary Engineer
Yelitza Angélica Zorrilla,	Sanitary Engineer
Efrain Jimenez,	Student of Sanitary Engineering
Ricardo L. Martínez,	Student of Chemical Engineering
Cristina Echeverry	Student of Social Comunication

Also, our acknowledgments to the institutions and persons that are participating in the Learning Alliances of Cali as Demo city.

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AHP	:	Analytic Hierarchy Process
ASOCARS	:	Asociación Colombiana Autoridades Ambientales – Colombian Association of Environmental autorities
BOD	:	Biological Oxygen Demand
CEDETES	:	Centro para el Desarrollo y Evaluación de Tecnologías en Salud Pública – Center for Development and Evaluation of Public Heath Technologies
CENICAÑA	:	Centro de Investigación de la Caña de Azúcar de Colombia – Research Center of Sugar Cane Crop
CINARA	:	Instituto de Investigación y Desarrollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico - Institute for the Research of Water Supply, Sanitation and Water Resource Conservation
COD	:	Chemical Oxygen Demand
CONPES	:	Consejo Nacional de Política Económica y Social – National Council of Social and Economic Policies
COP	:	Peso Colombiano – Colombian money
CRPML	:	Centro Regional de Producción Más Limplia – Regional Center of Cleaner Production
CVC	:	Corporación Autónoma Regional del Valle del Cauca – Regional Environmental Authority of Valle de Cauca department
DAGMA	:	Departamento Administrativo de Gestión del Medio Ambiente - Administrative Department for Environmental Management
DANE	:	Departamento Administrativo Nacional de Estadística - National Statistics Department
DAPM	:	Departamento Administrativo de Planeación Municipal – Municipal Administrative Planning Department
DNP	:	Dirección Nacional de Planeación – National Planning Department
DO	:	Dissolved Oxygen
DW	:	Drinking Water
EMCALI E.S.P	:	Empresas Municipales de Cali - Cali´s Municipal Company Service for drinking water and wastewater management
EMSIRVA E.S.P	:	Empresa de Servicio Público de Aseo de Cali - Cali´s Municipal Solid Waste Management
EPANET	:	Software that Models Water Distribution Piping Systems
FAO	:	Food and Agriculture Organization of the United Nations
FDE	:	Florida Defenders of the Environment
GBA	:	Global Business Alliance
GGE	:	Greenhouse Gas Emission
GRA	:	Grey Relational Analysis
GW	:	Grey Water
HIDROCCIDENTE	:	Ingeniería de Consulta, Interventoría, Asesoría y Construcción - Consulting Engineering Company, Inspection, and Construction Consulting
HIPERAGUAS	:	Ingeniera en el diseño de la sectorízacion de la red de acueducto y alcantarillado implementación de modelo -

		Engineering companies in the design of the sectorization of the water and sewage network deployment model
ICM	:	Integrated Catchments Management
INGESAM	:	Ingeniería de Saneamiento Ambiental – Sanitation Engineering Consulting
IWRM	:	Integrated Water Resources Management
LA	:	Learning Alliances
MAVDT	:	Ministerio de Ambiente, Vivienda y Desarrollo Territorial - Ministry of the Environment, Housing and Territorial Development
MBR	:	Membrane Bioreactor
MCRT	:	Mean Cell Residence Time
NITOGOI	:	Consortium EMCALI
NPS	:	Non-point Source
NPV	:	Relation of Net Present Value
O&M	:	Operation & Maintenance
POT	:	Plan de Ordenamiento Territorial – Territorial Ordinance Plan
PSMV	:	Plan de Saneamiento y Manejo de Vertimientos - Plan for Sanitation and Management of Wastewater Discharges
RAS	:	Collection system for wastewater
RBC	:	Rotating Biological Contractors
RH	:	Rainwater Harvesting
SBR	:	Sequencing Batch Reactor
SSPM	:	Municipla Public Health Secretariat
SDS	:	South Drainage System
SUDS	:	Sustainable Urban Drainage Systems
TSS	:	Total Suspended Solids
UAESPNN	:	Colombian National Natural Parks Special administration Unit
UASB	:	Upflow Anaerobic Sludge Blanket
UDDT	:	Urine Diverting Dry Toilet
UMATA	:	Unidad Municipal de Asistencia Técnica Agropecuaria – Municipal Unit for Technical Agricultural Attention
UNESCO - IHE	:	Institute for Water Education
USDA	:	United States Department of Agriculture
US EPA	:	United Stares Department of Environmental Protection Agency
UWM	:	Urban Water Management
WC	:	Water Closet
WHO	:	World Health Organization
WSSCC	:	Water Supply and Sanitation Collaborative Council
WUT	:	Water Use Tax
WWTP	:	Wastewater Treatment Plant

1 INTRODUCTION

Traditionally, cities around the world has solved the water problems through conventional systems such as centralized drinking water systems; collective sewers, stormwater drainage systems based in pipes or lined channels, and centralized wastewater treatment plants. However, these solutions in many cases have not been sustainable, on the contrary, the environment, especially water resources, has been affected in terms of quality and quantity, and the flooding has increased. The concept of "sustainable cities" is an international movement whose major objective is the construction of cities greener and healthier places for their habitants through the paradigm shift of urban water management; in this way, the efforts are focused to pollution prevention, attacking the water problems at the source through waste minimisation or elimination, the use of natural systems for wastewater treatment, and the cleaner production in the industry, and the implementation of sustainable urban drainage systems (SUDS), among others.

Cali municipality have many problems related with water management. The solutions implemented by institutions in their majority have been conventional. Although there have been interventions, the water problems has worse. On this way, may be is necessary starting to propose other type solutions, solutions with paradigm shift.

The SWITCH project considers the paradigm shift of water management in urban areas, including topics related to: urban drainage, water supply, multiple uses of water, rational usage of water, sanitation, domestic, and industrial wastewater management, urban cycle of water, planning, governability, and institutional aspects. Therefore, SWITCH project is considered for Cali municipality as an important opportunity for to research of solutions with paradigm shift focused in pollution control or wastewater management.

Universidad del Valle has been a member of the SWITCH project since February, 2006, with the support of the European Union, and managed by UNESCO-IHE. The process of strategic planning started in 2007 with data collection from different institutions, the conformation of the Learning Alliances, the project socialization, and problem identification associated to water resources through workshops. In 2009, the Learning Alliances were consolidated and the work was focused in the conceptualization of strategic planning, the development of a shared vision, construction of scenarios, and elaboration of strategic lines for Cali municipality in terms of pollution by wastewater. These strategic lines were developed for three study areas: 1) Cañaveralejo wastewater treatment plant (WWTP-C) drainage system, 2) South Expansion Area, and 3) South Drainage System (SDS).

This document is the last for the work package 5.3, where the proposals are consolidated, are presented with major level of detail, and a comparison of conventional solution versus solution with SWITCH approach is carried out in study cases. The present report includes an introduction (Chapter 1), a study area description that corresponds to Cali municipality and their water management problems (Chapter 2 and 3), a conceptual framework (Chapter 4), a methodology of proposals for each case study, selection of solution, and an economical comparison method. Subsequently, the proposals for pollution control in WWTP-C drainage system and Cali River basin are presented in Chapter 6, in Chapter 7 is shows strategies for pollution control in south expansion area, and for last, the strategies for decontamination of water resources in south drainage system is presented in Chapter 8

2 STUDY AREA DESCRIPTION

The City of Cali is the capital of the Valle del Cauca Department. It is located to the south-west part of Colombia between the Central mountain range and the Pacific Ocean; this location is near to the Port of Buenaventura which is the main commercial port in the Country. Cali is the third most important City of Colombia, with 560,3 km^2 of municipal area Figure 2.1.

Figure 2.1 Location of the Cali City

Cali covers an area of 56.025 ha, of which 43.889 are rural and 12.125 in urban areas which are located between 4.200 and 955 above sea level (m). The rural sector of Cali is formed by 15 villages, out of which 13 are located in the foothills and two in the flat land. These villages are: La Buitrera, El Saladito, La Elvira, Pance, La Paz, La castilla, Villacarmelo, Montebello, Navarro, Los Andes, Golondrinas, El Hormiguero, Pichindé, Felidia and La Leonera (Figure 2.2).

Cali's urban area has an extension of approximately 121 km^2. The areas of potential future development are located in south-eastern part of Cali: Cali – Jamundi expansion zone and special expansion area Navarro. In this sense, the city of Cali is composed by two areas; 1) consolidated area which is the existing urban area until year 2007 and consists of 22 "comunas" or districts, and 2) the future development area that is located to the south-east of the city and consists of two areas previously mentioned: Navarro and Cali-Jamundi sectors.

According to the National Statistics Department – DANE (DANE, 2005), the municipality of Cali has a total estimated population of 2.075.380 inhabitants, from which 979.530 are male and 1.095.850 are female. With this data, Cali is in terms of population the third largest city in Colombia after Bogotá and Medellin. In 2005, 85% of Cali citizens were located in income levels 1, 2 and 3. Income level is a way of economically classifying the sectors in the country. Hence, income levels 1 and 2 correspond to the most economical stressed groups, and 3, 4, 5 and 6 correspond to the economical middle class to the upper class economic groups.

Figure 2.2 Map of the Municipality Cali
Source: (EMCALI *et al.*, 2006b)

There are a wide range of temperatures between 10 and 24 °C, the regime of precipitation distribution presents two wet periods that correspond to the months of March-April-May and October-November-December and two dry periods for the months of January to February and June-July-August-September. The precipitation of the city varies between 1.300 mm/year in the south and 1.000 mm/year in the north, increasing in the southwest. In the mountainous rainfall varies between 1.300 and 3.000 mm/year. The average monthly relative humidity is introduced throughout the year with a distribution values higher in the months of May and November and lower in the months of January-February and July-August. The extreme of humidity is between 45 and 98% and an annual average of 65% at the station San Luis North and 73% in station Univalle South. In the municipality of Cali there are four climates based on air temperature and the spatial distribution of precipitation, which are: hot and moderated dry weather, middle humid weather, cold and moderated humid weather and humid cold weather.

Cali has a strategic geographic location which has contributed to the economic development of the city and has turned it into the region´s core in different aspects. As the administrative and service centre it has an action radius that covers the departments of Valle del Cauca, Southern Choco, Cauca and Nariño. According to the economic census held in Cali in 2005,

there are 51.641 economic units (DANE, 2005), out of which 60,4% correspond to the commercial sector, 30,1% to the services sector and 9,5% to the industry(Proexport Cali *et al.*, 2005). Despite to the fact that the commercial sector represents the main economic activity in the municipality with 60,4%, this economic sector represent around 36,4% of the employment rate. According to the economic census, the delivery of services is the main source of employment with 47% of the employment rate.

The city of Cali has seven rivers (see Figure 2.3) that form the landscape and hydrologic potential of the municipality, among these is the Cauca River (along the right side of the city) and the rivers: Pance, Meléndez, Lili, Cañaveralejo, Cali y Aguacatal which travel through the city and finally discharge to the Cauca River. The network drainage of the seven rivers has an overall of 757,56 km (DAPM *et al.*, 2000). The hydrographic network of the municipality extends predominantly in direction West – East, with the exception of the Cauca River that has a direction South-North. Around 92% of the river basin' areas are located at 1.200 m above sea level in the highest part of the municipality. This network offers the possibility of using its water for several uses by gravity or pumping operations. The Cauca River supplies about 76% of the population of Cali, through the production of the drinking water plants of Puerto Mallarino and the Cauca River (Cinara *et al.*, 2008b).

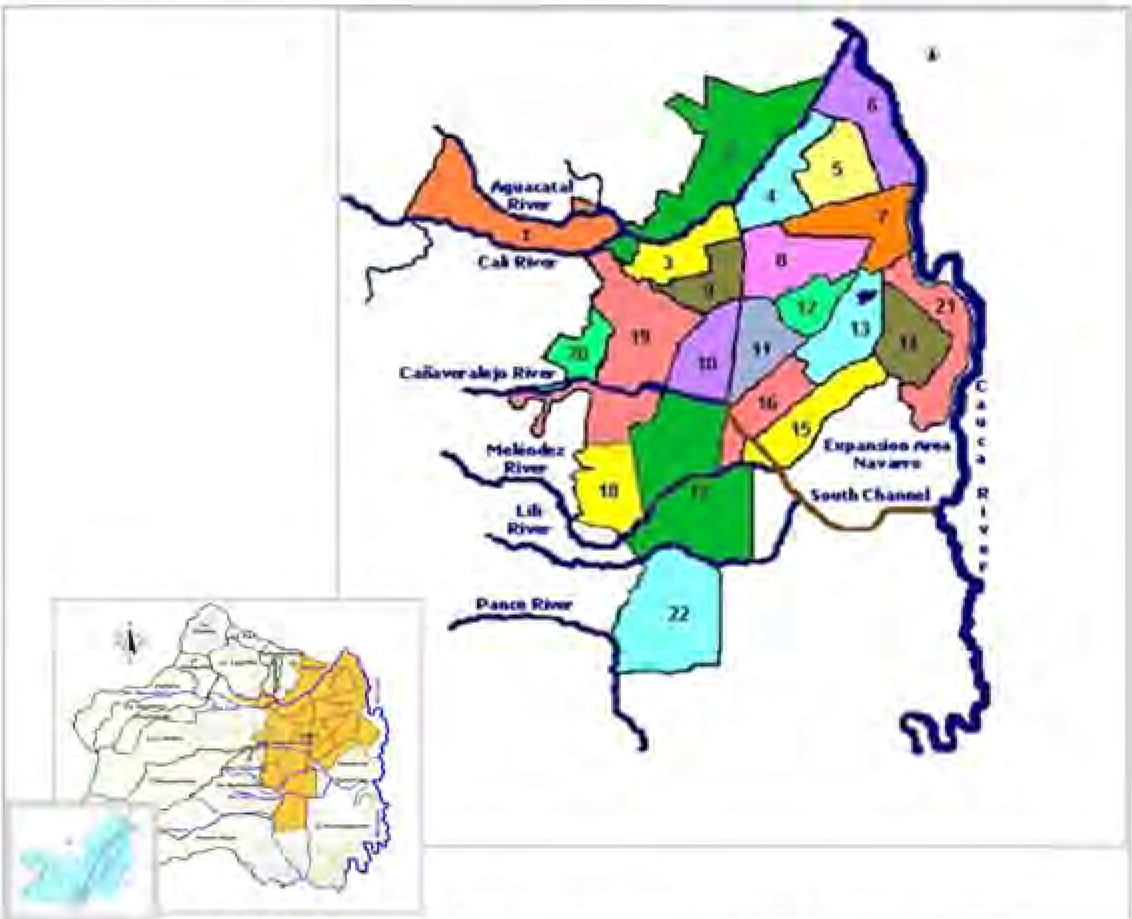


Figure 2.3 Urban area of the municipality of Cali and its seven rivers
Source: (DAGMA *et al.*, 2007)

The urban rivers are used with different purposes: water supply for human consumption, hydroelectric generation, industry, agriculture, recreation, extraction, of materials, landscaping, irrigation for aesthetic purposes, clothes washing (Aguatacal River) and is also

used as a source and receiving of solid waste dumping of industrial and domestic wastewater which has caused the deterioration of water quality. The groundwater constitutes an important resource that contributes considerably to supply the seasonal and spatial water deficit in the Valle del Cauca Department and specifically in Cali, becoming an alternative source of water supply for the municipality.

The quality of the groundwater in the municipality of Cali is classified in general terms as good, being the best in the sector of Pance (in the physical – chemical aspect). In the microbiological aspect there is located pollution in the sub river basin of Pance and Cauca River, as result of the septic tanks's infiltration by lack of sewage systems (DAGMA *et al.*, 2005). The municipality wetlands are located in the rural and urban zones. Many of the wetlands are located in private terrains with high deterioration levels. The urban area of the municipality of Cali has the following wetlands: El pondaje, Charco Azul, Panamericano, Los Cisnes and Las Garzas (see Figure 2.4). The rural area the main wetlands are: Mojica, Las Vegas, old riverbeds of the Lili, Cascajal and Meléndez Rivers, Pacheco, Ibis, Caño del Estero, Madrevieja, Cauca Seco, Marañón, Pascual and La Pailita. In general, the wetlands environmental problems are similar and originated by the impact caused by human beings. This is represented by sub-normal settlements, inadequate wastewater and solid waste management, among others.

Figure 2.4 Natural wetlands located in Cali Municipality

EMCALI is the company responsible for the delivery of water supply, sewage and energy services in the municipality of Cali. The current drinking water coverage in Cali is 97% according to the technical planning department of (EMCALI, 2007). The drinking water distribution system is supplied by five drinking water plants. Puerto Mallarino plant uses

Cauca River as its water source, treats and supplies around 76% of the drinking water demand in the City. This source has been suffering a continue water deterioration mainly due to deforestation, to presence of slums located in the protection area and to the discharge of wastewater. The two important sources of contamination upstream the water intake of Puerto Mallarino Plant are the discharge of South Drainage System (SDS), and the Navarro landfill. The mayor part of the Navarro landfill is unlined and consequently there is an uncontrolled leakage of landfill leachate towards the south channel and surounding water bodies (Cinara *et al.*, 2008b).

The company responsible for the collection, transport and disposal of the solid waste produced in the municipality of Cali was EMSIRVA, which was responsible for the collection, transport, and disposal of solid waste, it is in a process of liquidation, hence private companies are now also being contracted to complement the collection service. Navarro, the principal municipal dumpsite located in Cali was closed in 2008, and consequently about 1.484 ton/day of the waste produced in the city is currently being transported to the Yotoco landfill, which is situated 56 km north of Cali (Cámara de Comercio de Cali *et al.*, 2008).

Navarro was not considered a proper landfill by the environmental authorities - CVC, since the majority of its extension lacked protection measures for the handling of generated gases and leachate, which has generated a precarious environmental situation in the surroundings with contaminated discharges to water bodies and emissions of gases. Today, Navarro has been sealed with an impervious layer and is revegetated; however, the management of the produced leachate has still not been solved. The collected leachate is temporarily stored in ponds, awaiting the implementation of a treatment system. At the moment a proposal for leachate treatment has been elaborated and is under evaluation by the CVC before its approval.

3 DESCRIPTION OF THE PROBLEM

A general description of the problematic is related with pollution control for Cali municipality will be presented in this chapter. The details will be presented in chapters 5, 6 and 7, for each study area considered. It begins with the Cauca River. This water resource provides different socio-economic activities for the region being the main water source in south-western Colombia. Its geographic valley has a population of approximately 3.5 million and is base of the majority of the Colombian sugar and paper industries. The deterioration of the quality of this source is threatening safe water supply to the population, with the risk reaching acute and chronic levels beyond the capacity of the Cauca River and Puerto Mallarino treatment plants.

The level of contamination of the Cauca River is reflected in the oxygen curve recorded at the water intake point of the Puerto Mallarino, where DO levels reach values lower than 2 mg/L, when this point is reached, Emcali suspends raw water intake. The low DO levels caused operational shutdowns at the Puerto Mallarino plant for periods of approximately three hours. Additional to the problems caused by operational shutdowns due to contamination of the Cauca River, potential risk of contamination in the water has also been found, due to high concentrations of phenol compounds, some metals and organic matter, which cause by-product formations as a result of the disinfection process of the water treatment. The suspension of Puerto Mallarino operation by high quantities of pollution load is a critical aspect caused by discharge of the SDS during rainy periods, generating a high pollutant load in a short period of time, affecting the quality of raw water to be treated.

There has been a need for identifying the key water management problems in Cali municipality in terms of components: technological, social, environmental, economic and institutional framework.

The *technological* component includes the technological infrastructure used for water management, and solid waste management, it includes the management of solid waste because the inadequate disposition of the sewage system, channels, and public green areas have a considerable impact in the operation of the drainage system. Additionally, the supply system is also included since there is a close relationship between the consumption of drinking water and the production of wastewater. In relation with the expansion area, does not have the necessary infrastructure for the management of water and solid waste. The SDS is mainly a system for the management of natural surface water and a significant amount of wastewater enters the drainage system due to deficiencies in the system and illegal connections. According to (EMCALI, 2007), it reaches a percentage of wastewater of approximately 57%. The wastewater management system (Southern Sewage) covers 96,6% excluding the human settlements with incomplete development, which generally do not have centralized solutions and therefore, wastewater is directly discharged into rivers, creeks or channels, without receiving previous treatment.

Problems in sanitation management are recurrent due to the lack of an integrated system for management that type of waste and the increasing number of illegal waste disposition sites. Improper solid waste and sanitation disposition into the channels and pipelines is also a recurrent problem that affects the quality, continuity and coverage of the sanitation service, as well as citizenship cultural aspects. In the south Drainage system there are 25 illegal disposition sites of domestic solid waste and 21 of construction waste.

The Navarro landfill is located in the district of Navarro, close to the south channel. During approximately 40 years it received solid waste, until it was closed in 2008. The first 30 years of its existence it worked as an open landfill without protection or measures to mitigate impact, while the newer sections were built with waterproofing and system to capture leachate and stormwater. The leachate is collected in storage lagoons, but there currently is not a system to treat them. Samples have confirmed that Navarro´s sanitary landfill has discharges that contaminate the surrounding water bodies, both in regards to surface water and groundwater. Presently, the solid waste is being disposed in the sanitary landfill of Yotoco.

As mentioned above, one of the main problems of the system of Puerto Mallarino´s treatment plant is related to the high number of service suspensions per year due to turbidity increase and contamination loads that are not able to be treated by the system. In order to solve these problems, a reservoir was built with the objective of supplying the drinking water treatment plant of Puerto Mallarino when the Cauca River has high turbidity.

The *social* component is formed by all citizens located in the SDS, the future expansion area community and people supplied by the Cauca River, the settlements with incomplete development, the inhabitants settled at the river banks, protection zones of regulation systems and the hillside. The social component has a big impact about water resources in terms of uses. The drinking water consumption of the people determinates the amount of raw water extracted from rivers affecting their quantity, and also determinates the wastewater production that is discharged about rivers affecting their quality.

The *environmental* subsystem includes the surface and underground water sources, river protection areas, urban green zones, wetlands, forests and natural grasses existing in the study zone. The superficial water resources in the influence area of SUDS are Lili, Meléndez, Cañaveralejo and Cauca rivers, which receive the discharge of south channel and it is affected too by the domestic and industrial discharges upstream of the water intake of Puerto Mallarino plant in Cali. The rivers quality condition is not the best since water is contaminated with domestic and industrial waste that are discharged into rivers during their passage through invasions in the protection zones in settlements with incomplete development in rural and urban areas.This limits the use of water flows for human consumption and requires extremely expensive water treatment systems (Universidad del Valle - Cinara, 2008). The expansion area has the greatest amount of non-intervened wetlands. According to water conditions of commune 22, the commune has a wetland system that is the habitat of uncountable fauna and flora species that due to the areas urban development process are fundamental for the creation and structuring of public spaces.

Three aquifers are identified in the study area: Pance, Cali and Cauca. The aquifer recharging zones are related to the dejection zones of the Cali, Cañaveralejo, Meléndez and Pance rivers. Each of these aquifers has contamination problems. Pance´s aquifer is contaminated by the septic tanks that have operating and maintenance problems and infiltration fields. The Cauca aquifer is contaminated by leachates from the Navarro landfill, subnormal settlements located on the Cauca river banks, leaks of wastewater due to pipes in poor condition, and the recharge made with the Cauca river´s water (Gobernación del Valle del Cauca, 2008).

The green zones and parks of the urban zone have an area of 1000 ha, including 80 km of channels with protection zones. However, there is a development process in which the urbanization becomes denser, affecting the vegetation coverage. The decrease in vegetation areas represents a decrease in the natural capacity to retain stormwater, which results in higher

runoff peaks and flooding risk (Universidad del Valle *et al.*, 2007). Critical sites have been identified in the urban area and the river basin, where there are settlements in the protection zones that damage the quality and ecology of the rivers.

The main *economic* activities that are described due to their impact on water resources are the industry, commercial entities and the mining and agricultural sectors. The main use of soil in the southern zone is residential development. As part of the urbanization and settlement of commercial areas in the populated centers, the presence of gas stations, laundries and car washes are considered as generators of drinking water demands and contributors of wastewater with characteristics different from those of the domestic wastewater. The coal mines are located in the Lili, Melendez, Cañaveralejo river basins. The mining sector discharges are characterized by dissolved solids. The coal mines also generate acidity, sulphates and metals such as iron, manganese and aluminium (DAGMA *et al.*, 2007).

The *institutional framework* includes the institutions that intervene in the study zone, the standards that rule in the sector and the territory management through territorial planning. Although each institution has its own roles, functions and different jurisdiction areas, there are meeting points where they interact, and the work done by one has impact on the other.

The main institutions intervening in the zone are DAPM, EMCALI, DAGMA and the property developers, mainly in the expansion area. These institutions interact directly among themselves in the city´s wastewater management, and its relationship results from the public services provision (EMCALI), the urban environmental management (DAGMA) and DAPM, as the planning entity. However, two organizations must be included, CVC and the Colombian National Natural Parks Special Administration Unit (UAESPNN for its acronym in Spanish) in order to apply an integrate river basin management perspective, recognizing the upper and middle zone of the urban perimeter.

4 CONCEPTUAL FRAMEWORK

4.1 PARADIGM SHIFT IN WATER MANAGEMENT IN URBAN AREAS

The paradigm shift represents a change in a set of scientific accomplishments that are "universally acknowledged", which during a certain time provided problem and solution models for the community. A change in paradigm generally implies a deep change of mentality regarding the time and values that form a specific vision of the reality, where the variable is the speed and depth of the change.

Knowledge and technological advance have generated new proposals for water resource management in order to respond to environmental problems currently encountered. This progress promotes overturning the previous planning and water management paradigm to implement one in which human wellbeing and development is combined in a balanced manner with the environment.

The approach towards Urban Water Management (UWM) of the city of tomorrow will be based on sustainability in all its depth. Table 4.1 compares various aspects of water management in the city of today with that in the city of tomorrow and where it should be oriented towards the paradigm shift.

Table 4.1 Comparison of water management of the city of today with the city of tomorrow

ASPECT	CITY OF TODAY	CITY OF TOMORROW
UWM organisation		
Organisational structure	Separate entities for different types of water, Covering entire urban area	One entity for 'water' covering entire urban area City subdivided in water management units (WMU) with high level of responsibility Water is a tradable good between units
Units	Depending on preference of water entities	Determined by possibilities to manage water within a unit
Philosophy	Various types of water have no relationship	Various types of water are part of the same cycle and serve various purposes at different times
Drinking water		
Quality	One quality for all uses	One quality for drinking, a second quality for other uses
Distribution	Underground piping system, vendors	Drinking water through shops, second quality through piping system
Origin	From wherever available	From nearby
Wastewater		
Quality	Any quality wastewater is accepted	Only 'clean' wastewater is accepted, dischargers responsible for quality of wastewater submitted
Collection	Collection from domestic and industrial origin to point of discharge or (central) treatment	Collection of 'clean' wastewaterwithin the WMU to point of further processing Specific waste flows kept separate
Treatment	Predominantly of the activated sludge type	Further processing determined by the reuse/recovery options and the specific use of the water within the WMU Indirect reuse is objective
Discharge	Into nearest surface water	Depending on possibilities within WMU, *e.g.*: irrigation, groundwater recharge, surface water discharge
RAINWATER		
Approach	Removal as quick as possible so as not to have flooding problems	Make best possible use of this resource
Processing	Removal into sewer	Collection, temporary storage, followed by some type of treatment
Usage	None	Various options, *e.g.*: street cleaning, green areas, ground water recharge, or drinking/process water

Source: (Siebel *et al.*, 2002)

The conventional water cycle requires a re-design that includes actual inefficiencies such as the use of high quality drinking water in large amounts for domestic use, human faeces transportation, loss of chemical substances, among others. Even though the systems used 100 years ago faced the same inefficiencies, presently rapid population growth and higher water demand per capita, as well as higher industrial consumption and pollution load have caused these systems to not be able to naturally compensate the impacts, resulting in severe ecological damages (UNESCO-IHE *et al.*, 2007).

4.2 POINT AND NON-POINT SOURCE POLLUTION

Point sources of pollution were defined originally as pollution that enters the transport routes at discrete, identifiable locations and can usually be measured.Major point sources under this definition included the discharges of sewer systems and industrial wastewater sources.The sources of pollution are (Novotny, 2003):

- Municipal and industrial wastewater effluents.
- Storm sewer outfalls from larger urban centers.
- Combined sewer overflows.
- Bypasses of untreated sewage form sanitary sewers and treatment plants.
- Other sources, such as discharges from vessels, damaged storage tanks, and storage piles of chemicals.

Non-point source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water (US EPA, 1994). Diffuse pollution takes many forms and affects both surface water and groundwater.Can be also originate from a variety of activities from land use over a large area, for example agriculture, settlements, transport, and industry (UK Environment Agency, 2006). Some non-point sources are (Novotny, 2003):

- Agricultural runoff.
- Urban runoff from small communities with storm sewers.
- Urban runoff from unsewered settlement areas.
- Wet and dry atmospheric deposition over a water surface (including acid rainfall).
- Flow from mines (surface and underground).
- Runoff and snowmelt from roads and highways outside urban areas.

4.3 THREE STEP STRATEGIC APPROACH

4.3.1 General concept

This concept is based on the application of Cleaner Urban Water Management principles (Siebel *et al.*, 2002).

- Principle 1: Use a minimum input of resources per unit or product.
- Principle 2: Do not use input material of a higher quality than strictly necessary.
- Principle 3: Do not mix different waste flows.

- Principle 4: Evaluate other functions of by-products before considering treatment anddisposal.

This approach strongly focuses on sewage management, but also considers water supply, nutrient uses and other material flows associated with the urban water cycle. The three steps include: 1) prevention, 2) treatment for reuse, and 3) planned discharge with stimulation of self-purification capacity. The steps should be implemented in chronological order, and possible interventions under each step should be fully exhausted before moving on to the next step. This strategic approach is summarised in Figure 4.1 (Nhapi *et al.*, 2005).

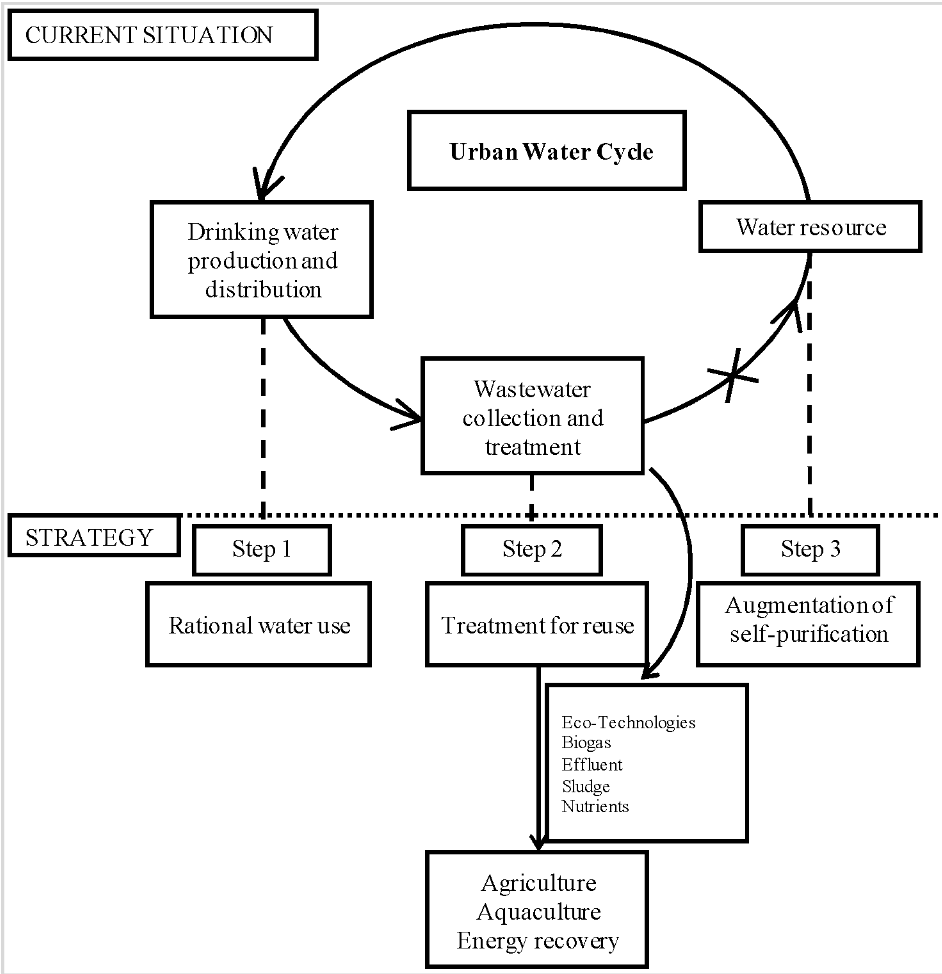


Figure 4.1 Schematic representation of the 3-Step Strategic Approach to wastewater management

Source: (Nhapi *et al.*, 2005)

4.3.2 Rational water use

Rational or efficient water use can have major environmental, public health, and economic benefits by helping to improve water quality, maintain aquatic ecosystems, and protect drinking water resources. Efficient water use, through behavioural, operational, or equipment changes, if practiced broadly can help mitigate the effects of drought.

The most important goal for this new paradigm is to reintegrate the water used and maintaining an ecological balance and environmental health. As to water use, efforts to reach the productive use of water have to be re-focused. In this sense, two approaches are required:

1) increasing the efficiency in satisfying real needs, and 2) improving water distribution efficiency according to its different uses (Gleick, 2000).

The efficient use actions have been supported by technological development, such as the appearance in the market of low consumption devices and strategies such as grey water recirculation and the use of rain water (Figure 4.2).

Grey water use Rain water uses

Figure 4.2 Efficient water use in the household

At the household level, it is possible to perform resource conservation with low consumption technologies in taps, toilettes, and washing machines. Some of these technologies may be adapted to existing old equipment (aerators, tank discharge interrupter switches, automatic flow reducers, anti-return valves, etc.).

All household wastewater, except toilet waste, is called greywater. This includes water from showering, bathing, and washing dishes and clothes. The greywater reuse offer a big potential water use reduction in household such as: 18% replacement of the current domestic demand if greywater is used just for garden watering, 13,5% water savings if grey water is used for toilet flushing only, an 30% savings if greywater is used for garden irrigation and flushing toilet (Christova-Boal, 1995). In ecological sanitation, greywater is source separated from toilet systems, allowing for simpler treatment systems than conventional wastewater treatment plants (Ridderstolpe, 2004).

Rain water is a component of the hydrologic cycle that feeds the surface, sub-surface and ground water run-off. Rainwater harvesting (RWH) have been studied in many countries as a way of promoting potable water savings in buildings (Ghisi *et al.*, 2007). Depending on precipitation intensity, rainwater constitutes a potential source of water for household (Helmreich *et al.*, 2009). Rainwater harvesting is a technology where surface runoff is collected during rain periods for be used with a primary treatment in laundry, garden irrigation, cleaning and flushing toilet; with a secondary treatment also can be used as water supply for households.

4.3.3 Treat for reuse

Municipal wastewater contains valuable resources and therefore it is irrational to treat it the conventional way with subsequent river discharge. Its components of water, organic matter

(energy), and nutrients should be reused. In many arid and semi-arid countries, wastewater is becoming increasingly important sourceof irrigation water. The demands of growing urban communities for both food and water requirethe agricultural sector not only to increase food production but also to reduce its use of naturalwater resources.At the same time the volume of sewage effluent is increasing, and safe disposalcan be difficult. The use of reclaimed wastewater for irrigation is the obvious solution.

In household level, systems such as greywater separation offer opportunities for direct reuse of wastewater at the point of generation for purposes such as car washing, toilet flushing, and on-plot irrigation. In some cases, urine could also be separated and reused directly (Larsen and Gujer, 1996 as cited in (Nhapi *et al.*, 2005))

4.3.4 Dispose and stimulate natural self-purification

All options under Step 1 and Step 2 should be exhausted before resorting to Step 3. In some cases the application of above steps might still leave some residual wastes and effluents and the last option remaining is discharge, usually into surface waters (river, lake, coastal sea). The conventional approach is to connect the effluent pipe to the nearest water resource via the shortest route. We seem, therefore, to rely fully on the self purification capacities of receiving water bodies. However, often this capacity is exceeded substantially, rendering water bodies anaerobic, eutrophic or with high concentrations of toxic compounds. Under the 3-Step Strategic Approach proposed here, we suggest to consider options to boost the natural purification capacity of receiving water bodies. This could for instance be achieved by allowing rivers to flow outside their often times artificial embankments.

4.4 ENVIRONMENTAL APPROACHES FOR POLLUTION CONTROL

4.4.1 Household-Centered Environmental Sanitation (HCES) approach

HCES approach was conceived by the Environmental Sanitation Working Group of the Water Supply and Sanitation Collaborative Council (WSSCC) at workshop in Switzerland in 1999. The HCES approach is a radical departure from past central planning approaches as it places the household and its neighbourhood at the core of the planning process (Figure 4.3). The approach responds directly to needs and demands of the users but attempts to avoid problems resulting from purely “bottom-up” or “top-down” approaches. It offers the promise of overcoming the shortcomings of unsustainable planning and resource management practices of conventional approaches. A new approach has been developed for people in developing countries: the “Household-Centre Environmental Sanitation (HCES) Approach”, which is aim towards a new paradigm in the water management (Morel *et al.*, 2003).

The basic principle is that interventions should start by controlling consumption. Reduction in wastewater generation is therefore necessary in view of the importance of conserving resources, investments and energy. This can be achieved via reduction of domestic water consumption, which will reduce sewage volume and treatment costs. On the far end of the scale we find dry sanitation, but significant reductions can also be achieved via demand management and water saving technologies in the household (water saving flush toilets, water efficient shower caps and taps, efficient dishwashers, laundry machines etc.). In addition demand management schemes should be aimed at educating families in efficient water use.

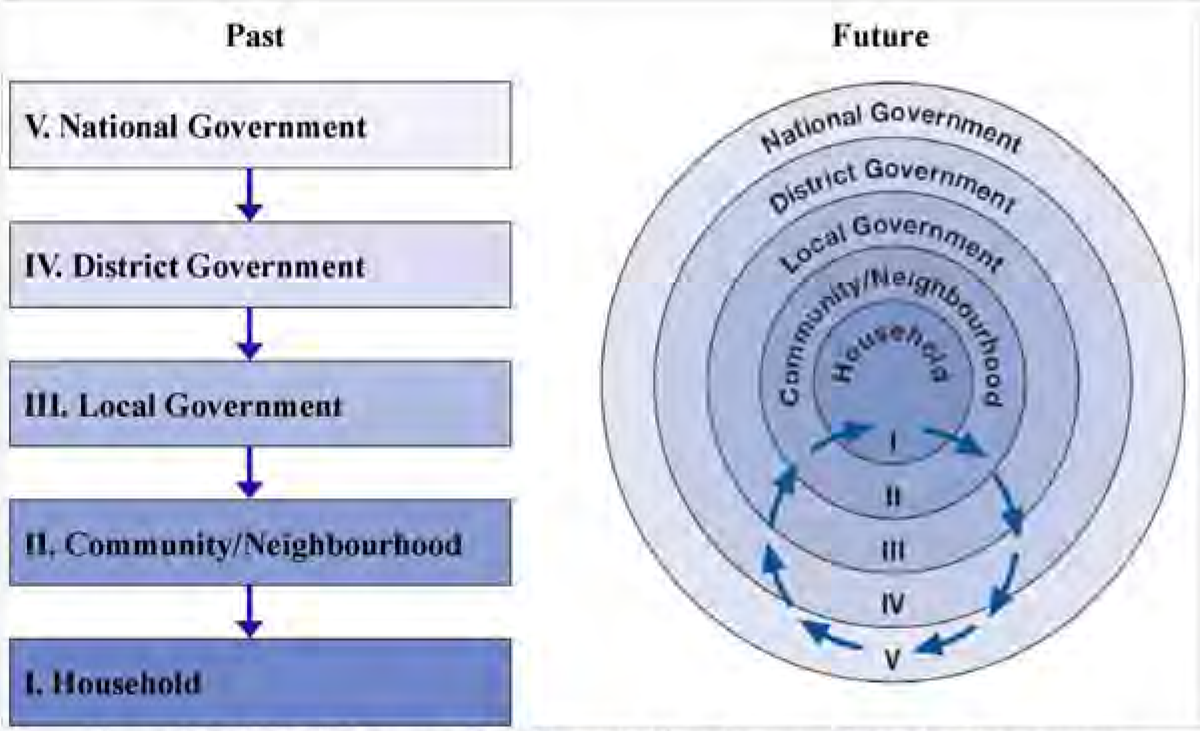


Figure 4.3 The HCES approach the household at the core of the planning process
Source: (Morel *et al.*, 2003)

Waste minimisation involves not only technology, but also planning, good housekeeping, and implementation of environmentally sound management practices (cleaner production).It also involves a special attitude of the users (education, demand management). Industries can also be compelled by legislation to strictly treat or pre-treat and reuse wastewater within their properties, wherever possible, and thus limit discharges to public sewers and streams. The successful implementation of a wide range of options under Step 1 will lead to smaller volumes of more concentrated wastewater reaching wastewater treatment facilities. This makes effective wastewater treatment aimed at resource recovery possible.

4.5 CENTRALISED AND DESCENTRALISED SOLUTIONS

The characteristics of satellite systems (also known as distributed systems), which may be considered as an integral part of a centralized treatment system and of decentralized systems which are self-sufficient treatment systems are illustrated on Figure 4.4 and described below. Satellite wastewater treatment systems present obvious utility for water reuse, the satellite treatment systems may also be used to reduce wastewater flows to the centralized facilities, or as means to eliminate or reduce discharges to impacted receiving water bodies. Three types of satellite systems illustrated on Figure 4.5 are described below (Gikas *et al.*, 2009).

- In the Interception type the wastewater is intercepted before reaching the collection system, diverted to a satellite system for treatment, and reused locally for applications such as toilet and urinal flushing, localized landscaping, including water features, and cooling water in high rise commercial or residential buildings.

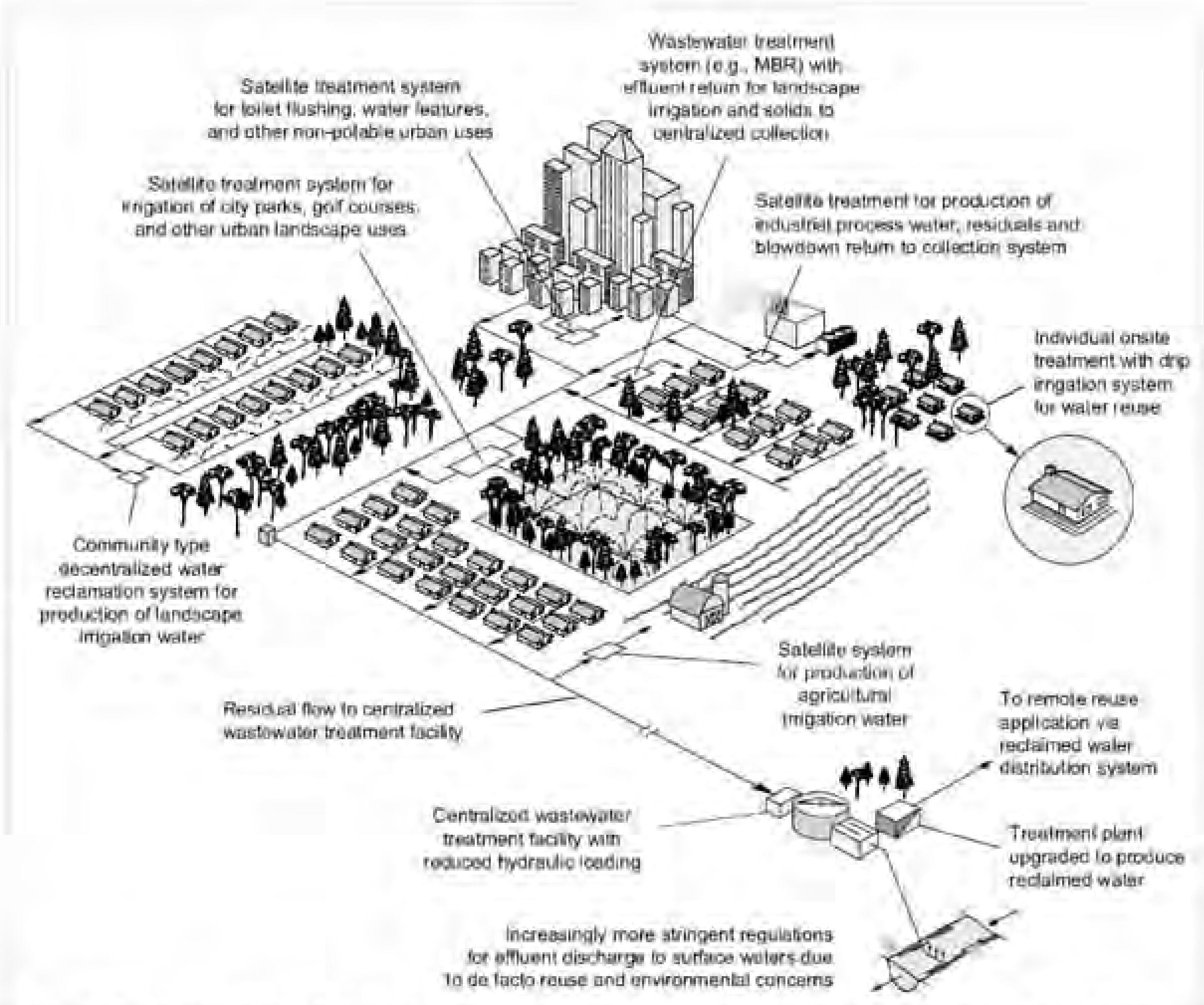
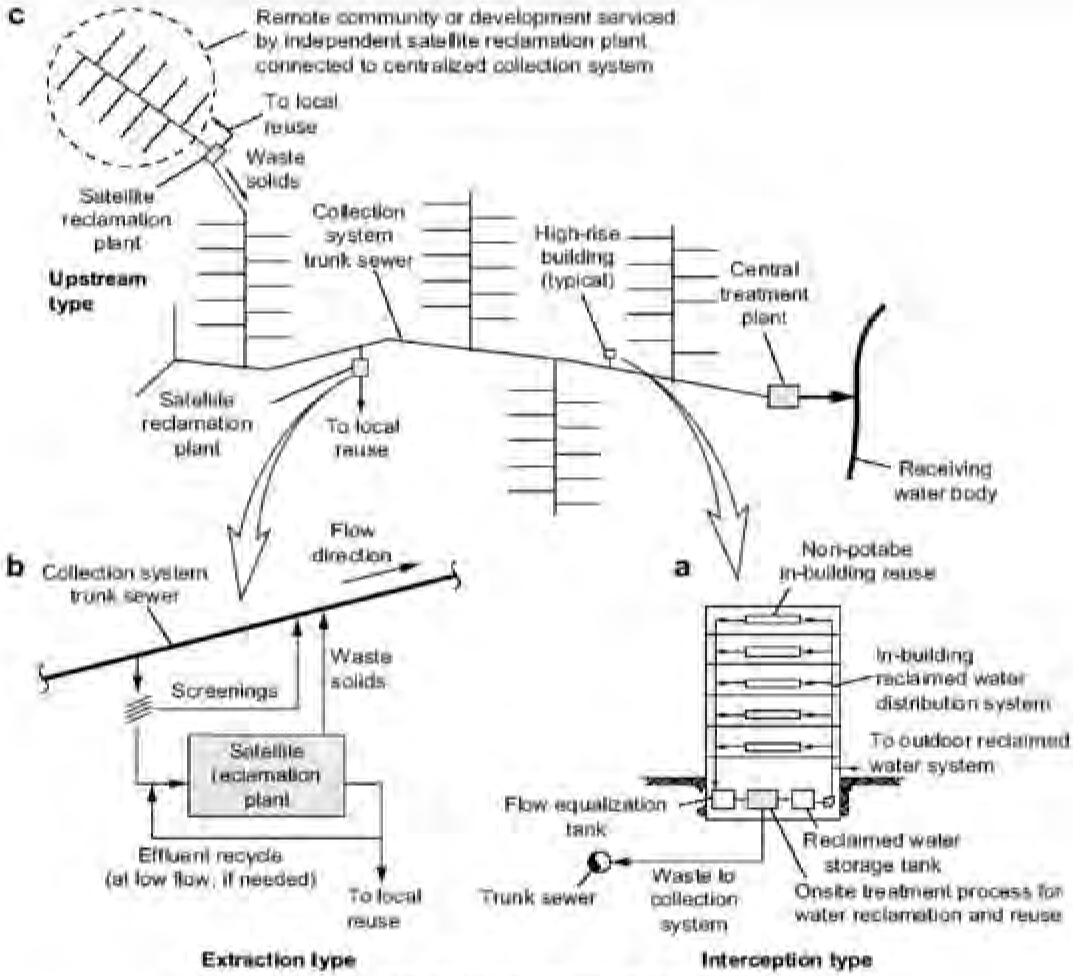


Figure 4.4 Ilustration of the applications for satellite and decentralized reclamation facilities in densely populated areas
Source: (Gikas *et al.*, 2009)

- In the extraction type the wastewater is literally mined from the collection system en route to the central treatment plant; typical applications of extraction type satellite systems include: park or green-belt irrigation, water reuse in high rise commercial or residential buildings, and cooling tower applications.

- Upstream type typically is used to treat wastewater generated at the outskirts of a centralized collection system, where there is an increased demand for reclaimed water for sub-urban park and meridian strip irrigation.

Decentralized treatment plants can be used for wastewater treatment generated from an individual isolated house to a cluster of houses or to a subdivision. Decentralized systems may also be used for the treatment of wastewater generated at universities campuses, or by isolated commercial, industrial and agricultural facilities. In all the above cases, reclaimed water is utilized typically at the vicinity of wastewater generation. Decentralized wastewater treatment systems usually are not linked to a central sewer wastewater collection system network and to a centralized treatment plant, however, in some occasions they may be connected with a centralized plant (Gikas *et al.*, 2009).



(a) interception type, (b) extraction type, and (c) upstream type

Figure 4.5 Scheme of three types of satellite water reclamation and reuse systems
Source: (Gikas *et al.*, 2009)

4.6 SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

In the late 80's and early 90's, concepts in the United States such as "source control" or "control at source", began to be heard referring to runoff reducing techniques. But this is only part of the possibilities linked to these new concepts. The use of the acronym BMP began to be used in the mid 90's, which stands for Best Management Practices, referring to techniques that have an impact on runoff volumes reduction and improvement of the quality of urban effluents, hence resulting in reductions in the drainage network and improvement of the quality of the receiving water where urban runoffs are discharged (Valentin, 2006).

The techniques used to eliminate polluting loads from urban runoffs are called SUDS: Sustainable Urban Drainage System. But while generally improving the quality of discharged effluents, they also contribute in the reduction of peaks in flow discharges or volumes.The first stage of the SUDS approach is to prevent or to reduce pollution and run-off quantities (see Table 4.2). Example of these techniques may include (Wright *et al.*, 2005).

- Not paving areas unnecessarily.
- Draining to lawns.
- Preventing or containing spills.

- Rainwater or stormwater storage.
- Sweeping and cleaning of paved areas and roads.

A main concept of the SUDS philosophy is trying to reproduce the hydrological cycle, aiming at the restoration of the infiltration capacity to reduce runoff peaks. Different SUDS techniques and main characteristics are shown in some of the technical factors that must be taken into account when applying SUDS are:

- Land availability.
- Types of pollutants to be eliminated and removal efficiency.
- Groundwater levels.
- Economic investment in the implementation, application, operation and maintenance of SUDS

Table 4.2 Classification and components of the SUDS

COMPONENT	DESCRIPTION
Preventive measures	It deals with any planning measure that avoids that the issues associated to surface runoffs.
Infiltration systems (control at source)	
Green mantles	Multilayer systems with green mantle covering roofs and terraces of all sorts. They are conceived to intercept and retain rain waters reducing runoff volumes and diminishing peak flows. They also retain pollutants; act as building insulators and help compensating the effect *"heat island"* that arises in cities.
Permeable surfaces	Pavements that allow water to pass through them facilitating its infiltration in the terrain or collecting it or retaining it in sub-surface layers for later reuse or evacuation.
Filtering strips	Strips of wide vegetated ground with little slopes, located between a hard surface and the receiving runoff medium (water flow or collection, treatment and/or evacuation or infiltration systems). They foster sedimentation of particles and pollutants carried by waters as well as infiltration and runoff reduction.
Wells and filtering trenches	Wells and trenches of little depths (1 - 3 m) filed with draining materials (granular or synthetic) where adjacent runoffs of waterproof surfaces are poured. They are conceived as filtering structures capable of totally absorbing storm waters according to their designs.
Systems of permeable transport (management in urban surroundings)	
Filtering drainages and French drainages	Trenches of little depths filled with filtering materials (granular or synthetic), with or without lower transport duct, conceived to capture and filter adjacent surface runoffs to transport them downriver. They may also allow the filtering and lamination of runoff volumes.
Green ditches	Vegetated terrain depressions designed to store and gradually infiltrate runoffs from adjacent surfaces. It fosters superficial underground flows also achieving the elimination of pollutants through filtering, absorption and biological transformations.
COMPONENT	DESCRIPTION
Passive treatment systems (basin management)	
Infiltration deposits	Vegetated terrain depressions designed to gradually filtering and storing runoffs from adjacent surfaces. They foster the transformation of a surface flow into an underground one additionally achieving the elimination of pollutants through filtering, absorption and biological transformations.
Surface containment deposits	Surface deposits designed to temporarily store runoff volumes generated upriver laminating peak flows. They favor sedimentation and with that, the reduction of pollution.
Buried contention deposits	When surface terrains are available, or in cases where the surrounding conditions are not fit for an open-sky infrastructure, these deposits are built underground. They are manufactured with a diversity of materials, the most common ones being reinforced concrete or plastics.
Retention ponds	Artificial Ponds with permanent sheet of water (depths between 1.2 y 2 m) with water vegetation, both emerging and submerged. Designed to guarantee long periods of runoffs containment (2-3 weeks), fostering sedimentation and the absorption of nutrients by the vegetation.
Wetlands	Similar to the above but of lesser depths and greater density of emerging vegetation, contribute with great ecological, aesthetic, educational and recreational potential.

Source: Adapted de (Ballard *et al.*, 2007; Castro *et al.*, 2005; National SUDS Working Group, 2004; Perales *et al.*, 2007)

Table 4.3 shows a summary of the performance characteristics of SUDS technologies, including hydraulic features, efficiency in pollutant removals, maintenance requirements, and added value in terms of habitat and aesthetics.

Table 4.3 Performance efficiency and value of BMP treatment systems

Treatment Facility	Hydraulic Design Robustness	% Removal Efficiency					Maintenance Requirements	Habitat and Aesthetic Value
		TSS	Total Nitrogen	Bacteria	Hydro-carbons	Total Metals		
Gully/Carrier Pipe System	High	10-30	-	-	5 - 10	10 -20	•Low to moderate •Costly to replace	• None
Filter (French Drain)	Low - Moderate	60-90	20-30	20 - 40	70 - 90	70 - 90	•Low to moderate •Costly to replace •Clogging potential	• Inconspicuous • Unobtrusive • No habitat value
Infiltration Basin/Trench	Low - High	60-90	20-50	70 - 80	70 - 90	70 - 90	•Moderate to high •Costly to reinstate •Susceptible to clogging	• Inconspicuous, unobtrusive • Limited habitat value
Swales	High	10-40	10-35	30 - 60	60 - 75	70 - 90	•More costly than conventional drainage	• Moderate visual appeal • Selective planting can enhance habitat value
Sedimentation Lagoon	Low - Moderate	50-85	10-20	45 - 80	60 - 90	60 - 90	• Moderate to high • Costly to desludge	• Some aesthetic value
Oil/Grit Interceptor	Low - Moderate	30-70	10-15	35 - 65	40 - 80	30 - 60	• Moderate to high • Costly to maintain	• None
Dry Detention Basin	Moderate to High	60-80	20-40	20 - 40		40 - 55	• Moderate	•Limited
Extended Detention Basin	High	30-60	5-20	10 - 35	30 - 50	20 - 50	• Moderate	• Moderate visual appeal • Can enhance habitat value
Detention Basin • 6-10 hour detention • 6-24 hour detention	High High	40-80 50-90	20-40 20-40	40 - 50 60 - 75	30 - 60 50 - 75	30 - 60 45 - 85	• Moderate to high • Moderate to high	• High aesthetic appeal • Moderate to high habitat value especially if vegetated
Retention Basin	High	80-90	20-40	40 - 60	30 - 40	35 - 50	• Moderate	• Moderate
Wetland	Moderate - High	70-95	30-50	75 - 95	50 - 85	40 - 75	• Moderate to high • Costly to replace plants	• High visual and habitat appeal

Source: Adapted from (Cereve *et al.*, 2010)

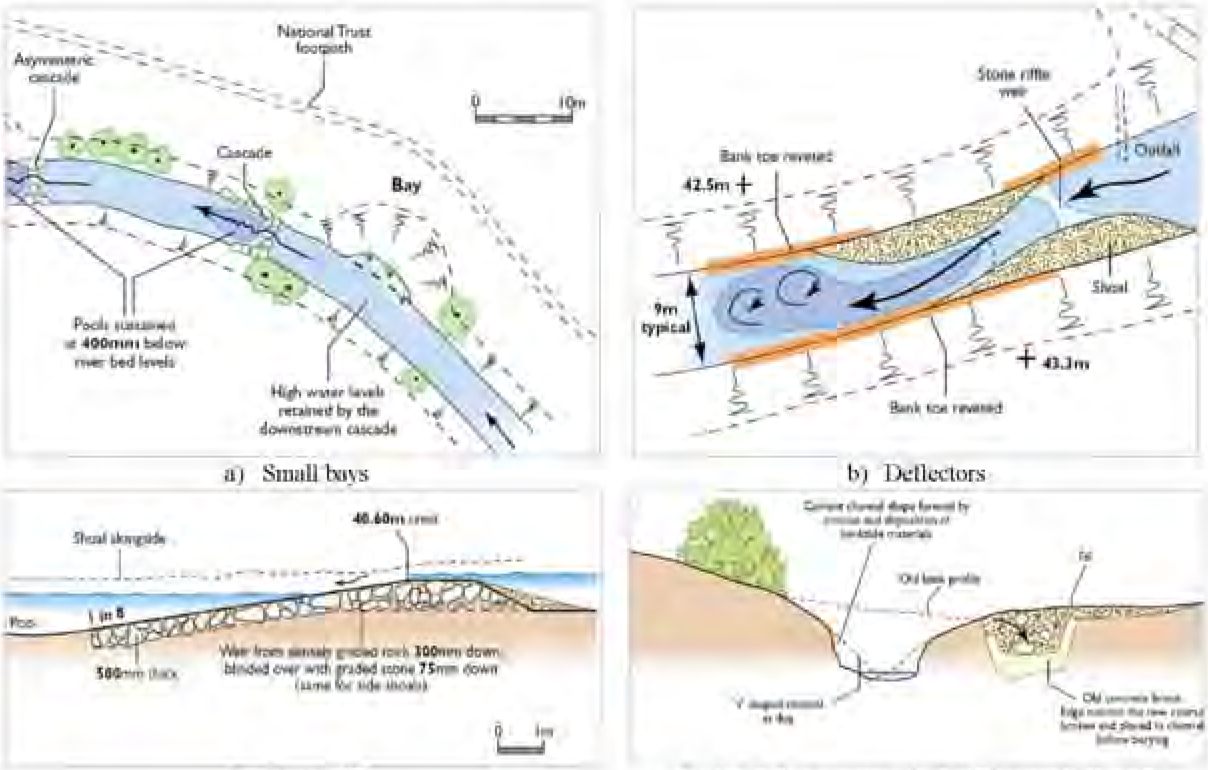
4.7 URBAN RIVER RESTORATION

As the urbanization process is a worldwide trend the degradation of river systems has become a widespread problem, hence river restoration is turning into a popular management strategy to improve both physical and ecological conditions in river systems. In general there are a large number of restoration actions and projects implemented for river restoration, including strategies such as stormwater management, bank stabilisation, channel reconfiguration, and riparian replanting. However, in the urban river context the experiences and techniques for river restoration are limited.

In general, restoration projects in urban rivers are both more expensive and more difficult than restoration in less densely populated catchments, which is due to spatial limitations with dense human infrastructure (e.g. roads, sewer lines), high property values, and finely subdivided land (Bernhardt *et al.*, 2007). To be effective, urban stream restoration efforts must be integrated within broader catchment management strategies. If not, stormwater and the correlated sediment input and other pollutant loads may limit the potential of restoration projects. There are examples of reconfiguration projects in urbanized catchments with structural failures, due to that the hydrology has been assumed on historic or reference data. Consequently, it is of extreme importance to have up-to-date information on the hydrological conditions and to use more sophisticated approaches incorporating empirical data on water and sediment flux through the target stream (Bernhardt *et al.*, 2007).

In this perspective, only in catchments where urban stormwater is retained, detained or rerouted to successfully reduce peak flows and improve surface water quality, is it appropriate to consider how to restore structural components through active in-stream reconfiguration (Walsh *et al.*, 2005)

Likewise, according to (Podraza, 2007) the best practices in small rivers are to implement measures to reduce rainwater discharge and measures within the river. The following in-stream measures are considered to have a potential in urban river restoration, see Figure 4.6 (The River Restoration Centre, 2002).



a) Small bays

b) Deflectors

c) Stone riffle

d) Replacing concrete drain with natural channel

Figure 4.6 In-stream measures for urban river restoration
Source: River Restoration Centre, 2002

Small bays

To support the recovery of shallow slack water (low speed water) habitat the option of creating small 'bays' can be considered. These bays would provide some shelter in high flows suitable for fish fry and invertebrates, and shallow margins should increase the macrophyte diversity within the reach.

Deflectors

Another technique to enhance a straightened channel is by building a series of low level structures in the bed that intermittently narrow the channel causing variation in flow currents and creates pockets of erosion and deposition (deepening of the bed and accreting at the banks). In a small channel the deflector structures should be small scale to avoid creating any scour of the river banks or significantly impeding flood flow.

Stone riffles

The stone riffle or the low weir is a small obstacle across the river which serves to regulate the water levels upstream, which can support the introduction of stable marginal planting ledges where water birds and mammals can roam. Additionally, the sight and sound of water cascading over the riffle can be enjoyed by people strolling in the area.

Replacing concrete drain with 'natural' channel

The most radical in-stream restoration action is the replacement of concrete drains to recover a "natural" channel. In most cases it will be impossible to restore the stream to its original form, but the experience shows that it is possible to recover natural characteristics.

In combination with in-stream strategies, it is indispensable to try to maximize the riparian corridor. A well vegetated, healthy riparian corridor provides a number of beneficial functions to the urban stream, such as (Kelly, 2001):

- Reduces watershed imperviousness by imposing development limits adjacent to the stream.
- Reduces flood impacts.
- Filters pollutants from runoff flowing overland to the stream.
- Provides wildlife habitat.
- Protects stream bank from erosion.
- Reduces stream warming.
- Provides large woody debris to the stream ecosystem.
- Maintains infiltration of rainfall and contributes to stream baseflow.

When actions have been taken to assure the riparian corridor and stream banks, attention can focus on improving the quality of in-stream habitat. Usually, habitat improvement consists of using large native rock, boulder or timber structures in a variety of configurations to alter the flow regime of a location within the channel of a perennial watercourse, with the purpose of creating pools, riffles, and feeding or resting areas (Kelly, 2001). An urban river restoration project in Vienna, Austria, where concrete riverbed was replaced with stones and gravel, the following ecological and human population results where found among others after three years of implementation (Goldschmid, 2007) (see Table 4.4)

Table 4.4 Results of urban river restauration in Austria

ECOLOGICAL	HUMAN POPULATION
• Water quality improvement • Improved river dynamics with deposition and erosion • Increased fish population, including appearance of endangered species. • High biodiversity of dragonflies • Formation of a solid macro-zoobenthos population. Increased number of ground beetles (carabidae) species in the area. • The first beaver arrived.	• Much better water quality • Better access to the river • New safe footpaths • High quality recreation area in front of the door • Higher quality of life.

Regarding the ecological improvements it is important to keep in mind that the restoration along an urban river stretch, that was turned into a concrete-lined channel, while the downstream river stretch remains under pavement will not restore the ecological conditions of the river system (Palmer *et al.*, 2005). Furthermore, it is important to emphasize that the experiences and investigations on urban river restoration are still limited.

4.8 POLLUTION CONTROL INSIDE CONTEXT OF WATERSHED

In the frame Integrated Water Resources Management (IWRM) promotes the use of mixtures of ecological and infrastructure technologies; and non-structural tools such as education, pricing incentives, regulations and restriction regimes (Universidad del Valle *et al.*, 2005).

Water has conventionally been managed within administrative rather than natural boundaries, in a fragmented rather than holistic manner, and in a technocratic rather than participatory way. Using principles of Integrated Water Resource Management (IWRM), Integrated River Basin Management (IRBM) or Integrated Catchments Management (ICM), catchment management initiatives often involve moves toward governance within natural boundaries to manage water more holistically, equitably, efficiently and sustainable. The organisation of water management according to the physical characteristics of a river basin is only one, albeit particularly appealing, form of IWRM aims (Gourbesville, 2008):

- To reconcile the aggregate supply of, and the demand for water, as well as among the competing demands for it, through structural and non-structural measures, on the supply as well as the demand side.
- To ensure that the watershed, the land that catches the rainfall and translates it into river flows and lake volumes, retains its capacity to do so.
- To steer water use in directions that are economically productive, socially equitable and environmentally sustainable.

4.9 MULTI - CRITERIA ANALYSIS (MCA)

The denomination of multicriteria as well as multiatributes comes from this circumstance, and these tools are used for the analysis of projects, plans, programmes and options either with a single objective or with several. These techniques attempt to solve problems with different objectives which normally are opposed. Multi-criteria analsis is also referred to in the literature as multi-objective decision making, multi-objective decision support system, and multi-criteria dicision aid. (Metcalf & Eddy, 2003) The most common objectives employed in environmental technologies are (WHO, 2006):

- To achieve a minimum cost or to maximize a benefit,
- To maximize employment,
- To maximize competitiveness,
- To optimize distributional impacts

Framework for multi criteria decision analyisis (see Figure 4.7) has a structure represented by matrix with columns representing the decision makers, their preferences, and evaluation criteria; and rows that represent decision alternatives. These elements are organized in hierarchical structure. The most general level is a goal. At this level a desired end state resulting from decision-making activity is specified. The decisions require analysis of the values of persons affected by the decision, who are often characterized by unique preferences with respect to the relative importance of criteria on the basis of which alternative decisions are evaluated. The preferences are typically operationalized in terms of weights assigned to the evaluation criteria. A criterion is a standard of judgment or a rule to test the desirability of alternative decision. The decision outcomes depend on the set of attributes for evaluation alternatives. Consequently, an entry in the intersection of each row and column of the decision matrix is the decision outcome associated with a particular alternative and attribute.

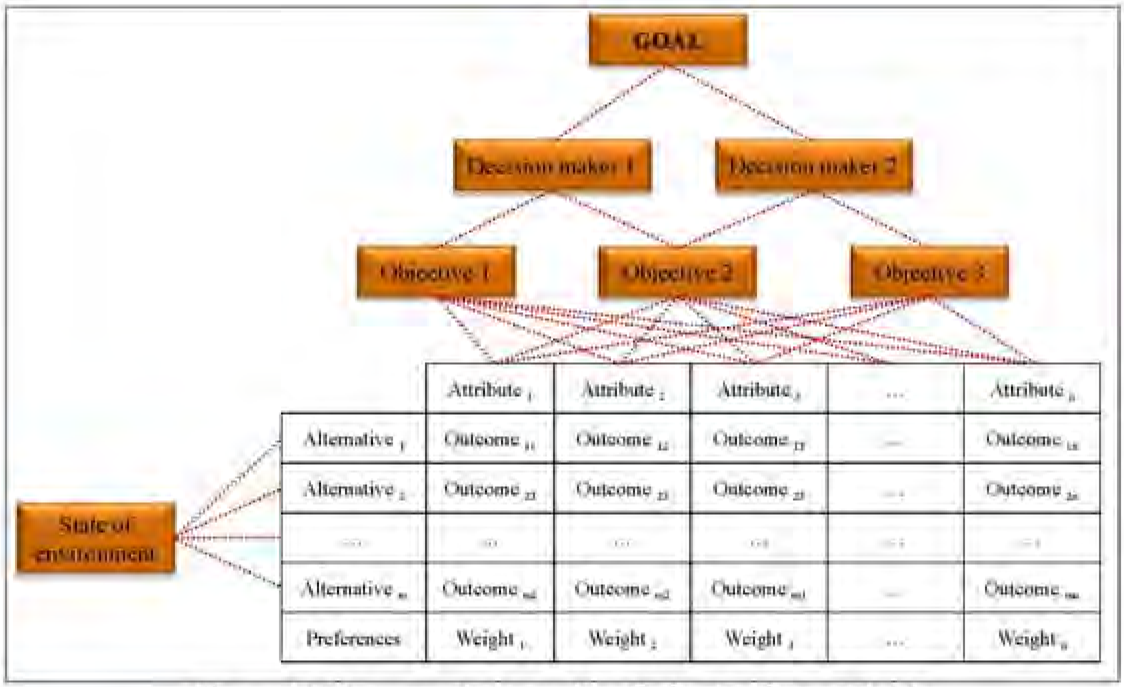


Figure 4.7 Framework for multi criteria decision analyisis

MCA can be presented in successive steps; these steps are (Metcalf & Eddy, 2003):

- Identifying the problem to be addressed
- Identifying the alternatives
- Identifying the criteria or attribute
- Scoring the alternatives in relation to each criterion
- Weighting the scores according to the weight or rank assigned to the criteria
- Evaluating the alternatives
- Sensitivity and risk analyses, and
- Producing a ranking of alternatives on which to make a recommendation

4.10 COST – BENEFIT ANALYSIS (CBA)

Cost – benefit analysis is a collection of methods designed to estimate the social consequences produced by this implementation. CBA makes a comparison of benefits and costs, both expressed in monetary terms, which have to be discounted over time (WHO, 2006). Cost – benefit analysis proceeds in four essential steps (Punmia *et al.*, 1998):

1) Identification of relevant costs and benefits
2) Measurement of costs and benefits
3) Comparison of cost and benefit streams accruing during the lifetime project
4) Project selection

A major shortcoming of the benefit – cost framework is its inability to include within its framework all relevant benefits and disbenefits that cannot be quantified in monetary terms. Even in situations where it is feasible to make a realistic estimation of a proportion of the benefits and disbenefits, there will always be a significant numer of attributes that cannot be expressed in money values.

5 METHODOLOGY

5.1 DESCRIPTION OF THE WATER MANAGEMENT PROBLEMS

Within the selection of strategies for water management in the city, it is indispensable to know and understand study area and their water problems. In order to achieve this objective, all documents made within the SWITCH Project Framework were revised and analyzed, diagnosis report, plans, programs and projects related to the learning alliances, update of diagnosis studies undertaken by institutions and documents elaborated by new integrants of the Learning Alliances. This includes all the information regarding the water resources, supply, sanitation, solid waste management, policy analysis, plans, programs and projects of the city of Cali, among others.

5.2 IDENTIFICATION OF STUDY AREAS

During 2007, the case study of Cali initiates with the establishment of the Learning Alliances (LA). LA teamwork in this year starts a strong work for in search of common objectives and to achieve sustainable results in terms of water management in Cali. For achieve this, three specific critical urban water management problems in the city, which were defined jointly by the stakeholders:

1. The water quality of the Cauca River and its impact on the water supply system of Cali.
2. The drainage system for South of the city of Cali.
3. The planned expansion area in the South of Cali, and the possibility of including innovative strategies.

In this document, the topic related Cauca river quality is focused to a specific problem: the contamination of Cauca River due the discharge of the Cañaveralejo wastewater treatment plant, therefore, the study area is limited to consolidated area of Cali city that drained the WWTP-C. On the other hand, the topic of South Drainage System (SDS) limited the study area to the Cañaveralejo River basin. The two principal reasons for choosing this river basin are: share common characteristics and problems with the rest of the river basins in the municipality of Cali and it is the basin with most severe alteration in the urban area.

5.3 IDENTIFICATION OF STUDY CASES

For the identification of specific solutions were selected six study cases inside study areas. Each study case was selected due to the possibility of solve problems through of the application of SWITCH concepts, and the problems identified have big implications about water resources of Cali city.

5.3.1 Case study 1 – WWTP-C drainage system

This case study corresponds to drainage area that transports the wastewater to Cañaveralejo treatment plant, is to say, the consolidated area of Cali city. The WWTP-C was selected as study area due to the high pollution load discharged to Cauca River, although the wastewater is treated to primary level. Additionally, the effluent treated could be reuse in sugar cane irrigation.

5.3.2 Case study 2 – South expansion area

Although in the south expansion area there are not problems to environmental level because has not developed, is considered as an opportunity for planning of urban water management that includes the SWITCH concepts. For this reason was selected as study case.

5.3.3 Case study 3 – Stormwater management in “Plaza de Toros” area

A pre-study of the implementation of Sustainable Urban Drainage System (SUDS) in the Cañaveralejo River basin will be carry out for lower area of basin, considering its potential and feasibility in the context of a consolidated urban area in Cali. The specific areas including in the case study are: the sports complex (velodorme, coliseum of the people), two soccer fields, and the bullfighting ring.

5.3.4 Case study 4 – Cañaveralejo River restoration in urban area

The Cañaveralejo River is the water resource that has received the major alteration of the seven rivers of Cali municipality, for this reason, has been selected as case study for urban river restoration. Among reasons of this alteration is the urbanization process and flooding problems. The urban river restoration can be a good alternative for Cañaveralejo River since could be improved the quality and quantity of the water, and recuperate their natural characteristics.

5.3.5 Case study 5 – On-site treatment of leachate from the Navarro landfill

Although the Navarro landfill was closed the problem related to leachate management is dormant. The lack leachate managment is affecting the groundwater of the area adjacent to Navarro landfill, and to the Cauca River by recharged phenomenon. For these reasons the on-site treatment of leachate was selected as case study.

5.3.6 Case study 6 – Strategies in rural area

The rural area of Cañaveralejo is considered a important case of study for the deterioration associated with human activities as agriculture, mining, water management, among others. This study case covered a wide area of the basin; therefore, the proposals will be to strategic lines with a detail level low.

5.3.7 Case study 7 – Strategies for incomplete development

The incomplete development is a big problem of the Cali municipality, since families from neighbor municipalities come to Cali city, in search of opportunities, are locating in areas of risk, protection areas of rivers, and discharging their domestic wastewater to Cali Rivers. The displacing phenomenon is related with violence, lack employment in the rural area of Cauca, Nariño, and other neighbor’s municipalities.

5.4 IDENTIFICATION OF POSSIBLE SOLUTIONS

A conventional solution and solution with SWITCH approach were identified for all case studys. To follow, will be presented the conventional solution for each case study.

5.4.1 Conventional Solution

The conventional solution consists in strategies or technological options proposed in other studies. A revision and analysis of alternatives and strategies proposed by institutions in the different local and regional plans was made. In the studies and research undertaken in the study area the options were characterized both technical as economically. Also, a meetings and workshop was undertaken with members of LA, officers of institutions, oriented to know the conceptualization, characteristics and perspectives of these proposals.

5.4.1.1 Case study 1

In the case of WWTP-C drainage system, the conventional solution is based in following documents:

- Plan for sanitation and management of wastewater discharges (PSMV) (EMCALI, 2007).
- Studies related with secondary treatment elaborated by EIDENAR research group de la Universidad del Valle (Universidad del Valle, 2009a).

5.4.1.2 Case study 2

For South expansion area, the conventional solution is the alternative analised and projected by the following documents in terms of drinking water and wastewater treatment:

- Report the feasibility studies for the delivery drinking water and sanitation services in this sector development (EMCALI *et al.*, 2006a).
- Studies and designs for water and sewage networks in the first stage of Cali-Jamundí corridor (EMCALI *et al.*, 2009).

5.4.1.3 Case study 3

The conventional solution for stormwater management for “Plaza de Toros” area corresponds to current management of stormwater. Basically is collect and transport the stormwater through pipes or channels that connect to SDS, and finally discharging to Cauca River.

5.4.1.4 Case study 4

The conventional solution is same to current solution in this case study. The current solution consists in the canalization of the Cañaveralejo River for avoid the flooding risk.

5.4.1.5 Case study 5

For case of the treatment of leachate from Navarro landfill, the conventional solution is bases in study carried out by EMSIRVA, which is under liquidation, through the consultancy firm Hidrosuelos.

5.4.1.6 Case study 6 and 7

To strategies in rural area and for incomplete development, the conventional solution consists in current management in term of strategic lines applied to area of case study.

5.4.2 Solution with SWITCH approach

According to the characteristics of the study areas, and types of problems, the pollution control strategies were considered at four levels: i) Pollution prevention and minimisation strategies, ii) decentralisation, iii) wastewater treatment using natural methods for agricultural reuse purposes, and iv) sustainable urban drainage system (SUDS). To continuation, are presented the steps for identified and selected the alternative with SWITCH approach.

5.4.2.1 Formulation of alternatives

These proposals are detailed in technical and economical aspects, starting with the revision of scientific documents (investigations, papers, etc.), books, and experiences to international, regional, and local level, and with the consult to experts. Pollution prevention alternatives includes saving water practices and/or implementation of technological options such as low consumption devices, rainwater harvesting, grey water reuse, cleaner production in urban industry, agricultural activities and mining; sustainable urban drainage systems (SUDS).

These strategies will be characterising by components, functions, and benefits. Other alternatives considered and that complement the SWITCH strategy are the proposals for wastewater treatment considering natural methods, and the use of effluent treated in irrigation of sugar cane. The strategies are the combination of the several options.

These alternatives and strategies have different potentials or possibilities of application in accordance with the sector where implementation is proposed and as such, the planning viability if it is a consolidated urban sector, a new development area, a rural area or concentrated or dispersed areas. To this effect, alternatives are formulated according to the characteristics of each study area and the problem confronting.

The alternatives and strategies identification potentially for implementation in the study area, were consulted with local actors of institutions related with water management, in such a way that they would be coherent with a local context. Discussions with the institutions were carried out through personal interviews, workshops and surveys.

5.4.2.2 Selection process

Along with the characteristics of the three study areas, pre-selection judgments were considered and different methodologies were used to select strategies, contemplating SWITCH concepts, which are later specified by study area.

In the cases study 1, 2 and 3, the selection of optimal alternatives for pollution prevention, and wastewater treatment with reuse option, will be based on the methodology of Analytic Hierarchy Process (AHP) and Grey Relational Analysis (GRA) (Zeng *et al.*, 2007). This methodology was used for wastewater treatment selection, is mentioned that AHP and GRA can be apply to other fields regarding the optimization of complicated multi-objective decision-making problems.

The selection criteria used were economic, environmental, technical and social. To each indicator and criteria is assigned a weight (see Appendix 1). Some indicators used are presented in Table 5.1. Since at local concept many indicators are not feasible of calculation

or submittal due to lack of information, the Table 5.2 show the indicators considered in the selection process of minimizing and prevention alternatives.

Table 5.1 Criteria and indicators used in selection of pollution control alternatives

CRITERIA	ENVIRONMENTAL	TECHNICAL	SOCIAL	ECONOMIC
INDICATOR	✓ Energy use ✓ Removal efficiency of nitrous and phosphorous ✓ Risks to human health ✓ Water usage ✓ Water losses ✓ Chemical consumption ✓ Land requirement ✓ Soil pollution ✓ Air pollution ✓ Water pollution ✓ Local Conditions ✓ Clime ✓ Hydrology ✓ Protection or reduction of biodiversity ✓ Climate Change ✓ Human Toxicity ✓ Photo-oxidant formation ✓ Acidification ✓ Eutrophication ✓ BOD Removal ✓ TSS Removal ✓ Metals Removal ✓ Coliform Removal	✓ Level of complexity ✓ Administrative performance ✓ Sludge production ✓ Knowledge of technology ✓ Durability ✓ Flexibility	✓ Compliance with current laws and regulations ✓ Acceptability ✓ Risks to human health ✓ Social inclusion	✓ Initial investment costs ✓ Operational and maintenance cost (O & M) ✓ Willingness to pay ✓ Financial feasibility ✓ Market feasibility ✓ Affordability

Table 5.2 Criteria and indicators used in selection of alternatives minimisation and prevention.

CRITERIA	INDICATORS
Economic	Initial investment costs
	Operational cost
Environmental	Save drinking water
	BOD Removal
	TSS Removal
Technical	Level of complexity
Social	Support institutional
	Social acceptance

Strategies for pollution prevention and minimisation

The proposal is focused in Cali households due to the fact that the consolidated zone is mainly made out of single family households. The pre-selection criteria as the market availability, effluent quality and social preference to sanitary low consumption options were considered. A consultation was carried out with local businesses and import companies to determine the availability and costs of different technologies. Regarding the effluent quality for rainwater harvesting systems and greywater reuse systems, the possible uses of these alternative sources and quality requirements, were determined. Social preference of low consumption sanitary

options was identified through a 200 social survey (See Appendix 2). With these indicators, the number of technological options was reduced.

Wastewater treatment with natural methods, for agricultural reuse

For cases study 1 and 2, technology selection indicators for agricultural reuse purposes, considered the effluent agronomic quality, under the standards of FAO (Ayers *et al.*, 1987) as well as the lineaments of the World Health Organization, in terms of risks for the different exposed groups (WHO, 2006). Due to the lack of domestic wastewater microbiology studies, the microbiological quality was defined as the maximum concentration of helminth eggs considered as less or equal to 1 helminth egg/L. Other indicators considered are shown in Table 5.3.

Table 5.3 Criteria and indicators of technology selection for treatment of wastewater considering agricultural reuse

CRITERIA	CONSIDERATIONS OF INDICATOR FORMULATION	INDICATOR
TECHNICAL	Land availability	Required area [ha]
	Agricultural use capacity – NPK effluent concentrations lower than the maximum for sugar cane harvesting (Pre-selection)	NPK Concentration [mg/L]
	Effluent agronomic quality	Use restriction degree
		pH = 6,5 - 8,4; BOD < 30 mg/L; SS < 30 mg/L; Microbiologic quality < 200 NMP coli fecal/100 mL
	Effluent microbiologic quality	Helminth egg concentration [helminth egg/L]
	Power requirement	Installed power [W/person]
ENVIRONMENTAL	Domestic wastewater treatment technical norms – Minimum efficiency (Pre-selection)	TSS 90% removal and BOD 85% removal
	Sludge management	Liquid mod production [L/person-year]
ECONOMIC	Initial investment	€ Million PNV
	Operation and maintenance	€ Million PNV
SOCIAL	Easiness of operation and maintenance	1 Easy operation, 2 Moderate operation 3 Complex Operation
	Land property	1 Own, 2 to be obtained

Methodology and results of the criteria and indicator weights are shown in Appendix 1, made through surveys to officers of related institutions and members of Learning Alliances. Indicators as institutions support were collected through consultation with relevant members of institutions and members of Learning Alliances. Likewise, in each study area, specific aspects are detailed to identify the different selection criteria and indicators not only on the issue of minimizing and prevention as well as on the issue if treatment methods with natural methods or reuse.

At cases study 1 and 2, an agricultural plan was proposed, considering the reuse purposes. The agricultural plan is defined as the relationship of systems and subsystems, that once integrated, seek a productive objective. (Moscoso *et al.*, 2002b). The plan considers the activities for such a purpose, as well as the seeding and required area definition, harvest periods, water crop requirements, selection of irrigation systems, marketing channels, agronomic management and costs of each activity.

Since the agricultural activity in the plain zone of the Cauca River high basin shows a high degree of mono-crop of sugar cane for production of sugar and bio-fuel production, the

selection of crop to irrigate with wastewater is summarised in sugar cane as crop to be evaluated. Once the crop type is selected, the zones to harvest near Cali municipality and expansion area were delimitated. The foregoing was carried out with the implementation of ArcGIS version 9,0 software, as product of cartographic inceptions.

Once the area to harvest was identified for each case (Cali municipality and expansion zone) with the current land use, the polygonal criteria was used for identify the potentially area to irrigate with domestic wastewater of Cali municipality and future expansion zone. These criteria include: slope, main road closings, and vulnerability of the aquifer system contamination.

The water requirement was estimated through a simplify water balance (Sokolov *et al.*, 1981), determining temporality and the amount of water required for irrigation with wastewater, at multiannual monthly aggregation scale. As a particular application of this methodology, a balance in terms of effective rain (Pe) was established, and the real evaporation and transpiration of the sugar cane crop (EVt). Pe determination was carried out using USDA (Schneiderman *et al.*, 2007) and the EVt methodology, combined with the (Doorenbos *et al.*, 1977) FAO method and the evaporator metering tank (CENICAÑA, 2004).

Decentralized sanitation in peri-urban areas

The alternative of decentralized sanitation in peri-urban areas consists in two elements: prevention and minimisation strategies applied to household level, and natural systems. This solution is proposed for case study 3. The prevention and minimizing strategies selection was based on selection results developed in case study 1. Regarding natural system as wastewater treatment, the solution with SWITCH approach is based in proposal of Health Secretary.

Sustainable Urban Drainage Systems (SUDS) in the consolidated urban area

This issue designed first a limited urban zone showing higher flood degrees. For the SUDS technologies a model developed by (Woods-Ballard *et al.*, 2007) is applied based on technologies requirements, specific characteristics of the study zone and expected impacts.

Urban river restoration

The selection process for the urban river restoration issue has been done through a technical and socio-economic feasibility based on experiences and international study cases. In section 8.5 is presented more detail of selection process.

On-site treatment of leachate from The Navarro Landfill

On the treatment selection of lixiviate in situ from Navarro garbage dump, a decision support model was used, developed by UNESCO-IHE of Holland investigators (Vargas, 2007). This selection model comprises seven stages, including among others, the leachate characteristic analysis and normative requirements on discharge levels, technological feasibility analysis, pre-selection and finalist a multi-criteria analysis. This latter analysis considers such aspects as local conditions, treatment technical processes and environmental and socioeconomic aspects.

Strategies for informal settlements and Strategies in the rural area

For this two issues, alternatives will be developed in a conceptual way, therefore, they do not account for a selection process.

5.4.3 Estimation of costs

The costs of initial investment and O&M to conventional solution based in previous studies, corresponds to data found in these studies and projected to PNV. If the conventional solution consists in current water management, the cost is not estimated.

The costs for solution with SWITCH approach are based on literature review, calculation methods for SWITCH options were identified allowing the pre-dimensioning of alternatives and the estimates of initial, operational and maintenance costs. Cost alternatives were calculated based on city local conditions and particular characteristics of each study area. To the technological proposal for pollution prevention and minimisation, the regional experiences and experimental applications carried out in the city of Cali were taken, allowing an approach to prefeasibility level costs (Appendix 2). Regarding the wastewater treatment systems, the initial treatment investment costs were calculated from the main activity costs, such as: land, geo-membrane, geo-textile, gravel, etc. The unit value for each item is the one submitted by Valle del Cauca Government, through Decree No.0532 of May 03, 2010.

The operational and maintenance costs for wastewater treatment were calculated under the (WHO, 2006) considerations for cases study 1, 2 and 3. On the other hand, the O&M costs for pollution prevention to cases study 1, 2 and 3 were calculated identifying the main activities and requirements.

5.5 COMPARISON OF CONVENTIONAL SOLUTION VERSUS SOLUTION WITH SWITCH APPROACH

5.5.1 NPV Analysis

The NPV analysis consists in the comparison of NPV cost of initial investment and operation and maintenace for identify the profitability of an investment or project. NPV compares the value of a project today to the value of that same project in the future, taking inflation and returns into account. If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should probably be rejected. This methodology of comparison was used in case study 3, 4 and 5.

5.5.2 Cost-benefit analysis

5.5.2.1 Introduction

Considering that the economic resource availability in the local context is limited and the environmental projects generally get a low budget assignment, it is required that the initiatives like pollution control of water resources in addition to optimize the resource use, contribute to attain economic and social community well being. There are different options for pollution control of water resources, among them there are those considered as conventional options and those that may be considered as alternative options, including in the latter those involving the SWITCH project concepts.

A key aspect in the definition of the most viable alternative is the evaluation economical. The trend of the context is focused to the selection in financial analysis from the private optical, when the water and sanitation investment have public implications related with environmental and social elements.

With the objective of make an integral analysis where are linked multiple stakeholders of water management, a profitability analysis of the options proposed in each area are carry-out, including the costs related with environmental benefits.

The implementation of option with SWITCH approach was evaluated, considering that the cost-benefit estimate of the profile was made. For the future, it is recommended to make a socio-economic evaluation including other eco-systemic benefits and services.

For the evaluation the activity developed following the proposed methodology by Miranda (2001), although the price-account relation is not integrated to the socio-economical analysis. This technique was developed in several stages:

- Identification and quantification of direct and indirect cost of each alternative.
- Determination of direct and indirect benefits for each alternative
- Design of methodologies aimed to correctly quantify not only the costs but also the benefits of each alternative.
- Based on the foregoing quantification methodology, the flow of financial resources is obtained to be used for the initial project investment (technology installation) and the operational and maintenance stage, as well as the income flow generated by the production of goods and/or services of the project during its useful life
- Comparison of costs and benefits of each alternative and determination of profitability levels using the net current value and the internal rate of return.

5.5.2.2 Alternative benefit and costs

The first step was the identification of impact of two components: benefits or positive impacts, and costs. The benefits and the cost were analyzed, keeping in mind their magnitude, location in time and project length.

The estimated costs correspond to those generated by technological option implementation. "Incremental costs" were considered, that is to say the difference between the costs "with" and "without" technological option (it is necessary to consider the optimum base situation). The economic costs representing the use of land, labor or capital were taken into consideration. Likewise, the costs for the initial investment period and project operation were also considered.

Benefits are those positive contribution of a project aimed to satisfy the community needs. The benefit analysis was carried out in the same way established for the costs; consequently:

- The expected project benefits were identified
- The incremental benefits were calculated.
- The benefit not economical elements were excluded.
- The benefit value was added in each installation and operation period.

Environmental and economic benefits were also considered. The environmental benefits associated with improvements shown by the project in the environment, particularly quality, flow air and water state. Financial and economic benefits are related with those activities generating some type of income of monetary savings.

The common benefits of the alternatives, including benefits to health, environment and other social areas were not taken into consideration.

5.5.2.3 Evaluation cost - benefit

The cost – benefit analysis included the cash flow of costs and benefits of each option. The cash flow result is brought to present net value to carry out the comparison using a social discount rate according to water and health improvement projects in a horizon involving different aspects of this type of investments.

A social discount rate of 11% was used, and an evaluation period of 30 years, since this period includes the horizon period of the project, of the different infrastructure of water and sanitation involved.

The evaluation was made including two important criteria: economic efficiency or the difference between benefits and costs, and the relation of Net Present Value ($NPV_{benefits}/NPV_{costs}$) (Brent, 2006).

6 PROPOSALS FOR POLLUTION CONTROL IN WWTP-C DRAINAGE SYSTEM AND CALI RIVER BASIN

6.1 INTRODUCTION

Although the strategies for decontamination of water resources in this chapter will be focused to pollution control in WWTP-C drainage system, the description of study area and their problems will be under basin approach, therefore, upper basin of Cali river will be included.In this way, this chapter presents several proposals to reduce the pollution in WWTP-C drainage area by wastewater with proposals for pollution prevention and minimisation, improving the efficiency of WWTP-Cañaveralejo that includes natural methods, and reuse of treated effluent of WWTP-C in irrigation. In this way, are presented strategies for pollution control by wastewater in Cali municipality with new approach that includes analysis of an innovative proposal versus conventional solution.

6.2 DESCRIPTION OF STUDY AREA

As mentioned earlier, the zone is composed by two parts: an area that corresponds to Cali River basin and an area of drainage to WWTP-C. The description starts with the Cali River basin area. Cali River basin has approximately 12.352 ha of total area. Inside rural area there are 10 settlements, such as: part of Andes, Pichindé, La Leonera, Felidia, Saladito, La Castilla, La Elvira, La Paz, Golondrinas, and Montebello, with approximately 19.044 habitants (UMATA, 2005) (Figure 6.1).

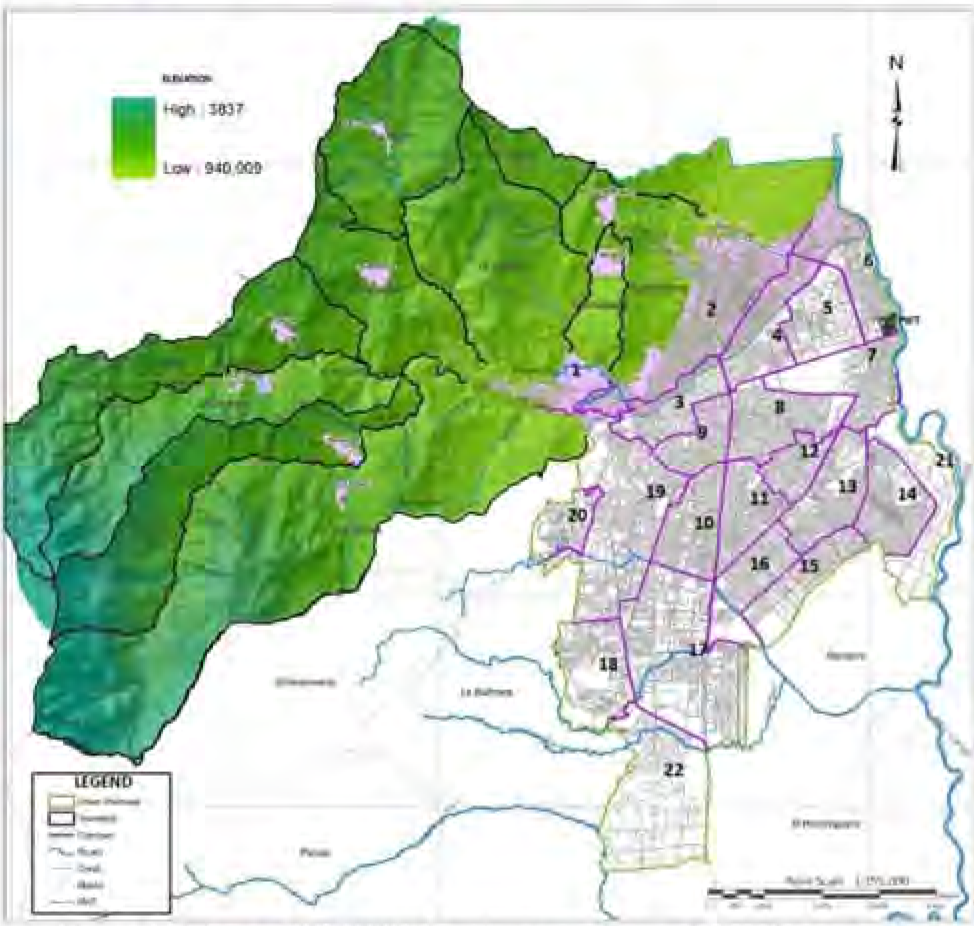


Figure 6.1 Area of WWTP-C drainage system and Cali River basin

The climate is defined by its topography and its elevation above sea level, the temperature varies between 10 °C and 24 °C. People in this area works in several activities such as: agricultural, mining, and cattle farming. However, the majority of people work in commercial activities. In Golondrinas it´s practiced the artisanal mining of coal with low technological resources (Figure 6.2).

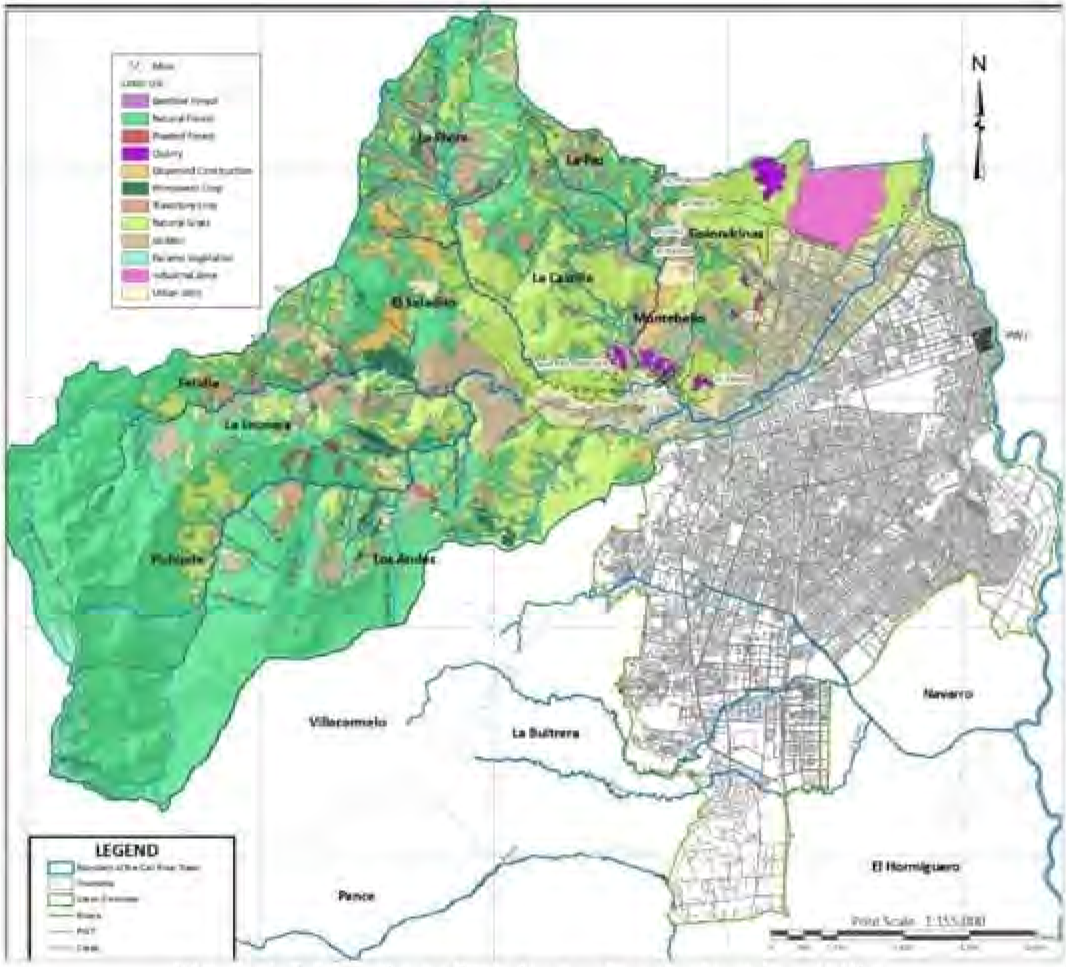


Figure 6.2 Location of mining and agricultural activities

The wastewater treatment is the most serious problem in the rural area since none of the settlements have wastewater treatment system. The coverage in 2009 for each settlement of Cali river Basin area is shown in Table 6.1.

Table 6.1 Coverage of water supply and sanitation in rural area of Cali River basin

SETTLEMENT	COVERAGE WATER SUPPLY (%)	COVERAGE DRINKING WATER (%)	TOTAL COVERAGE (%)	COVERAGE SEWER* (%)
El Saladito	43	ND	43	14
Golondrinas	SD	97	97	45
La Castilla	22	38	59	5
La Elvira	52	46	98	12
La Paz	52	46	98	4
Los Andes	38	34	72	21
Montebello	24*	ND	24*	6

Source: (Secretaria de Salud Municipal, 2009), *(UMATA, 2005)

The WWTP-C drainage system corresponds to the urban area of Cali that is connected to Cañaveralejo wastewater treatment plant. This area is located at an elevation ranging from 900 to 1.200 m above sea level, and averages temperatures of approximately 24°C.The precipitation can vary between 1.000 – 1.400 mm/year (see Figure 6.3). The WWTP- drainage area is composed by a stormwater drainage system, and an infrastructure that collect, transport and treat the wastewater produced by near of 70% to 80% of Cali citizens (Figure 6.4)

The Cañaveralejo wastewater treatment system is located between district 6 and 7. The operation of the treatment plant started in December 2001, with a primary treatment that can be run as conventional or as Advanced Primary Treatment or TPA, for its acronym in Spanish. TPA has been used for improve the efficiencies and decrease the amount of pollution load discharged to the Cauca River.

To the WWTP-C drainage system drains industries settled in urban area, both the sewer as the stormwater system. This economical sector is constituted by legal and illegal establishments. According with (Cinara, 2007), economical sector of Cali urban area have 4.857 production units, where 9,44% of them belong to the industrial sector.In data of 1990 – 1996 were found four main industrial areas: chemical industry (22%), food industry (19%), rubber industry (8%), and paper and press industry (9%). Also there are small industries of chemical, paper, rubber and graphic art located in zones of low and middle income level. The commercial activity represents the main economic activity with 60,4% of commercial establishments.And services sector with 30,1% of establishments dedicated to the delivery of services.

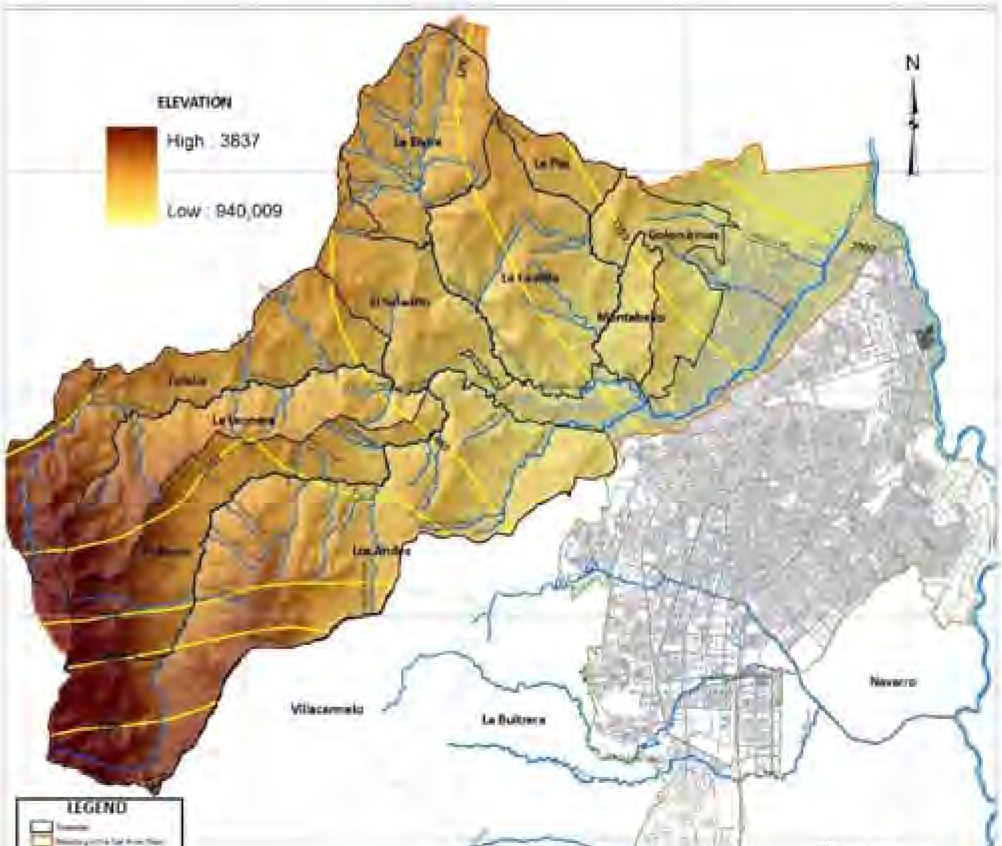


Figure 6.3 Topography and isohyets of WWTP-Cañaveralejo drainage area

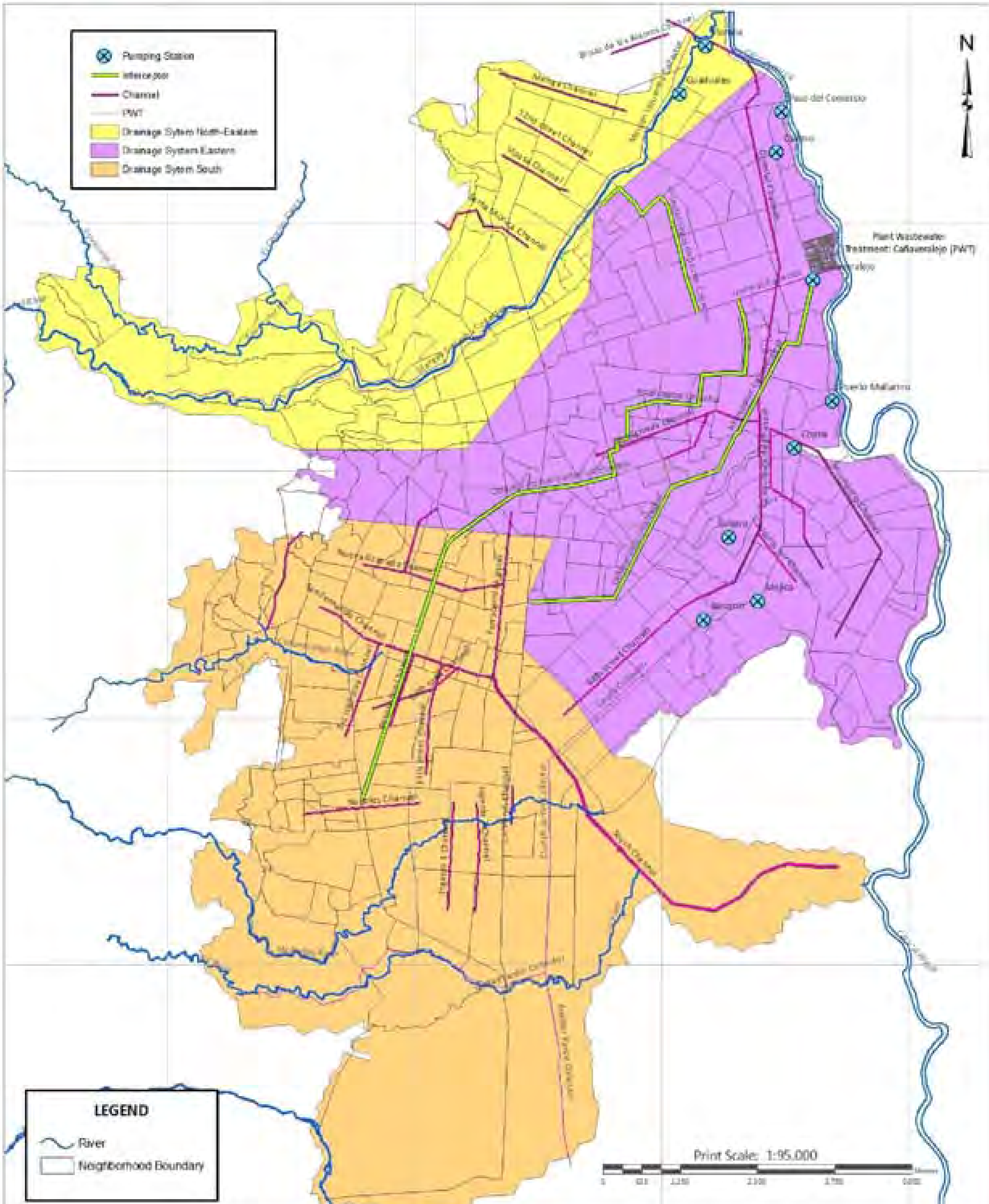


Figure 6.4 Drainage areas of sewer system of Cali city

Between 2004 and 2005 DAGMA undertook an inventory of industries located in WWTP-C drainage system. A database of environmental declaration for 162 industries was generated. Figure 6.5 shows that a high percentage of industries are located in district 2 and 3; in terms of industrial process Figure 6.6 shows a high percentage of food industries, health centers, and services located in Cali city. However, 162 industries are considered as a very low number for a city with a size as Cali.

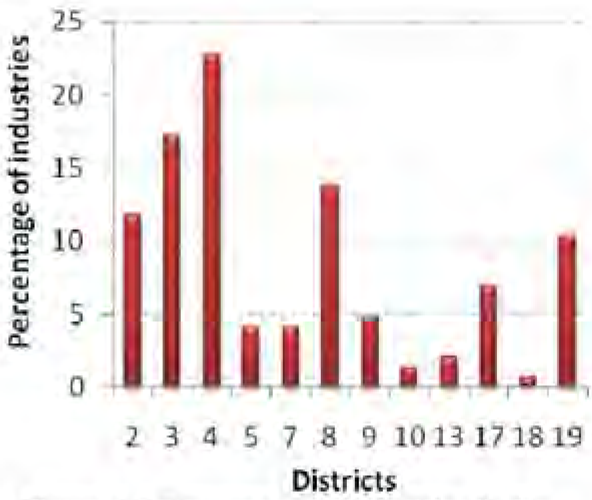


Figure 6.5 Percentage of industries in the different districts of Cali city
Source: (DAGMA, 2004)

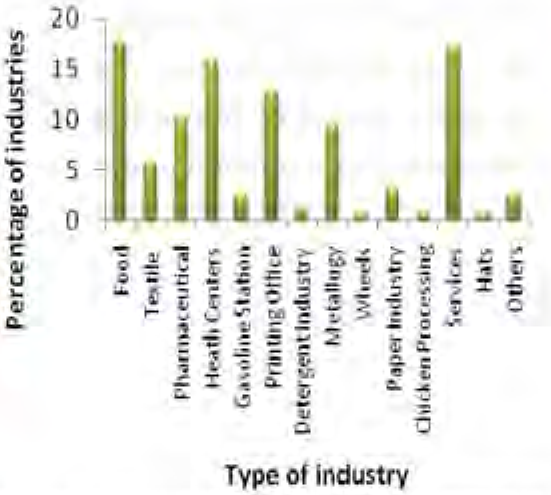


Figure 6.6 Distribution of industry types in Cali city
Source: (DAGMA, 2004)

In end of 2009, and early of 2010, DAGMA in agreement with CRPML and Cinara-Univalle as an important activity inside Learning Alliances carried out the diagnosis of 201 industries of Cali urban area, such as veterinaries, laundries, funeral services and metal-mechanic industries (Figure 6.7). Is necessary to mention that industries diagnosed in this project do not corresponds to total industries located in Cali city; just a limited number of industries of specific sectors mentioned were included. In Table 6.2 are shows the main data of industries that participated.

Table 6.2 Some characteristics of industries diagnosed by CRPML and DAGMA.

DATA	VETERINARIES	LAUNDRIES	FUNERAL SERVICES	METAL-MECHANIC INDUSTRIES
Industries legalized	152	44	116	48
Industries that participated in the project	85	21	50	48
Industries discharging in to sewage (%)	39	100	66	29
Industries discharging in to runoff channels (%)	0	0	0	
Industries with pre-treatment (%)	ND	8	58	ND
Industries with wastewater treatment	1	0	13	0

Source: (DAGMA *et al.*, 2010)

The problems related with water management in the Cali city are various, however, for understand them, is necessary to know the components, as shown above. The WWTP-C drainage system and Cali river basin has many problems both in rural area as in urban area.The water resources have been affected by uses of rivers and soil. The multiple water intakes and discharges of domestic and industrial wastewater have reduced the flow of all Cali Rivers, and have decreased the water quality. One of the main factors of this deterioration is the population located in protected areas because they discharging the domestic wastewater and solid waste into rivers.

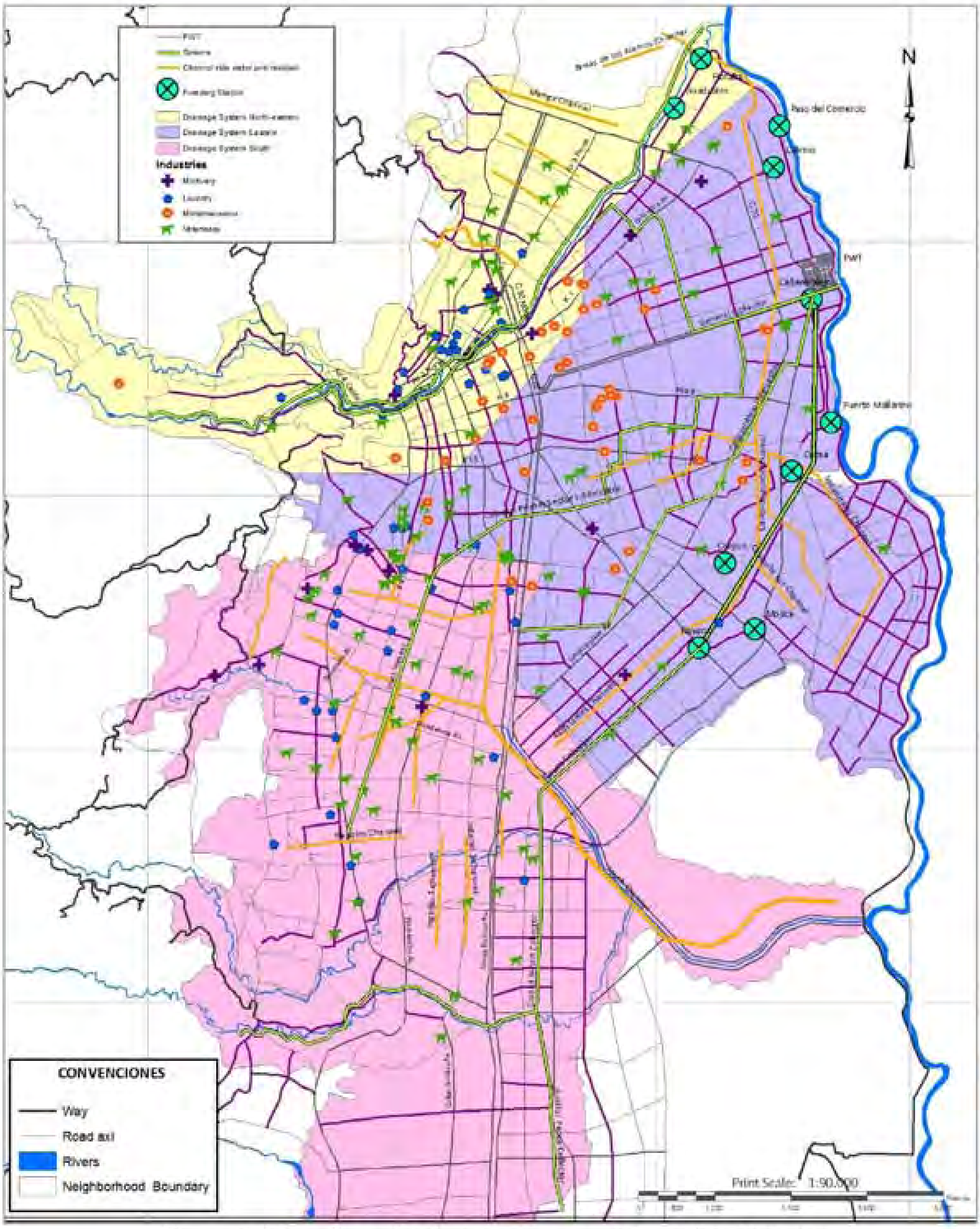


Figure 6.7 Location of industries diagnosed located in Cali city
Source: (DAGMA *et al.*, 2010)

Other practices that affected the water resources are inadequate practices of agricultural, cattle farming, coal mining, exploitation of gravel (Triturados El Chocho), and to the diminution of forest coverage in upper basin of Cali River. Additionally, the water intake of several settlements makes a strong pressure about flow of Cali River especially in summer periods, generating water scarcity. One of the most problems of Cauca River in the part of Cali city is discharges with high pollution loads from the sewer system and stormwater infrastructure (see Figure 6.8).

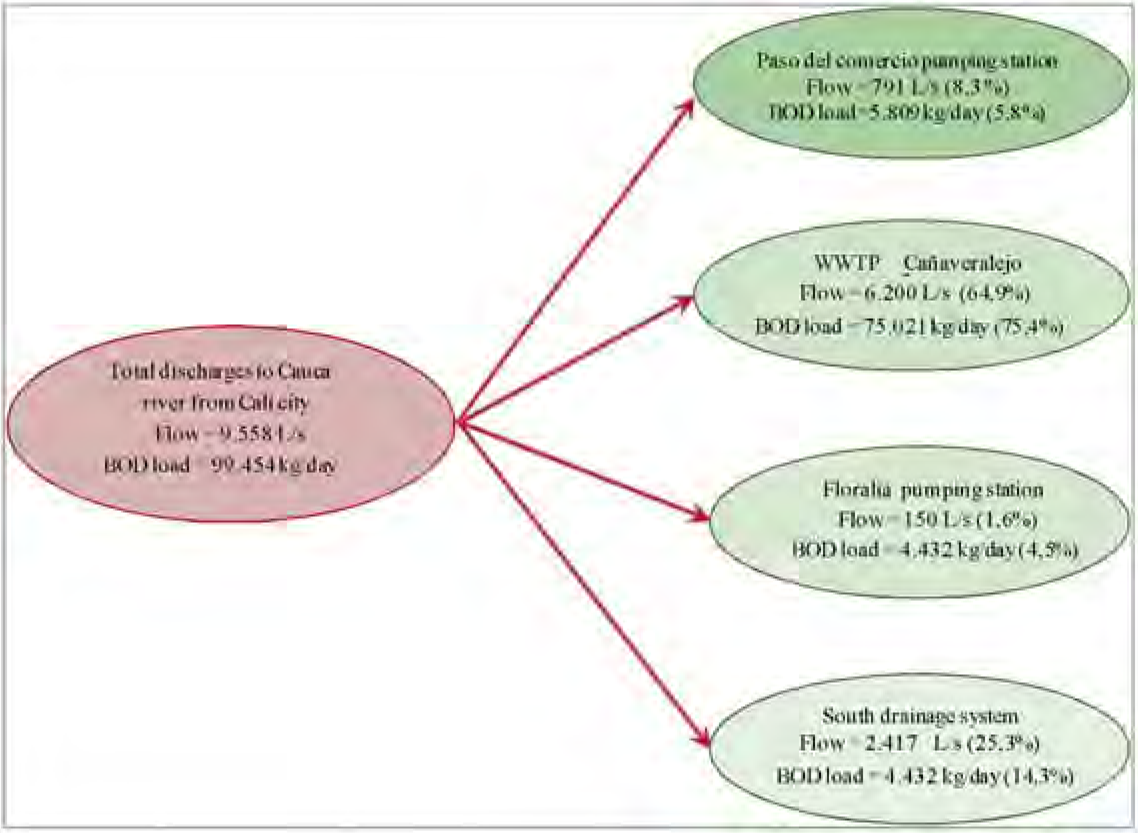


Figure 6.8 Distribution of BOD load in Cauca River from Cali city
Source: (Universidad del Valle *et al.*, 2009)

6.3 CONVENTIONAL SOLUTION

6.3.1 Description

The conventional solution for WWTP-C drainage area has an "end-of-pipe" approach, where all the investments are to improving the wastewater treatment plant Cañaveralejo. Therefore, in houses do not apply pollution prevention and minimisation, into conventional solution is expected the drinking water consumption patron will be same, could be change, but related with changes of tariff.

Primary treatment

The water management activities for Cali starting approximately in 1955 when a consulting firm proposes a first route of sewer system and three wastewater treatment systems. One of the sites proposed corresponds to the currently location of WWTP-C. Among 1963 to 1970 a big percentage of sewer system was built by EMCALI.

In 1974 with the emergence of Decreto ley 2811 de 1974, the environmental authority (CVC) encouraged to the implementation of the wastewater treatment system for region. In order to meet the wastewater discharges policy, EMCALI elaborated a feasibility study for wastewater treatment for Cali. This study shows as result that Cali city needs three wastewater treatment plants.

In 1985, a study of feasibility for domestic wastewater treatment was developed considering conventional technologies and natural methods. Among 1989 and 1991 a pre-dimensioning of

the primary and secondary treatment was carried-out for check the land requirement. Subsequently, a definitive design of primary treatment was developed, and their built was started in 1997. The design parameters of Cañaveralejo wastewater treatment plant are shows in Table 6.3.

Table 6.3 Design and operating parameters of the Cañaveralejo WWTP

Parameters	Design
Design period	2015
Area of influence (ha)	9.800
Population served (inhab)	2.060.000
Average flow (m^3/s)	7,6
Maximum flow (m^3/s)	12,24
BOD concentration (mg/L)	211
TSSconcentration (mg/L)	180

Source: (Universidad del Valle, 2010a)

In 2001, Cañaveralejo wastewater treatment plant (WWTP-C) started operation under modality of conventional primary treatment with effluent discharge into Cauca River, however, due to pressure of environmental authority to EMCALI for the meeting the standards, changed the conventional primary treatment by Advanced Primary Treatment.To the date WWTP-C is operating with Advanced Primary Treatment and discharging to Cauca River. In 2005, 38% of the total BOD load discharged to the Cauca River comes from Cali's city, with a flow of 3.417 L/s with a BOD load of 41.921 kg/day (EMCALI, 2006). In 2009, the flow in WWTP-C increased to 7,7 m^3/s, and the BOD and TSS loads reached 66.893 and 75.482 kg/day, respectively (DAGMA, 2009).

The wastewater from Cali's city is transported to WWTP-C through of the central collector, Aguablanca, Cañaveralejo, and Navarro pumping stations. The components of the plant are described in Table 6.4 and can be seen in Figure 6.9.

Table 6.4 Components of wastewater treatment plant of Cañaveralejo

COMPONENTS	DESCRIPTION
Coarse screens	There are two coarse screens mechanical of 2 by 2,6 meters, height and wide, respectively. The bars separation is 10 cm.
Pumping station	This component const of four screw pumps with a nominal capacity of 2 m^3/s.
Flow mixing tank	In this tank the flows coming from several sewage collectors are mixed. There are a pH measuring system, and two bypasses that deviated excess of wastewater during the rainy season.
Fine screens	The objective of this component is retains the particles greater than 2,5 cm.
Aerated grit chambers	This consists of six aerated chambers with a volume of 394 m^3, where the air is injected through of diffusers
Primary sedimentation tanks	Eight circular primary settling tanks, with 47,5 m of diameter and 4,20 m of height.
Sludge line	The sludge line is composed by thickener, aerobic digester, sludge dewatering, and a thermal drying system in construction. Finally, the dry sludge is disposed in a mono-fill.
Odor control	This system consists in soil beds that make pass the gas that produce bad odor through a biologic filters.
Energy generation	The biogas produced during the anaerobic digestion of the sludge obtained through the wastewater treatment processes, is used as fuel in two sets of engine-generators with purpose to generate the electricity for the internal use of the WWTP-C.

Source: (EMCALI, 2006)

Figure 6.9 Components of Cañaveralejo Wastewater Treatment Plant

Secondary treatment

Since 2005, the Universidad del Valle through the EIDENAR research group has been developing several projects related to wastewater treatment in Cali, composting of biosolids, and reuse of WWTP-C effluent. In the wastewater treatment topic, researches have been focused in the evaluation of different technologic alternatives to conventional level.

The project developed by (Universidad del Valle, 2009a), was divided in two phases. The first phase the wastewater produced by Cali city was characterized to determine the potential of implementing a biological treatment as a technological option. Also, the suspended and attached growths technologies were evaluated on laboratory scale, and contact stabilization option on pilot scale. The experimental system reached efficiencies higher than 90%, 90% and 95% for COD, BOD and TSS, respectively.

In second phase, the conventional activated sludge and contact stabilisation alternatives were evaluated on a pilot-scale. The pilot-scale results show that contact stabilisation offers more benefits that the conventional activated sludge option. Additionally, in this research the requirement area was calculated with a pre-dimensioning Table 6.5, and the operation and maintenance costs were calculated for the two options but to pilot scale (€ 23.293 for contact stabilisation and € 22.604 for activated sludge).

Table 6.5 Volume required and treatment area.

Characteristics	Contact Stabilisation	Conventional
HRT (h)	4,95	5,0
Design Flow (m^3/s)	7,6	7,6
Total volume (m^3)	67.962	136.800
Global area (ha)*	3,00	4,38
Available area (ha)	11,3	11,3

*Include sedimentation secondary
Source: (Universidad del Valle, 2009a)

Although there are many technological options to secondary treatment that could be applied for to complement WWTP-C, there are an important limiting factor, requirement of land. Among 1989 and 1991, based in a pre-dimensioning carried-out by NITOGOI consortium, EMCALI acquired a piece of land of 22 ha (Universidad del Valle, 2009b). Since this date,

the land available for secondary treatment implementation is limited. There are land available located in the other side of the Cauca River, terrain used for sugar cane production, however, the negotiation and purchase could take much time and money. In this way, is indisputable that contact stabilisation or activated sludge are technologies with great possibilities of be implemented as secondary treatment for Cali city, in term of land requirement.

For all reasons presented before, the conventional alternative to implement as secondary treatment in WWTP-C will be activated sludge, in modality of contact stabilisation. In the contact stabilisation is used two separate tanks or compartments for the treatment of the wastewater and stabilisation of the activated sludge. The stabilised activated sludge is mixed with the influent wastewater in a contact zone. In stabilisation zone, return activated sludge is aerated (Figure 6.10) (Metcalf & Eddy, 2003).

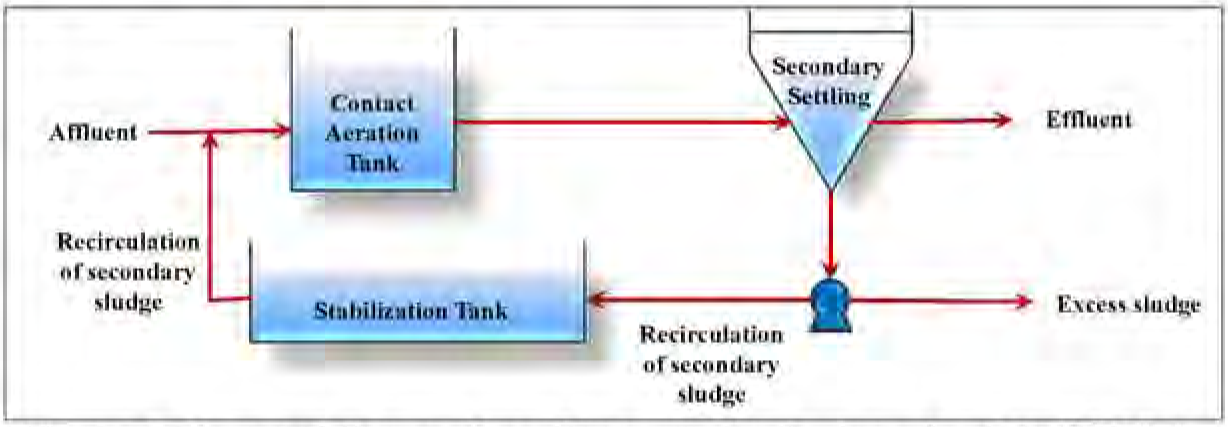


Figure 6.10 Conceptual diagram of secondary treatment technology selected for WWTP-C

The contact stabilization process is quite effective in the removal of colloidal and suspended organic matter. Compared to the conventional activated sludge, the contact stabilization process has greater capacity to handle shock organic loadings because of the biological buffering capacity of the sludge re-aeration tank.The process also presents greater resistance to toxic substances in the sewage as the biological mass is exposed to the main stream containing the toxic constituents only for a short time (Punmia *et al.*, 1998).

According the pre-dimensioning undertaken by (Universidad del Valle, 2010b), the contact stabilization system would consist of eight lines of treatment, with 8 tanks of aeration, 8 secondary settling tanks, and 8 stabilisation tanks (see Table 6.6 and Figure 6.11).

Table 6.6 Summary of volume tanks projected for contact stabilization option

DATA	AERATION TANK	STABILISATION TANK	SECONDARY SETTLING
Volume (m^3)	2.820	6.184	9.007
Number of tanks	8	8	8

Source: (Universidad del Valle, 2009a)

In summary, the conventional solution will be composed by: advanced primary treatment, activated sludge in contact stabilization modality, and effluent treated will be discharge into Cauca River.

Figure 6.11 Location of conventional solution in WWTP-C area

6.3.2 Initial investment costs

Some results of research developed by (Universidad del Valle, 2010b) are the initial investment and operation and maintenance costs for activated sludge technology. The initial investment estimated for contact stabilisation in 2009 was € 45.023.659 and the main items of this cost are shown in Table 6.7 (Punmia *et al.*, 1998; Universidad del Valle, 2010b).

Table 6.7 Initial investment of activated sludge as secondary treatment proposed for complement WWTP-C

ACTIVITY	AMOUNT	UNIT VALUE (EUROS)	TOTAL VALUE (EUROS)
Generals	1	24.216	24.216
Contact reactor	8	395.524	3.164.195
Stabilisation reactor	8	781.033	6.248.270
Secondary settling	8	954.162	7.633.296
Tank 1	6	63.353	380.120
Tank 2	2	105.855	211.710
Tank 3	4	97.407	389.628
Tank 4	4	22.595	90.383
Pumping stations	12	167.815	2.013.790
Hydraulic civil works	1	129.205	129.205
Equipment	1	2.785.514	2.785.514
Complementary civil works	1	1.532	1.532
Electric installations	12	258.086	3.097.043
Others	1	18.854.751	18.854.751
TOTAL (Euros)	45.023.659		

Source: (Universidad del Valle, 2010b)

6.3.3 Operation & maintenance costs

In Guidelines for the safe use of wastewater, excreta and greywater focused in agricultural use published by WHO (Otterpohl *et al.*, 2008), the range for operation and maintenance costs for contact stabilisation is 4,0 – 8,0 US dollars/in-habitants per year, if Cali city will be connected near to 2.060.000 inhabitants, the O&M cost per year assuming 6,0 US dollars /inhabitants per year will be €9.980.000 approximately.

6.4 SOLUTION WITH SWITCH APPROACH

6.4.1 Pollution prevention and minimisation

6.4.1.1 Description of the options

The possible alternatives for pollution prevention and minimisation for WWTP-C drainage zone extracted to the literature are presented in Table 6.8. In summary, the strategies for household are: low consumption devices, rainwater harvesting, and greywater reuse.

The amount of alternatives is very high for carry-out the selection process; therefore, this amount should be reduced through of a first filtration of alternatives.This first filtration is based in technical and social aspects through three indicators: market availability, effluent quality requirements and social acceptance of low consumption devices. The market availability refers to technologies available in our country, that is to say, technologies that can be purchase easily in colombian market.Some low consumption devices are not available in the colombian market, such as Urine Diverting Dry Toilet (UDDT) and Urine Diverting WC models, therefore were eliminated of selection process.

Table 6.8 Pollution prevention and minimisation strategies

LOW CONSUMPTION DEVICES	Simple practices	
	Flushing toilets – 6 L	
	Dual flush toilet – 6 and 4 L	
	Flushing toilets – 2,3 L or high efficiency toilets	
	Urine Diverting Dry Toilet (UDDT)	
	Urine Diverting WC models	
RAINWATER HARVESTING	Rainwater harvesting simple system without treatment	
	Rainwater harvesting with treatment	Pre-treatment with greenroof
		Chlorination
		Rapid sand filter
		Slow sand filtration (Bio-sand filter)
		Activated carbon filter
		Ceramic water filter
		Metal membrane filter
		Rotating disc filter
GREYWATER REUSE SYSTEM	Direct reuse system with pre-treatment	Grease trap + screens
		Sedimentation
	Mulch bed system	
	Greywater reuse system with treatment	Cartridge filter
		Sand filter
		Chlorination
		UV disinfection
		Membrane filtration
		Activated carbon filter
		Electro-coagulation
		Coagulation
		Ion exchange
		Rotating Biological Contractors (RBC)
		Membrane Bioreactor (MBR)
		Sequencing Batch Reactor (SBR)
		UASB
		Fluidized bed reactor
		Constructed Wetland

Source: (Li *et al.*, 2009)

The effluent quality requirement depends of uses possible in household, for the rainwater harvesting and the greywater reuse systems proposed to the study area, the effluent will be used for garden irrigation, flushing the toilet, house cleaning, and for wash clothes.In this way, the effluent quality is for non-potable uses; therefore, the quality is less restrictive compared with an effluent used for drinking, shower, and in the kitchen.In terms of

technologies whose effluent quality is very high or for potable uses such as:metal membrane filter and rotating disc filter for rainwater harvesting, UV disinfection, membrane filtration, electro-coagulation, coagulation, ion exchange, RBC, MBR, SBR, UASB, fluidized bed reactor for greywater reuse, are eliminated of selection process.

Although the alternatives proposed must not meet high quality standards, should meet a minimum quality for domestic reuse due topolluted from roof in case of rainwater harvesting, or in case of greywater could have bacteriological pollution (Ochoa, 2007), being a risk for human health. Therefore the alternatives without treatment are eliminated.

The social acceptance of low consumption devices was measured through a survey (Appendix 2) carried-out in August, 2010. Due to that WWTP-C drainage area is composed by existing housing; the interview was focused on what low consumption device (flushing toilet 6L, dual flush 4 – 6L, and flushing toilets 2,3L) the community members would select.

The results were forceful, showing clearly a great acceptance of the high efficiency toilets or flushing toilets of 2,3 L (see Figure 6.12). Additionally, the purchase intention also was identified with 3 payment options: direct payment, pay by installments or subsidy payment. To three payment options had good acceptance, therefore there are great possibilities to be implemented in Cali city (see Figure 6.13). For these reason, the flushing toilet 6L and dual flush toilet were removed o the technological options.

Figure 6.12 Social acceptance of low consumption devices by citizens of urban area of Cali city

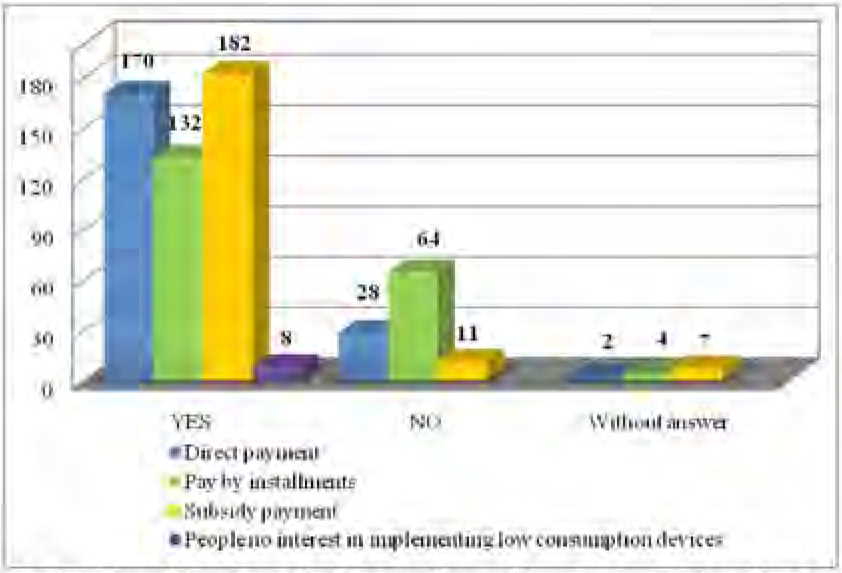


Figure 6.13 Purchase intention flushing toilets of low consumption by Cali citizens

Finally, the technologies pre-selected for study area and their combination are shows in Figure 6.14. The results of technological options combination are 9 strategies that will be ranked in the following section.

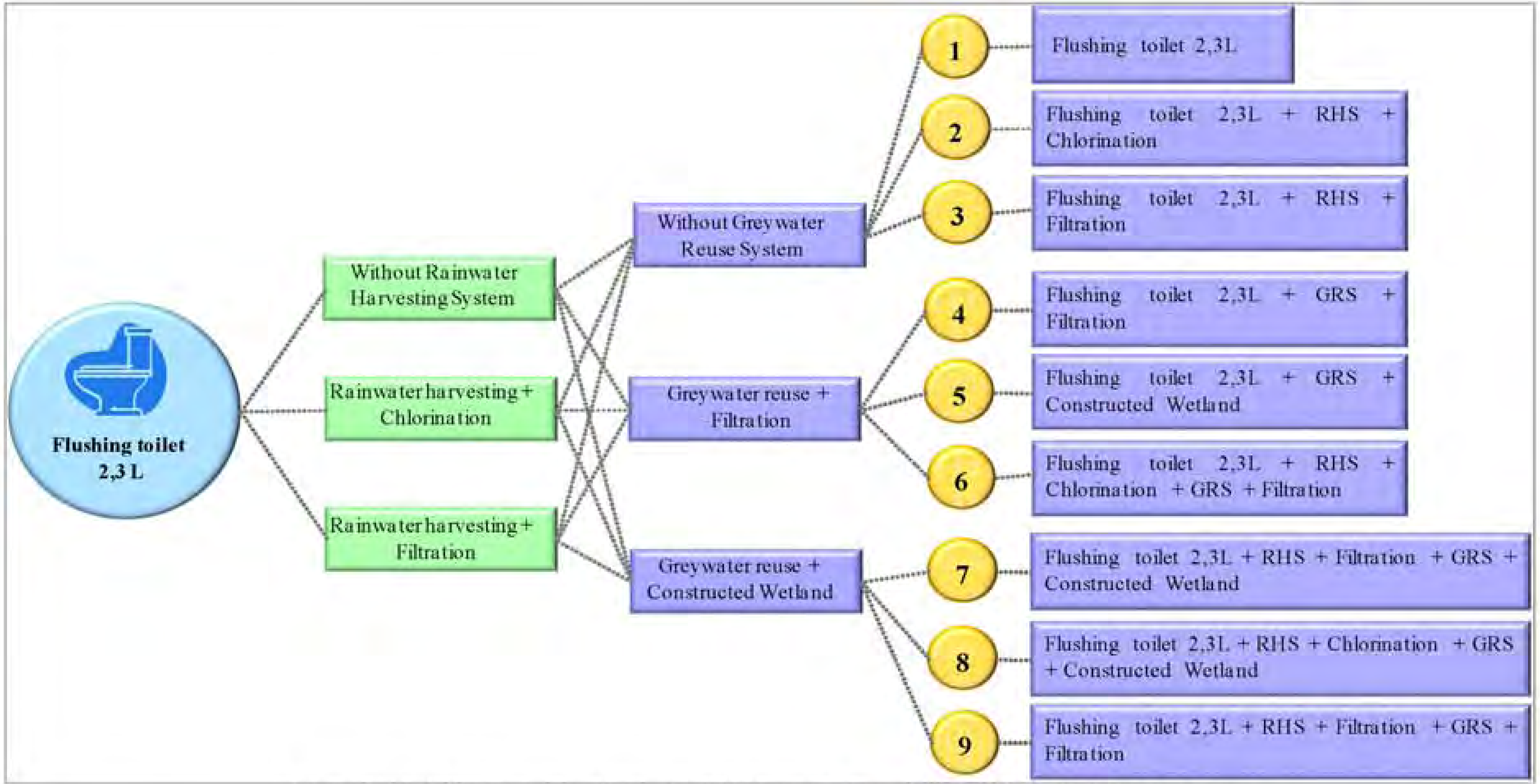


Figure 6.14 Pollution prevention and minimisation alternatives for WWTP-C drainage area

6.4.1.2 Selection

The selection of alternative for pollution prevention and mininimisation to WWTP-C drainage system will be based on the methodology of analytic hierarchy process (AHP) and grey relational analysis (GRA) (Zeng *et al.*, 2007). According with methodology, each criterion is valuated with indicators that can be quantitative or qualitative, and represents the criteria. Basically, selection of indicators started with a literature revision, of the indicators of literature applicable to our case, are selected the indicators with available information, and relevant for pollution prevention alternatives selection. The indicators are presents in Table 6.9.

Table 6.9 Criteria and indicators for selection of pollution prevention alternative forWWTP-C drainage area

CRITERIA	INDICATOR	QUALIFICATION
Economic	Initial investment	Initial investment includes the materials, manpower, and the modifications inside households for alternative implementation, among others.
	Operation & maintenance	O&M cost was determinate identifying the main activities, the frequency, and personal necessary for carry-out the activity.
Technical	Complexity level	The qualification of this indicator was based in consult undertaken to professionals of working group
Social	Institutional support	This indicator was measured through questionnaires for identify the knowledge institutional low consumption devices, rainwater harvesting systems and greywater reuse systems, additionally to know institutionally, if would focus its efforts in implement the pollution prevention alternatives.
	Social acceptance	The qualification of this parameter was calculated through of analysis of data collected in questionnaires applied to citizens located in existing zone of Cali in August, 2010.
Environmental	BOD removed and TSS removed	The BOD and TSS removed indicator was calculate with BOD and TSS concentration data measured to WWTP-C inlet, and flow discharged to sewer with the pollution prevention implemented. These indicators are presented in term of load (kg/m^3).
	Drinking water saved	This indicator was calculated with drinking water consumption average per household, and water consumption by alternative (see Table 6.10)

Table 6.10 Drinking water consumption per use in household

ACTIVITY	L/per-day	m^3/month
Drinking	5,5	0,66
Food preparation	10	1,2
Drinking and food preparation	10	1,2
Washing dish	10	1,2
Shower	10	1,2
Washing hands and teeth	4	0,48
Flushing toilet*	70	8,4
House cleaning	15	1,8
Laundry	20	2,4
Garden irrigation	8,0	0,96
Total	162,5	20

Source: (Cinara, 2007)

Table 6.11 Indicators used for technology selection of pollution prevention alternatives for WWTP-C drainage area

Alternative	ECONOMICS		TECHNICAL	ENVIRONMENTAL			SOCIAL	
	Investment (Euros)	Costs/year (Euros)		Water Saved (m^3/year)	BOD Remov (kg/year)	TSS Remov (kg/year)	Institutional Acceptance	Social Acceptance
T1	160,0	0,0	0,1	84,2	30,2	26,0	0,3	0,97
T2	706,0	42,7	0,5	134,6	18,6	16,0	0,6	0,95
T3	866,0	42,7	0,5	134,6	18,6	16,0	0,6	0,95
T4	897,5	42,7	0,5	133,9	18,8	16,2	0,4	0,95
T5	897,5	42,7	0,5	133,9	18,8	16,2	0,4	0,95
T6	1443,5	85,4	0,9	162,7	12,2	10,5	0,2	0,92
T7	1603,5	85,4	0,9	162,7	12,2	10,5	0,2	0,92
T8	1443,5	85,4	0,9	162,7	12,2	10,5	0,2	0,92
T9	1603,5	85,4	0,9	162,7	12,2	10,5	0,2	0,92

In is showed the indicators by criteria and their values. The criteria and indicators were identified; therefore, the following step is illustrating the hierarchy system (Figure 6.15).

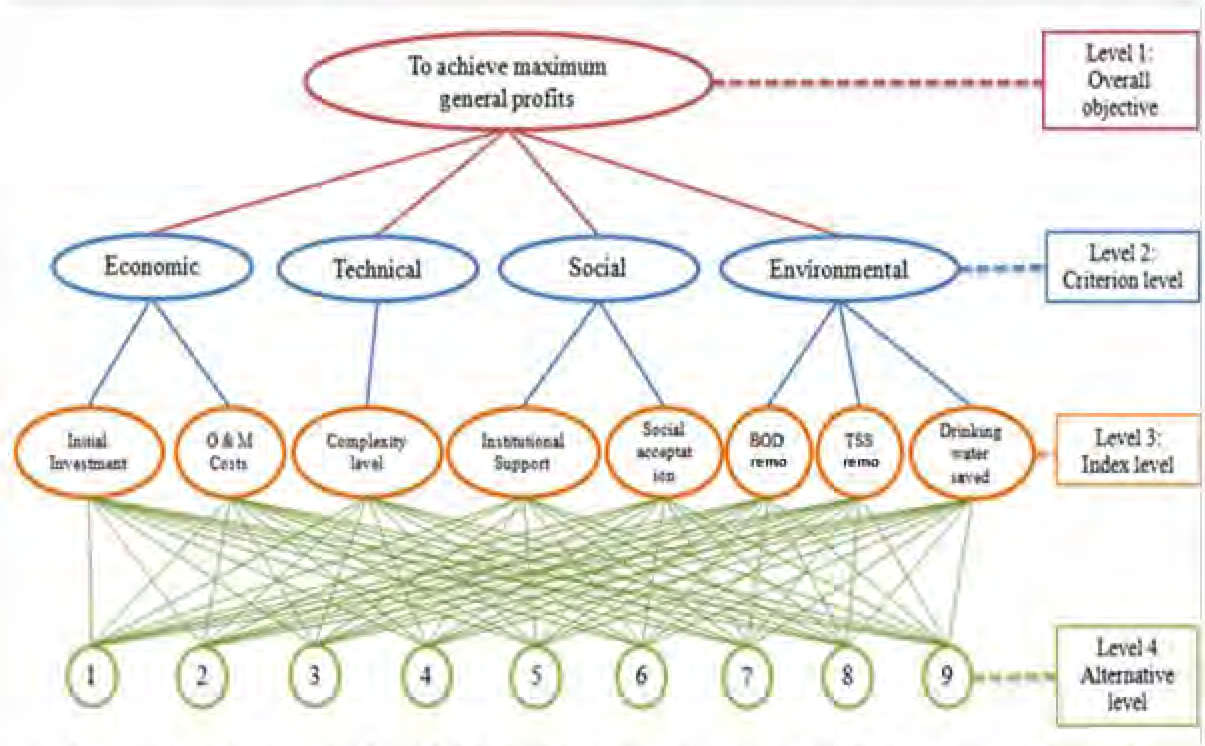


Figure 6.15 Conceptual model to technology selection for pollution prevention and minimisation strategies of WWTP-C drainage area

With a conceptual model clearly, is necessary identifying the weights of criteria.These weights were quantified with decision makers through structured interviews.The results shown that decision makers identifies to their judgments, that criteria with highest importance is the environmental, the technical and social criteria have the same importance level and the economical criteria occupy the lowest importance level according to consultation (see Table 6.12). To this level of the selection process, where each alternative has been characterised, the normalisation technique was applied to prevent logic errors and for compare in unit terms, therefore should be evaluated as a multi-objective problem, where each indicator have an objectivethat can be maximising or minimising (see Table 6.12).

Table 6.12 Criteria weights for pollution prevention alternatives selection

CRITERIA	INDICATOR	WEIGHT	OBJECTIVE
Economic	Initial investment	0,19	Minimise
	O&M costs		Minimise
Technical	Complexity level	0,25	Minimise
Social	Institutional support	0,25	Maximise
	Social acceptance		Maximise
Environmental	Drinking water saved	0,32	Maximise
	BOD removed		Maximise
	TSS removed		Maximise

The first normalisation data and grey relational coefficients are presented in Table 6.13. In order to improve the data comparability, the primary grey relational coefficient is normalised and secondary grey relational coefficient weighted by criteria is obtained (see Table 6.14).

Table 6.13 Normalized data of each option and the resultant primary grey relational coefficients for index level

ALTERNATIVE		ECONOMICS		ENVIRONMENTAL			TECHNICAL	SOCIAL	
		O&M costs	Initial investment	Drinking water saved	BOD removed	TSS removed	Complexity level	Institutional support	Social acceptance
NORMALISED DATA	1	1,00	1,00	0,52	1,00	1,00	1,00	0,97	1,00
	2	0,23	0,23	0,83	0,62	0,62	0,20	1,00	0,91
	3	0,18	0,23	0,83	0,62	0,62	0,20	1,00	0,91
	4	0,18	0,23	0,82	0,62	0,62	0,20	0,78	0,96
	5	0,18	0,23	0,82	0,62	0,62	0,20	0,78	0,96
	6	0,11	0,12	1,00	0,40	0,40	0,11	0,45	0,56
	7	0,10	0,12	1,00	0,40	0,40	0,11	0,45	0,56
	8	0,11	0,12	1,00	0,40	0,40	0,11	0,45	0,56
	9	0,10	0,12	1,00	0,40	0,40	0,11	0,45	0,56
	1	1,00	1,00	0,48	1,00	1,00	1,00	0,93	1,00
	2	0,37	0,37	0,72	0,54	0,54	0,36	1,00	0,83
	3	0,36	0,37	0,72	0,54	0,54	0,36	1,00	0,83
	4	0,35	0,37	0,72	0,54	0,54	0,36	0,68	0,92
	5	0,35	0,37	0,72	0,54	0,54	0,36	0,68	0,92
	6	0,34	0,34	1,00	0,43	0,43	0,34	0,45	0,50
	7	0,33	0,34	1,00	0,43	0,43	0,34	0,45	0,50
	8	0,34	0,34	1,00	0,43	0,43	0,34	0,45	0,50
	9	0,33	0,34	1,00	0,43	0,43	0,34	0,45	0,50

Table 6.14 Normalized data of each option and the resultant secondary grey relational coefficients for index level

CRITERIA	NORMALIS. PRIM. GREY RATIONAL COEFFICIENT									SECONDARY GREY RATIONAL COEFFICIENT								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
ECONOMICS	0,34	0,91	0,92	0,93	0,93	1,00	1,00	1,00	1,00	0,33	0,79	0,81	0,82	0,82	0,99	1,00	0,99	1,00
ENVIRONMENTAL	1,00	0,78	0,78	0,77	0,77	0,78	0,78	0,78	0,78	1,00	0,60	0,60	0,59	0,59	0,60	0,60	0,60	0,60
TECHNICAL	0,34	0,93	0,93	0,93	0,93	1,00	1,00	1,00	1,00	0,33	0,83	0,83	0,83	0,83	1,00	1,00	1,00	1,00
SOCIAL	0,74	1,00	1,00	0,78	0,78	0,68	0,68	0,68	0,68	0,56	1,00	1,00	0,60	0,60	0,51	0,51	0,51	0,51

The largest grey relational grade indicates that an alternative obtained the maximum general benefits compared with other options. Of this way the alternatives included in pollution prevention process for WWTP-C drainage area are ranked. The rank of alternatives is shown in Figure 6.16.

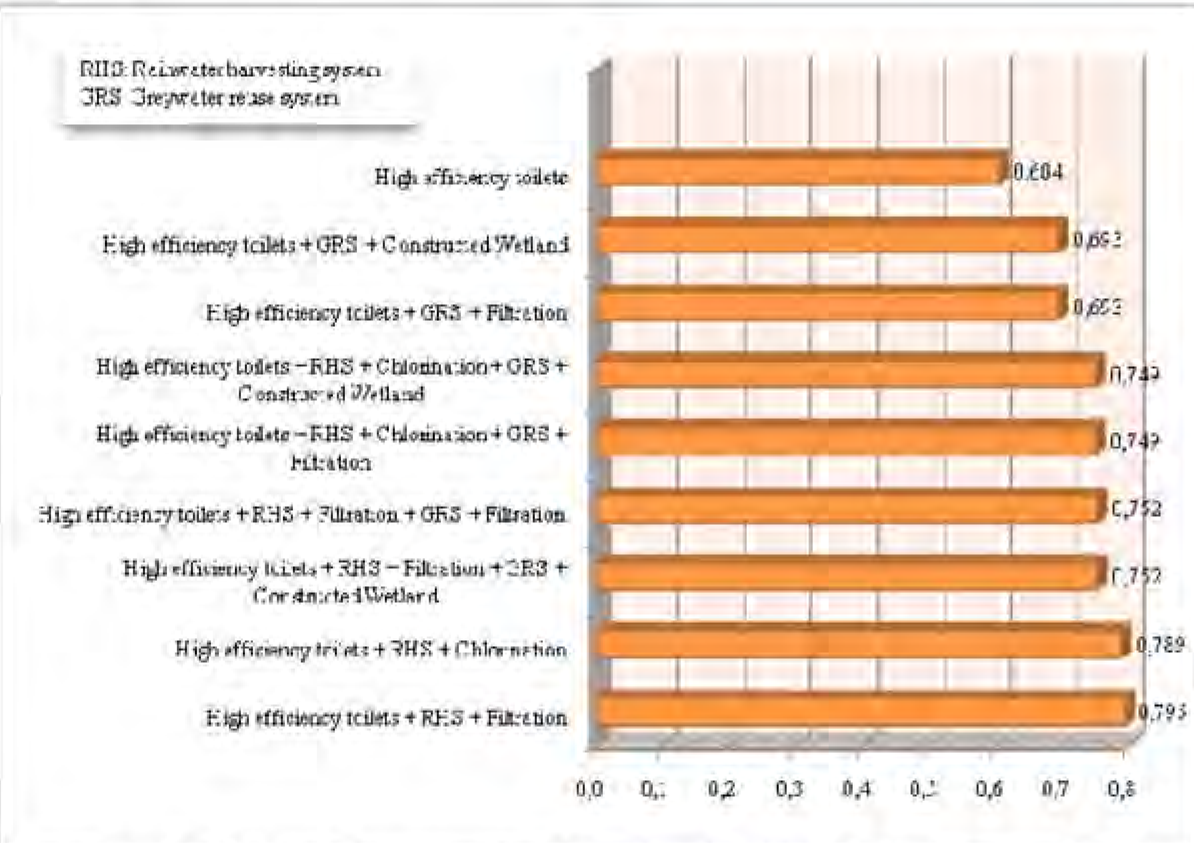


Figure 6.16 Rank of pollution prevention alternatives for WWTP-C drainage zone based on the AHP and GRA methodology

The results of selection process for pollution prevention and minimisation using AHP and GRA methodology shows that the alternatives have results with minimal differences; the variation is between 0,604 and 0,795. The reason of these results is related with weight assigned to criteria, since the data is very close between them. If is affect the criteria weight, for example, to the technical criterion is assigned a big weight, the options with major rank are 6, 7, 8 and 9, with minimal differences among them. The results are similar if a big weight is assigned to other criteria.

However, the results used for selection of pollution prevention and minimisation options for urban area of Cali city, are the values found using weight criteria assigned by experts. According with rank, the options is divided in three blocks according to value of integrated grey rational coefficient; in the first block is integrate two alternatives composed by low consumption device and rainwater harvesting system, in the second block there are four alternatives and are the resulted of combination of low consumption devices, rainwater harvesting and greywater reuse system. For last, the third block is integrated by an alternative that propose the implementation of low consumption devices or the combination of low consumption device and greywater reuse system.The option selected according with results of integrated grey rational coefficient is flushing toilet of 2,3 L, a rainwater harvesting system

with filtration, since offered highest water quality compared with option composed by flushing toilet of 2,3 L, and a rainwater harvesting system with chlorination.

For the analysis comparative of conventional solution versus innovative or SWITCH solution will be used the alternatives with highest grey relational grade: high efficiency toilets with rainwater harvesting system with filtration. Is necessary clarifying that although the SWITCH solution proposes the alternative mentioned before, are not closed for rest of alternatives.

6.4.1.3 Estimation of initial investment

The alternative for pollution prevention and minimisation proposed for Cali city is flushing toilet of 2,3 L with rainwater harvesting system with filtration as treatment, according with selection process. The determination of initial investment was undertaken taking as base the data of costs of projects carried-out in the region and related with rainwater harvesting. With base in these projects the main cost items were identified and are shown in Table 6.15. Regarding with high efficiency toilets, the cost was supplied by an enterprise that distributed the product in Cali (GBA, 2010).

Table 6.15 Initial investment of pollution prevention alternatives proposed for WWTP-C drainage area.

COMPONENTS RAINWATER HARVESTING	COSTS (Euros)
High efficiency toilet	160
Pipe of transport	230,00
Storage Tank (1 m^3)	109,96
Internal hidraulic network	166,00
Small Pump	40,00
Rapid Sand Filter	160,00
TOTAL OPTION 3	705,96

6.4.1.4 Estimation of operation and maintenance costs

Operation and maintenance costs were calculated initially identifying the main O&M activities, personal requirement, electric energy consumption and chemical inputs. Once main items of O&M cost are identified, using the price list of regional government, these are calculated per year. The system selected can be operates by housing residents, since is a system easy of operate, therefore the personal costs for the operation are negligible. However, for the operation of the systems that requires pumping is necesary energy. Therefore, the cost of energy per year used for system operation is €31,5, calculated assuming a operation of two hours per day.On the other hand, the main activities of maintenance are: storage tank cleaning and the filter media. For estimation of these costs, requires a person with a dedication of 4 hours per year, with a cost of €33,6. Finally, the costs of O&M for option selected are €64,1.

6.4.2 Wastewater treatment and effluent reuse

6.4.2.1 Description of the options

Two of WWTP-C complementary treatment technological options are pre-dimensioned in the SWITCH project framework (Universidad del Valle, 2010a), considering as treatment objective, the agricultural reuse, emphasizing natural application methods given their proven efficiency for the proposed method objective (Moscoso *et al.*, 2002a) and based on the

conceptual framework of the project. Therefore, four technological options were finally proposed, that arose from the combination of different wastewater treatment units and final effluent disposition.

This universe of technologies considered the implementation of agricultural reuse with the WWTP-C effluent without complementary secondary treatment, given that previous investigations by Universidad del Valle indicated that the effluent of this current system may be used according to Agrological Quality criteria established by FAO in (Ayers *et al.*, 1987). Similarly, the WWTP-C effluent reuse was considered in combination with the complementary activated sludge in the contact stabilization modality, option described under numeral 6.2.2 as conventional solution.

The two proposed options with natural method implementation included the current WWTP-C advanced primary treatment combined with Facultative Pond technologies and the WWTP-C combined with horizontal sub-surface constructed wetland.

From the formulated technological options, the option of implemented the agricultural reuse with the WWTP-C effluent without complementary secondary treatment was excluded (advanced primary treatment), given that under the directions of (WHO, 2006). Regarding microbiologic quality, exhibits use restrictions due to the high degree of total Coli forms E.coli and helminth eggs. Furthermore, it does not comply with the minimum efficiency requirements of 80% removal of organic load required by the local norms (CVC, 1984).

The technological pre-dimensioning options considering natural methods was carried out based on proposed methodologies by (Kadlec *et al.*, 1996; Madera *et al.*, 2003b; Mara, 2003; Mara, 1987; Mara, 2006; Mara *et al.*, 2007; Mara *et al.*, 2001; Peña, 2002,2008; Reed *et al.*, 1995).The option pre-dimensioning contemplating the activated sludge technology was carried out based on scaling of the pilot plant performed by Universidad del Valle investigations (Universidad del Valle *et al.*, 2008). Table 6.16 shows the dimensioning and requirements of total area for each WWTP-C secondary treatment technological option.

Table 6.16 Dimensioning and area requirement of WWTP-C.complementary treatment technologies

T	Tecnology (T)	No. of Proposed Units	Lenght (m)	Width (m)	Depth (m)	Total Area (ha)
T1	Activated mud in the stabilization modality by contact	1	-	-	-	3
T2	FacultativePonds	3	2.153	431	1,5	278,1
T3	Subsurface horizontal flow built marsh soils	4	1.575	225	0,6	141,8

Activated sludge in the contact stabilization modality (T1)

This alternative is composed by the current WWTP-C primary treatment, the secondary treatment proposed, consists in activated sludge in the contact stabilization modality (Figure 6.17).

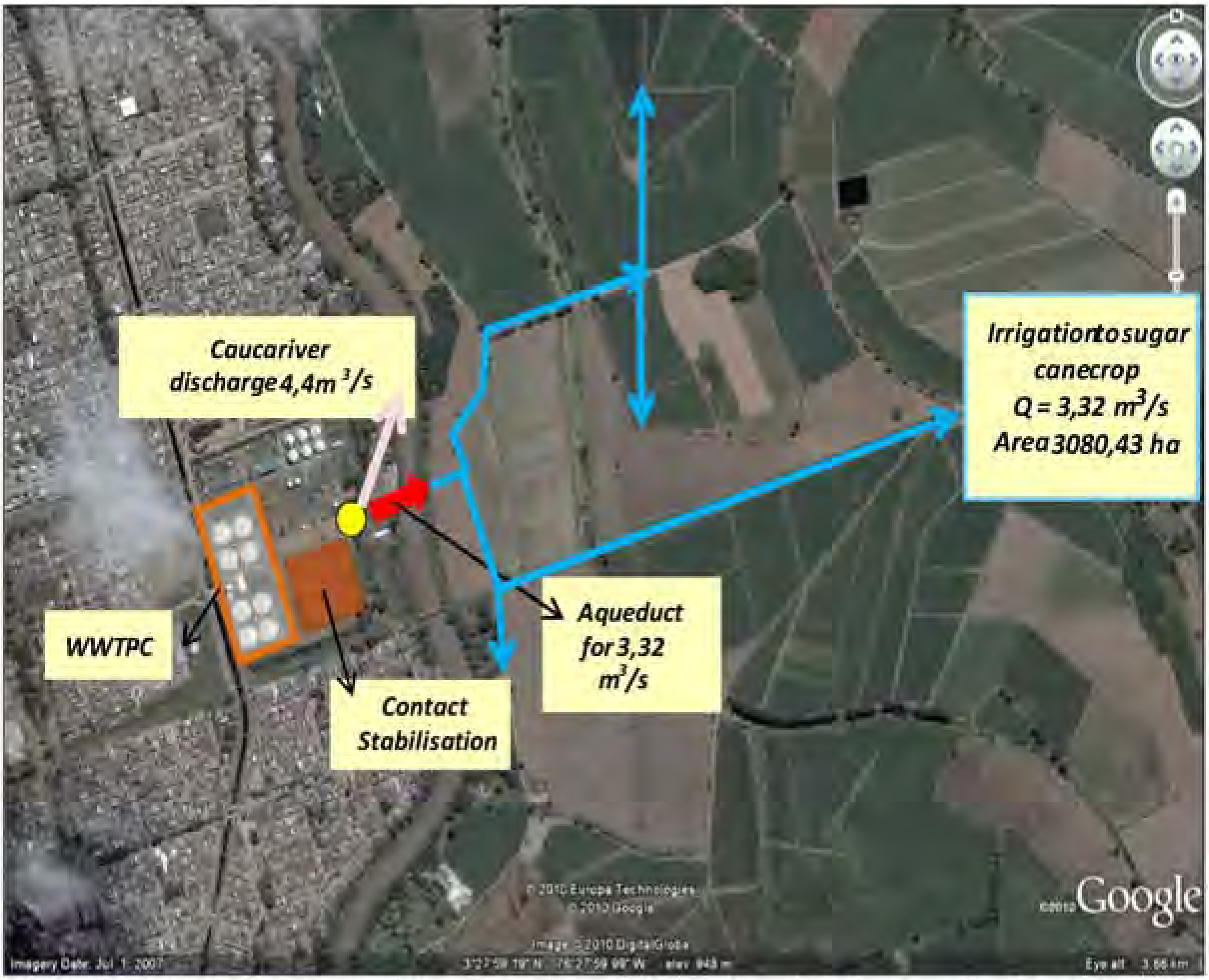


Figure 6.17 Wastewater reuse alternate scheme with activated sludge as secondary treatment

This alternative was proposed to improve the WWTP-C efficiency through the application of a conventional secondary treatment, for achieve a BOD and TSS removal of 80%, according to local norms (CVC, 1984). In research of (Universidad del Valle *et al.*, 2008)this alternative was evaluated to pilot scale.

FacultativePonds (T2)

This alternative is made out of the current WWTP-C primary treatment and facultative ponds as secondary treatment (Figure 6.18). The design methodology for facultative pond was described by Mara (2003) considering as initial data and design parameters, the effluent characterization of WWTP-C – Primary Treatment (see Table 6.3 of item 6.3.1).

In terms of functioning principle and pollution removal parameter, facultative ponds are designed to remove BOD under aerobic conditions; however, the also contribute to removal of pathogenic through long periods of hydraulic retention allowing sedimentation of Helminth eggs and bacteria mortality, associated to solar energy ultraviolet rays and increase of pH for algae activities (Oakley, 2005).

Figure 6.18 Wastewater reuse alternative scheme with facultative Ponds as secondary treatment

Facultative ponds exhibit removal of BOD_5 efficiencies of 60% to 70% at temperatures of 20 to 25°C with hydraulic retention times of 4 to 6 days (Peña *et al.*, 2004) removal of SS is 80% and SSV removal of 50% (Romero, 2005). It is possible to remove up to 2,0 to 2,5 log of fecal coli forms and 2,0 to 3,5 log of E. Coli in facultative ponds with nominal retention times of 7 to 23 days.

Facultative ponds designed with hydraulic retention times of 10 days minimum may obtain a removal of 2,0 of fecal coli forms and E. coli at 25°C. Helminth egg removal is 100% by sedimentation (Oakley, 2005). Area requirements depend on climate, design and treatment level. The disadvantage of stabilization ponds is the required area; in tropical and subtropical climates, an area requirement of 2 to 2,5 m^2 / person maybe estimated (Oakley, 2005). Mara (2003) proposes an area of 0,27 m^2 / person for facultative ponds. For 24°C an area of 0,60 m^2 / person is estimated (Suarez *et al.*, 2003).

In sludge and odor management, facultative Ponds generate between 0,4 and 0,6 m^3 of wet sludge per 1.000 m^3 of wastewater treated. The fundamental advantage of the use of facultative ponds as a secondary treatment is the low production of sludge, compared with other processes (Oakley, 2005). The generation of bad odors is the product of anaerobic conditions by organic overload (excessive flow, industrial discharges, decomposition of accumulated sludge), tree blocking or structures causing an oxygen transference reduction induced by the wind (MOPT, 1991) quoted by (Oakley, 2005) decomposition of scums and floating material. Therefore, daily odor monitoring is important as well as the removal of scums and floating material (Oakley, 2005).

Horizontal sub-surface constructed wetland (T3)

This alternative consists of a current WWTP-C primary treatment and horizontal sub-surface constructed wetland as secondary treatment (Figure 6.19). The methodology of design used is the process proposed by (Reed *et al.*, 1995). Design data is shown in Table 6.17.

Figure 6.19 WWTP-C Wastewater reuse alternative scheme with marsh soil ns as secondary treatment

Table 6.17 Initial design criteria – Subsurface marsh soil flow

PARAMETER	VALUE
Average flow (L/s)	7.600
BOD Efficiency (%)	75
Wastewater Temperature (°C)	24
Medium	Gravel
Depth ground layer (m)	0,20
Medium hydraulic conductivity (m^3/m^2-d)	5.000
Medium porosity (%)	40
Slope	0,003
Hydraulic retention time (d)	0,99
Depth (m)	1,0
Relation length/width	7

In terms of operational principle and removal of pollutants, horizontal sub-surface constructed wetland are typically built in the form of a bed or channel containing a proper medium and emerging vegetation (EPA, 2000). The medium use is coarse gravel and sand, 0,45 ato1 m in thickness and 0 to 0,5% slope (Romero, 2004).

Expected BOD_5 and TSS removal in horizontal sub-surface constructed wetland is 60 to 90%. Nitrogen removal is above 75%. Phosphorous removal efficiency depends on the type of medium or soil, reported efficiencies range from 30 to 50%. Pathogenic bacteria removing

efficiency is higher than 90% and helminth egg removal ranges between 95 and 100% (Madera *et al.*, 2003a).

Regarding production of sludge and odors, horizontal sub-surface constructed wetland do not produce neither bio-solids nor residual sludge, avoiding further treatment and disposition, becoming an advantage for this type of wastewater treatment systems (EPA, 2000). Among the main advantages of horizontal sub-surface constructed wetland, is the prevention of mosquitoes and odors as the water level is below the medium surface (EPA, 2000; Romero, 2004).

6.4.2.2 Selection of alternatives

To formulate the SWITCH strategy regarding wastewater managment generated by Cali, the Analytic Hierarchy Process and Grey Relational Analysis (AHP-GRA) described by (Zeng *et al.*, 2007) was implemented. The first proposed step in the methodology is the selection conceptual model preparation, where definition was made of: The objective function, the identified criteria for the selection process, the effectiveness of indicators and alternatives to be selected (Figure 6.20).

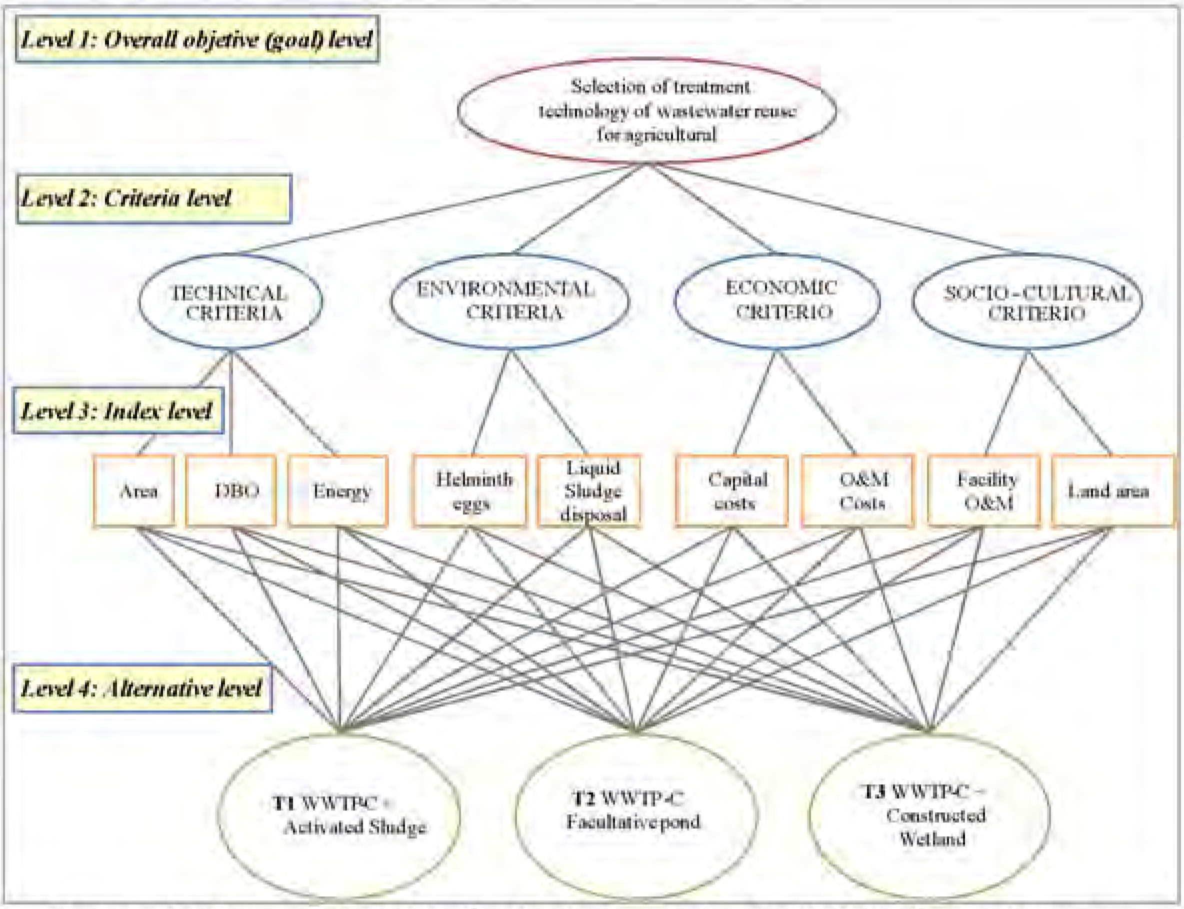


Figure 6.20 Conceptual model of technology selection for WWTP-C complementary secondary treatment

For the specific issue of criteria definition for wastewater treatment selection, considering agricultural reuse, the main criteria found in the literature review, have been the environmental, economical, technical and socio cultural (Abbassi *et al.*, 2008; Galvis *et al.*, 2007; Manga *et al.*, 2001; Metcalf *et al.*, 1995; Moscoso *et al.*, 2002b). Once elaborated the

conceptual model, the relative importance of selected criteria was defined through consultation with experts as well as the effectiveness indicator for each criteria. The results obtained from the consultation, produced a relative importance of 43,4% for the environmental criteria, followed by the socio cultural criteria (29,5%), technical criteria (21,2%) and finally the economic criteria (5,9%) (Appendix 1).

Estimate of the relative importance between the effectiveness indicators was carried out using descriptive statistics, in conformance with the referenced weights given by each expert. To estimate a unique reference weight, the occurrence probability of 75% was taken; this refers to the existing probability between the consulted experts to obtain a minimum relative weight for a specific indicator. Table 6.18 shows the results of this procedure.

Table 6.18 Importance of criteria and selection indicators for treatment technology of AR for agricultural reuse

CRITERIA		WT.	INDICATOR		WT.	RANK
C1	TECHNICAL	0,21	I1	Arearequirement (ha)	0,300	2
			I2	BOD concentration in wastewater (mg/L)	0,400	1
			I3	Power requirement (kW-h/inhabit-day)	0,300	3
C2	ENVIRONMENTAL	0,43	I4	Helminth egg concentration (hh/L)	0,570	1
			I5	Mud production (L-inhabit/year)	0,430	2
C3	ECONOMIC	0,06	I6	Initial investment cost (Million Euros)	0,436	2
			I7	O&M cost (Million Euros)	0,564	1
C4	SOCIOCULTURAL	0,30	I8	O&M easiness (1=easy, 2=medium, 3=Complex)	0,468	2
			I9	Land property (1= Own, 2=Ground acquisition)	0,532	1

The effluent agronomic quality is fundamental for the selection process as advocated by different authors of wastewater treatment technology selection for agricultural reuse (Ayers *et al.*, 1987; Metcalf & Eddy, 2003; Moscoso *et al.*, 2002a; Nascimento *et al.*, 2008; WHO, 2006). This indicator establishes the (Madera *et al.*, 2003b) directives of water quality for irrigation under the combination of different physicochemical parameters.

Because the current WWTP-C primary treatment delivers a restricted degree effluent (Silva, 2008) under the agronomic quality, the complementary treatment system effluent is guaranteed in all proposed technological options; therefore, able for agricultural reuse. Using the methodology for selection process, three treatment options as a function of the proposed indicators were characterised (Table 6.19).

Table 6.19 Characterization of treatment technological options of AR according to effectiveness indicators

CRITERIA	INDICATOR		ACTIVATE SLUDGE T1	FACULTATIVE PONDS T2	CONSTRUCTED WETLAND T3
TECHNICAL	I1	Arearequirement (ha)	3,0[1]	278,10	141,80
	I2	BOD concentration in wastewater (mg/L)	44,0[2]	23,60	42,00
	I3	Power requirement (kW-h/inhabit-day)	22,0[4]	0,00[4]	0,00[4]
ENVIRONMENTAL	I4	Helminth egg concentration (hh/L)	2,51[3]	0,80	0,69
	I5	Mud production (L-inhabit/year)	2.050[4]	62,50[4]	0,00[4]
ECONOMICAL	I6	Initial investment cost (Million Euros)	136.116,0	51,92	45,35
	I7	O&M cost (Million Euros)	9,89[4]	1,98[4]	2,47[4]
SOCIOCULTURAL	I8	O&M easiness (1=easy, 2=medium, 3=Complex)	3,00	2,00	1,00
	I9	Land property (1= Own, 2=Ground acquisition)	1,00	2,00	3,00

Source: [1] (Universidad del Valle *et al.*, 2008) [2] Vásquez (2009).[3]Jimenez *et al,*.(2010)[4] (WHO, 2006)

Characterization of treatment technologies as a function of land property was determined in the Learning Alliances (LA), at the meeting of presentation of treatment alternatives to EMCALI manager's office, where the limitation of land acquisition to implement natural methods as an alternative for the WWTP-C secondary treatment were discussed.

Once the technological options were characterized, data normalization technique was carried out to prevent errors associated with manipulation and allows comparisons in terms of unit (Romero, 1997). To normalize, it was important to establish if the values follow a maximum or minimum function, allowing for the higher importance with regards to the more or less value, according to the case, thus the concentration of helminth eggs in the effluent is expected to be a function of minimum. Afterwards, the Grey Relational Analysis (GRA), was implemented, estimating the first gray relational coefficient which relates the referenced scheme, that is to say, the technical options to be selected and the indicator optional scheme (Table 6.20).

Table 6.20 Normalization of raw data and estimate of the first grey relational coefficient

CRITERIA	INDICATOR	NORMALIZATION			FIRST GREY RELATIONAL COEFFICIENT		
		T1	T2	T3	T1	T2	T3
TECHNICAL	I1	1,00	0,01	0,02	1,00	0,34	0,34
	I2	0,54	1,00	0,56	0,52	1,00	0,53
	I3	0,00	1,00	1,00	0,33	1,00	1,00
ENVIRONMENTAL	I4	0,27	0,86	1,00	0,41	0,78	1,00
	I5	0,00	0,00	1,00	0,33	0,33	1,00
ECONOMICAL	I6	0,00	0,87	1,00	0,33	0,80	1,00
	I7	0,20	1,00	0,80	0,38	1,00	0,71
SOCIOCULTURAL	I8	0,33	1,00	0,50	0,43	1,00	0,50
	I9	1,00	0,50	0,33	1,00	0,50	0,43

The second grey relational coefficient estimate allowed relating the reference scheme (technological options) and the criteria optional scheme. For the estimate, it was necessary to normalize the first grey relational coefficient as done with the raw data and weigh the result by the relative weight of each criterion (Table 6.21).

Table 6.21 Estimate of the second gray relational coefficient

CRITERIA	1st Weighted gray relational coefficient			Normalization of the 1st gray weighted coefficient			2nd gray relationalcoefficient		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
C1	0,608	0,801	0,615	1,000	0,759	0,988	1,000	0,554	0,963
C2	0,376	0,590	1,000	1,000	0,637	0,376	1,000	0,452	0,325
C3	0,362	0,912	0,839	1,000	0,397	0,432	1,000	0,332	0,346
C4	0,732	0,734	0,462	0,631	0,629	1,000	0,448	0,447	1,000

The integrated grey relational vector was obtained relating the referenced schema and weighting of alternatives based on the relative weight of each criteria. This latter step allows the selection of the secondary treatment option complementary to WWTP-C, which is the complementary technology of activated sludge in the modality of stabilization by contact. (Figure 6.21)

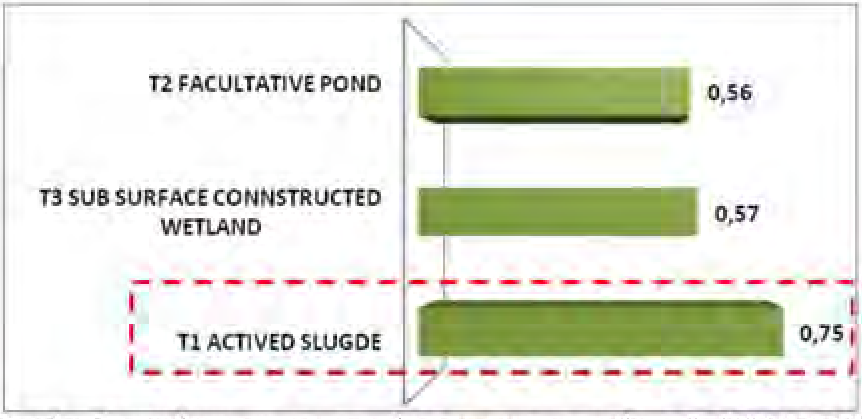


Figure 6.21 Rank of complementary secondary treatment options forWWTP-C based on the AHP and GRA methodology

6.4.2.3 Definition of the agricultural plan for implementation of wastewater reuse

The definition of the agricultural plan for implementation of wastewater reuse at WWTP-C was carried out keeping in mind only two aspects: first, the definition of the irrigation potential area and second, the plantation hydric requirement. These activities were only taken into consideration because the evaluated local context shows 58,14% practice of sugar cane monoculture corresponding to 186.441 ha of the plain zone Cauca river high basin in the Department del Valle (CVC, 2010a). This suggests that the agricultural plan is widely developed for the sector and in terms of evaluation the agricultural reuse allows sufficient definition with only the previous activities.

The selection of the potential area for irrigation arises from the water needs for the plantations. Under this condition, an estimate of needs was carried out through a water balance simplified (Sokolov *et al.*, 1981) allowing the termination of temporariness and the amount required for irrigation (Figure 6.22). As a particular application of this methodology, a balance in terms of differential between effective precipitations, (Pe) and real sugar cane evapo-transpiration (EVt). The determination was done using USDA (2004) quoted by (Schneiderman *et al.*, 2007) methodology and EVt through the FAO (Doorenbos *et al.*, 1977) combined method and the evaporating tank metering (CENICAÑA, 2004).

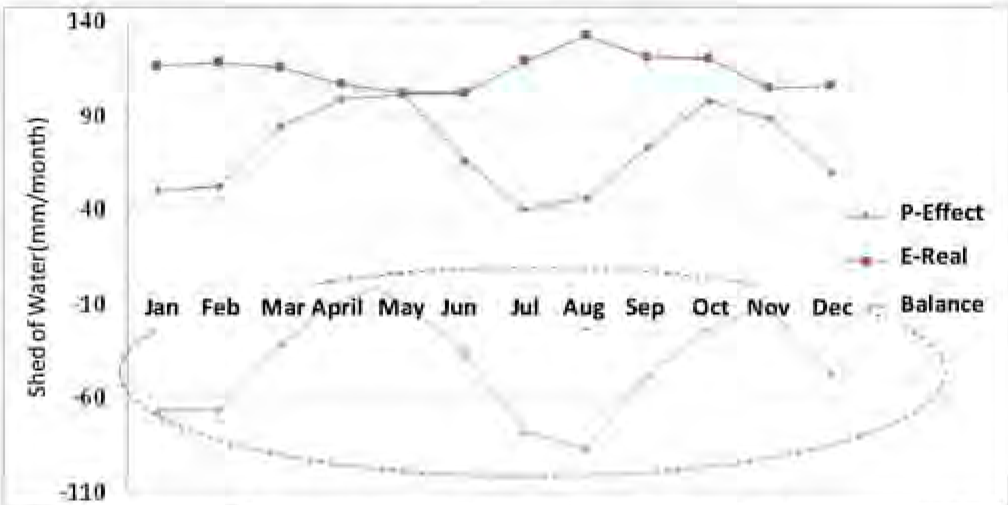


Figure 6.22 Estimate of water demand through simplified hydric balance in WWTP-C drainage area

Climatological data necessary to calculate the water balance simplified were taken at the Guachal-zambolo, reference station, pertaining to Sugar Cane Research Center – CENICAÑA, located at the border of Guachal river right of Cauca river, to be representative of the area to dispose WWTP-C wastewater, with the registration period of 17 years (1993 to 2010) and with a multiannual monthly aggregate.From the water balance results at the study zone, it is observed that the treated wastewater reuse shows a potential of 365 days per year, where there are deficit or a negative water balance (Figure 6.23). It is important to estimate more detailed temporary aggregations (daily) avoiding over dimensioning of water requirement.According to the estimates, 100% of the wastewater offer, 7,6 m^3/s, projected for 2015 (year in which WWTP-C reaches its design flow) supplies water requirements for 7.038 ha of sugar cane during the critical month of August. Despite potentiality of agricultural reuse as a function of the irrigation area, additional criteria were considered to estimate the effective potential area (Table 6.22).

Table 6.22 Criteria used to estimate e the irrigation area with WWTP-C treated wastewater

	CRITERIA	SELECTION INDICATOR
1	Current land use	*Indicator:* Consumption and commercially processing harvests. Given the conditions of the study zone, sugar cane plantation areas were selected
2	Proximity of WWTP-C to the point of delivery for irrigation	*Indicator:* Limiting property with the delivery point proposed by WWTP-C. Properties located in the 2,5 km strip parallel to Cauca river, were selected. According to studies by CVC (2004), it was identified that these properties use Cauca river water
3	Slope towards the irrigation wastewater delivery	*Indicator:* Lower topographic level to the WWTP-C delivery points proposed. Delivery points favoring the land sloped were selected, guaranteeing the preference risk at the study zone for this culture (irrigation by furrows – gravity)
4	Physical limits for delivery of water for irrigation	*Indicator:* Physical limitations for water conveyance. Main roads like Cali-Palmira and rivers. see Figure 6.23
5	Vulnerability to contamination of the aquifer system	*Indicator:* Low aquifer system vulnerability. Areas were selected where the contamination vulnerability is low, according to studies by CVC using (Foster *et al.*, 2003) methodology. Cauca river high basin at the Department del Valle del Cauca, exhibits an excellent underground water reserve in terms of quality and estimated in 10,000 Mm^3 where 12% annual reload (3.500 Mm^3) of this system is used for irrigation of sugar cane (CVC, 2010a).

Under these criteria, the definition process of irrigation potential area was carried out as a product of the cartographic interceptions with support of ArcGIS version 9.0 software. The estimated potential irrigation area was 3.080,43 ha (see Scenario 2, Figure 6.23), with which 43% is reused (3,32 m^3/s) of the wastewater flow generated by Cali municipality (during the year 2015).

Figure 6.23 Scenarios of wastewater reuse potential with estimate of different areas for irrigation in the month

6.4.2.4 Estimation of initial investment

To use WWTP-C effluent in agriculture (sugar cane irrigation), incremental costs between the situation without reuse and the situation with agricultural reuse were estimated (Figure 6.24). The estimated costs were broken down in initial investment cost and operating and maintenance costs, considering 2010 marketing prices.

Figure 6.24 Elements to be considered in the cost estimates using WWTP-C effluent in agriculture

Cost estimate of wastewater transferring system

Due to the fact that the potential area for agricultural reuse is located at the right margin of Cauca River (Figure 6.23), it is proposed to dimension the transferring structure of treated wastewater to make it available for use in sugar cane irrigation. The cost estimates were calculated based on pre designs prepared by Universidad del Valle (2008) for the pilot transfer operation with 1 m^3/s flow. Therefore, as estimated cost of the proposed wastewater transfer system for this project, the initial investment to transfer 3,32 m^3/s was estimated in €1.863.516and operation maintenance €93.176.

Cost estimates of transferring and distribution of wastewater for agricultural irrigation

To estimate the costs of transferring and distribution of WWTP-C wastewater for agricultural use, it was necessary to determine the sugar cane water requirement to proceed with the pre dimensioning of the system. Based on climatologic information of the study zone, the irrigation module found was 1,08 m^3/s-ha. Considering the proposed irrigation area scenario (3.080 ha), it was established that the irrigation system flows 3,32 m^3/s. these estimates correspond to the month of august which is the critical deficiency month.

The conduction and distribution network system was designed with this flow, considering the topography of the zone, the physical limits of the system (rivers and roads) and the users' required demand (sugar cane farmers). Once designed the network, piping dimensioning scenarios were carried out supported by EPANET tool version 2. Therefore, the initial investment estimated costs for the conduction and distribution system were €1.395.749. According with COLPOZOS (2010a) the operation and maintenance cost model for the irrigation system at the Valle del Cauca reaches a 5% cost of the initial investment system (€69.787).

Pumping systemcostestimate

After estimation of the design flow and the total dynamic hydraulic charge, a pump-motor set of 1.600 HP was selected to meet the needs, the initial investment cost is €702.000 (COLPOZOS, 2010a). Operation costs were estimated based on energetic requirement and the costs associated with maintenance were determined under the cost method implemented by COLPOZOS, as a 5% of the operation costs (Table 6.23).

Table 6.23 Initial investment of agricultural reuse of WWTP-C treated wastewater

ELEMENT	INITIAL INVESTMENT COST (€)
WWTP-C wastewater transfer system	1.863.515
Conduction and distribution wastewater irrigation system	1.395.693
Wastewater Pumping system	702.000
TOTAL	3.961.264

6.4.3 Estimation of operation and maintenance costs

The costs of operation and maintenance for this option have three elements (see Table 6.23). The first element is the WWTP-C wastewater transfer system, whose O&M costs were calculated by Universidad del Valle (2008). The second element: conduction and distribution wastewater irrigation system, and third element: wastewater pumping system. This two elements were calculated according with COLPOZOS (2010a) the operation and maintenance cost model for the irrigation system at the Valle del Cauca that reaches a 5% cost of the initial investment system.

Table 6.24 Operation and maintenance costs of agricultural reuse of WWTP-C treated

ELEMENT	O&M COSTS (€)
WWTP-C wastewater transfer system	197.501
Conduction and distribution wastewater irrigation system	69.787
Wastewater Pumping system	2.335.785
TOTAL	2.603.075

6.5 COMPARISON OF THE ALTERNATIVES

6.5.1 Alternatives description

The pollution prevention and minimisation strategy selected for households of WWTP-C drainage area integrates a flushing toilet of 2,3 L as low consumption device, and a rainwater harvesting system with filtration. This strategy has as main objective and benefit the reduction of drinking water consumption and wastewater production.

The scenario to work in this document is the implementation of pollution prevention and minimisation strategy in 30% of Cali city households. This value due to that 72,5% of population corresponds to income level 1, 2 and 3, therefore, there are less economical possibilities of implement pollution prevention strategy, and because the Cali population is composed by people with several educational and cultural levels that could be a limiting factor to the apply this proposal.

The zones of Cali city selected for implement the pollution prevention alternative are areas supplied by drinking water plants of La Reforma, Río Cali and Puerto Mallarino. The main objective for theintervention location in this area responds to the impact of river water extraction by drinking water plants, especially in Melendez and Cali rivers. The number of users (near to 618000 Cali citizens) and amount of water saved by area is shows in Table 6.25.

Table 6.25 Distribution of the pollution prevention alternative in Cali city

Drinking water plant	Users	Water consumption (m^3/month)	Drinking water saved		% Application by income level		
			m^3/month	m^3/s	1-2	3-4	5-6
Cali River	82.400	824.000	824.000	0,32	5%	5%	10%
La Reforma	20.600	206.000	206.000	0,08		5%	
Puerto Mallarino	20.600	206.000	206.000	0,08		5%	
TOTAL	123.600	1.236.000	1.236.000	0,48	30%		

The solution with SWITCH approach consists in a integrated system that includes the implementation of secondary treatment (activated sludge) with the effluent reuse. In this way, according with water demand of cultivation, 43% of WWTP-C effluent will be used in sugar cane irrigation (3,32 m^3/s). According with PSMV (EMCALI, 2007) in 2016 will start the operation of secondary treatment, and to the same time, is proposed that initiate the operation of irrigation district with WWTP-C effluent.

For the implementation of WWTP-C effluent reuse, the potential area of irrigation was identified based in a scenario of area, where the scenario selected corresponds to an irrigation area of 3.080,5 ha. Considering the water balance undertaken, irrigation will be carry-out in continuous form during the 365 days of year. The main characteristic of the conventional solution and solution with SWITCH approach are shows in Table 6.26.

Table 6.26 Characteristics of alternatives proposed for WWTP-C drainage area

PARAMETER	UNITS	CONVENTIONAL	SWITCH APPROACH
Flow affluent to WWTP-C	m^3/s	7,6	7,5
BOD affluent to WWTP-C	mg/L	229	229
TSS affluent to WWTP-C	mg/L	197	197
BOD effluent of WWTP-C	mg/L	48,64	48,64
TSS effluent of WWTP-C	mg/L	65,07	65,07
BOD load discharged to Cauca river	kg/day	31.850,8	15.869,3[a]
TSS load discharged to Cauca river	kg/day	43.022,1	21.435,3[a]

6.5.2 Identification and estimation of costs and benefits

In this first phase of the project analysis, all related costs and benefits are identified. The task at this stage of the analysis is to identify the costs and estimate the value of the benefits to be produced by the two solutions. The costs are:

- Initial investment of conventional solution: this cost is integrated by initial investment of activated sludge in the contact stabilisationmodality
- Initial investment of solution with SWITCH approach: consists in initial investment of pollution prevention strategy, of activated sludge, and infrastructure for reuse of effluent in sugar cane irrigation
- Operation & maintenance costs of conventional solution: corresponds to O&M costs of activated sludge in Euros per year
- Operation & maintenance costs of solution with SWITCH approach: these costs are composed by O&M costs of activated sludge, pollution prevention alternative, and of infrastructure for WWTP-C effluent reuse in Euros per year.

The initial investment and O&M of the secondary treatment for the solution with SWITCH approach and the convention are costs common, hence for cost-benefit analysis were not taken in account.

The identification of benefits was divided in three types of beneficiaries: users, water and sanitation providers, and environment. Table 6.27 shows benefits by beneficiaries, and benefits included in water and sanitation tariff.

Table 6.27 Benefits identified for the solution with SWITCH approach in WWTP-C drainage area

BENEFITS	BENEFICIARIES
WASTEWATER TREATMENT	
Reduction in consumption of drinking water	Users
Reduction in production of wastewater	Users
Less dependency to centralized drinking water system	Users
Water and sanitation saving tariff	Users
Improving of well-being	Users
Reduction in payment by contamination discharge tax	W&S providers
Reduction in infrastructure for collect and transport runoff	W&S providers
Reduction in drinking water treatment cost (downstream of Cali city)	W&S providers
Reduction in drinking water treatment costs (for Rio Cali, La Reforma, and Puerto Mallarino drinking water plants)	W&S providers
Reduction of wastewater treatment costs	W&S providers
Reduction of cost by sludge treatment	W&S providers
Ecosystem improvement of Cali and Melendez river due decreasing to water extraction	Environment
Reduction in BOD and TSS load discharges to Cauca River	Environment
Improving health of users located downstream of Cali city	Environment
Reduction impact of sludge by toxics disposed in soil	Environment
Reduction of greenhouse gases	Environment
Reduction of energy consumption	Environment
EFFLUENT REUSE	
Decrease in cost of fertilizer	Farmers
Reduction in payment by use tax	Farmers
Less consumption of groundwater for irrigation	Farmers
Diminution in drinking water treatment cost (downstream of Cali city)	W&S providers
Reduction in pay by contamination discharge tax	W&S providers
Reduction in BOD and TSS load discharges to Cauca River	Environment

The benefits estimation was carried out with data available; therefore, the sevenbenefits used for financial evaluation of this study area are shown in Table 6.28. The benefits as reduction in consumption of drinking water and production of wastewater are included in water and sanitation saving tariff benefit. The other benefits are qualitative, and although are important, the estimation requires some information that at the analysis moment was not available, but is part of a future socioeconomical evaluation.

Table 6.28 Benefits identified for comparative analysis of the conventional solution and solution with SWITCH approach proposed for WWTP-C drainage area

No	BENEFITS	DEFINITION
B1	Water and sanitation tariff saving by implementation of solution with SWITCH approach	Are avoided cost by water and sanitation tariff by decrease drinking water consumption, and by reduce wastewater production
B2	Acquisition of carbon credits by reduction of greenhouse gases emission	Corresponds to economical income that could be acquired by reduction of greenhouse gases emission. This cost can be consider a indirect measure of environment improving by reduction of greenhouse gases
B3	Avoided cost by use of less amount of fertilizer	Because wastewater carries the necessary nutrients (i.e. nitrogen and phosphorus) for crops to grow and develop, there is a benefit associated with the savings in the purchase of simple and compound fertilizers (urea and NPK, respectively). The estimation of this benefit is determined by the differential costs of fertilizers of the conventional solution and the solution with SWITCH approach.
B4	Reduction in payment by use tax of groundwater	This reduction is associated with the cost that farmers will no longer have to incur for the use of water because the water demand for the crops will be met with the effluent from the Cañaveralejo WWTP, not with the extraction of underground water.
B5	Avoided cost in infrastructure for uptake groundwater	The implementation of a conventional solution would involve the use of underground water for meeting the water needs for irrigation, but with the implementation of a solution with SWITCH approach, this demand for water will be met with the effluent from the Cañaveralejo WWTP.
B6	Saving cost by O&M of groundwater wells	Based on the description of the above benefit, there would be additional funds available because the implementation of a solution with SWITCH approach, operation and maintenance of the walls for extracting underground water would not be done.

The initial investment for conventional solution and solution with SWITCH approach are €45.023.659 and €136.235.298, respectively; the O&M costs for two solutions are: for conventional solution is €9.980.000 per year, and for solution with SWITCH approach is €20.493.475 per year. The procedure of benefit estimation is described to following.

B1- Water and sanitation tariff saving by implementation of solution with SWITCH approach

The drinking water consumption and wastewater production in 30% of Cali households can reduce with implementation of pollution prevention strategy.This diminution has implications about the tariff of water and sanitation. For benefit estimation was used: 4.2 m^3/month thevolume of drinking water saving by household, the implementation of pollution prevention will be to 30% of the Cali households, a currently average of drinking water consumption of 20 m^3/month, and a the average tariff of water and sanitation of €1,6 (SUI, 2009). The benefit estimation is shows in Table 6.29 for each five years.

Table 6.29 Estimation the benefit water and sanitation tariff saving (B1) in WWTP-C drainage area

YEAR	1	5	10	15	20	25	30
	2011	2015	2020	2025	2030	2035	2040
Cost of a conventional solution (Euros)	210.493.414	234.660.319	251.196.161	258.799.976	260.320.739	260.320.739	260.320.739
Cost of SWITCH solution (Euros)	210.272.708	233.556.787	249.735.915	256.236.197	256.653.427	255.549.895	254.446.362
Savings (Euros)	220.706	1.103.532	1.460.246	2.563.778	3.667.311	4.770.843	5.874.376

B2 - Acquisition of carbon credits by reduction of greenhouse gases emission

The estimation of amount money by sell carbon credits was calculated based in the quantity of carbon dioxide that could be reduced to the apply conventional solution or the solution with SWITCH approach. Applying pollution prevention in Cali households reduces in BOD load treated by WWTP-C; therefore, greenhouse gases emission will decrease. For calculate the kg of CO_2 reduced is used a factor of 1,2 kg CO_2/kg BOD (Gori *et al.*, 2009) and a mean cell residence time (MCRT) of 6,3 days as operation parameter for Cali city (Universidad del Valle, 2009a). Acquisition of carbon credits by energy consumption saving was calculated for solution with SWITCH approach by not use of energy for pump groundwater of 41 well to irrigation, and for conventional solution by not use energy for pump WWTP-C effluent for reuse in irrigation. The factor used for calculate kg CO_2/kW was 0,3. Therefore, the net value of carbon credits is the subtraction among carbon credits by BOD load reduced and carbon credits by avoided energy consumption. The estimation of this benefit starts in 2016 when secondary treatment will operate (see Table 6.30).

Table 6.30 Estimation the benefit acquisition of carbon credits by reduction of greenhouse gases emission (B2) in expansion area

YEAR	1	5	10	15	20	25	30
Cost of a Conventional solution (in €)	0	0	1.651	2.477	3.303	4.129	4.954
Cost of SWITCH solution (in €)	0	0	575	575	575	575	575
Savings (in €)	0	0	-1.076	-1.902	-2.728	-3.553	-4.379

B3 - Avoided cost by use of less amount of fertilizer

Taking into account an area of 3.080 hectares to be irrigated using the effluent from the Cañaveralejo WWTP, the estimated needs for fertilizers would be 21.560 sacks of urea per year and 12.320 sacks of NPK per year. These needs were estimated based on data reported by the (Ministerio de Agricultura y Desarrollo Rural, 2009) about the need for fertilizer per hectare.

An estimation of this benefit has to consider the contribution of nutritional load available from the effluent of the C-WWTP as a function of its concentration of nitrogen and phosphorus. In this specific case, there was confirmation to show that wastewater contributes 100% of the nutritional needs for sugar cane crops. This benefit was economically quantified by multiplying the cost of a sack of fertilizer (NPK= €24,7; and urea €26,9) by the potential irrigation area (Table 6.31).

Table 6.31 Estimation the benefit avoided cost by use of less amount of fertilizer (B3) in WWTP-C drainage area

YEAR	1	5	10	15	20	25	30
Cost of a conventional solution(in €)	0	0	0	0	0	0	0
Cost of SWITCH solution (in €)	0	0	884.678	884.678	884.678	884.678	884.678
Savings (in €)	0	0	884.678	884678	884.678	884.678	884.678

B4 - Reduction in payment byuse tax of groundwater

This benefit was estimated at prices of 2010 based on the structure of the water use tax (WUT) which depends on the extracted volume of water for irrigation and the cost of a cubic meter of underground water, i.e. 0,000268 €/m^3 (CVC, 2009). An estimate of the various solutions considered in this project is shown in Table 6.32.

Table 6.32 Estimation the benefit reduction in payment by use tax of groundwater (B4) in WWTP-C drainage area

YEAR	1	5	10	15	20	25	30
Cost of a conventional solution(in €)	0	0	0	0	0	0	0,00
Cost of SWITCH solution (in €)	0	0	70.065	70.065	70.065	70.065	70.065
Savings (in €)	0	0	70.065	70.065	70.065	70.065	70.065

B5 - Avoided cost in infrastructure for uptake groundwater

Based on the results obtained, the estimated flow rate for irrigation of the area is 3,32 m^3/s. According to the hydro-geological characteristics of the area, pre-dimensioning calculations showed that extraction of water at this flow rate would entail the construction of 41 wells with a depth of 150 m, a pumping rate of 80 L/s, and at a unit cost of €120.000 (COLPOZOS, 2010a). A breakdown of these cost savings during the timeframe in review is shown in Table 6.33.

Table 6.33 Estimation the benefit avoided cost in infrastructure for uptake groundwater (B5) in expansion area

YEAR	1	6	10	15	20	25	30
Cost of a conventional solution (in €)	0	0	0	0	0	0	0
Cost of SWITCH solution (in €)	0	4.920.000	0	0	0	0	0
Savings (in €)	0	4.920.000	0	0	0	0	0

B6 - Saving cost by O&M of groundwater wells

Based on information supplied by COLPOZOS S.A. about operation and maintenance requirements, the estimated costs of operating a deep well with the above mentioned design characteristics are related with the power consumption involved. Using a power consumption of 75 hp for each of the wells described above, an operating time of 18 hours, and a cost of €0,12 per Kw-h, the estimated operation cost of each well is €65.172 for a total saving of €2.672.052. Additionally, according to the maintenance cost model used by COLPOZOS (2010), 5% of the operation costs are assumed as maintenance costs. Hence, the estimated total benefit of O&M was €2.805.680 (Table 6.34).

Table 6.34 Estimation the benefits saving cost by O&M of groundwater wells (B6) in WWTP-C drainage area

YEAR	1	5	7	15	20	25	30
Cost of a conventional solution(in €)	0	0	0	0	0	0	0
Cost of SWITCH solution (in €)	0	0	2.805.68	2.805.68	2.805.68	2.805.68	2.805.68
Savings (in €)	0	0	2.805.68	2.805.68	2.805.68	2.805.68	2.805.68

6.5.3 Results of cost-benefit analysis

Once the annual cost and benefits are quantified, the evaluation criteria are estimated: economic efficiency or the difference between benefits and costs, the relation of Net Present Value ($NPV_{benefits}/NPV_{costs}$) (Brent, 2006). The data of costs and benefits are distributed through 30 years for analysis (see Table 6.35 and Figure 6.25). It is important mention that the estimation of cost and benefits is based to preliminary data.

Table 6.35 Relation of costs and benefits to implement the solution with SWITCH aproach in WWTP-C drainage area

BENEFITS (Euros)	YEARS						
	1	5	10	15	20	25	30
B1	220.706	1.103.532	1.460.246	2.563.778	3.667.311	4.770.843	5.874.376
B2	-	-	1.076	1.902	2.728	3.553	4.379
B3	-	-	884.678	884.678	884.678	884.678	884.678
B4	-	-	70,065	70,065	70,065	70,065	70,065
B5	-	-	-	-	-	-	-
B6	-	-	2.805.680	2.805.680	2.805.680	2.805.680	2.805.680
TOTAL BENEFITS	220.706	1.103.532	5.221.747	6.326.105	7.430.464	8.534.822	9.639.180
Costs (Euros)	YEARS						
	1	5	10	15	20	25	30
C1	3.172,647	3.172,647	3.172.647	3.172,647	3.172.647	3.172.647	3.172.647
Initial Invest.	2.908.555	2.908.555	2.908.555	2.908.555	2.908.555	2.908.555	2.908.555
O&M	264.092	264.092	264.092	264.092	264,092	264.092	264.092,00
C2	-	-	2.603.075	2.603.075	2.603.075	2.603.075	2.603.075
Initial Invest.	-	3.950.039	-	-	-	-	-
O&M	-	-	2.603.075	2.603.075	2.603.075	2.603.075	2.603.075
Total Costs	3.172.647	3.172.647	5,775.722	5.775.722	5.775.722	5.775.722	5.775.722
Cash flow	- 2.951.940	- 2.069.114	- 553.975	550.383	1.654,741	2.759.099	3.863.458

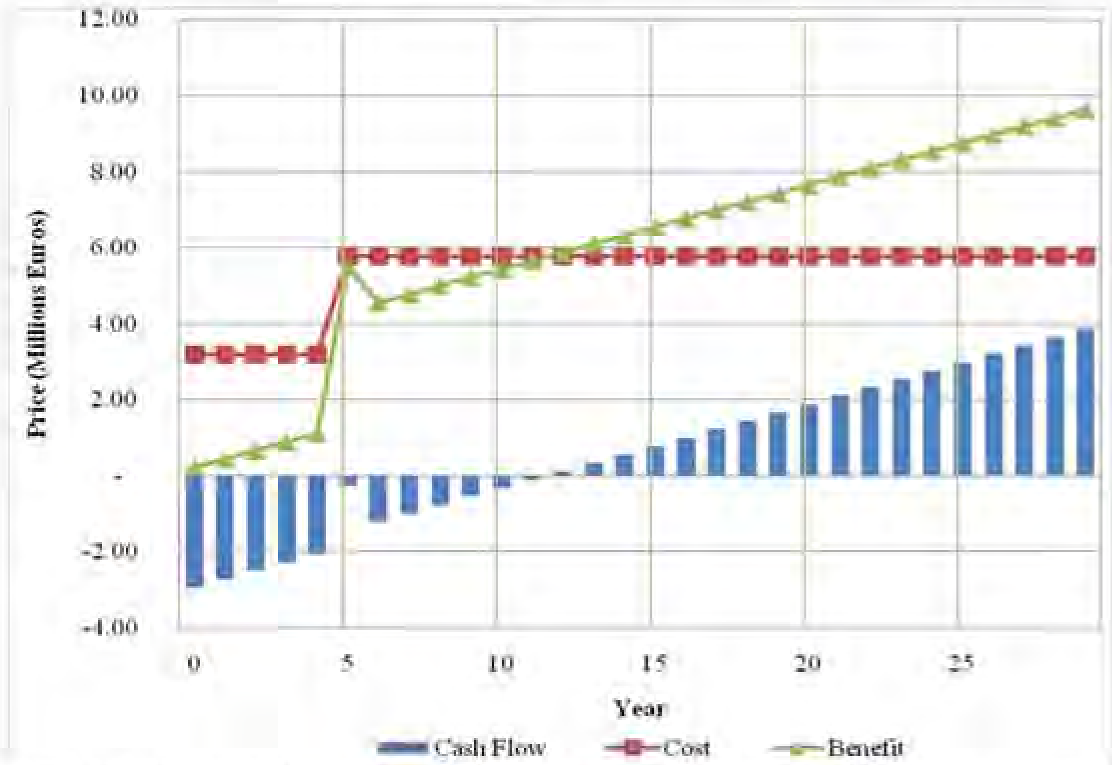


Figure 6.25 Behaviour of cost and benefits of alternatives for WWTP-C drainage area during analysis period

The cash flow relates to difference among the benefits and costs. In Figure 6.25 the cash flow between year 1 and 12 is negative, the reason of this behaviour is because the costs are highest than benefits, on the contrary, between year 13 and 30 the cash flow is positive because benefits are highest than costs. This behaviour is expected, since in this year the line of costs and benefits is crossed, is to say, are the same. This point is also called the breakeven.

Regards to trend of benefits, between the years 1 and 5 has a growing trend directly related with the implementation of pollution prevention and minimisation in Cali households.This crescent trend increases in the year 7 because in this point, the project start receiving the benefits related with reuse.Also is identified a peak in year 6, relates the cost saving by the

wells that not be build for irrigation, since irrigation will be carried-out with WWTP-C effluent.

The trend of costs shows a stable behaviour among years 1 – 5, and 6 – 30. Between years 1 and 5 the costs correspond to the application of pollution prevention and minimisation strategy (initial investment and O&M), subsequently, there are a peak related with the initial investment of infrastructure for reuse, and there are other breakeven.The costs among years 6 and 30 are highest because was added O&M of reuse system.

The main objective of the economic efficiency criterion is to maximise the difference between benefits and costs. This difference is the efficiency effect of the project. This indicator in SWITCH solution is negative. This means that costs estimated are highest than benefits. Regarding to cost-benefit relation, the solution with SWITCH approach has a value of 0,8, is to say, in financial terms the SWITCH project is not feasible or cost effective (see Table 6.36). However, for complete the evaluation is necessary carry-out a socio-economical assessment. This analysis will be execute in remaining time period of the project.

Table 6.36 Indictors of economical feasibility for solution with SWITCH approach in WWTP-C drainage area

NPV Costs	40.592.235,57
NPV Benefits	32.422.399,88
NPV Benefit-NPV costs	-8.169.835,69
NPV Benefit/NPV costs	0,80

7 STRATEGIES FOR POLLUTION CONTROL IN SOUTH EXPANSION AREA

7.1 INTRODUCTION

Urban development in the expansion area is viable provided that there is availability of public water supply and basic sanitation services. As of today, the proposals for urban development (DAPM, 2010) and feasibility study of public utilities (EMCALI *et al.*, 2009; EMCALI *et al.*, 2006a) consider water supply from the Puerto Mallarino facility by expanding the southern municipal matrix networks. These networks will be complemented with different pumping systems and the installation of a new pipeline from the drinking water treatment plant. As far as sanitation is concerned, there is proposal for a separate sewerage system where wastewater is pumped to the Cañaveralejo Wastewater Treatment Plant (WWTP-C) and rainwater is discharged into the water network in the area (EMCALI *et al.*, 2006a).

In general, the proposal for water management in the Cali-Jamundi corridor addresses conventional strategies for water supply and sanitation following the same principles applied to the completion of previous water supply and sanitation works in the consolidated area of the city. These conventional strategies, however, have not shown efficient results in controlling pollution in the area in which the water quality in the receiving bodies of water has deteriorated over time.

The approaches to the water resource management in the expansion area have an impact on the quality of water in the Cauca River and thus generate repercussions on the quality of water supply to the city of Cali because the Cali-Jamundí corridor is located upstream of the drinking water treatment plant.

7.2 DESCRIPTION OF STUDY AREA

The South Expansion Area, also called the Cali-Jamundí Corridor, is an area 1.669 ha located in the southern part of the city (Figure 7.1). This is the future development area promoted for the construction of urban developments at medium-high socio-economic levels. The trend of urban stratification in expansion area shows that 6% is income level 1-2, 28% is income level 3-4, and 66% is income level 5-6.

Strata is a way of economically classifying the sectors in the city; hence, strata 1 and 2 correspond to the most economically stressed groups and strata 3, 4, 5 and 6 correspond to middle class to upper class economic groups.

The south expansion area is not provided with a scheme of general urban development. The offers of urban development are individual, principally requested by construction companies that have purchased land in the sector to develop their own areas. According to the Municipal Planning Department (DAPM, 2010), there currently are four approved urbanization developments (partial urbanization plans) and five was proposed equivalents to 33% the planning area. The population densities reported in the plan proposals (both approved and under review) range from 179 to 426 inhabitants/ha with an average of 317 inhabitants/ha. These proposals have been prepared considering an area of 517,75 ha out of the 1.669 ha of the study area. For research and comparison purposes aiming at keeping a balance, the estimates for development area and population density are 1,358 ha and 302 inhabitants/ha, respectively (as reported in previous public utility studies completed in the area).

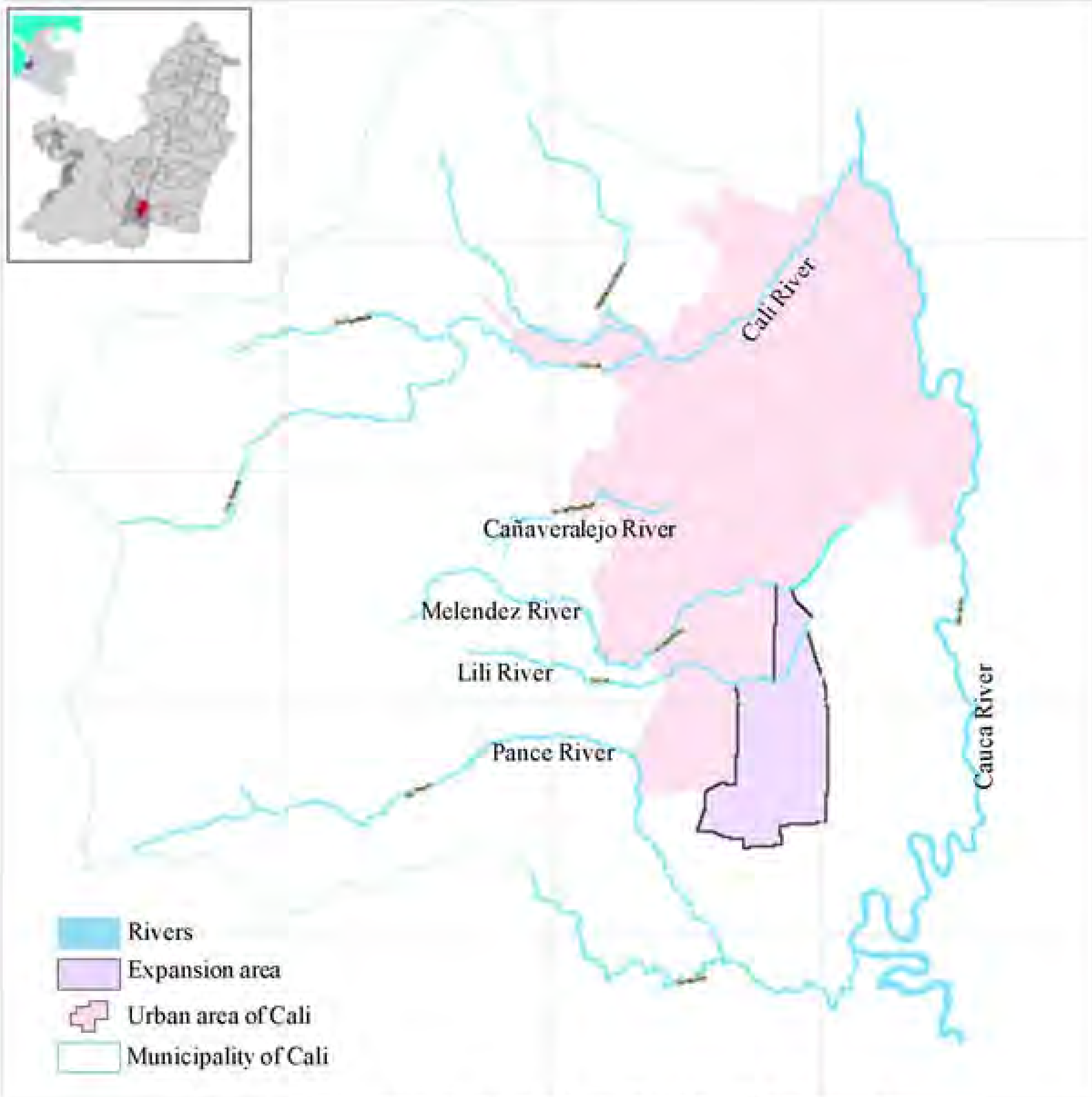


Figure 7.1 Location expansion area: Corridor Cali-Jamundi

The area has a tropical climate with temperatures between 20 and 30 °C. Precipitation and evapotranspiration data from CVC weather monitoring stations show that precipitation and evaporation in a typical hydrological year have a bimodal behavior.The following periods are identified: two rainy periods from March to May and from October to December; and two dry periods from January to February and From June to September.

The monthly average multiannual precipitation in the study area is 121,60 mm, with a maximum precipitation of 195,9 mm in April and a minimum precipitation of 51,22 mm in July. Meanwhile, evaporation in the area has slight fluctuations. There is a monthly average multiannual evaporation of 123,58 mm with a maximum evaporation of 143,44 mm in August and a minimum of 105,10 mm in November.Its topography is uniform with a slight descending slope towards the Cauca Rive. Currently, this area is mostly used for agricultural purposes. Around the area there are several sugar cane culture areas. For more information of south expansion area see Appendix 3.

7.3 CONVENTIONAL SOLUTION

7.3.1 Description

EMCALI in 2005 hired the consultancy firm Hidrooccidente to make the feasibility studies for the delivery drinking water and sanitation services in this expansion sector. Therefore, all the information described in the section Cali-Jamundi corresponds to the study carried out by EMCALI and Hidrooccidente S.A. (2006). Following is a synthesis of the results obtained by the consulting firm that developed the pre-feasibility study.

Drinking water system

For the analysis of the drinking water provision, an amount ranging between 200 and 340 L/inhab/day according to the income level. The total flow calculated is 1.067 L/s. Water supply would be done through the expansion of the matrix network south of Cali, which would supply the sector by gravity and another one by re-pumping. It was already defined that the TSS would supply the Cali Jamundi sector with a flow of 510 L/s. The system would be strengthened with the installation of a new pipeline brought from Puerto Mallarino. This pipeline would be called Navarro Transmission Pipeline. Figure 7.2 shows a scheme of this proposal.

Figure 7.2 Proposed drinking water layout and supply zones in the sector Cali Jamundi
Source (EMCALI *et al*., 2006a)

Sewage system

For this study, the wastewater production was estimated between 170 L/per/day to 272 L/per/day, considering a return rate 0,8. The total flow calculated is 853,6 L/s. The Cali-Jamundi area was divided in four drainage sectors according to the sewage system. Four alternatives were analyzed for this zone, including the combined or individual sewage system options for the four sectors. In its final recommendations the firm Hidrooccidente is the most appropriate option should include separate sewerage system.

Wastewater treatment

The selected alternatives proposed for the treatment of the wastewater generated in the area Corredor Cali- Jamundí were:
Alternative 1: Pumping to WWTP-C
Alternative 2: Conventional activated sludge system
Alternative 3: UASB system plus low rate activated sludge system
Alternative 4: UASB system plus aerated Ponds

The alternatives 2, 3 and 4 refer to the proposed wastewater treatment plant in the sector Cali-Jamundí called WWTP-South. Hidrooccidente firm recommended the alternative 1 (Pumping to WWTP-C) to the expansion area Cali-Jamundí wastewater management according with technical, economic, and environmental results.

7.3.2 Initial investment costs

The study conducted by Hidrooccidente reports the estimated costs of proposed preselected alternatives for each of the water supply and sanitation components. Infrastructure costs and other factors taken into account in the calculations are shown in Table 7.1 below.

Table 7.1 Economic assessment of alternatives presented by Hidrooccidente for South expansion area

INFRASTRUCTURE DESCRIPTION	COST (Euros) NET PRESENT VALUE AS OF 2005	CONSIDERATIONS IN THE CALCULATIONS
Drinking water network	-	• No discussion of costs. Costs are calculated with network dimensioning data within the framework of the SWITCH project
Drainage & sanitary sewerage system	-	• Estimated costs for volume rain harvesting that required no drainage
Wastewater treatment	€29.924.360	• Initial investment on secondary treatment facilities using activated sludge for the water flow in the expansion area • Investment and replacement of the South-Navarro and Navarro pumping systems. • Investment on impulse piping from the southern zone to the Navarro station. • Investment on impulse piping from Navarro to the Cañaveralejo WWTP. • Variable costs (chemical supplies and transportation) associated with secondary treatment. • Electric power consumption for secondary treatment. • Cost of sludge disposal. • Electric power consumption for the South-Navarro and Navarro-Cañaveralejo WWTP pumping systems. • Maintenance cost of the South-Navarro-Cañaveralejo impulse piping. • Operation and maintenance costs were estimated considering a time frame from 2010 to 2030.

Source: (EMCALI *et al.*, 2006a)

The following considerations and calculations provided a common ground of comparison for updating and completing these data at the current prices of 2010.

Water supply infrastructure

In order to have the same comparison base between the conventional option and the solution with SWITCH approach, a main water supply network and pumping infrastructure were pre-dimensioned, under the same use and pressure control criteria, using the flows defined in the option proposed by Hidroccidente. Figure 7.3 shows a scheme of the network, the assigned demands and pipeline diameter. The total estimated cost network drinking water is € 3.177.544.

Figure 7.3 Drinking water network in expansion area with conventional option

Construction of the drinking water pumping station has been scheduled to take place in stages because the final pumping power is not required since year 1. Installed pumping power will be increased stepwise depending on the demand for water (Figure 7.4). The plan of investment pumping station for drinking water including for year 1 a requirement investment of € 46.667, for year 5 € 115.556, for years 10 and 15 € 28.889, and for year 20 the higest investment € 246.667.

Figure 7.4 Projected demand and pumping requirements with conventional option

Sanitary sewage system infrastructure

As with the water supply network, a sewage network was pre-dimensioned, considering a design similar to the SWITCH solution, using the flows defined by Hidroccidente, with a pumping station to the WWTP-C (Figure 7.5). The total estimated cost is € 1.061.138.

Figure 7.5 Sewer system for expansion area with conventional option

The data presented in connection with this item did not consider costs incurred in primary treatment and associated operation and maintenance costs. Estimating these costs involved reusing the initial investment cost of the Cañaveralejo WWTP (€46.023.659) considering a direct relation between the design flow rate and the flow rate to be contributed by the expansion area.

Based on these considerations and cost forecasts for a 30-year timeframe at an 11% discount rate, the costs of each of the above listed items are shown in Table 7.2 below.

Table 7.2 Infrastructure costs for water and sewer in expansion area

DESCRIPTION INFRASTRUCTURE	NET PRESENT VALUE (Euros, €)
Network drinking water	2.862.652
Pumping station drinking water	157.426
Sanitary sewer system	955.980
WWTP Primario	4.758.959
WWTP Secundario & Pumping	18.515.609
Total cost invesmest	27.250.626

7.4 SOLUTION WITH SWITCH APPROACH

7.4.1 Pollution prevention and minimisation

7.4.1.1 Description of the options

The various alternatives were proposed for the residential sector, considering housing as the unit of analysis within the framework of the concept of household-focused sanitation. The alternatives were designed on five major fronts: low consumption devices, use of rainwater, greywater reuse, descentralisation, and natural methods for wastewater treatment. Alternate

sources were associated with the different uses of water in the household. With regard to low consumption devices, identification was made of various kinds of excreta evacuation facilities and taps for different residential use applications.

The review of excreta evacuation facilities included dry toilets, separating toilets, dry urinals, conventional 6 L flushing toilets, dual-flush toilets (6 L for fecal feces and 4 L for urine) and 2,3 L high-performance flush toilets. The following uses of rainwater were considered: washing clothes, garden irrigation, housekeeping, and cleaning of common areas. One of the proposals involved greywater reuse for flushing toilets, irrigating gardens, and housekeeping or cleaning common areas. Consideration of the different uses and alternatives gave rise to the creation of strategies based on a combination of possibilities of incorporating various low consumption devices together with the use of potential supply sources.

The formulation of strategies initially considered low consumption devices available on the Colombian market and the potential water sources that can be used for filling the devices. Figure 7.6 shows a diagram illustrating the different possibilities depending on the kind of use, equipment to be installed, and water supply sources. It is worth noting that the installation of low consumption appliances at the new urban development projects has been mandatory since 1998 as established in Colombian regulations in law 377 and associated decree 3102 of 1997.

Figure 7.6 Minimisation and prevention options in the management of water in the house

The various options will be formulated based on the following considerations

- After installing grey water treatment facilities, grey water will be used both for flushing toilets and irrigating gardens.
- Using rainwater supply for flushing toilets will not be considered an option because rainwater is an inconsistent water source in the study area where there are only two annual seasonal rainy periods.

- One of the constant options is the use of ultra water saving taps. Considering that the study area is new and the price difference is not significant, these kinds of taps do not need major operation and maintenances.

- Drinking water will be used for cooking and personal hygiene (e.g. bathing and washing hands).

Taking into account that both single-family and multiple-family housing units will be built in this area, two different types of combinations will be proposed which are related with the possibilities for using water at each kind of housing unit.

The formulation of various options for multi-family housing units considered an additional use of water, i.e. using water for common area housekeeping. The use of rainwater for washing clothes was not considered because water distribution could raise conflicts among the users at residential complexes.

The various strategies that suit the combinations for single-family housing units are listed in Table 7.4, and the strategies for multi-family housing units are listed in Table 7.3 and Table 7.5 below.

An economic analysis of a residential housing unit where dry urinals are installed and considering initial investment, operation and maintenance, and water tariffs for a 10-year time frame (see Table 7.5 below) revealed that this combination is not competitive in comparison to other alternatives because of its high cost to the families. Hence, it was not considered in the subsequent analysis.

Table 7.3 Formulation of water use in multifamily housing

OPTION	WATER USE	TOILET FLUSHING	LAUNDRY	GARDEN IRRIGATION	CLEANING COMMUNE AREAS
	DEVICES	6 L WC			
1	Source supply	Drinking water	Drinking water	Drinking water	Drinking water
2		Greywater	Drinking water	Greywater	Greywater + Rain harvesting
3		Drinking water	Drinking water	Rain harvesting	Rain harvesting
	DEVICES	DUAL-FLUSH			
4	Source supply	Drinking water	Drinking water	Drinking water	Drinking water
5		Greywater	Drinking water	Greywater	Gris + Rain harvesting
6		Drinking water	Drinking water	Rain harvesting	Rain harvesting
	DEVICES	2,3 L WC			
7	Source supply	Drinking water	Drinking water	Drinking water	Drinking water
8		Greywater	Drinking water	Greywater	Greywater + Rain harvesting
9		Drinking water	Drinking water	Rain harvesting	Rain harvesting
	DEVICES	DRY URINAL + 6 L WC			
10	Source supply	Drinking water	Drinking water	Drinking water	Drinking water
11		Greywater	Drinking water	Greywater	Greywater + Rain harvesting
12		Drinking water	Drinking water	Rain harvesting	Rain harvesting
	DEVICES	DRY URINAL + 2,3 L WC			
13	Source supply	Drinking water	Drinking water	Drinking water	Drinking water
14		Greywater	Drinking water	Greywater	Greywater + Rain harvesting
15		Drinking water	Drinking water	Rain harvesting	Rain harvesting

Table 7.4 Formulation of strategies for using water at single-family housing units

OPTION	WATER USE	TOILET FLUSHING	LAUNDRY	GARDEN IRRIGATION
	DEVICES	6 L WC		
1	Source supply	Drinking water	Drinking water	Drinking water
2		Grey water	Drinking water	Grey water
3		Grey water	Drinking water+Rain harvesting	Grey water
4		Drinking water	Drinking water	Rain harvesting
5		Drinking water	Drinking water+Rain harvesting	Rain harvesting
	DEVICES	DUAL FLUSH		
6	Source supply	Drinking water	Drinking water	Drinking water
7		Grey water	Drinking water	Grey water
8		Grey water	Drinking water+Rain harvesting	Grey water
9		Drinking water	Drinking water	Rain harvesting
10		Drinking water	Drinking water+Rain harvesting	Rain harvesting
	DEVICES	2,3 L WC		
11	Source supply	Drinking water	Drinking water	Drinking water
12		Grey water	Drinking water	Grey water
13		Grey water	Drinking water+Rain harvesting	Grey water
14		Drinking water	Drinking water	Rain harvesting
15		Drinking water	Drinking water+Rain harvesting	Rain harvesting
	DEVICES	DRY URINAL + 6 L WC		
16	Source supply	Drinking water	Drinking water	Drinking water
17		Grey water	Drinking water	Grey water
18		Grey water	Drinking water+Rain harvesting	Grey water
19		Drinking water	Drinking water	Rain harvesting
20		Drinking water	Drinking water+Rain harvesting	Rain harvesting
	DEVICES	DRY URINAL + 2,3 L WC		
21	Source supply	Drinking water	Drinking water	Drinking water
22		Grey water	Drinking water	Grey water
23		Grey water	Drinking water+Rain harvesting	Grey water
24		Drinking water	Drinking water	Rain harvesting
25		Drinking water	Drinking water+Rain harvesting	Rain harvesting

Table 7.5 Economic analysis incorporating devices low consumption for excreta disposal

	WC 6 L	Dual flush	WC 2,3 L	Dry urinals + WC 6 L	Dry urinals + WC 2,3 L
Initial Investment (Euros)*	330.000	430.000	800.000	1.490.000	1.490.000
O&M annual (Euros)*	0	0	0	8.614	8.614
Monthly water consuption (m3)**	3,6	2,7	1,38	2,52	0,97
	WC 6 L	Dual flush	WC 2,3 L	Dry urinals + WC 6 L	Dry urinals + WC 2,3 L
Cost water consuption (Euros)***	153.360	115.020	58.788	107.352	41.322
Net present value 10 year	1.300.500	1.157.875	1.172.025	2.130.638	1.736.595

* Considering two toilets per household.
** 5 people per home, with 3 flush for evacuation of urine and 1 for evacuation excreta by person.
*** Average cost strata 4, 5 and 6 for water and sewer.

A social survey conducted in August 2010 (see Appendix 2) enabled identifying that the dwellers of these new housing development projects have a preference for dual-flush and 2,3L toilet facilities.

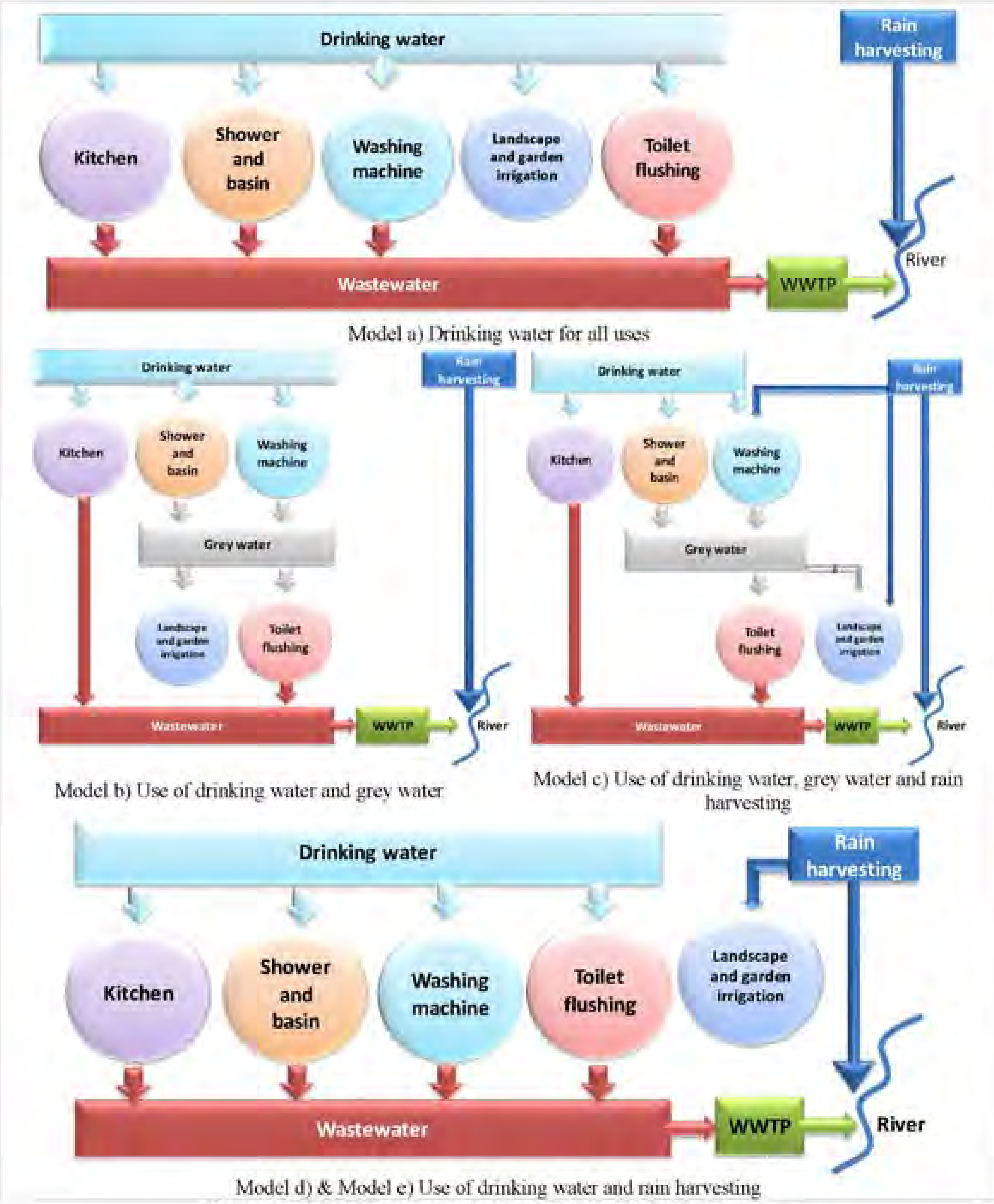
The results of this survey are shown in Figure 7.7. It established that 94% of the people prefer higher performance facilities. Consequently, the design and analysis of the various options will be performed considering only these kinds of facilities.

Figure 7.7 Preference for toilet facilities in the expansion area

From an initial number of 25 different combinations in single-family housing units and 15 apartments and based on the aforementioned considerations, the analysis was narrowed down to combinations for single-family housing units from strategies 6 to 15 listed in Table 7.4 and for multi-family housing units from strategies 4 to 9 listed above in Table 7.4.

For the purpose of managing water sources and uses in houses and apartments in the same manner linking them with each kind of excreta evacuation technology, several water supply combinations were formulated based on the following scenarios (see Figure 7.7 and Figure 7.8)

- Using drinking water for all purposes.
- Drinking water used for cooking, personal hygiene, and laundry, and using grey water for flushing toilets and irrigating gardens.
- Other option is use drinking water for cooking, personal hygiene, and laundry; and using grey water for flushing toilets and irrigating gardens. Supplementary use of rainwater for laundry, housekeeping, and garden irrigation.
- Also drinking water can be used for cooking, personal hygiene, laundry, flushing toilets, and housekeeping.
- To use drinking water for cooking, personal hygiene, laundry, and flushing toilets; and using rainwater for housekeeping and garden irrigation



Model a) Drinking water for all uses

Model b) Use of drinking water and grey water

Model c) Use of drinking water, grey water and rain harvesting

Model d) & Model e) Use of drinking water and rain harvesting

Figure 7.8 Water use models in the residential sector

7.4.1.2 Selection

The Figure 7.9 shows a hierarchy decision model for optimizing minimisation and prevention alternative selection. At the top of the hierarchy, the overall objective is to achieve the maximum general profits. The criteria considered in the selection of optimal minimisation and prevention alternative lie at the criterion level, which mainly consist of economic, technical, social and environmental criterion. In function of indicators viable of quantify, is included capital investment and O&M cost, level of complexity, institutional support, acceptance social, load BOD, load TSS and drinking water demand The scheme level (alternative level) lists the minimisation and preventions schemes to be compared and evaluated.

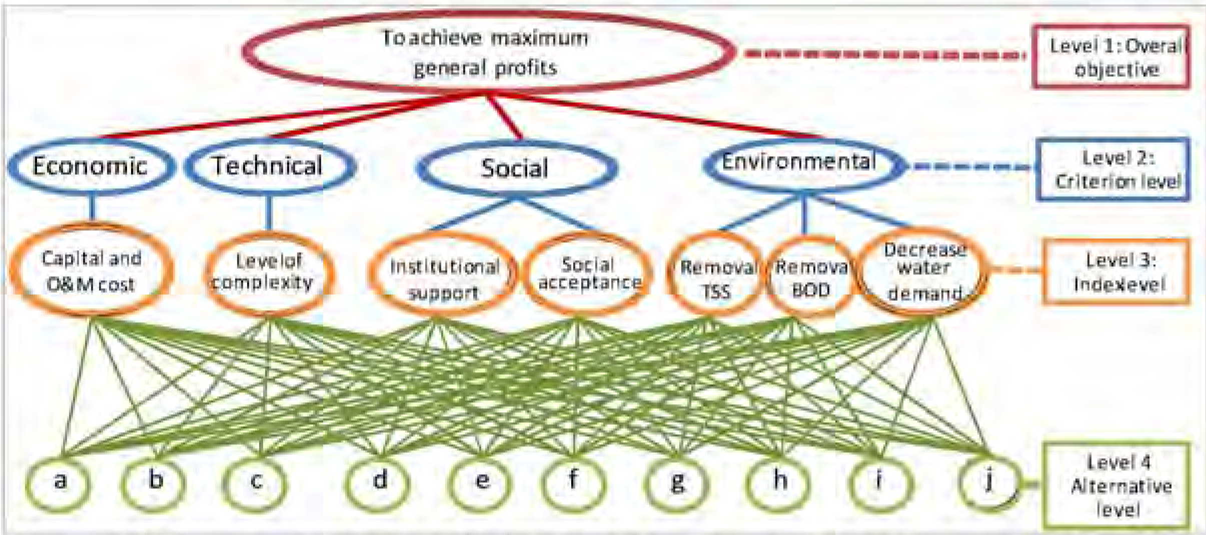


Figure 7.9 Hierarchy decision model for optimizing minimisation and prevention alternative selection

Table 7.6 presents a useful objective hierarchy for the minimisation and prevention alternative selection. The indicators were calculated based on the following considerations:

Table 7.6 An objective hierarchy for the minimisation and prevention alternative selection

CRITERIA	Index \ Strategy	a	b	c	d	e	f	g	h	i	j
ECONOMIC	Capital and O&M cost extern infrastructure	1,9	1,6	1,5	1,6	1,6	2,0	1,6	1,4	1,8	1,5
	Capital and O&M cost in housing infrastructure	0,1	0,4	0,8	0,5	0,5	0,3	0,6	1,0	0,7	0,7
ENVIRON-MENTAL	Decrease water demand	0,20	0,32	0,33	0,23	0,24	0,2	0,3	0,3	0,3	0,3
	Removal efficiency load BOD	0,40	0,58	0,58	0,40	0,40	0,43	0,60	0,61	0,43	0,43
	Removal efficiency load TSS	0,393	0,570	0,575	0,403	0,401	0,420	0,597	0,602	0,428	0,434
TECHNICAL	Level of complexity	0,6	1,6	1,7	0,8	1,1	0,6	1,6	2	1	1
SOCIAL	Institutional support	0,75	0,28	0,23	0,62	0,36	0,25	0,09	0,08	0,21	0,12
	Social acceptance	0,53	0,52	0,47	0,53	0,47	0,41	0,41	0,36	0,41	0,35

- A development area of 1.358 ha in total with a gross population density of 302 inhabitants/ha, is to say, 410.380 inhabitants in total. The data were collected for the purpose of comparing them against the previous feasibility study of public utilities in the area (EMCALI *et al.*, 2006a).
- An average of four individuals in each housing unit. This is consistent with the current trend among economic income levels 3 through 6 in the city (DAPM, 2008). This generates a total of 102.595 housing units.
- 15% of these housing units are single-family houses and 85% are apartments in multi-family housing complexes. This is based on a review of real estate supply in the south of Cali in districts 17 and 22, which are adjacent to the study area and have similar growth characteristics.
- It is estimated that 30% of all houses and apartments will use traditional water supply systems and 70% of them will use state-of-the-art systems. This traditional vs. state-of-the-art ratio was selected based on the following factors:

  - ✓ Compliance with regulations for efficient use of water which requires mandatory use of low consumption appliances, rainwater, and grey water at new housing development projects (Congreso de Colombia, 1997).

- ✓ The results of the social survey indicate a rate of acceptance of new water sources above 98% (see Appendix 2).
- ✓ At the present time, some housing projects are being promoted in the area (insert reference). In addition to this, EMCALI conducted the final studies of the water supply and sewerage networks using conventional facilities in 27% of the area (EMCALI *et al.*, 2009)

The following aspects described below were taken into account in establishing the methods of calculation and/or assigning a score to each of the indicators shown in Table 7.6 for each category.

Environmental Aspects

In this respect, the following three indicators were considered: decreasing the demand for drinking water, the BOD removal efficiency, and TSS load removal efficiency. Calculation of these values entailed estimating water consumption in each of the uses, the impact of the various water sources on the drinking water needs, and the production of wastewater. BOD and TSS loads were estimated based on the characterization of domestic wastewater and rainwater in similar areas.

Economic Aspects

This considered an analysis of capital and O&M costs at the level of the necessary external networks including, among others, water supply, pumping stations, rainwater and sanitary sewerage, and treatment plant in the area if all options are implemented. These costs were estimated as a direct function of the supply flow rate, transportation flow rate, and layout of each of the options. Another consideration was the cost of additional infrastructure required on a residential level. The allocation of costs involved incorporating a normalized value to the different options of costs associated with each kind of technology.

Technical Aspects

The complexity level was incorporated to this criterion as an indicator. It was assigned qualitatively a value as a function of the potential alternate sources and uses based on consultation with local subject matter experts.

Social Aspects

The social aspects considered were institutional support and social acceptance of various water uses and sources. To identify these aspects, a number of surveys were conducted using questions that determine support and acceptance, as applicable. These surveys are described in detail in Appendix 2. Figure 7.10 and Figure 7.11 shows the results in relation to each water source and the possibilities of using water for different purposes. Figure 7.10 refers to the use of rainwater for domestic purposes. It shows a high rate of acceptance of all uses from this source. It is accepted at a greater extent by the community more than by staff members at institutions. Washing clothes was the use that had the least acceptance, particularly on an institutional level.

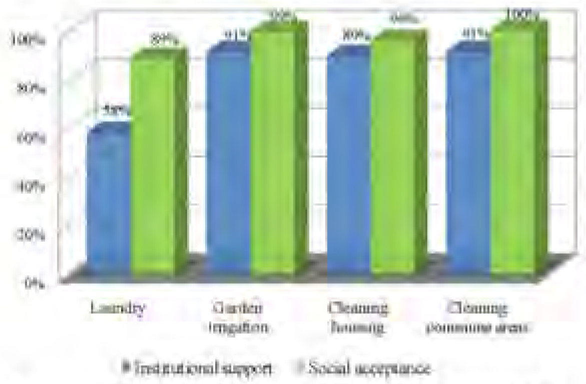


Figure 7.10 Institutional support and social acceptance of rainwater use in new projects of houses in the south of Cali

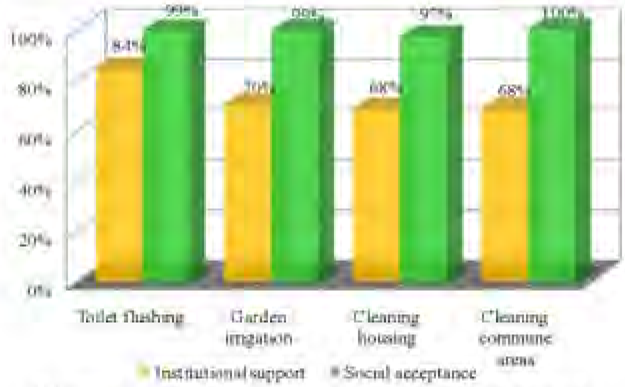


Figure 7.11 Institutional support and social acceptance of greywater reuse in new projects of houses in the south of Cali

Figure 7.11 refers to the use of grey water for domestic purposes. This water source has a high rate of acceptance for all purposes. It is primarily accepted by the community more than by staff members at institutions. Using grey water for flushing toilets had a high rate of acceptance on an institutional level. The buy-in or acceptance of each alternative was determined by multiplying the ratios for each use by the sources and the excreta flushing facilities to be installed with each combination.

In applying the AHP technique, an important consideration task was the identification of the relative weight of the indicators assigned by the decision-making center, i.e. municipal urban planning and water management institutions. These weights were determined based on information from the surveys using Saaty's technique as described in the methodology. The peer-comparison matrix that resulted from a frequency analysis is shown in Table 7.7, and the weights for each criterion after standardization are graphically presented in Figure 7.12.

Table 7.7 Comparison criteria selection

	ENVIRONMENTAL	ECONOMIC	TECHNICAL	SOCIAL
Environmental	1	3	1	1
Economic	1/3	1	1	1
Technical	1	1	1	1
Social	1	1	1	1

Figure 7.12 Weighting of selection criteria identified among decision makers in water management in Cali

It is worth emphasizing that although decision makers tend to give more relevance to environmental criteria, there is an evenly distributed relation among the different criteria which, in general, are deemed equally and mutually important. Despite a limited availability

of local resources, the least important criterion was economic in nature. Other aspects such as technical and social issues have a large impact on the selection of water management technologies. The normalized data can be found in Table 7.8. The resulting primary and secondary grey relational coefficients are shown in Table 7.9, Table 7.10 and Table 7.11, respectively. The intermediate steps of weighting and normalizing the weighted ratios are shown in Table 7.12 and Table 7.13

Table 7.8 Normalized data of each option for index level

CRITERIA	Index \ Strategy	a	b	c	d	e	f	G	h	i	j
ECONOMIC	Capital and O&M cost extern infrastructure	0,7	0,9	1,0	0,9	0,9	0,7	0,9	1,0	0,8	0,9
	Capital and O&M cost in housing infrastructure	1,0	0,2	0,1	0,2	0,2	0,3	0,1	0,1	0,1	0,1
ENVIRONMENTAL	Decrease water demand	0,6	1,0	1,0	0,7	0,7	0,7	1,0	1,0	0,8	0,9
	Removal efficiency load BOD	0,7	1,0	1,0	0,7	0,7	0,7	1,0	1,0	0,7	0,7
	Removal efficiency load TSS	0,7	0,9	1,0	0,7	0,7	0,7	1,0	1,0	0,7	0,7
TECHNICAL	Level of complexity	1,0	0,4	0,4	0,8	0,5	1,0	0,4	0,4	0,8	0,5
SOCIAL	Institutional support	1,0	0,4	0,3	0,8	0,5	0,3	0,1	0,1	0,3	0,2
	Social acceptance	1,0	1,0	0,9	1,0	0,9	0,8	0,8	0,7	0,8	0,7

(DW) Drinking water (GW) Grey water (RH) Rain harvesting
a. WC dual+DW b. WC dual+DW+GW c. WC dual+DW+GW+RH d. WC dual+DW+RH
e. WC dual+DW+RH f. WC 2,3 L+DW g. WC 2,3 L+DW+GW h. WC 2,3 L+DW+GW+RH
i. WC 2,3 L+DW+RH j. WC 2,3 L+DW+RH

Table 7.9 Primary grey relational coefficients

CRITERIA	Index \ Strategy	a	b	c	d	e	f	g	h	i	j
ECONOMIC	Capital and O&M cost extern infrastructure	0,64	0,80	0,96	0,80	0,78	0,61	0,83	1,00	0,71	0,85
	Capital and O&M cost in housing infrastructure	1,00	0,36	0,34	0,35	0,35	0,41	0,35	0,33	0,34	0,34
ENVIRONMENTAL	Decrease water demand	0,54	0,92	1,00	0,60	0,63	0,64	0,92	1,00	0,72	0,77
	Removal efficiency load BOD	0,57	0,91	0,91	0,57	0,57	0,61	1,00	1,00	0,61	0,62
	Removal efficiency load TSS	0,57	0,90	0,91	0,58	0,58	0,60	0,98	1,00	0,61	0,62
TECHNICAL	Level of complexity	1,00	0,42	0,41	0,65	0,50	1,00	0,42	0,41	0,65	0,50
SOCIAL	Institutional support	1,00	0,42	0,40	0,73	0,47	0,41	0,34	0,34	0,39	0,35
	Social acceptance	1,00	0,96	0,79	0,99	0,79	0,67	0,66	0,59	0,67	0,58

Table 7.10 Weighted primary grey relational coefficients

Criteria \ Strategy	a	b	c	d	e	f	g	H	i	j
ECONOMIC	0,82	0,58	0,65	0,58	0,57	0,51	0,59	0,67	0,53	0,60
ENVIRONMENTAL	0,56	0,91	0,94	0,58	0,59	0,62	0,97	1,00	0,65	0,67
TECHNICAL	1,00	0,42	0,41	0,65	0,50	1,00	0,42	0,41	0,65	0,50
SOCIAL	1,00	0,69	0,59	0,86	0,63	0,54	0,50	0,46	0,53	0,46

Table 7.11 Normalized weighted primary grey relational coefficients

Criteria \ Strategy	a	b	c	d	e	f	g	H	i	j
ECONOMIC	0,62	0,87	0,79	0,88	0,90	1,00	0,86	0,76	0,97	0,85
ENVIRONMENTAL	0,56	0,91	0,94	0,58	0,59	0,62	0,97	1,00	0,65	0,67
TECHNICAL	0,41	0,98	1,00	0,64	0,83	0,41	0,98	1,00	0,64	0,83
SOCIAL	1,00	0,69	0,59	0,86	0,63	0,54	0,50	0,46	0,53	0,46

Table 7.12 Secondary grey relational coefficients

Criteria \ Strategy	a	b	c	d	e	f	g	h	i	j
Economic	0,435	0,693	0,577	0,705	0,737	1,000	0,682	0,552	0,902	0,667
Environmental	0,400	0,762	0,829	0,413	0,419	0,434	0,901	1,000	0,455	0,469
Technical	0,333	0,936	1,000	0,449	0,627	0,333	0,936	1,000	0,449	0,627
Social	1,000	0,487	0,418	0,676	0,442	0,388	0,369	0,353	0,382	0,353

(DW) Drinking water
(GW) Grey water
(RH) Rain harvesting
a. WC dual+DW
b. WC dual+DW+GW
c. WC dual+DW+GW+RH
d. WC dual+DW+RH
e. WC dual+DW+RH
f. WC 2,3 L+DW
g. WC 2,3 L+DW+GW
h. WC 2,3 L+DW+GW+RH
i. WC 2,3 L+DW+RH
j. WC 2,3 L+DW+RH

Table 7.13 Weighted secondary grey relational coefficients

Criteria \ Strategy	a	b	c	d	e	f	g	h	i	j
Economic	0,08	0,13	0,11	0,13	0,14	0,19	0,13	0,10	0,17	0,12
Environmental	0,13	0,25	0,27	0,13	0,14	0,14	0,29	0,32	0,15	0,15
Technical	0,08	0,23	0,25	0,11	0,15	0,08	0,23	0,25	0,11	0,15
Social	0,25	0,12	0,10	0,17	0,11	0,10	0,09	0,09	0,09	0,09
$\sum$	0,54	0,72	0,72	0,54	0,53	0,50	0,74	0,76	0,52	0,52

A selection process using AHP-GRA, which combines different criteria and indicators, allowed establishing an eligibility order of options. It is presented graphically illustrated in Figure 7.13

The most viable option is strategy h, which involves installing a 2,3 L WC, using grey water for evacuating excreta and irrigating gardens, and using rainwater for washing clothes and cleaning common areas.

Figure 7.13 shows that there is no significant different between the strategy with the highest score (h) and other strategies such as g, b, and c which are highlighted with a dotted line. These alternatives share something in common which is the use of grey water. The use of this water source has not only a remarkable impact on the reduction of environmental indicators which, in the selection model, constitute a major weight criterion, but also a high rate of social acceptance. Rainwater harvesting is another strategy that improves environmental conditions. It is listed among the alternatives of strategies h and c.

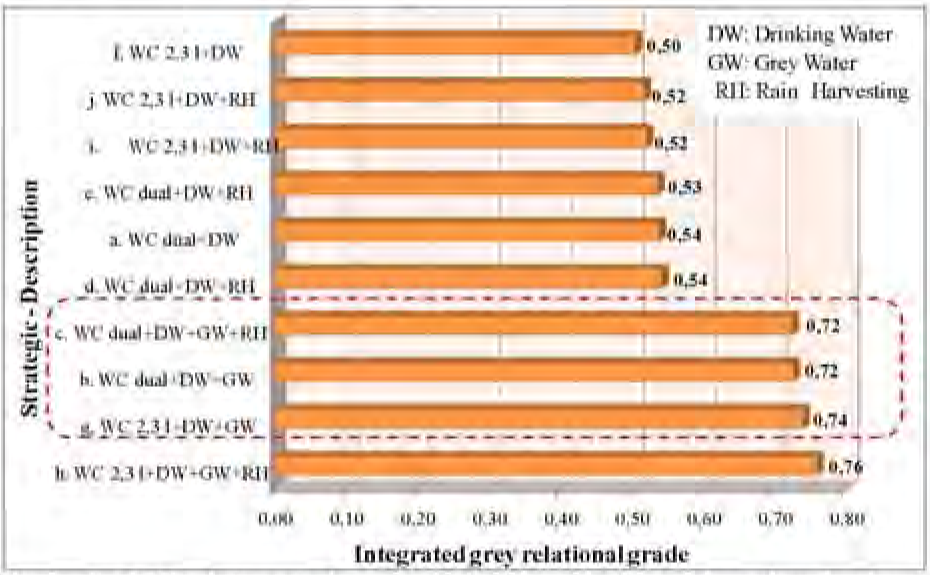


Figure 7.13 The integrated grey relational grade for each optional scheme

Strategies b and g consider only one additional source to drinking water. From the perspective of internal networks, this makes this option viable because the installation and O&M of the system becomes less complex. These two alternatives differ from each other by the toilet flushing system to be implemented. The four most feasible options for water management have a similar degree of eligibility. This shows that designers and builders have a wide range of options available for urban planning purposes. They can make the best choice depending on the financing conditions, environmental considerations, and economic benefits that suit the users' needs. A determining factor in the selection process is the number of housing units that will embrace these new approaches to water management planning, which has a direct influence on the water flows to be transported and the BOD and TSS loads to be carried to a treatment system. Figure 7.14 and Figure 7.15 illustrate the change in the total annual BOD and TSS loads contributed by the residential sector in the form of wastewater and rainwater collected on the decks vs. the percentage of housing units that use low consumption appliances and alternative water sources.

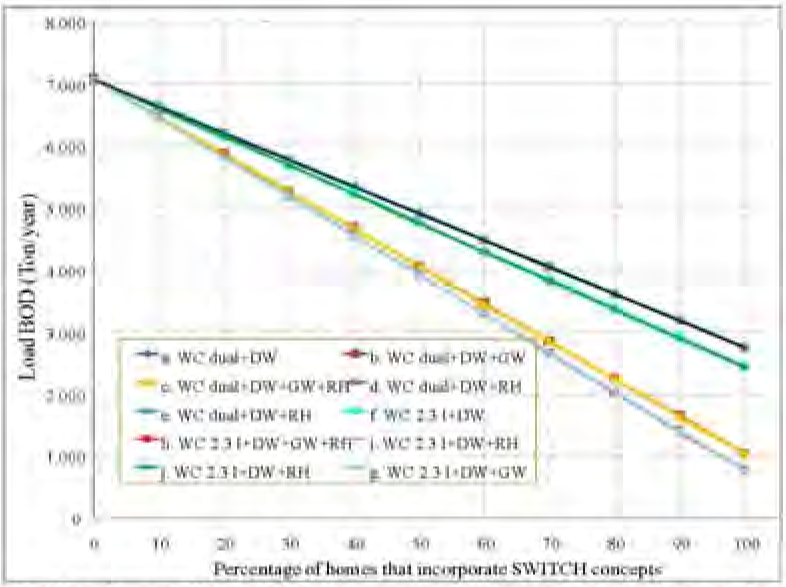


Figure 7.14 BOD load contributed by the expansion zone according to the percentage of households that incorporate low consumption devices and alternative water sources

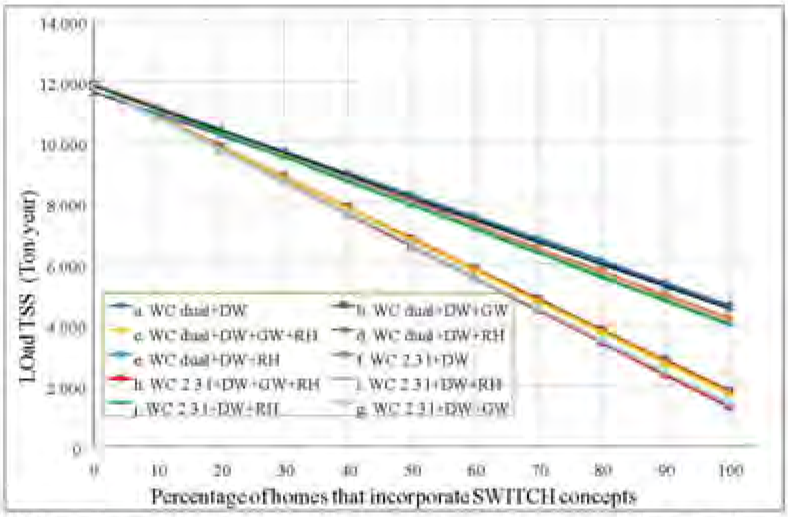


Figure 7.15 TSS load contributed by the expansion zone according to the percentage of households that incorporate low consumption devices and alternative water sources

For cost-benefit analysis purposes, although strategies h, g, b, and c have the same degree of feasibility of implementation, only option h will be analyzed. It involves installing a 2,3 L WC, using grey water for evacuating excreta and irrigating gardens, and using rainwater for washing clothes and housekeeping of common areas.

7.4.1.3 Initial investment costs

The identified costs are associated with the main initial investment needs for:

- Primary water supply networks
- A sewerage system
- A drainage system
- WWTP
- Additional internal infrastructure in the housing unit, including the training costs associated with the implementation of new technologies.

The following considerations or assumptions were taken into account in calculating the costs:

- Total population growth at a constant rate in the area over a 20-year period.

- Incorporation of the initial cost of investment in water and sewerage matrix networks in year 1. Although the area is not densely populated, this kind of investment has to be made from the outset of the project because the complexity of changing or replacing these networks on the main streets does not allow these works to be done frequently.

- Construction of the drinking water pumping station has been scheduled to take place in stages because the final pumping power is not required since year 1. Installed pumping power will be increased stepwise depending on the demand for water. In this respect, there is a plan for two WWTPs (one in year one and the other in year 10) using decentralized systems. The need for treatment will be consistent with the generation of wastewater in the area.

Primary water supply networks

The primary water supply network was presized using the area-based demand allocation method based on EPANET's software for checking pressure and speed values in conformance with current Colombian regulations.

A layout of the network, allocated demands, and pipe sizes are shown in Figure 7.16. The estimated total cost was € 2.943.107.

The initial investment cost during the analysis period is presented in Table 7.14.The water supply system calls for the installation of a booster pumping station directly at the network. This pumping station was calculated in several stages consistent with the increase of the demand, as graphically shown in Figure 7.17.

Figure 7.16 Drinking water network in expansion area with minimisation and prevention option

Table 7.14 Cost initial investment pumping station of drinking water with minimisation and prevention option

YEAR	INITIAL INVESTMENT (Euros)
1	31.111
5	31.111
10	115.556
15	28.889
20	164.444

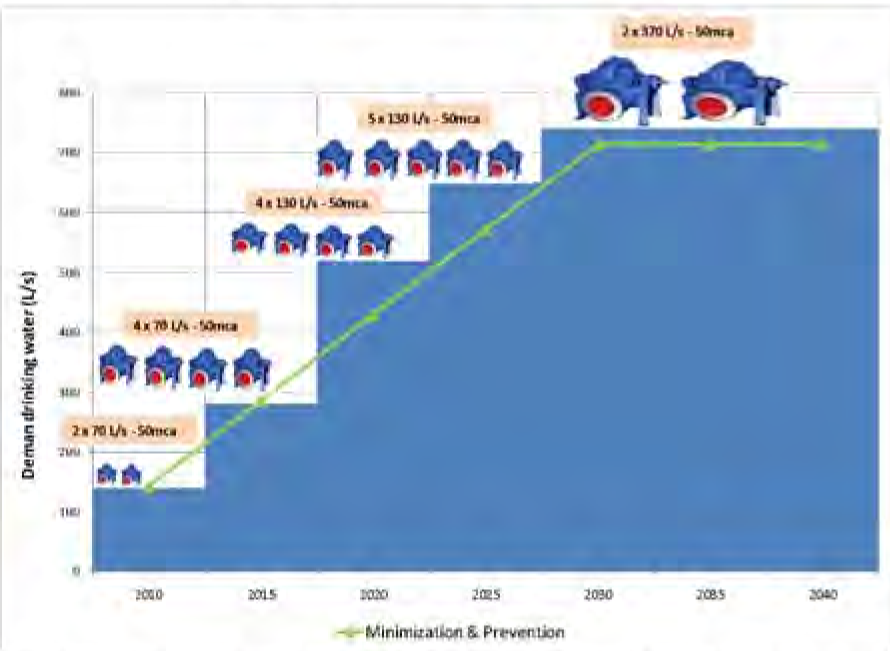


Figure 7.17 Projected demand and pumping requirements with minimisation and prevention option

Sewerage system

A calculation was made of the two primary sewerage networks that will carry wastewater. Each line leads to a wastewater treatment plant. El The cost of the system if wastewater is discharged into the Cauca river is € 895.134.

WWTP South with natural system

Two wastewater treatment plants (one in year 1, and the other in year 10) were considered in the analysis in such a way that they meet the treatment needs based on the density of population in the area. The treatment scheme consists of the following: High rate Anaerobic Pond + Secondary facultative pond + Rock Filter.

The calculation the natural treatment systems, is made using the methodology presented by (Kadlec *et al.*, 1996; Madera *et al.*, 2003b; Mara, 2003; Mara, 1987; Mara, 2006; Mara *et al.*, 2007; Mara *et al.*, 2001; Peña, 2002,2008; Reed *et al.*, 1995).

Four main items that include the biggest construction costs have been considered to give a first idea about the budget needed to build the plant: land, excavation, impermeabilization and gravel. Values of excavation, liner and gravel take into account costs for installation and movement of material.The cost presented in Table 7.15.

Table 7.15 Cost initial investment treatment with natural system: High rate Anaerobic Pond+ Secondary facultative pond + Rock Filter with minimisation and prevention option (values in Euros)

TREATMENT UNIT	LAND	EXCAVATION	LINER	GRAVEL	SUBTOTAL
High rate Anaerobic Pond	65.318	122.898	52.734	0	240.949
Secondary facultative pond	307.684	323.068	223.048	0	853.800
Rock Filter	191.072	80.250	136.159	458.572	866.054
				TOTAL	1.960.803

Additional internal infrastructure in the housing units

The pollution prevention and minimisation strategy selected for households of expansion area integrate:

As low consumption device

- Toilet of 2,3 L
- Tap high efficient in kitchen, basin and shower.

As alternative sources

- Rainwater harvesting system with filtration for use in washing clothes in house.
- Rainwater harvesting system for use in cleaner commune areas and garden irrigation in multifamily.
- Greywater reuse system with treatment, for use in flushing toilet and garden irrigation in house.
- Greywater reuse system with treatment, for use in cleaner commune areas and garden irrigation in multifamily.

Low consumption device

While the cost of a conventional toilet is €64, the unit cost of a 2,3 L toilet is €160. The additional cost per housing unit if two toilet units are installed is €192.

Greywater system

Greywater although different system configurations have been reported in practice, a grey water recycling system generally includes: a grey water storage tank, a treatment unit and a green water storage tank (see Figure 7.18) (Liu *et al.*, 2010). Be considered as wetland treatment system as a viable technology in contexts such as local (Dallas *et al.*, 2004; Gross *et al.*, 2007; Liu *et al.*, 2010).

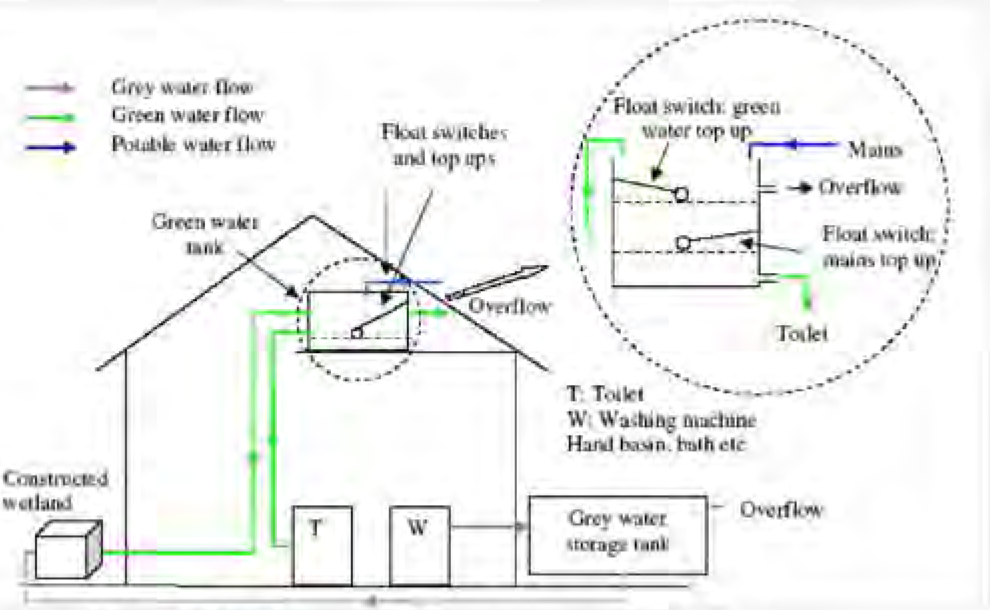


Figure 7.18 Ilustration of greywater recycling system
Source: (Liu *et al.*, 2010)

Since these kinds of systems are not available in Cali, within the framework of the project a wetland was built in an income level 3 house in the urban area based on the characteristics of raw greywater presented by Birks and Hills (2007) (see Appendix 4). Because there are not regulations in place regarding the quality parameters for using grey water in Colombia, Chinese standards for BOD and total coliforms were adopted in light of the fact that they provide the best quality standards for the intended use (Li *et al.*, 2009).

The pre-dimensioning of the system was calculated following the methodology proposed by (Reed *et al.*, 1995). The cost of the system was €200, including raw and treated water storage tanks. The estimated cost of additional internal piping for collecting greywater and distributing treated water was €100. If a pumping system and valves are added, the cost would be €80. The average training cost is €15. The total cost of a greywater system in a housing unit is €395. On a multifamily level, the wetland is sized based on the same criteria mentioned above for single-family housing units, for a 15-apartment building. The costs are presented in Table 7.16.

Table 7.16 Cost initial investment to implement grey water in multifamily in expansion area

ITEM	UNIT	QUANTITY	VALUE UNIT (Euros)	SUBTOTAL (Euros)
Gray water collection pipe	m	100	2	204
Treated grey water supply pipe	m	100	1	141
Storage Tanks	Unit	4	209	835
Accessories	Global	1	69	69
Pipe Installation	m	200	0	40
Pump	Unit	1	48	48
Valve	Unit	2	16	32
Excavation	m^3	20	6	120
Grave	m^3	20	16	320
Membrane	m^2	35	6	196
Plants	Unit	125	2	190
Training	Global	1	15	15
			SUBTOTAL (Euros)	2,195
			COST PER APARTMENT (Euros)	161

Rainwater harvesting system

The components of a rainwater collection system comprise facilities for rainwater capture, collection, carriage, interception, treatment, and storage (CEPIS *et al.*, 2001). Because they are common, the deck and the gutter and downspout system for collecting rainwater will not be considered. The cost of the system is associated with a raw water receiving and storage tank, a filtering system, and a treated water storage tank or vessel. The storage facilities were sized based on the mass curve method (CEPIS *et al.*, 2001; Materon, 1997) and daily precipitation data from 2007 to 2009 (see Appendix 5). Although this analysis revealed that a house would need a 5,5 m^3 tank, a cost-effective suggestion was made to use two plastic tanks (i.e. a low one and a high one) with a capacity of 1 m^3 each, which will meet the demand 78% of the time.

The cost of the storage facilities (i.e. two 1 m^3 tanks/vessels) and a pump is €120. The rapid sand filter has a local cost of €160. The estimated cost of internal piping for distributing treated water is €60. The average training cost is €15.The total cost of the rainwater system for a house is €355.

The uses and the devices for collecting rainwater in multifamily are different as well as the system configuration which requires larger water storage tanks and the lack of filtering systems that suit the use of water (i.e. irrigating gardens and housekeeping of common areas). The sizing of the storage facilities was determined using the mass curve methodology (CEPIS *et al.*, 2001; Materon, 1997) and daily precipitation data from 2007 to 2009. Because ferrocement costs 19% less than concrete and meets structural requirements and performance (Londoño *et al.*, 2001) the use of ferrocement storage tanks is suggested. The costs of a rainwater system for multifamily consisting of 4 buildings and 15 apartments by building are presented in Table 7.17.

Table 7.17 Initial investment to implement rain harvesting in multifamily in expansion area

ITEM	UNIT	QUANTITY	VALUE UNIT (Euros)	SUBTOTAL (Euros)
Storage tanks ferrocement 84 m^3	Unit	1	2776	2776
Drive pumps	Unit	4	28	112
Plastic tanks 2 m^3	Unit	4	209	836
Valve	Unit	4	40	160
Pipe	Global	1	400	400
Training	Global	1	15	15
			TOTAL (Euros)	4284
			COST PER APARTMENT (Euros)	86.4

A summary of the initial cost of investment in additional infrastructure for internal networks in a housing unit is presented in Table 7.18. The costs of additional investment in housing infrastructure during the years of increased population density in the area are shown in Table 7.19.

Table 7.18 Cost initial investment to implement minimisation and prevention in household in expansion area

SYSTEM	COST (€)	
	HOUSE	APARTAMENT
WC 2,3 L	192	192
Grey water	395	161
Rain harvesting	355	86.4
TOTAL	942	409.4

Table 7.19 Cost initial investment to implement minimisation and prevention in household in expansion area (millions €)

HOUSING TYPE	VPN	YEAR																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
HOUSE	4,1	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
APARTAMENT	10,6	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3
TOTAL	14,8	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9

7.4.1.4 Estimation of operation and maintenance costs

The O&M activities of the solution with SWITCH approach are related with maintenance of rainwater harvesting system and greywater reuse system, since flushing toilet of 2,3 L do not requires maintenance activities additional compared with conventional flushing toilet. The maintenance of rainwater harvesting system and greywater reuse system is associated with workers required for filter cleaning and/or costs of electrical supply for pumping systems.

The maintenance frequency for greywater reuse system is 6 times per year with a duration of 6 hours by maintenance activity, whose represents a estimated cost of € 30,9. In relation to electricity consumption, using pumps of 2HP, the electrical demand according with requeriments (the time of filling up the storage tank), would a cost of € 9,1, for a O&M total cost of € 80 annual per household.

For rainwater harvesting system, the frequency of maintenance activities will be highest than greywater reuse system due to that water quality is high. Is suggested a maintenance frequency of 8 times per year, with a duration of 4 hours, that represents a approximately cost of € 27,5. The electrical demand depends of requirements, but is estimated a electrical cost of € 12,5. The total cost of O&M for rainwater harvesting system is € 80 annual per household.

7.4.2 Wastewater treatment and effluent reuse

7.4.2.1 Description of the options

The proposed technological options were pre-designed with the treatment objective of reusing water for farming purposes and an emphasis on the use of natural methods based on their proven efficiency (Moscoso *et al.*, 2002a), the conceptual framework of the project, and successful local experiences (high Cauca River basin), such as the anaerobic and facultative ponds in the municipalities of Guacarí, La Union, Roldanillo and Toro, with BOD_5 removals

between 80 and 85% (Corrales *et al.*, 2000) and experiences in the rural municipality of (community of La Voragine) formed by a septic tank with an anaerobic filter and a subsurface-flow horizontal constructed wetland working with Scirpus, sp.; results show an excellent organic matter removal (Madera *et al.*, 2003b).

Proposals were initially made for 18 different wastewater treatment options in the expansion area of Cali. The proposals were the result of combining different treatment units using natural methods and final effluent disposal (see Table 7.20).

Table 7.20 Treatment options for the south expansion area within the framework of the SWITCH project in 2009

ID	TREATMENT TECHNOLOGY (T)	EFFLUENT USE OR DISPOSAL
1	Primary Facultative Pond+ Rock Filter	Cauca river
2	Primary Facultative Pond+ MaturationPond	Irrigation
3	Primary Facultative Pond (3/4Q) + Fishing Pond (Q/4)	3/4 Q Cauca river Q/4 Effluent Fishing Pond for Irrigation
4	Primary Facultative Pond with baffles+ Rock Filter	Irrigation
ID	TREATMENT TECHNOLOGY (T)	EFFLUENT USE OR DISPOSAL
5	Primary Facultative Pond with baffles (3/4Q) + Fishing Pond (Q/4)	3/4 Irrigation Q/4 Efluent Fishing Pond for Irrigation
6	Anaerobic pond+ Secondary facultative pond+ Rock Filter	Cauca river
7	Anaerobic pond+ Secondary facultative pond+ Maturation pond	Irrigation
8	Anaerobic pond+ Secondary facultative pond+(Q/4) Fishing pond	3/4 Q Cauca river Q/4 Efluent Fishing Pond for Irrigation
9	Anaerobic pond+ Secondary facultative pond with baffles+ Rock Filter	Irrigation
10	Anaerobic pond+ Secondary facultative pond with baffles+(Q/4) Fishing pond	3/4 Irrigation Q/4 Efluent Fishing Pond for Irrigation
11	High rate Anaerobic Pond+ Secondary facultative pond with baffles+ Rock Filter	Irrigation
12	High rate Anaerobic Pond+ Secondary facultative pond with baffles+(Q/4) Fishing pond	3/4 Irrigation Q/4 Efluent Fishing Pond for Irrigation
13	Anaerobic pond+Sub surface Constructed Wetland	Cauca river
14	Anaerobic pond+Sub surface Constructed Wetland+ Maturation pond	Irrigation
15	Anaerobic pond+Sub surface Constructed Wetland+ (3/4Q) Fishing pond	3/4 Q Cauca river Q/4 Efluent Fishing Pond for Irrigation
16	High rate Anaerobic Pond+Sub surface Constructed Wetland	Cauca river
17	High rate Anaerobic pond+Sub surface Constructed Wetland+ Maturation pond	Irrigation
18	High rate Anaerobic pond+Sub surface Constructed Wetland+ (3/4Q) Fishing pond	3/4 Q Cauca river Q/4 Efluent Fishing Pond for Irrigation

To identify the range of wastewater treatment options available, an assessment was conducted of the institutional support from the company that provides water and sewerage services in the study area with regard to the implementation of each of the treatment technologies within the framework of learning alliances.

Out of the results of this assessment six technology options were excluded which involved implementing fishing ponds because of their highly complex operation and maintenance. From the technologies listed in Table 7.20 those that considered the Cauca River as a final disposal alternative were also excluded because these options were only designed having treatment as an objective in accordance with local regulations (CVC, 1976) that require an 80% organic load removal efficiency as a performance indicator (BOD_5 and TSS).

In addition to the above, a physicochemical characterization of the effluent achieved with these four different technologies did not meet the agronomic quality standards proposed by the FAO in 1987 (Ayers *et al.*, 1987). In this respect, the range of technology options to be characterized based on the reuse of water for farming purposes (irrigation of sugar cane fields) consists of the six following options:

- Primary Facultative Pond+ Maturation Pond.
- Anaerobic pond+ Secondary facultative pond+ Maturation pond.
- Anaerobic pond+ Secondary facultative pond with baffles+ Rock Filter.
- High rate Anaerobic Pond+ Secondary facultative pond with baffles+ Rock Filter.
- Anaerobic pond+Sub surface Constructed Wetland+ Maturation pond.
- High rate Anaerobic pond+Sub surface Constructed Wetland+ Maturation pond.

The various treatment technologies were sized based on the methodologies of dimensioning. The size and total area requirements for each of the options that comprise the range of technologies are presented in Table 7.21.

Table 7.21 Area requirement and size of wastewater treatment options for the south expansion area

ID	TECHNOLOGY (T)	AREA (ha)	HRT (h)	LENGTH (m)	WIDTH (m)	DEPTH (m)	TOTAL AREA (ha)
1	Primary Facultative Pond	11,84	12,28	500	236,89	2	17,51
	MaturationPond	5,66	3	350	161,73	1	
2	Anaerobic pond	0,65	1	120	54,37	3	11,59
	Secondary facultative pond	5,19	4	345	150,33	1,5	
	Maturation pond	5,76	3	360	159,88	1	
3	Anaerobic pond	0,65	1	120	54,37	3	9,06
	Secondary facultative pond with baffles	5,19	4	345	150,33	1,5	
	Rock Filter	3,22	0,4	270	119,28	0,6	
4	High rate Anaerobic Pond	1,01	1,02	181,74	113,58	4	9,42
	Secondary facultative pond with baffles	5,19	4	345	150,33	1,5	
	Rock Filter	3,22	0,4	270	119,28	0,6	
5	Anaerobic pond	0,65	1	120	54,37	3	14,76
	Sub surface Constructed Wetland	8,4	1,03	430	195,35	0,6	
	Maturation pond	5,71	3	360	158,61	1	
6	High rate Anaerobic pond	1,01	1,02	181,74	113,58	4	15,12
	Sub surface Constructed Wetland	8,4	1,03	430	195,35	0,6	
	Maturation pond	5,71	3	360	158,61	1	

7.4.2.2 Selection of alternatives

A review of the literature available in the field was conducted in order to determine the specific criteria for selecting the most suitable wastewater treatment technology considering water reuse for farming. The most relevant criteria are environmental, economic, technical, and sociocultural in nature (Abbassi *et al.*, 2008; Galvis *et al.*, 2007; Manga *et al.*, 2001; Metcalf *et al.*, 1995; Moscoso *et al.*, 2002b).

The formulation of the SWITCH strategy involved the implementation of an Analytic Hierarchy Process and a Grey Relational Analysis (AHP-GRA) as described by (Zeng *et al.*, 2007). These analyses enabled the selection of the kind of wastewater treatment technology to be deployed in the expansion area. Similarly, in the case of Cali the first step was preparing an outline of the conceptual approach, including a definition of the following aspects: the target

function, a list of the criteria for the selection process, the effectiveness indicators, and alternatives to be selected (Figure 7.19).

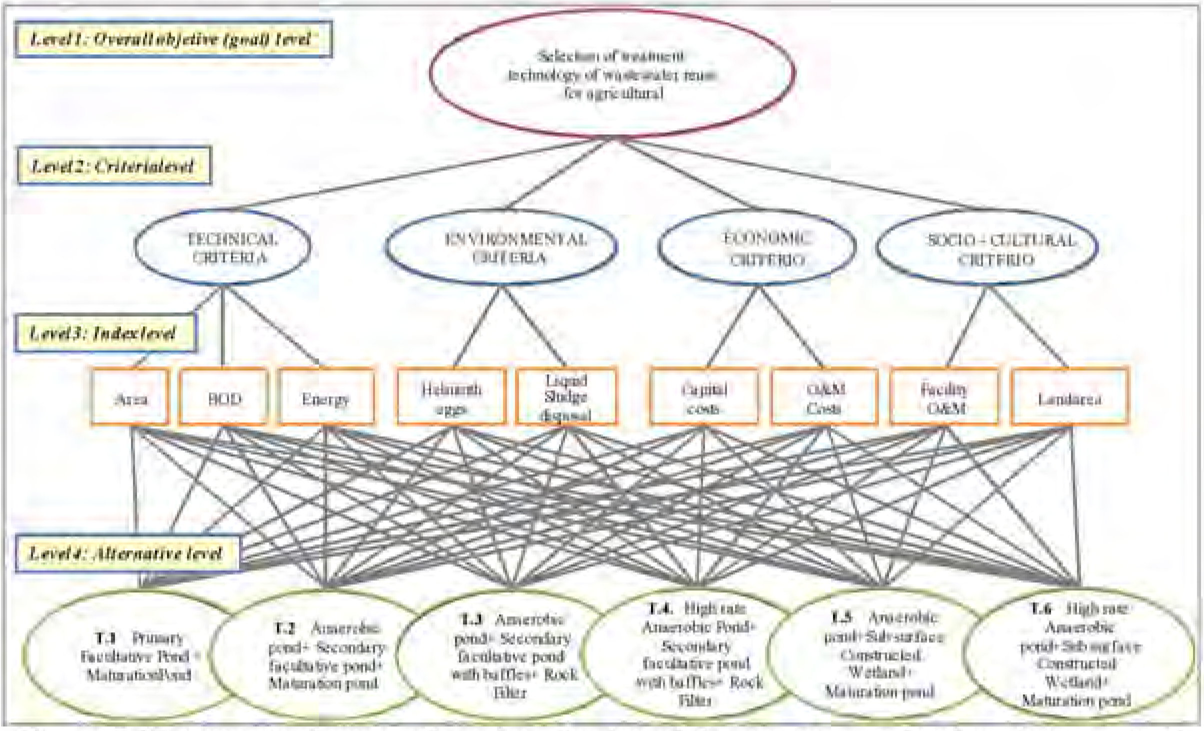


Figure 7.19 Conceptual approach to the selection of the treatment technology using natural methods and targeting water reuse in irrigation for south expansion area

The formulation of performance criteria and indicators was based on the results of the survey conducted among experts in the case of Cali where Saaty's matrix was used (Romero, 1997; Zeng *et al.*, 2007) for comparing the level of relevance of a criterion with respect to other criteria. The results of this survey yielded the following rates of relative relevance: environmental criteria (43,4%), followed by sociocultural (29,5%), technical (21,2%), and economic criteria (5,9%) (Appendix 1)

The relative relevance of the performance indicators was determined using descriptive statistics based on the reference weights provided by the experts. A single reference weight was calculated based on a likelihood of occurrence of 75%. This rate refers to the existing likelihood after consulting with experts for the purpose of assigning a single relative weight to each specific indicator. The results of this statistical process are shown below in Table 7.22.

Table 7.22 Relevance of criteria and indicators for the selection of a wastewater treatment technology in irrigation for south expansion area

CRITERIA		WEIGHT	INDICATOR		WEIGHT	RANK
C1	TECHNICAL	0,21	I1	Area required (ha)	0,300	2
			I2	Concentration of BOD in wastewater (mg/L)	0,400	1
			I3	Power consumption (kW-h/inhabitants-day)	0,300	3
C2	ENVIRONMENTAL	0,43	I4	Concentration of helminth eggs (he/L)	0,570	1
			I5	Sludge production (L-inhabitants/year)	0,430	2
C3	ECONOMIC	0,06	I6	Initial investment cost (in euros)	0,436	2
			I7	O&M cost (in euros)	0,564	1
C4	SOCIOCULTURAL	0,3	I8	Ease of O&M (1=easy, 2=medium, 3=complex)	0,468	2
			I9	Land ownership (1= own, 2= land purchase)	0,532	1

Indicators such as agronomic quality indicators (Ayers *et al.*, 1987) and the physicochemical quality of the effluent (FAO, 1999) are critical for the process of selecting a wastewater treatment technology aiming at reusing water for farming. According to (Nascimento *et al.*, 2008), local evidence was found that showed that the wastewater effluent from the primary treatment system at the Cañaveralejo WWTP meets acceptable agronomic and physicochemical quality standards in accordance with the guidelines of both (WHO, 2006) and FAO (1999).

In the specific case of the expansion area, only the physicochemical quality indicator suggested by FAO (1999) was considered in the criteria for the selection of a wastewater treatment technology. This indicator describes the allowed concentration of BOD, TSS, Fecal coliform, and pH of water to be able to reuse (i e commercially processed foods and are consumed).

These parameters were obtained from characterizations of the reference effluent in compliance with the requirements set forth in local regulations (CVC, 1976). It is worth noting that the expansion area of Cali is a projected area, and the characterization of wastewater in this area was taken from a reference that features similar sociocultural conditions (effluent from the wastewater treatment facility in the south of the city).

In this scenario and taking into account the removal efficiencies of the proposed technologies (Galvis *et al.*, 2007; Silva, 2008; Silva *et al.*, 2008) the physicochemical quality of the effluent was not considered a selection criterion because all technologies meet the water quality requirement for reusing water for farming purposes under the guidelines of the FAO (1999).

The selection process also entailed the use of an Analytic Hierarchy Process (AHP) to characterize the six different wastewater treatment options as a function of the proposed indicators (see Table 7.23). The characterization of the various treatment technologies as a function of land ownership was completed within learning alliances at a meeting where the treatment alternatives were presented to the (EMCALI, 2007). The presentation included the possibility of purchasing land given the area required for the deployment of each technological option.

Table 7.23 Characterization of wastewater treatment technologies based on performance indicators for south expansion area

CRITERIA	INDICATOR		T1	T2	T3	T4	T5	T6
TECHNICAL	I1	Area required (ha)	17,51	11,59	9,06	9,42	14,76	15,12
	I2	Concentration of BOD in wastewater (mg/L)	31,70	37,40	16,30	17,20	9,40	9,40
	I3	Power consumption (kW-h/inhabitants-day)[1]	0,00	0,00	0,00	0,30	0,00	0,30
ENVIRONMENTAL	I4	Concentration of helminth eggs in wastewater (hh/L)	0,04	0,17	0,00	0,00	0,00	0,00
	I5	Sludge production (L-inhabitants/year)[1]	62,50	107,50	107,50	107,50	45,00	45,00
ECONOMIC	I6	Initial investment cost (in million euros)	10,06	6,11	6,53	6,49	10,83	11,06
	I7	O&M cost (in thousand euros)	503,03	305,55	326,49	324,62	541,51	553,14
SOCIOCULTURAL	I8	Ease of O&M (1=easy, 2=medium, 3=complex)	1,00	1,00	3,00	3,00	3,00	3,00
	I9	Land ownership (1= own; 2= land purchase)	2,00	2,00	2,00	2,00	2,00	2,00

Sources: [1](WHO, 2006).

* T1. Primary Facultative Pond+MaturationPond. T2. Anaerobic pond+Secondary facultative pond+Maturation pond. T3. Anaerobic pond+ Secondary facultative pond with baffles+Rock Filter. T4. High rate Anaerobic Pond+Secondary facultative pond with baffles+Rock Filter. T5. Anaerobic pond+Sub surface Constructed Wetland+Maturation pond T6. High rate Anaerobic pond+Subsurface Constructed Wetland+Maturation pond.

After characterizing the technological options, the data underwent normalization which helps preventing logical errors associated with data manipulation and allows making comparisons in terms of the unit. In normalizing it was important to determine whether the values follow a maximum or minimum function. This enabled giving more relevance based on the lowest or highest value, as applicable (Romero, 1997). Therefore, investment required for implementation aimed at water reuse is expected to follow a minimum function. Then a Grey Relational Analysis (GRA) was performed to estimate the first coefficient that links the reference scheme (i.e. technological options to be selected) with the optional indicator scheme (Table 7.24).

Table 7.24 Normalization of raw data and estimation of the first grey relational coefficient

CRITERIA	INDICATOR	NORMALIZATION						FIRST GREY RELATIONAL COEFFICIENT					
		T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
TECHNICAL	I1	0,517	0,782	1,000	0,962	0,614	0,599	0,509	0,696	1,000	0,929	0,564	0,555
	I2	0,297	0,251	0,577	0,547	1,000	1,000	0,415	0,400	0,542	0,524	1,000	1,000
	I3	1,000	1,000	1,000	0,000	1,000	0,000	1,000	1,000	1,000	0,333	1,000	0,333
ENVIRONMENTAL	I4	0,000	0,000	0,100	0,100	1,000	1,000	0,333	0,333	0,357	0,357	1,000	1,000
	I5	0,720	0,419	0,419	0,419	1,000	1,000	0,641	0,462	0,462	0,462	1,000	1,000
ECONOMIC	I6	0,607	1,000	0,936	0,941	0,564	0,552	0,560	1,000	0,886	0,895	0,534	0,528
	I7	0,607	1,000	0,936	0,941	0,564	0,552	0,560	1,000	0,886	0,895	0,534	0,528
SOCIOCULTURAL	I8	1,000	1,000	0,333	0,333	0,333	0,333	1,000	1,000	0,429	0,429	0,429	0,429
	I9	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

The estimation of the second grey coefficient enabled correlating the reference scheme (technological options) and the optional criteria scheme. To estimate the coefficient, the first grey relational coefficient had to be normalized (as it was previously done with raw data) and the result was weighted based on the relative weight of each criterion (Table 7.25).

Table 7.25 Estimation of the second grey relational coefficient

CRITERION	First weighted grey relational coefficient						Normalized first weighted grey coefficient						2nd grey relational coefficient					
	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
C1	0,62	0,67	0,82	0,59	0,87	0,67	0,95	0,88	0,72	1,00	0,68	0,88	0,86	0,71	0,52	1,00	0,48	0,72
C2	0,47	0,39	0,40	0,40	1,00	1,00	0,83	1,00	0,97	0,97	0,39	0,39	0,65	1,00	0,90	0,90	0,33	0,33
C3	0,56	1,00	0,89	0,89	0,53	0,53	0,94	0,53	0,60	0,59	0,99	1,00	0,84	0,39	0,43	0,42	0,96	1,00
C4	1,00	1,00	0,73	0,73	0,73	0,73	0,73	0,73	1,00	1,00	1,00	1,00	0,53	0,53	1,00	1,00	1,00	1,00

An integrated grey vector was obtained which relates the reference scheme and the weighting of alternatives based on the relative weight of each criterion. This enabled assigning a weighted weight to each technological option taking into account the selection criteria. This last step led to the selection of a treatment option for the future expansion area of Cali, i.e. a technology consisting of a high rate anaerobic pond, a facultative pond, and a T4 rock filter (Figure 7.20).

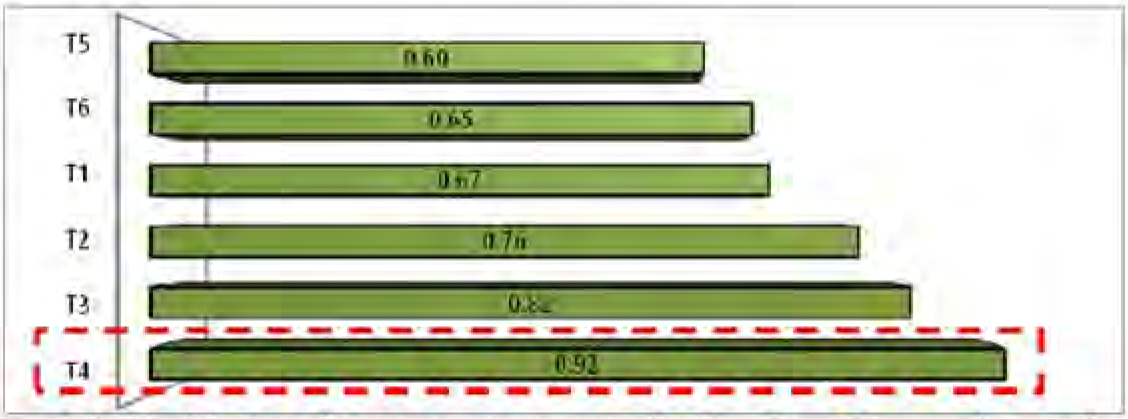


Figure 7.20 Prioritization of wastewater treatment technology for south expansion area based on the second grey integrated relational coefficient

7.4.2.3 Definition of a farming plan for implementing reuse of wastewater.

In the same extent that the selection of a suitable wastewater treatment technology is a key component to water resource management, the definition of a farming plan is an indispensable part of implementing the reuse of wastewater. It allows determining the potential of irrigation in terms of multiple parameters.

The farming plan for the expansion area was established taking into account only the two following aspects: the definition of the potential irrigation area and the water needs for the crops. Only these two activities were considered because an assessment of the local region provided evidence of single-crop (sugar cane) practices in 58,14% (which equals 186,441 ha) of the geographic valley of the Cauca river in the Valle del Cauca State (CVC, 2010a). This implies that the farming plan is at an advanced stage of development, so in terms of an assessment of water reuse for farming purposes, a definition of only the above listed activities is sufficient.

The selection of a potential area for irrigation emerged from the water needs for the crops. This condition provided the basis for estimating the water needs using a simplified water balance (Sokolov *et al.*, 1981) which allowed determining the seasonality and the amount of water required for irrigation (Figure 7.21).

The specific use of this methodology led to performing a water balance in terms of a differential between effective precipitation (Pe) and actual evapotranspiration from sugar cane crops (EVt). Pe was calculated using the USDA methodology (Schneiderman *et al.*, 2007) and EVt was determined based on a combination of the FAO method (Doorenbos *et al.*, 1977) and an evaporimetric tank (CENICAÑA, 2004).

The necessary climatological data for performing the simplified water balance were taken from the El Palacio reference station, which is located on the basin of the Jamundi river, because it is representative of the expansion area about which there is historical information available for the last 40 years (from 1970 to the present) with a multiannual monthly aggregation scale.

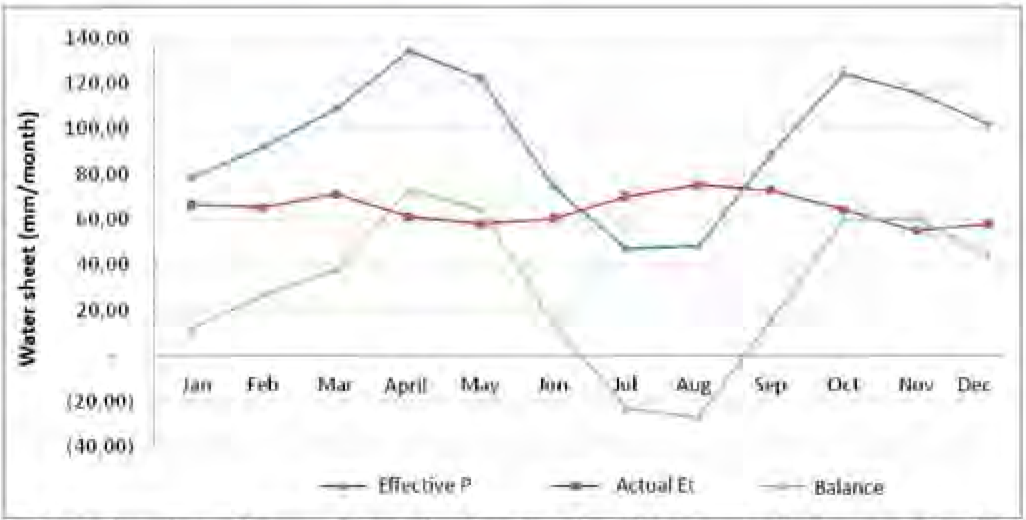


Figure 7.21 Estimation of water demand using the simplified water balance method for South expansion area

The results of the water balance show that the reuse of treated wastewater has a seasonality of 62 days/year in the months of July and August when there is a water deficit or a negative water balance (Figure 7.21). The estimates reveal that the supply of wastewater fully meets the water needs for crops, thus guaranteeing reuse of water resources and a minimum adverse impact on water sources because there would be no wastewater discharges during this deficit period.

The following additional criteria were considered in determining the potential area for irrigation using treated wastewater: 1) The proximity to the point of delivery of wastewater from the treatment system; 2) The current use of water (irrigation of sugar cane fields); 3) The slopes that benefit irrigation by gravity; 4) Enclosures along main roads; and 5) The vulnerability of the water-bearing system (Foster *et al.*, 2003). This last criterion was taken into account considering that the study area has an excellent estimated reserve of 10.000 Mm^3 of high quality underground water. 12% of the annual average recharge (3.500 Mm^3) of this system is used for irrigating sugar cane fields (CVC, 2010a).

The implementation of reusing water for farming involves incremental costs, but also translates into economic and environmental benefits such as improvement of the quality of the water bodies that receive wastewater, savings in fertilizers, and savings in the payment for credit instruments, among others. The benefits associated with this implementation will be later discussed in detail in the cost-benefit analysis which provides a comparison of a conventional proposal for the expansion area and a proposal devised in accordance with the philosophy and guidelines of the SWITCH project.

7.4.2.4 Estimation of initial investment

The review of the implementation of reusing wastewater from the effluent of the treatment plant proposed for the expansion area of Cali for farming purposes (irrigation of sugar cane fields) included estimating incremental costs of two scenarios; one without reusing water and the other reusing water for agriculture.

The estimated costs were broken down into initial investment at market prices of the year 2010.

Estimation of costs of a wastewater carriage and distribution system for agricultural irrigation

To estimate the costs of a system for carrying and distributing treated wastewater in the expansion are for agricultural use, we had to determine the water needs for the sugar cane crops which provided the basis for presizing the system.Based on climatological information available about the study area, the irrigation rate was determined to be 0,34 L/s-ha. Considering a proposed area for irrigation of 997,60 ha, the design flow rate of the irrigation system was found to be 336 L/s.The estimates were calculated for the month of August which is the most critical month in terms of water deficit.

This design flow rate was then used for plotting the carriage and distribution network taking into account the topography of the area, the physical boundaries of the system (rivers and roads), and the current demand on the part of the users (sugar cane producers). After plotting the network, several piping sizing scenarios were created using the version of EPANET-2 software. Therefore, the estimated costs of the initial investment on a system for carrying and distributing treated wastewater for irrigation were €255.245.

Estimation of the pumping system costs

After estimation of the design flow and the total dynamic hydraulic charge, a pump-motor set of 50 HP was selected to meet the needs. The initial investment cost is €74.600 (COLPOZOS, 2010a) (see Table 7.26).

7.4.2.5 Estimation of operation and maintenance costs

According to COLPOZOS (2010a) the model of operation costs of irrigation systems in the Valle del Cauca State yields a cost that equals 5% of the maintenance on the system. The operation costs were estimated based on energetic requirements and the costs associated with maintenance were determined under the cost method implemented by COLPOZOS, as a 5% of the operation costs (Table 7.26).

Table 7.26 Summary of implementation costs for reusing treated wastewater from the C-WWTP for farming purposes

ITEM	INITIAL INVESTMENT COST (€)	O&M COSTS (€)
Wastewater carriage and distribution system for irrigation	255.245	12.762
Wastewater pumping system	74.666	12.165
TOTAL	329.912	24.927

7.5 COMPARISON OF THE ALTERNATIVES

7.5.1 Alternatives description

A cost–benefit analysis (CBA) was carried out to analyze conventional solution and solution with SWITCH approach for expansion area. The conventional solution consists in conventional water management in households, and pumping wastewater to WWTP-C complemented with activated sludge, as secondary treatment, and effluent discharge on Cauca River. The solution with SWITCH approach consists in the application of pollution prevention and minimisation in expansion area households, and treatment with natural system and reuse of 100 % effluent in driest months (July-August) in sugar cane irrigation.

The pollution prevention and minimisation strategy selected for households of expansion area integrate:

As low consumption device

- Toilet of 2,3 L.
- Tap high efficient in kitchen, basin and shower.

As alternative sources

- Rainwater harvesting system with filtration for use in washing clothes in house.
- Rainwater harvesting system for use in cleaner commune areas and garden irrigation in multifamily.
- Greywater reuse system with treatment, for use in flushing toilet and garden irrigation in house.
- Greywater reuse system with treatment, for use in cleaner commune areas and garden irrigation in multifamily.

The scenario to work in this document is the implementation of pollution prevention and minimisation strategy in 70% of expansion area households. These households are projected at a constant rate in a time of 20 years.

The treatment with proposed in reuse integrated natural system in WWTP south conformed by high rate anaerobic pond+ secondary facultative pond + rock filter. In this way, according with water demand of cultivation, 100% of WWTP-South effluent (336 L/s) will be used in sugar cane irrigation 997 ha in driest months (July-August). The main characteristic of the conventional solution and solution with SWITCH approach are shows in Table 7.27:

Table 7.27 Characteristics of alternatives proposed for south expansion area

PARAMETER		UNITS	CONVENTIONAL	SWITCH APPROACH
Drinking water demand		L/s	1067	714
Wastewater production		L/s	854	336
BOD load discharged to Cauca river	Driest months	kg/day	3729	0
	Wet months*	kg/day	3827	1516
TSS load discharged to Cauca river	Driest months	kg/day	2421	0
	Wet months*	kg/day	7213	2934

*Includes load rain harvesting

7.5.2 Identification and estimation of costs and benefits

The costs associated with implementing conventional alternative were presented in item 6.3.2.2 and the costs of implementing the alternative with SWITCH approach were presented in items 6.3.3.1.3 for strategies of pollution prevention and minimisation and 6.3.3.2.3 for application of natural methods for wastewater treatment considering the effluent reuse.

In the same way as in area of WWTP-C drainage area, the identification of benefits was divided in three types of beneficiaries: users, water and sanitation providers, and environment. Table 7.28 shows benefits by beneficiaries, and benefits included in water and sanitation tariff considered in expansion area.

Table 7.28 Benefits identified for the solution with SWITCH approach in south expansion area

BENEFITS	BENEFICIARIES
POLLUTION PREVENTION ALTERNATIVE	
Reduction in consumption of drinking water	Users
Reduction in production of wastewater	Users
Reduction in water and sanitation tariff	Users
Reduction in payment by contamination discharge tax and use tax	W&S providers
Reduction in drinking water treatment costs (for Puerto Mallarino drinking water plant)	W&S providers
Reduction of wastewater treatment costs	W&S providers
Reduction of cost by sludge treatment	W&S providers
Reduction inBOD and TSS load discharges to Cauca River	Environment
Reduction of energy consumption	Environment
Less dependency to centralized drinking water system	Users
Reduction in infrastructure supply and sanitation	W&S providers
Reduction in drinking water treatment cost (downstream of expansion area)	W&S providers
Improving health of users located downstream of Cali city	Environment
Reduction impact of sludge by toxics disposed in soil	Environment
Reduction of greenhouse gases by decreasing pumping	Environment
Reduction of greenhouse gases by decreasing load BOD and TSS	Environment
Decrease in cost of fertilizer	Farmers
Reduction in payment by use tax	Farmers
Less consumption of groundwater for irrigation	Farmers
Diminution in drinking water treatment cost (downstream of expansion area)	W&S providers
Reduction in pay by contamination discharge tax	W&S providers
Reduction inBOD and TSS load discharges to Cauca River	Environment

The cost-benefit analysis will be carried-out in the expansion area using the same benefits the area of WWTP-C drainage area (B1-B6). For the particular case involved two additional benefits:

- B1 Water and sanitation tariff saving by implementation of solution with SWITCH approach.
- B2 Acquisition of carbon credits by reduction of greenhouse gases emission.
- B3 Avoided cost by use of less amount of fertilizer.
- B4 Reduction in payment byuse tax of groundwater.
- B5 Avoided cost in infrastructure for uptake groundwater.
- B6 Saving cost by O&M of groundwater wells.
- B7 Saving cost in payment bydischarge BOD and TSS.
- B8 Saving cost in infrastructure drinking water and sanitation (sewerage and treatment).

The procedure of benefit estimation is described to following with the particularities of expansion area.

B1- Water and sanitation tariff saving by implementation of solution with SWITCH approach

The drinking water consumption and wastewater production in 70% of Cali households can reduce in 61% with implementation of pollution prevention strategy. This diminution has implications in pay the tariff of water and sanitation. For benefit estimation was used: 518 L/s thevolume of drinking water saving in all area and a the average tariff of water and sanitation for strata 4, 5 and 6 of €/ m^3 1.4 (SUI, 2009). This benefit star in year two is when the first

inhabitants use water, in the first year begins construction of housing. The benefit estimation is shows in Table 7.29 for each five years.

Table 7.29 Estimation the benefit water and sanitation tariff saving (B1) in expansion area

YEAR	1	5	10	15	20	25	30
Saving water demand (m^3/year)	-	1.538.957	3.462.653	5.386.349	7.310.045	7.694.784	7.694.784
Total tariff saving (€)	-	2.206.864	4.965.444	7.724.024	10.482.604	11.034.320	11.034.320

B2 - Acquisition of carbon credits by reduction of greenhouse gases emission

The estimation of amount money by sell carbon credits was calculated based in the quantity of carbon dioxide that could be reduced to the apply conventional solution or the solution with SWITCH approach.Applying pollution prevention in expansion area households reduces in BOD load the wastewater treated by WWTP-C; therefore, greenhouse gases emission will decrease. For calculate the kg of CO_2 reduced is used a factor of 1,2 kg CO_2/kg BOD (Gori *et al.*, 2009). Acquisition of carbon credits by energy consumption saving was calculated for solution with SWITCH approach by not use of energy in station pumping booster of drinking water. The factor used for calculate kg CO_2/kw was 0,3.

The identification of this benefit in relationship with the reduction in BOD load andthe pumping groundwater, starts at a constant rate in the second year associated with the densification of the area. This benefit for the booster pump station of drinking water, occurs in stages every five years depending on the installation of pumps and demand projection. The benefit estimation is shows in Table 7.30 for each five years.

Table 7.30 Estimation the benefit acquisition of carbon credits by reduction of greenhouse gases emission (B2) in expansion area

YEAR	1	5	10	15	20	25	30
Reduction CO_2 by load BOD	-	0,78	1,76	2,74	3,72	3,92	3,92
Carbon credits sold (Euros)	-	*1,7*	*3,8*	*5,9*	*8,0*	*8,5*	*8,5*
Saving energy in pumping station drinking water	-	653	2237	1212	1212	3449	3449
Reduction Kg CO_2 by less energy consumption	-	0,20	0,67	0,36	0,36	1,03	1,03
Carbon credits sold(Euros)	-	*0,4*	*1,4*	*0,8*	*0,8*	*2,2*	*2,2*
Carbon credits sold total (Euros)	-	*2,1*	*5,3*	*6,7*	*8,8*	*10,7*	*10,7*

B3 - Avoided cost by use of less amount of fertilizer

In order to estimate this benefit, you have to consider the nitrogen and phosphorus nutritional load offered by the Southern WWTP. In the 997 has defined for re-use in the expansion area, the estimated fertilizer requirements were 408 sacks of urea/year and 233 sacks of NPK/year.

The nutrients balance was made between the treated wastewater contribution and the crop needs. These were 100% met according to the sugar cane nutritional needs.The economic quantification of this benefit was calculated considering the cost per sack of fertilizer, NPK= €24,66; and urea= €26,94, multiplied by the potential irrigation area. The benefit estimation is shows in Table 7.31 for each five years.

B4 - Reduction in payment by use tax of groundwater

This benefit was calculated using 2010 prices, based on the economic instrument structure of rate per water usage (TUA for its acronym in Spanish), which depends of the volume extracted for irrigation and the cost established per m^3 of groundwater, which corresponds to 0,000668 €/m^3 (CVC, 2009). The benefit estimation is shows in Table 7.31 for each five years.

B5 - Avoided cost in infrastructure for uptake groundwater

According to the hydro-geological characteristics of the zone for flow extraction for agricultural reuse (336 L/s), four wells 150 m deep must be constructed, with a unit cost of€ 120.000 (COLPOZOS, 2010b). The well investment will be done according to wastewater production rates. The benefit estimation is shows in Table 7.31 for each five years.

Table 7.31 Estimation the benefit B3, B4, B5, B6, and B 7 in expansion area

YEAR	2	5	10	15	20	25	30
Save fertilizer (€)	273,87	1095,48	2464,84	3834,19	5203,54	5477,41	5477,41
Save payment by use tax of groundwater(€)	60,18	240,72	541,62	842,53	1143,43	1203,61	1203,61
Save initial cost in groundwater well (€)	120.000	120.000	120.000	120.000	-	-	-
Save cost O&M groundwater wells (€)	0	11.396	22.793	34.190	45.586	45.586	45.586
Save payment by discharge BOD and TSS (€)	961,25	3.845,00	8.651,26	13.457,52	18.263,77	19.225,02	19.225,02

B6 - Saving cost by O&M of groundwater wells

According with the operation and maintenance requirements provided by COLPOZOS S.A., the operation estimates for a deep well with the above mentioned description, correspond to the energy consumption. Taking into account that the power required for the described wells is 75HP/well with an operation time of 18 hours and at a cost of0,12 €/Kw-h. Therefore, the operational cost is 10.854 €/well. Additional to this, according to the maintenance cost model used by COLPOZOS (2010b) 5% of the operation cost is assumed as a maintenance cost. Therefore, the total estimate O&P benefit was €45.586. The benefit estimation is shows in Table 7.31 for each five years.

B7 - Saving cost in payment by discharge BOD and TSS

To estimate this benefit, 2010 prices were used, based on the economic instrument structure of the Retributive Rate (TR for its acronym in Spanish), which is an estimate of the flow discharged into the river, the BOD and TSS concentrations and the time of discharge. This instrument is ruled by Decree 3100 (MAVDT, 2003) which considers the price per discharged load of €0,042/ kg BOD_5 and € 0,018 / TSS kg. The benefit estimation is shows in Table 7.31 for each five years.

B8 - Saving cost in infrastructure drinking water and sanitation

The implementation of the minimisation and prevention strategies represent a decrease of water flor, both in terms of water supply, as wastewater production, resulting in lower construction demands, smaller pumping stations, and therefore, lower infrastructure costs.

In water treatment, the application of natural methods and decentralized systems is more economical than pumping water to Cañaveralejo's WWTP. These savings were calculated

based on the estimate costs of the conventional alternative and the solution with a SWITCH Project approach.

The investment in internal networks is done from year one to year twenty, where the entire area population is completed. Therefore, no investments are required after such period of time. Table 7.32shows the benefit estimate for each five years.

Table 7.32 Estimation the benefit saving cost in initial investment of infrastructure drinking water and sanitation (B8) in expansion area

YEAR	1	5	10	15	20	25	30
Conventional solution	15.972.669	115.555	28.888	28.888	246.666	-	-
Solution with SWITCH approach	5.830.155	31.111	2.076.359	28.888	164.444	-	-
Save Initial investment	1.0142.514	84.444	-2.047.470	0	82.222	-	-

7.5.3 Results of cost-benefit analysis

The implementation of minimisation and prevention strategies and the decentralized treatment using natural methods for agricultural re-use were financially evaluated, considering that the cost-benefit estimate of the profile was made. For the future, it is recommended to make a socio-economic evaluation including other eco-systemic benefits and services.

Costs and benefits were quantified in the financial evaluation process, and later the evaluation was made including the following criteria:

- Economic efficiency or the difference between benefits and costs
- The relation of Net Present Value ($NPV_{benefits}/NPV_{costs}$) (Brent, 2006).

The data of costs and benefits analysis are distributed through 30 years, this date for every five years shown in Table 7.33. The cash flow is shown in Figure 7.22:

Table 7.33 Summary costs and benefits of implementing the solution with a SWITCH approach in the expansion zone

YEAR		1	5	10	15	20	25	30
BENEFITS (€)								
B1	Water and sanitation tariff saving by implementation of solution with SWITCH approach	0	2.206.864	4.965.444	7.724.024	10.482.604	11.034.320	11.034.320
B2	Acquisition of carbon credits by reduction of greenhouse gas emission	0	2	5	7	9	11	11
B3	Avoided cost by the use of less fertilizers	0	1.095	2.465	3.834	5.204	5.477	5.477
B4	Reduction in tax payment for the use of groundwater	0	241	542	843	1.143	1.204	1.204
B5	Avoided cost in infrastructure for the uptake of groundwater	0	0	0	0	0	0	0
B6	Saving cost by O&M of groundwater wells	0	11.397	22.793	34.190	45.587	45.587	45.587
B7	Reduction in payment by discharge tax to wastewater (BOD and TSS)	0	3.845	8.651	13.458	18.264	19.225	19.225
B8	Saving cost by water and sanitation infrastructure	10.142.514	84.444	-2.047.470	0	82.222	0	0
	TOTAL BENEFITS	10.142.514	2.307.889	2.952.431	7.776.355	10.635.033	11.105.824	11.105.824
COSTS (€)								
C1	Pollution Prevention	1.855.462	3.004.526	4.440.856	5.877.186	7.313.516	5.745.320	5.745.320
	Initial investment	1.855.462	1.855.462	1.855.462	1.855.462	1.855.462	0	0
	O&M (Euro/ year)	0	1.149.064	2.585.394	4.021.724	5.458.054	5.745.320	5.745.320
C2	Reuse of WWTP-C effluent	329.912	4.986	11.218	17.449	23.681	24.928	24.928
	Initial investment	329.912	0	0	0	0	0	0
	O&M	0	4.986	11.218	17.449	23.681	24.928	24.928
	TOTAL COST	2.185.374	3.009.512	4.452.074	5.894.636	7.337.198	5.770.248	5.770.248
CASH FLOW (€)		7.957.139	-701.623	-1.499.643	1.881.720	3.297.835	5.335.576	5.335.576

Cost and benefits for the analysis period shown in Figure 7.22 indicate the different trends associated to the impact caused in the analyzed savings and the investment requirements for the implementation of a solution with a SWITCH approach.

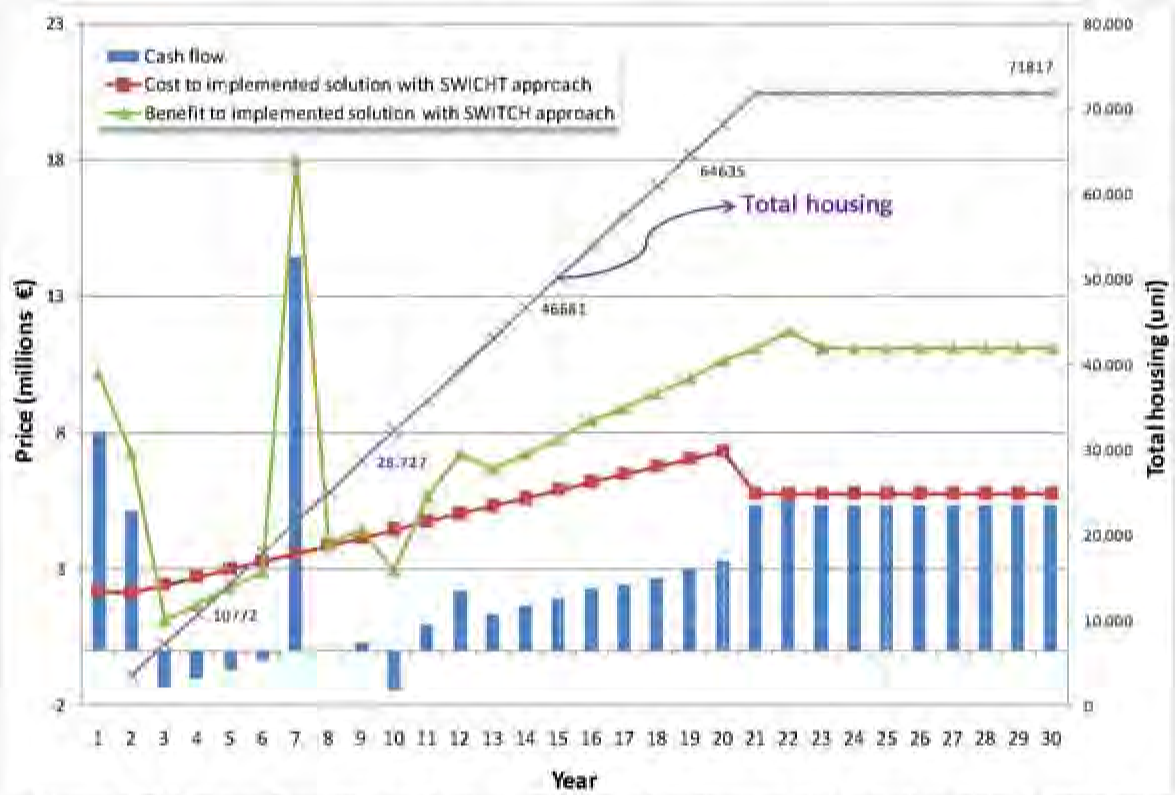


Figure 7.22 Costs, benefits and net cash flow to implement the solution with a SWITCH approach in the expansion zone

In general, the cost for the implementation of a solution with a SWITCH approach shows a constant rate increase between year 3 and year 20, when the future inhabitants are estimated to be located. Both the initial investment, as the O&M costs increase due to the flow demand and wastewater production. After this period, since the initial investment requirements are not present, costs are associated to O&M minimisation and prevention activities, as well as agricultural re-use.

Benefits are a result of different variables, being the distribution of investment in external infrastructure, the most relevant. This is a fluctuating variable throughout time, associated to investment planning. Likewise, these benefits are affected by investments saved in groundwater infrastructure, which is considered every four years.

A benefit showing constant increase are the savings caused by tariffs, which show growth between year 2 and 21. After that year, savings become constant because the area has reached the maximum possible population. A benefit generating low impact are the carbon credits because the low emission factors estimated are a result of general studies that not necessarily reflect the local situation and the carbon credits purchase does not have a significant impact in the benefit's price.

Considering both the costs and benefits, during the first year the benefits are 78% above the costs required for the implementation of a solution with a SWITCH approach, which are

associated with the optimization of the water supply, sewage and treatment systems. The incorporation of minimisation and prevention strategies decrease the volumes of drinking water supply, recollection, transportation and wastewater treatment, decreasing the diameter of required pipelines and therefore, the amount of work and installation costs.

On the other side, the management of lower wastewater volumes in a decentralized manner demand smaller sewage and WWTP systems. Added to this, the usage of natural methods generates lower conventional water supply costs and the pumping and treatment of wastewater towards the WWTP-C, complemented with activated sludge. In 2010 (year 1), the cost of the implementation of a solution with a SWITCH approach is 85% for the implementation of the minimisation and prevention option, and 15% for the implementation of the re-use.

Costs between years 1 and 2 decrease due to the balance between investments increase and O&M for minimisation and prevention strategies, while the initial investment is not made for the re-use.An increase in benefits is shown in year 7, due to savings in water supply and sanitation infrastructure, and explicitly, because during that year the conventional option includes the initial investment made for the implementation of secondary treatment with activated sludge in the WWTP-C, which is a technology with a considerable cost equal to €14.663.724.

Benefits decrease in year 10 because a solution with SWITCH approach is projected, the construction of the second Southern WWTP. The benefit increased in year 11 due to cost savings in a groundwater well. After year 23, a constant net flow is shown because the costs of a solution with a SWITCH approach do not represent an initial investment, but are related to O&M costs and the benefits become permanent as a result of water and sanitation tariff savings and savings in fertilizers and economic instruments by the use of wastewater for the irrigation of sugar cane crops.

Figure 7.22 shows the summary of the financial evaluation made. Implementing the solution with SWITCH approach is economically feasible because benefits are obtained are more than the costs, representing savings by € 23.601.836. The cost/benefit ratio is 1,70, demonstrating the financial profitability of the proposal.

Table 7.34 Indicators of the economic feasibility of the implementation of a solution with a SWITCH approach in the expansion area

NPV Costs	33.667.946
NPV Benefits	57.269.782
NPV Benefit-NPV costs	23.601.836
NPV Benefit/NPV costs	1.70

The profile evaluation shows the financial feasibility of considering the minimisation and prevention strategies, decentralized treatment with natural system, and water re-use in the expansion area. The implementation of these concepts is feasible in new urban areas due to the great impact in initial investments for hydro-sanitation infrastructure, and in the case of agricultural re-use, infrastructure investment.

8 STRATEGIES FOR DECONTAMINATION OF WATER RESOURCES IN SOUTH DRAINAGE SYSTEM

8.1 INTRODUCTION

The South Drainage System was developed to manage the drained stormwater generated by the rainfall precipitated over the urban area. The three rivers of Lili, Meléndez and Cañaveralejo runs through the area, however these rivers have been intervened to different extent and all have been intercepted by the South Channel, in their way out of the urban area, before it connects to the CaucaRiver. The South Channel, which to a great extent is coated in concrete, was mainly built to improve the draining capacity of the rivers to avoid flooding. The SDS covers the urban districts 10, 17, 18, 19, 20 and 22, and due to the interception of rivers it is also influenced by the rural districts of Buitrera, Los Andes and Villacarmelo (see Figure 8.1)

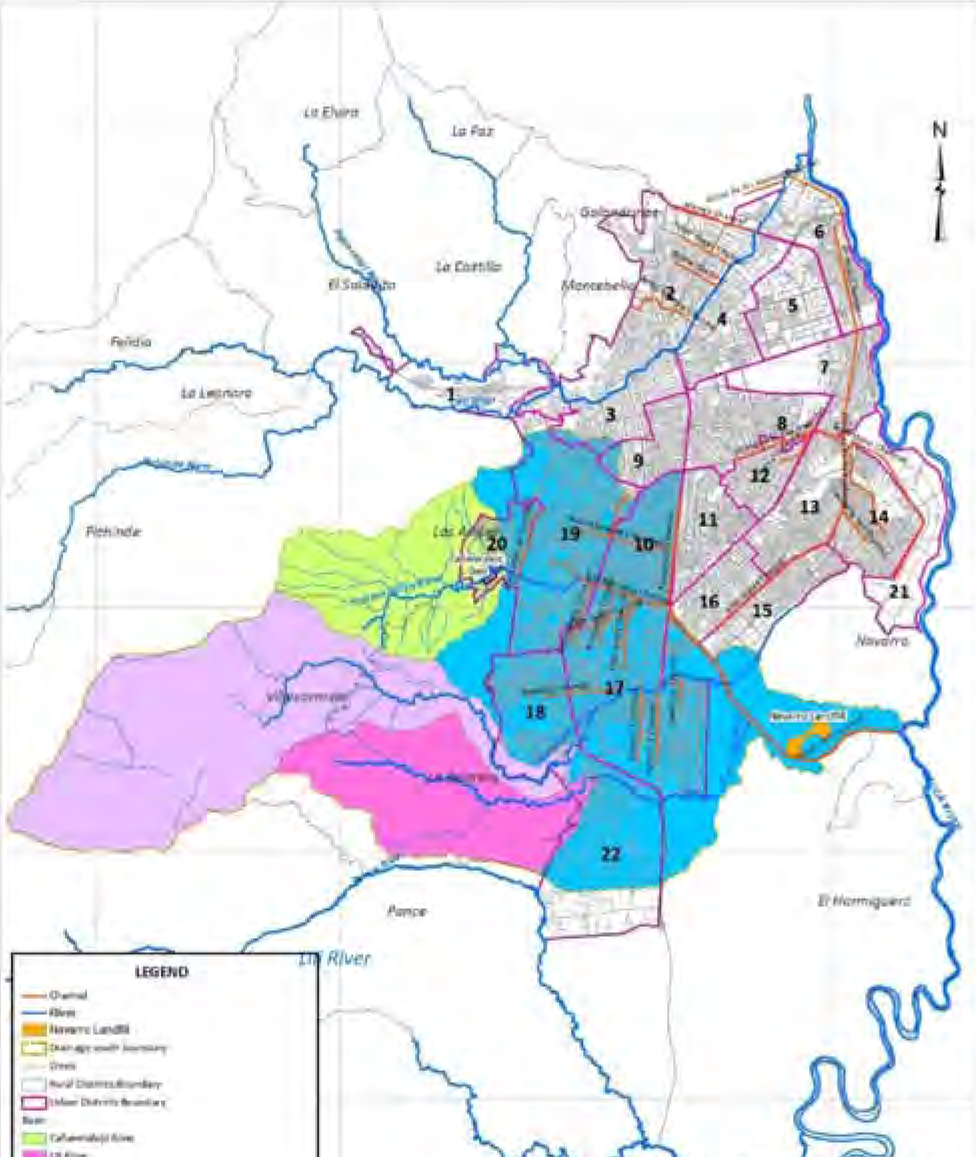


Figure 8.1 Overview of the South Drainage System with the Lili-Meléndez-Cañaveralejo water basin

The main land uses employed in the rural area are forestry (both protective and productive), agriculture (animal raising and crop cultivation), mining and residential. In the urban area, the south of Cali has a land use that is mainly residential, commercial and with other service installations such as schools and health centers, while the industrial sector is limited. However, in the centre of the city there is an industrial area, mainly consisting of informal industries draining untreated wastewater to the stormwater channels.

Stormwater system

As mentioned, the main purpose of the South Drainage System is to drain stormwater out of the urban area in the south of Cali. In total, the SDS has 36,4 km of channels, out of which a majority are concrete coated. The drainage system is completely managed by gravity. Among the main channels of the SDS are: Nápoles, Puente Palma, Ferrocarril, Cañaveralejo and the South channel.

The CañaveralejoRiver basin has a regulation dam, the Cañaveralejo dam, situated next to the Siloe district (20th urban district), which is where the river enters the urban area of Cali. The dam was built to retain water flows during heavy rain events to avoid flooding of the downstream city. In terms of human intervention of the Cañaveralejo, Lili, and Meléndez Rivers, which all are modified and finally connected to the South Channel, the Cañaveralejo River is the most affected one, with a section of approximately 3,9 km that is channelized and concrete coated, where the river completely loses its natural characteristics and turns into a stormwater channel. Even though the drainage system was considered for the transportation and disposal of stormwater and surface water coming from the intercepted rivers, wastewater discharges to the stormwater system is common in most parts of the SDS.

These effluents enter the system for different reasons, such as erroneous or illegal connections and malfunctioning separation structures (EMCALI, 2007). Moreover, the South Drainage System presents problems of severe accumulation of sediments in channels, causing flow obstructions, which increases the risks for flooding. Additionally, the illegal disposal of solid waste in the channel system is contributing to the flow obstruction and sedimentation. In events of heavy rains, the accumulated sediments are resuspended, causing high levels of solids and organic matter in the SDS.

Wastewater management

In the urban area of the South Drainage System there is an extensive sewage network for the wastewater transportation. According to the Municipality of Cali (2008), all urban district in the SDS area, except the districts 18 and 20, have 100% sewerage coverage. District 18, has 67,3% sewerage coverage, while district 20 only has 58%, which represents one of the lowest coverages in the city. The total sewerage coverage in the south of the city is 96,6% (EMCALI, 2007)

There are wastewater collectors covering the major part of the SDS area; the main collectors can be seen in Table 8.1. These collectors are connected to the wastewater treatment plant of Cañaveralejo (WWTP-C) situated at the north-eastern part of the city, outside of the SDS area. Additionally, the district of El Caney, a small residential area, which forms part of district 17, has its own wastewater treatment plant.

Table 8.1 Main collectors in the area of the South Drainage System

NAME	DISCHARGE	TRIBUTARIES
Pance Collector	Río Lili Marginal	Cra 127, Cra 125, Calle Las Chuchas, Alferez Real, and Berchmans Collectors
Ciudad Jardín Collector	Cauca Collector	Pance and Marginal Río Lili Collectors
Marginal Río Lili Collector	Ciudad Jardin Collector	Auxiliary Marginal Río Lili Collector
Cañaveralejo Collector	Oriental Interceptor	Lucio Velasco, Venezuela and Reforma Collectors

Source: (Universidad del Valle - Cinara, 2008)

The wastewater collection and transportation systems are formed by separate sanitary sewer system and combined sewerage. The combined sewerage, which handles wastewater and stormwater in a joint manner, has separation structures to separate the stormwater from the sewerage during rain events in order to reduce the amount of stormwater transported to the WWTP-C. However, inventories have shown that these facilities are not working properly; hence wastewater is discharged directly to the stormwater drainage system. Furthermore, as mentioned earlier it is common with illegal or erroneous connections of wastewater directly to the stormwater channels.

Furthermore, the South Drainage System receives untreated industrial wastewater mainly from informal activities in the city centre. According to (EMCALI, 2007) 533 industries were identified as potential polluters to the South Drainage System, out of which 85% are located in the Ferrocarril Channel subsystem which drains to the South Channel.

In the peri-urban area, especially located at the foot of the mountain or on the slopes, there are still many settlements, both formal and informal, that discharge their wastewater directly to the water bodies without prior treatment (DAGMA *et al.*, 2004b). EMCALI has installed wastewater collectors in river margins during the last years and made improvements within the wastework network according to the Plan for Sanitation and Discharge Management (PSMV, abbreviation in spanish) (EMCALI, 2007), but there are still no official results of the impact on water quality of these infrastructure developments. The pollution from wastewater in the South Drainage System is significant; according to (EMCALI, 2007) the average content of wastewater is approximately 14.3%.

Solid waste management

A plan for the integrated management of solid waste is under implementation and the collection service for domestic solid waste in the urban area has a rather high coverage. However, the presence of litter in public spaces and illegal waste dumping sites around the city is a frequent problem, which is evidence for a malfunctioning waste management in the city. Likewise, there is still no plan for an integrated system to manage construction waste, hence the lack of management experience the same problems as the domestic waste. An inventory of illegal waste dumping sites found a total of 25 for domestic solid waste and another 21 for construction waste within the South Drainage System (EMCALI, 2007).

The inadequate disposal of domestic solid waste and construction waste, affecting water bodies, channels and pipe systems, is a recurrent problem that is related to the quality, continuity and coverage of the waste collection service, as well as the environmental consciousness and culture of the residents.

The Navarro landfill located next to the South Channel received waste from the city during decades until it was closed in 2008. The oldest sections of the landfill were not build with

protection liner, while the newer sections have. In general, the produced leachate does not receive any treatment and the leachate that is being captured is just being stored in a pond system. However, different investigations have confirmed that Navarro landfill is contaminating the adjacent water bodies, including both surface water and groundwater, and generating severe public health risks (DAGMA *et al.*, 2004a). At present, the solid waste is being transported and disposed in a landfill in the Yotoco municipality, situated 56 km north of Cali.

Water basin management

As the South Drainage System is connected to the upstream water basin through the intervention of the Lili, Meléndez and Cañaveralejo rivers, the management of these basins directly affects the urban system. A brief description of this area is consequently included here.

The upper part of the water basins is located within the national park "Los Farallones", forest reservation or forest protection buffer zone, which implies that the area is under protection and has plans for its conservation. However, the forest protection classification does not mean that this area is completely covered with forest; in fact, the tree basins are affected by deforestation in the protected forest area. According to the forest inventory carried-out by Tolima University and the regional environmental authority - (CVC, 2007), the protected forest area is 23,4% in the Cañaveralejo-Melendez-Lili river basin, while the forest coverage in the basin is only 10,8%, and very fragmented (see Figure 8.2).

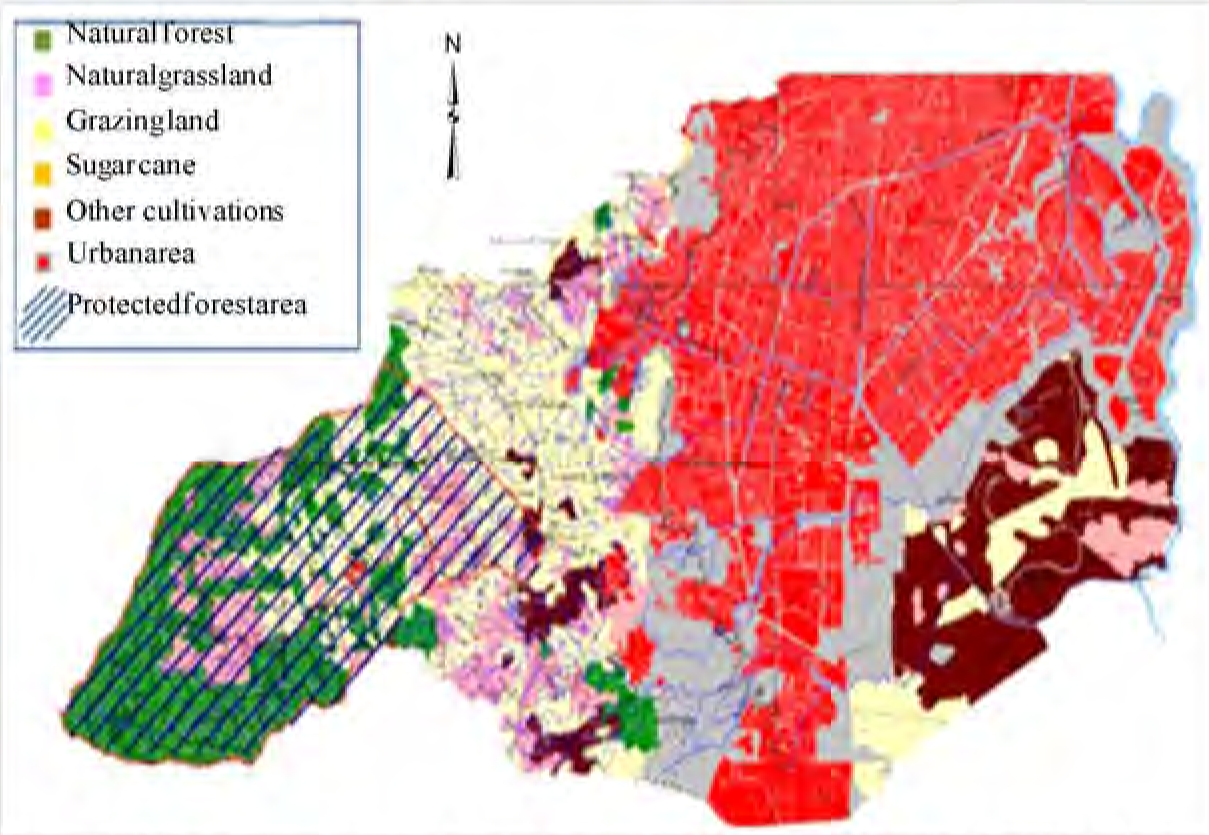


Figure 8.2 Land use coverage and protected areas in the Cañaveralejo-Meléndez-Lili River basin

Source: Adapted from (CVC *et al.*, 2008a)

This information shows that only about 50% of the protected forest area is actually covered with forest in the two basins, which is due to the human settlements and activities in the area.

In the upper-middle basins of the SUDS influence area the human intervention is more significant, characterized mainly by dispersed settlements and only some nucleated areas. The area has agricultural activities, with cultivations and animal breeding, where cattle grazing are one of the activities contributing most to the erosion problem in the water basin.

Another important contributor to erosion is the mining activities developed by the communities in the area. These activities are mainly small scale and with rudimentary methods, generating contaminated run-off.Regarding water and sanitation services, there are both community based and individual solutions. The water is mainly supplied by superficial water bodies through community based systems (68%), while for sanitation it is most common with individual solutions (80%) (UMATA, 2005).

The majority of the generated wastewater is infiltrated in the soil or directly discharged to water bodies without prior treatment. The Municipal Public Health Secretariat (SSPM, abbreviation in spanish) has supported the development of community based water and sanitation installations in a few nucleated settlements.

The deforestation, agricultural and mining activities and human settlements are all responsible for the quality and quantity deterioration that the rivers are suffering before entering the urban perimeter. Different causes for the deficiencies in the described water basin management can be identified, including: social situation, displacement processes, environmental unawareness among the communities, but an important factor is the lack of a comprehensive participative planning process, control and coordination by the different authorities in the municipality of Cali.

8.2 CAÑAVERALEJO RIVER BASIN: STUDY AREA FOR APPLICATION OF SWITCH STRATEGIES

The Cañaveralejo River is born at 1.800 meters above sea level in the western mountain ridge, just outside the limit of the Farallones National Park, with an approximate length of 9 km before it is intercepted by the South Channel, at about 960 meters above sea level. The river basin limits in the north-west with the Cali river basin and with Melendez River basin in the southwest, and in the east it is influenced by the South Drainage System (see Figure 8.3).The basin has an estimated area of 2.882 ha.

The water quality in the higher part of the Cañaveralejo river is good according to ICA-NSF indicator; however, once the river passes through the areas with more populated human settlements its quality is deteriorated, see Figure 8.4. The water contamination in the middle and lower part of the basin is associated with the discharge of wastewater and solid waste from settlements in the river margins and tributary streams, of which some corresponds to settlements with incomplete development (or informal settlements). Another important factor that is generating an increase of the concentration of solids, especially in the rainy seasons, is related with deforestation, agriculture and cattle grazing in the middle part of the asin, and the occupation of the protection strips along the river.

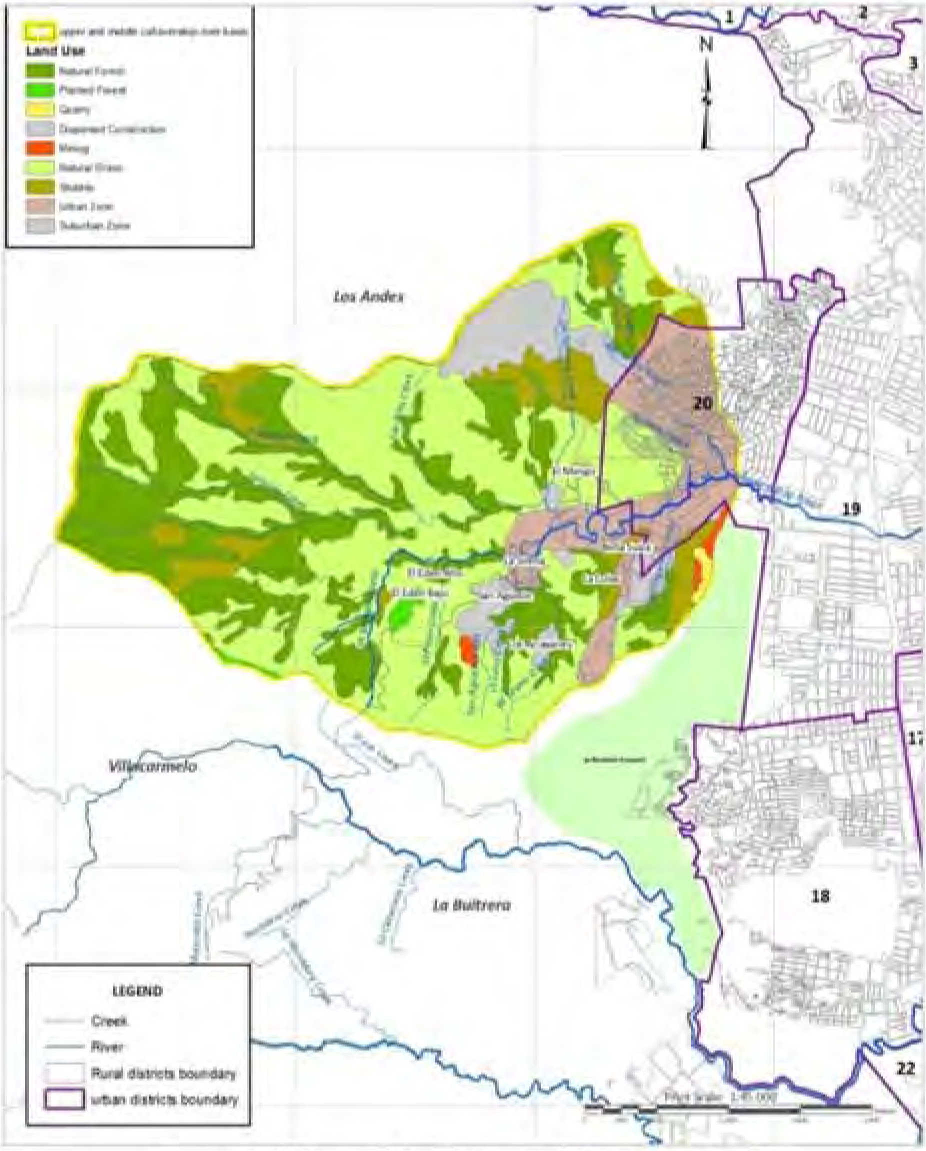


Figure 8.3 Map of the Cañaveralejo River Basin

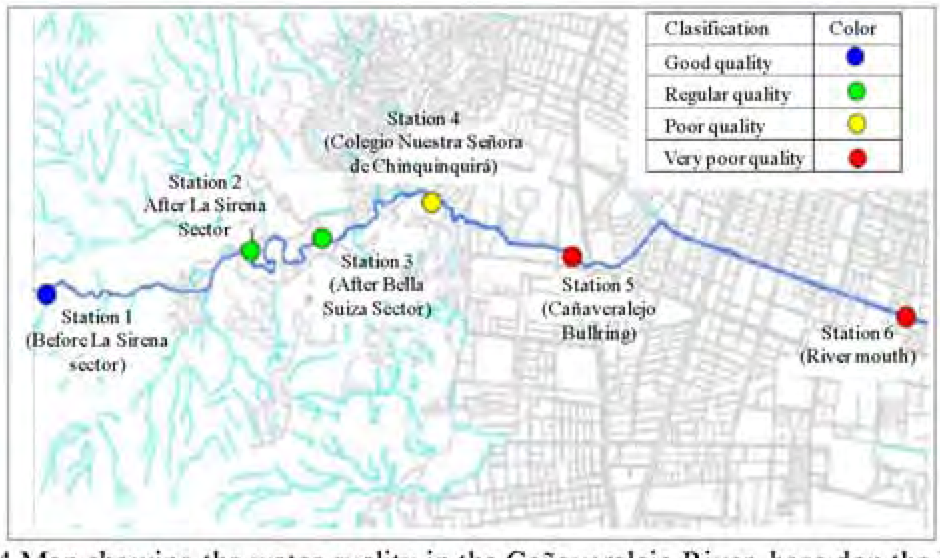


Figure 8.4 Map showing the water quality in the Cañaveralejo River, base don the ICA-NSF indicator

Source: (DAGMA *et al.*, 2004b)

The higher part of the river basin is characterized by relatively high forest coverage, with natural vegetation, presence of small-scale cultivations, small-scale ecotourism, (place of recreation, horseback, riding, biking, hiking, camping, among others) low levels of deforestation and cattle grazing (see Figure 8.5, Figure 8.6 and Figure 8.7). In the middle part of the basin problems with deforestation, cattle grazing and mining activities, and human settlements within the protection strip of the river are more frequent (see Figure 8.8).

Figure 8.5 Ecotourism Center in the higher part of Cañaveralejo River Basin. La Perojosa Park

Figure 8.6 Terraced fields. Agroecological work in the higher part of Cañaveralejo River Basin

Figure 8.7 Farm with small-scale cultivations with acid soils that require higher input of fertilizers in the higher part of Cañaveralejo river Basin

Figure 8.8 Union of the La Carolina Creek and Cañaveralejo River after passing through La Sirena Sector in the middle part of the river basin

The lower part of the Cañaveralejo River basin is located within the urban area of Cali and characterized by low coverage of green areas. At the entrance of the urban area the river passes through the Cañaveralejo dam, constructed to retain high river peaks in rain events to mitigate flooding in the urban area. After crossing the street "Calle 3" the Cañaveralejo River is turned into a concrete-lined channelized water body (see Figure 8.9).

Figure 8.9 Cañaveralejo River –Channel in the lower basin

8.3 CASE STUDY 1 – STORMWATER MANAGEMENT IN "PLAZA DE TOROS" AREA

8.3.1 Description of current solution (conventional solution)

In this chapter a pre-study of the implementation of sustainable urban drainage system in the Cañaveralejo River basin considering its potential and feasibility in the context of a consolidated urban area in Cali. It is important to state that this is just the first approach and preliminary results presented in this report, while in the remaining project time the study will be extended, including more SUDS technologies and modulation.

The Cañaveralejo River basin is divided into three sub-basins, upper, medium and lower; the current study focuses on the lower basin. The lower basin is characterized for being densely constructed (see Figure 8.10), mostly with residential and commercial purposes, and for having minimal green areas, although there are areas where there have been attempts to recover the vegetation on the river banks. The area has a flat topography, with slopes less than 1% in average (Universidad del Valle *et al.*, 2004). Furthermore, the protective forest strips are in general deteriorated and almost non-existent, since there are streets adjacent to the river and it is limited by areas with constructed walls and buildings, leaving an insecure, small public area and poor natural conditions (Alarcon, 2010). The Cañaveralejo River is completely channeled between "Calle 5" and the mouth of the river, losing its natural conditions, generating a lack of sense of belonging among the community, leading to a lack of interest in its recovery.

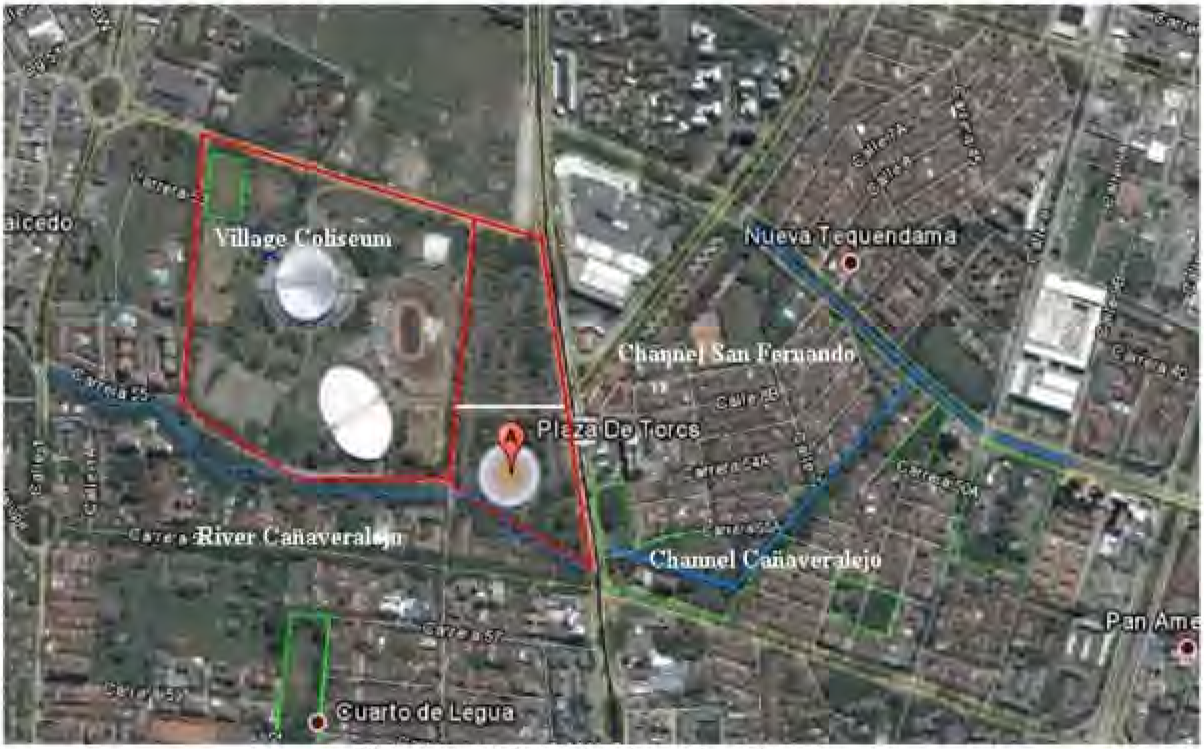


Figure 8.10 Localization of study area
Source: (Google maps, 2010)

Moreover, the sewage system does not function properly; the channels receive wastewater contributions due to erroneous connections and to the malfunctioning or absolute absence of separating structures, with the function to minimize wastewater discharges to the stormwater channel. Evaluations of the drainage and sewerage system in the South Drainage System was conducted which generated the following conclusions (HIPERAGUAS *et al.*, 2007) and (Forero *et al.*, 2003):

- Wastewater pollution of the Cañaveralejo River and tributary canals
- Combined conduction of highly diluted wastewater to the WWTP-C
- Increased vulnerability of the Cañaveralejo drainage subsystem for normal precipitation events, increasing the risk of flooding of buildings within the service area of the sewer system
- Increased road network failure of drinking water supply and other services in the districts of the separating structures

8.3.2 Solution with SWITCH approach

8.3.2.1 Description

The study area has been chosen to permit the application of series of SUDS technologies. The area is delimited by the sports complex (Velodrome, Coliseum of the People), the bullfighting (Plaza de toros), following the course of the Cañaveralejo channel up to the crossing between the South East Highway "Calle 10" and street "Carrera 50", as presented in Table 8.2.

The specific area has been selected since the area is densely populated and has lost its infiltration capacity, the concentration times in the corresponding channels are short (Forero *et al.*, 2003); all runoffs drain to the stormwater drainage system and flooding events occur in

winter time exceeding the designed hydraulics of the sewage system causing economic losses, inconvenience and discomfort to the inhabitants of the sector.

A selection matrix has been adapted for the pre-selection of SUDS technologies (Ballard *et al.*, 2007), which takes into account parameters on soil use, characteristics of the area, potential water treatment quality, selection of environmental factors, and community acceptance see Table 8.2.

According with general characteristics of case study, technical, and economical requirements of the SUDS exposed in the selection matriz Table 8.2, the technological alternatives that conform more to the context are infiltration basin y previous pavements. To continuation is mentioned some items that favoring implementation and compatibility of technology pre-selected for the case study (see Table 8.3 y Table 8.4).

Table 8.2 SUDS pre-selection matrix

SUDS Type	Technique	Low density	Residential	Local roads	Commercial	Soils		Area draining to a single SUDS component		Water quality treatment potential		Hydraulic control	Maintenance	Investment Cost	Habitat creation potential
						Impermeable	Permeable	0 – 2 ha	> 2 ha	Total suspended solids removal	Heavy metals removal	Runoff volume reduction			
Retention	Retention pond	Y	Y	Y1	Y2	Y	Y3	Y	Y6	H	M	L	M	M	H
	Subsurface storage	Y	Y	Y	Y	Y	Y	Y	Y6	L	L	L	L	M	L
Wetland	Shallow wetland	Y	Y	Y1	Y2	Y4	Y5	Y5	Y7	H	M	L	H	H	H
	Extended detention wetland	Y	Y	Y1	Y2	Y4	Y5	Y5	Y7	H	M	L	H	H	H
	Pond/wetland	Y	Y	Y1	Y2	Y4	Y5	Y5	Y7	H	M	L	H	H	H
	Pocket wetland	Y	Y	Y1	Y2	Y4	Y5	Y5	N	H	M	L	H	H	H
	Submerged gravel wetland	Y	Y	Y1	Y2	Y4	Y5	Y5	Y7	H	M	L	M	H	M
	Wetland channel	Y	Y	Y1	Y2	Y4	Y5	Y5	Y7	H	M	L	H	H	H
Infiltration	Infiltration trench	Y	Y	Y1	Y2	N	Y	Y	N	H	H	H	L	L	L
	Infiltration basin	Y	Y	Y1	Y2	N	Y	Y	Y6	H	H	H	M	L	M
	Soakaway	Y	Y	Y1	Y2	N	Y	Y	N	H	H	H	L	M	L
Filtration	Surface sand filter	N	Y	Y1	Y2	Y	Y	Y	Y6	H	H	L	M	H	M
	Sub-surface sand filter	N	Y	Y1	Y2	Y	Y	Y	N	H	H	L	M	H	L
	Perimeter sand filter	N	N	Y1	Y2	Y	Y	Y	N	H	H	L	M	H	L
	Bioretention/filter strip	Y	Y	Y1	Y2	Y	Y	Y	N	H	H	L	H	M	H
	Filter trench	Y	Y	Y1	Y2	Y	Y3	Y	N	H	H	L	M	M	L
Detention	Detention basin	Y	Y	Y1	Y2	Y	Y3	Y	Y6	M	M	L	L	L	M
Open channels	Conveyance swale	Y	Y	Y1	Y2	Y	Y	Y	N	H	M	M	L	L	M
	Enhanced dry swale	Y	Y	Y1	Y2	Y	Y	Y	N	H	H	M	L	M	M
	Enhanced wet swale	Y	Y	Y1	Y2	Y4	Y5	Y	N	H	H	L	M	M	H
Source control	Green roof	Y	Y	N	Y2	Y	Y	Y	N	n/a	n/a	H	H	H	H
	Rain water harvesting	Y	Y	N	Y2	Y	Y	Y	N	M	L	M	H	H	L
	Pervious pavements	Y	Y	N	Y2	Y	Y	Y	Y	H	H	H	M	M	L

Conventions
Y= Yes N= No n/a= not applicable H= high potencial M= medium potencial
1 = may require two treatment train stages, depending on type and intensity of rad use receiving water sensitivity
2 = may require three treatment train stages, depending on receiving watercourse sensitivity
3 = with liner
4 = with surface baseflow
5 = with liner and constant surface baseflow, or high ground water table
6 = possible, but not recommended (implies appropriate management train not in place)
7 = where high flows are diverted around SUDS component
Source: Adapted of (Ballard *et al.*, 2007)

Table 8.3 Criteria of technology selection for Coliseum of the People (Coliseo del pueblo)

CASE STUDY	INFILTRATION BASIN
Coliseo del Pueblo (Infiltration Deposit and Conduction Channel)	Permeable
	Area of 0 – 2 ha
	Commercial uses
	Suspended solids
	Runoff volume reduction
	Maintenance
	Initial investment

Table 8.4 Criteria of technology selection for bullfighting (Plaza de Toros Cañaveralejo)

CASE STUDY	PREVIOUS PAVEMENTS
Parqueadero Plaza de Toros Cañaveralejo	Permeable
	Area of 0 – 2 ha
	Commercial uses
	Suspended solids, Heavy metals removal
	Runoff volume reduction
	Maintenance
	Initial investment

Important areas have been found within the study area where alternatives sustainable drainage systems are proposed, supported by the SUDS selection matrix: these areas are mentioned below. The sports complex (Velodrome, Coliseum of the People), has a potential for the implementation of infiltration deposits, since it features two soccer fields in grassland and greenery between the two structures, which can be used to drain runoffs from roofs of the Coliseum and the velodrome, besides having a parking area where the effective waterproof area can be reduced by using porous pavement with cobblestones for that purpose.

As with the sports complex, the bullfighting ring has a wide parking area and is proposed for runoff control at the source, to implement, porous pavements, including cobblestone paving, with a potential of achieving an infiltration volume of 3.165 m^3.

<u>Pre-design of SUDS alternatives</u>

Given the availability of area in the sports complex and the Cañaveralejo bullfighting ring, two SUDS alternatives were selected in this first phase of the study: impermeable paving and infiltration deposit, with the aim to control runoff peaks caused by rainfall and to reduce storm water flowing into the sewage system. These options will contribute to the control of floods and diffuse or non-point contamination.

Infiltration basin

The grass soccer field in the sports complex is used for the pre-design of an infiltration deposit to store and infiltrate runoff water produced by the roof of the Coliseum of the People; the runoff volume is channeled and taken to the soccer fieldwhich is proposed to have a depression for the accumulation and infiltration of rainwater, see Figure 8.11.

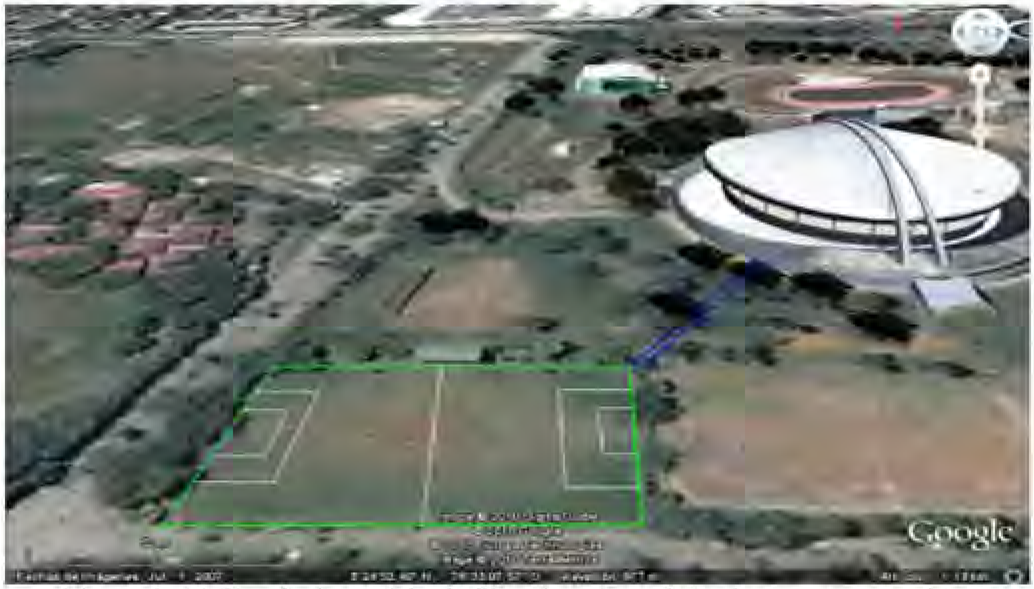


Figure 8.11 Pre-design of the infiltration deposit in the sports complex
Source: (Google maps, 2010)

Information of the infiltration deposit and channel is shown in Table 8.5 and corresponding schematic drawings are presented in Figure 8.12. A rainfall intensity curve was used to calculate runoff volume, with a return period of 10 years and 360 minutes of rainfall, (Forero *et al.*, 2003), which equals a storage volume of 936,62 m^3.

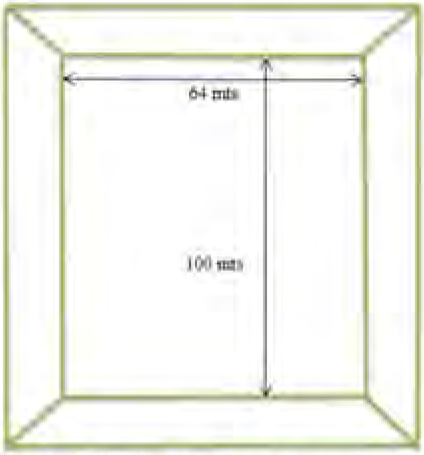
Table 8.5 Infiltration Deposit and Conduction Channel Pre-dimensioning Data

INFILTRATION DEPOSIT	
Area m^2	6,400
Slope	m = 1 (45°)
Storage volume (m^3)	1,920
Depresion (m)	0,3
CONDUCTION CHANNEL	
Manning's Coefficient (n)	0,035 (field with scarce vegetation)
Design Flow Q(m^3/s)	0,21
Slope S (m/m)	0,001
Base b (m)	0,6
Water depth h (m)	0,5
Free edge h' (m)	0,2
Levee crown m	1,18
Longitude (m)	86

Given the storage volume of the infiltration basin, the design hietogram peak calculated for the Coliseum of the People's roof is controlled, avoiding that this is discharged to the stormwater drainage system of the area, and thereby decreasing downstream flooding probabilities.

Pervious pavements

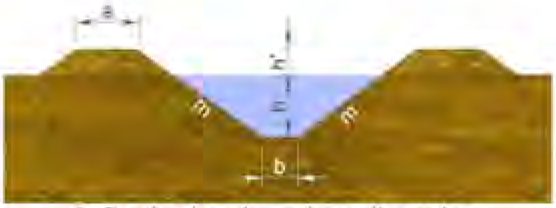
The area of the Bullfigting ring represents a scenario in which the sealed asphalt of the parking lot is changed for vehicle rectangular concrete (12x24x0,8) cm; the effective area of the parking lot is 3,2 ha, for a runoff production volume of 3.165 m^3 , according to the design hietogram (Forero *et al.*, 2003). Shows the corresponding cobblestone, which is installed over a fine sand layer (10 cm) and the asphalt material base and sub-base are used. Figure 8.13 and Figure 8.14.



a) Plant view: Infiltration deposit pre-dimension.

b) Profile view : Infiltration deposit pre-dimension

c) Construction of infiltration basin.



d) Conduction channel pre-dimension.

Figure 8.12 Infiltration deposit and Channel

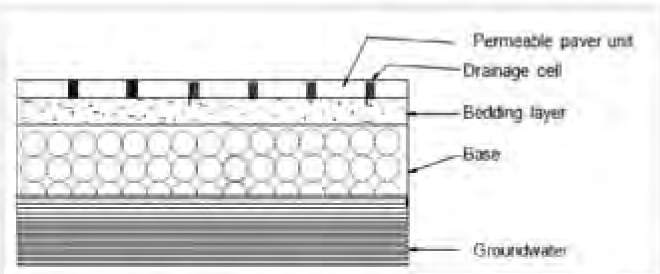


Figure 8.13 Scheme of the proposed cobblestone

Figure 8.14 Installation of cobblestone

8.3.2.2 Initial investment costs

The estimated cost of the infiltration deposit pre-dimensioning proposals, considering cost data from the Government of Valle del Cauca are presented in Table 8.6.

Table 8.6 Cost estimation: Infiltration basin and channel.

ITEM	UNIT	QUANTITY	UNIT VALUE (COP)	SUB-TOTAL (COP)	TOTAL (COP)	TOTAL (EURO)
Grass removal	m^2	7.000	$ 844	$ 5.908.337	$ 52.435.012	€ 21.550
Machine Excavation without removal	m^3	1.982	$ 2.500	$ 4.955.600		
Mechanical debris removal <=10 km	m^3	1.934	$ 14.660	$ 28.366.220		
Existent grass placement	m^2	7.000	$ 1.886	$ 13.204.855		

For costing the scenario of changing the sealed asphalt for permeable pavement (cobblestone), the case once the parking lot asphalt layer is recovered is considered. Likewise, the use of the base and sub-base in the installation of the cobblestone decreases its cost. Therefore, costs are

estimated considering the same material is used to replace the asphalt layer. See Table 8.7 and Table 8.8.

Table 8.7 Cost estimation: Pervious pavement installation

ITEM	UNIT	QUANTITY	UNIT VALUE	SUB-TOTAL	TOTAL (COP)	TOTAL (EURO)
Demolition	m^2	31.213	$ 5.000	$ 156.067.700	$ 896.527.781	€ 368.472
Mechanical debris removal <=10 km	m^3	4.369	$ 14.660	$ 64.062.669		
Rectangular vehicle concrete cobblestone 12 x 24 x 8 (includes fine sand, labor, finish work, minor tools)	m^2	1.092.473	$ 21.670	$ 676.397.411		

Table 8.8 Cost estimation: Replacement of asphalt (conventional alternative)

ITEM	UNIT	QUANTITY	UNIT VALUE	SUB-TOTAL	TOTAL (COP)	TOTAL (EURO)
Demolition	m^2	31.213	$ 5.000	$ 156.067.700	$ 1.102.545.572	€ 453.146
Mechanical debris removal <=10 km	m^3	4.369	$ 14.660	$ 64.062.669		
3" asphalt layer (includes supply and installation)	m^2	31.213	$ 28.270	$ 882.415.203		

8.3.3 Comparison of solutions

8.3.3.1 NPV analysis

The proposed SWITCH alternative with the implementation of an infiltration basin, to retain the direct runoff from the rough of the Coliseum of the People represents an important benefit, since the applied hydrological characteristics and the design hietogram for the South Drainage System represents a 100% reduction of runoff in the specific area, which corresponds to 937 m^3 of stormwater. The study area is equal to 5% of the polygon of the selected study area; even if it represents a low percentage the peak of the runoff is controlled regarding the rough of the Coliseum. The runoff of this area is discharged to the San Fernando Channel, which according to modulation by (Forero *et al.*, 2003), suffers from overflow for 10-year rain events. The concentration times for the discharge of stormwater from the San Fernando tributary areas are 35, 51 y 90 minutes, respectively, of which the last corresponds to the area where the Coliseum is located. With the proposed infiltration basin and pervious pavement, it is expected that equilibrium is generated with the area without measures for runoff control, since the upstream runoff is retained improving the conditions in the critical section of the channel. However, a detailed modulation is necessary to evaluate the impacts of the proposal, which will be conducted during the remaining project time. Furthermore, a cost-benefit study is proposed to be able to compare the estimated investment of € 368.472 Euro with the generated benefits, including the prevention of flooding and reduced discharge and resuspension of contaminants.

The alternative of replacing the asphalt surface in the parking area next to the Bullfighting ring for pervious pavement, contributes to the retention of runoff mentioned above. When the costs are prepared between the installation of pervious pavement and the replacement of asphalt, the pervious pavement represents a saving of €84.674 Euro. Furthermore, the expected lifetime of the cobblestone is 30 years compared to 10 - 20 years for the asphalt. Consequently, the proposed strategy for the implementation is taking advantage of the need for replacement of asphalt and at this moment install pervious pavement. To avoid accumulation of sediments and clogging of the cobblestone system, it is recommended to extend the frequency of sweeping and cleaning of the parking area.

As the study area where the appplication of SUDS strategies is completely consolidated, the inital costs of this type of alternative in general are relatively high. Consequently it is indispensible to take into account the benefits of avoiding flooding, reducing discharge of contaminants to the receiving water bodies.

8.4 CASE STUDY 2 – CAÑAVERALEJO RIVER RESTORATION IN URBAN AREA

8.4.1 Description of current solution (conventional solution)

In the urbanization process of the city of Cali the rivers have been intervened and altered when they pass through the urban area. The Cañaveralejo River has been selected as a case study for urban river restoration since it is the river that has received the major alteration of the seven rivers of Cali. The restoration of urban river strategy has been considered as it has a potential of re-establishing natural characteristics regarding river hydraulics and in addition it can contribute to improve the ecological and esthetical values of the river system. The Cañaveralejo River has natural meandering characteristics as it enters the urban area, where it has been altered as it passes through the Cañaveralejo dam. The dam has a controlled outlet and areas that are flooded during heavy rain events as a way to retain the increased water flow (see Figure 8.15). After the dam construction the river continues its rather natural way until it crosses underneath the street of "Calle 3", where it loses its natural river bed conditions and turns into a concreted channel until its outlet in the South Channel.

Figure 8.15 Cañaveralejo Dam

Apart from losing its natural river characteristics, from the street "Carrera 50" the river completely has lost its original stretch. In Figure 8.16 the original river stretch can be seen in a map from 1954. At this time the development of the city had still not reached the Cañaveralejo River and the river had its outflow directly to the Cauca River. As the river no longer has natural characteristics when it enters "Carrera 50" it changes name to Cañaveralejo River-Channel.

Figure 8.16 Map from 1954 showing the original river stretch of the Cañaveralejo River before its canalization
Source: (Jiménez, 2005)

A part from losing its ecological, esthetical and landscaping values, the dynamics of the natural water body is lost by the channelization. In a river, natural process of sedimentation, resuspension, velocity changes and water buffering occurs, while a lined storm water channel does not offer these characteristics and therefore loses its natural flooding capacity. In general, the sedimentation of solids is not desired within a stormwater channel as it obstructs the water flow and implies considerable resuspension of solids in major flow events. In the case of the Cañaveralejo subsystem, the river drains the upstream micro basin and brings sediments and bigger particles, such as sand and rocks, into the channelized system, where it partly deposits contributing to flow obstruction and resuspension of material, see Figure 8.17.

The transition from river to channel is also a factor that increases the risks for flooding in the urban centre, due to the huge amount of water drained from the water basin in heavy rain events, which as the river enters the urban area is led into a stormwater channel with limited size.

Figure 8.17 Accumulation of sediments in the Cañaveralejo River-Channel

Due to the significant alterations made on the Cañaveralejo River after the street of "Calle 3" in the urban area, this part of the river has been selected as a case study for the application of urban river restoration measures. The area under consideration is delimited by "Calle 3" and covers the stretch until the interception with San Fernando Channel in "Carrera 50", see Figure 8.18.

Figure 8.18 Map of the study area with the selected river stretch

As mentioned earlier, the channel was built completely coated with concrete and has a trapezoidal form, as shown in Figure 8.19. The first section of the selected river stretch is still partly surrounded with green areas; however the vegetated buffer strip or forest protection area of 30 metres along the river is not met and in some parts there are no distant at all between the river/channel and constructions. In the stretch located in "Carrera 50" there are just a few metres of buffer strip along the sides of the channel (Figure 8.19).

Figure 8.19 Few meters of buffer strip along the sides of the Cañaveralejo river – Channel

8.4.2 Solution with SWITCH approach

8.4.2.1 Description

The first step and often one of the most difficult is taking the decision on which specific stretch of the urban river to select for the implementation of restoration actions, as it requires the consensus among a large number of diverse stakeholders. In this case, since a conceptual pre-design is considered, the decision has been taken as mentioned in the study area description, namely from the point where the river intersects with the main street of "Calle 3" until the river/channel intercepts with San Fernando Channel in "Carrera 50" (Figure 8.18). The reasons to choose this specific river stretch are the following:

1. It is the first stretch of the river that has been concrete-lined, which means that river restoration actions will generate connectivity with the upstream river system.
2. The final part of the selected river stretch has experienced problem with flooding during heavy rain events; restoration actions can contribute to the improvement of hydraulic conditions.
3. And finally, there is a proposal elaborated by a Cañaveralejo river protection initiative "Cali, the city of water" (Caicedo, 2010), where an ecological corridor is projected along the river system from the outskirts of Cali until the river reaches the street of "Carrera 50". The restoration of the river in the selected stretch would enhance the benefits of the ecological corridor.

Since a proposal for the improvement of the surrounding nature areas already has been elaborated in the framework of "Cali, the city of waters", the alternative presented here is focusing on in-stream restoration actions that will complement the ecological corridor. Furthermore, at this stage of the pre-design process only a schematic and conceptual design is elaborated which has been broadly cost estimated.

Schematic design

Due to the limitations in existing urban development a complete restoration to the form the river had before the intervention will not be possible, however natural river characteristics should be aspired, for example rocks and trees should be introduced once again in the river zone.

As the river has been concrete-lined in the selected stretch, with a concrete foundation both in the bottom and wall sections of the channel (see Figure 8.20), it has been considered indispensable as a first action to *remove the concrete lining* to recuperate more "natural" river characteristics.

Secondly, to contribute to the improvement of flooding control in the selected stretch it is considered important to *widen the cross section of the river bed*, where possible to allow a greater flow capacity. The walls must still be well protected against erosion as the flows can be violent in heavy rain events; therefore it is projected to install *graded and erosion resistant river walls* are constructed with reused concrete elements. see the proposed cross section for the Cañaveralejo River in Figure 8.21. As shown in the figure, for the new proposed river channel section efforts must be done to remove construction or impermeable surfaces around the water course to be able to widen the river channel and *extend the green area on both sides of the river*.

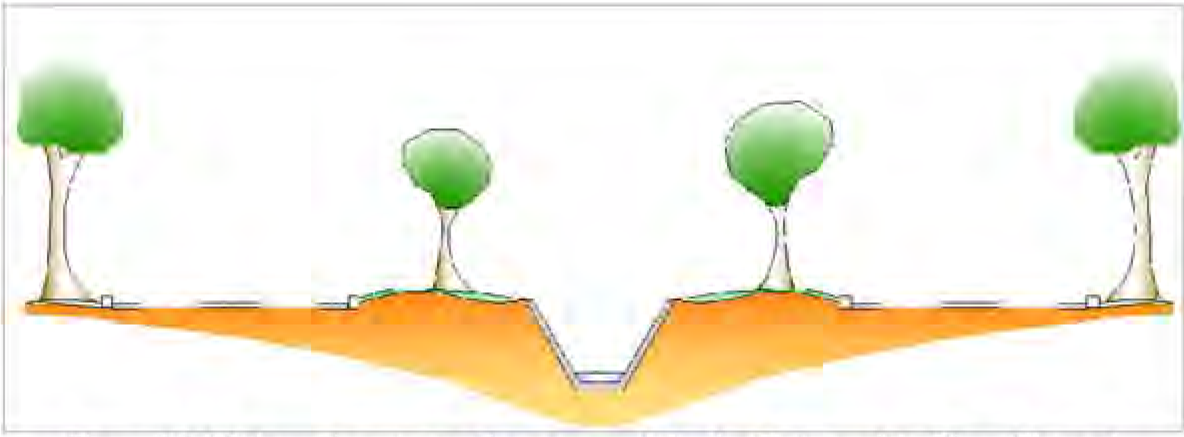


Figure 8.20 Schematic cross section proposed for the Cañaveralejo River-Channel

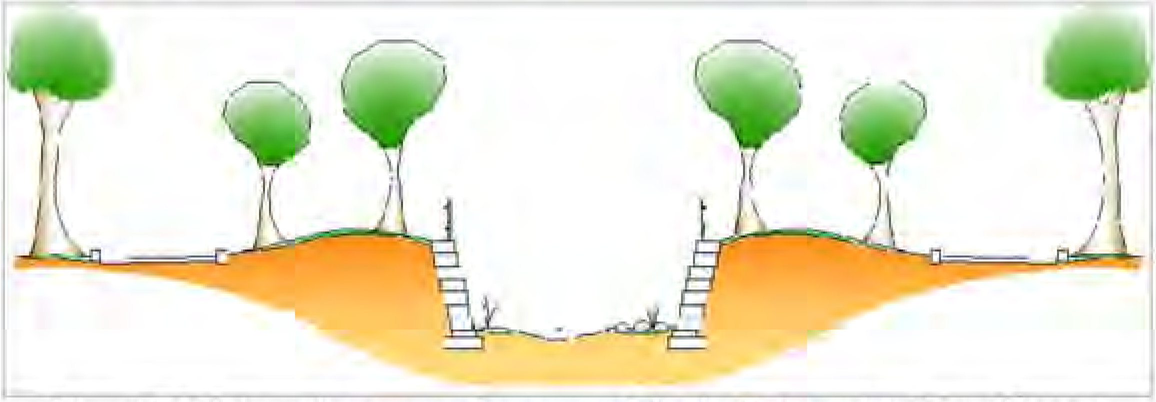


Figure 8.21 Schematic cross section proposed for the Cañaveralejo River-Channel

The proposal also includes other in-stream actions such as the *construction of deflectors* to intermittently narrow the channel by creating curved obstacles at the side of the river channel (see Figure 8.21), which will generate variation in the current and create pockets of erosion and deposition. Moreover, the *installation of stone riffles* is projected, which works as an obstacle across the river, which serves to regulate the water levels upstream and can contribute to the aeration of the stream. In Table 8.9 the proposed characteristices of the river restoration is presented.

Table 8.9 Characteristics of the alternative of restoring natural river system

SIZE SPECIFICATIONS:	TOTAL LENGTH FROM "CALLE 3" TO "CARRERA 50": 1 km
Estimated removal efficiency	Preventive measurement enhancing auto-purification processes
Benefits/Advantages	Natural deposition of sediments Flow retention and natural water buffering Restoration of aquatic ecosystem Recovering landscape and green area
Limitations/Disadvantages	Spatially competing with existing infrastructure *(roads, buildings etc.)* Investments in alternative stormwater channels is required
Time frame of implementation	Medium/long term
Main activities for the preparation of alternative	Detailed pre-design combined with hydraulic modelling Cost-Benefit Analysis

An example of the outcome of the projected restoration of the selected stretch in the Cañaveralejo River is the characteristics of Cali River in the urban area see Figure 8.22, which is considered an achievable restoration result.

Figure 8.22 The River Cali, as it runs through the urban area

However, the type of in-channel river restoration actions proposed for the Cañaveralejo River should be complemented with implementation of stormwater management actions (e.g. sustainable urban drainage systems) in the drainage area to avoid problems with erosion and structure failures (Walsh *et al.*,2005).

8.4.2.2 Initial investment costs

The cost estimations for the implementation of restoration actions in the selected stretch in the Cañaveralejo River/Channel, will consider the following main items: demolition and removal of concrete, excavation, construction of walls, taking into account costs the movement of material. However, due to there is not designs of the alternative for Cañaveralejo river, the cost estimations are based on similar international project experiences (Consejeria de Medio Ambiente, 2009). The purpose of this costing exercise is to know the approximate cost implications to build the plant, to be able to compare the result with the generated benefits (Consejería de Medio Ambiente, 2009). The estimated cost for the proposed 1 km restoration project in the Cañaveralejo river channel is €940,500.

8.4.2.3 Operation & maintenance costs

The operation and maintenance cost in restored rivers is normally low, since it is desired that they turn into self regulated systems (FDE, 2007). The need of maintenance, e.g. dredging to preserve river depth, is mainly dependent on the state and management of the upstream basin. Consequently, the O&M cost for the 1km river strip proposed for restoration has not been estimated.

8.4.3 Analysis of solutions

As can be seen from the estimated costing, the implementation of this restoration project requires a significant inversion. A recommended strategy is to carry out the work taking advantage of natural deterioration of the concrete lined stormwater channel and the need of investment in maintenance, i.e. instead of investing in demodulation of the existing channel construction with new concrete lining, the river restoration project is implemented. Due to the economic implications and the necessity of improved management of stormwater in the water basin this alternative is considered to be implemented on a medium to long term, the installation of SUDS would in this sense be the main action on a short term.

The hydraulic effects of the proposed restoration actions are currently being investigated with the elaboration of a computer model, which will generate a result of the restoration impact. According to the outcome of the computer modelling it will be possible to establish the potential benefits regarding improved water management and prevention of flooding. Furthermore, it is considered important to perform a cost-benefit analysis to include the social and environmental impacts that the proposed river restoration will have.

Additionally, an important factor that could facilitate the implementation of an urban river restoration project is the proved strong movement for the protection and conservation of the rivers in Cali, both among the general public and organizations.

8.5 CASE STUDY 3 – ON-SITE TREATMENT OF LEACHATE FROM THE NAVARRO LANDFILL

8.5.1 Description of study area

The management of solid waste is an international issue, which creates environmental problems mainly due to the generation of leachate and gases from landfills. The solid waste produced by human activities has over the years been disposed in open-air and unlined (without impermeable protection layer) landfills. Only during the last decades improved measures have been implemented to minimize waste and emission generation. These mitigation measures incorporates preventive actions e.g. cleaner production strategies including among other waste separation and recycling, and control actions implemented at the disposal site. The control actions first of all include the adequate construction of landfills with permeabilization and collection systems for gases and leachate, but also the installation of leachate treatment system. Since the Navarro landfill in Cali is closed the potential for preventive measures are limited, consequently the present study will focus on the management of leachate.

The main objective of the development of this theme is to analyse and preselect alternatives for the adequate management of leachate produced in the Navarro Landfill, evaluating the potential of both conventional and natural treatment methods considering environmental and socio-economic aspects.The main characteristics of the Navarro landfill have been described earlier (see “Master Plan” and “Diagnose report” - Univalle, 2008 and 2010); however, it is considered important to make a brief background description here to facilitate for the reader.

The Navarro landfill was the main disposal site for solid waste in the Cali Municipality for almost 40 years, before it was closed down in 2008.The landfill is located next to the South Channel about 2 km prior to its outlet in the Cauca River in the rural district of Navarro, see Figure 8.23.

The Navarro landfill occupies an area of 40 ha, divided between 17 ha “old dumpsite”, 12 ha “transitory landfill”, 5,3 ha of leachate storage Ponds, while the rest is unexploited area (CVC, 2008 y DNP *et al.*, 2009). The total quantity of waste that was deposited in Navarro has been estimated to 10 millions m^3, according to CVC (2008). The composition of disposed waste has not been fully determined, however, it is considered that there has been a predominance of domestic waste with a high content of food residues (Valencia, 2005).

Figure 8.23 Overview of the Navarro landfill and the possible site for a leachate treatment plant

Until 2001 the Navarro landfill was employed as an open-air dumpsite without the installation of impermeable layers, which implies that contaminated leachate from these areas today still drains uncontrolled to surface and groundwater with a continuous impact on the environment creating significant exposure risk for humans, which affects public health. The more recent cells, referred to as the transitory landfill, were built with impervious layer and drainage system for the collection of leachate. The leachate that is collected in the drainage system is led to storage ponds. However, at the moment there is no leachate treatment; a situation that implies that the contaminated leachate sooner or later overflows from the storage ponds into nearby surface waters.

According to the CVC (El Pais, 2009), the old sections of the landfill was not closed in a proper way according to the director of CVC, José William Garzón and needs to be improved, while the newer sections have been sealed after its closedown. This sealing was made by the construction of terraces with clay layers installed and thereafter covered with soil and planted with trees, see Figure 8.24. The purpose of the sealing is to minimize the infiltration of rainwater through the waste, hence reducing the production of leachate, controlling the drainage of biogas and also to recover the landscape.

Figure 8.24 Sealing and vegetation reestablishment of the transitory section of the Navarro landfill

8.5.1.1 Leachate characteristics

The volumetric liquid flow rate and the composition of disposed waste are the two main factors that determine the characteristics of the leachate produced from a landfill(Renou *et al.*, 2008). The liquid flow rate is greatly influenced by the climate conditions (e.g. precipitation and evaporation), the compactness and the water content of the waste, and the type of sealing installed over the landfill. The physiochemical quality of the leachate is dependent on these previous aspects, which in turn are strongly dependent on the age of the landfill.

Flow characteristics

The available information about estimated leachate production diverge significantly, with a variation from 3,9 L/s to 5,94 L/s reported by INGESAM (2005) and according to measurements made by CVC (2004) the production is estimated to 7,6 L/s.

Based on the data from CVC, in 2004, 5 L/s were collected and led to the storage ponds, while the remaining 2,7 L/s were discharged to the adjacent oxbow lake, of which an estimated 0,9 L/s infiltrates to the upper aquifer in the area. However, since the new sections of the landfill has been sealed after that these studies were conducted, important changes in the leachate dynamics is likely to have occurred due to the reduction of rainwater infiltration, which has an impact on the quantity, but also on the quality of the leachate.

Leachate quality

Two types of leachate have been differentiated at the landfill, new and old leachate, which depend on the decomposition state of the waste where the leachate is generated. The quality of new and old leachate is presented in Table 8.10.

Table 8.10 Quality of new and old leachate produced in the Navarro landfill.

PARAMETER	UNIT	LEACHATE TYPE	
		New [a]	Old [b]
pH	Units	6,64	8,5
Total Solids	mg/L	48.020	13.506
Total Suspended Solids	mg/L	1.410	198
Total Dissolved Solids	mg/L	46.610	13.309
COD	mg O_2/L	62.700	6.269
Total Alkalinity	mg $CaCO_3$/L	-	665
Total hardness	mg $CaCO_3$/L	-	1.700
Calcium hardness	mg $CaCO_3$/L	-	600
Magnesium hardness	mg $CaCO_3$/L	-	1.100
Chloride	mg Cl^-/L	-	2.147
Total Nitrogen	mg/L	1.900,7	736
Ammoniac Nitrogen	mg/L	955	578
Phenols	µg Phenol/L	-	321
Cyanide	µg CN^-/L	-	7,84
Mercury	µg/L	-	3,21
Cadmium	mg/L	-	< 0,04

Source: [a]Garzón and Vélez, 2005; [b]CVC, 2002, cited by (Valencia, 2005)

The new leachate has significantly higher content of solids and organic matter, as an example the COD is 62.700 mg/L compared to 6.269 mg/L in the old leachate. When it comes to toxicity parameters, there are only values available for the old leachate.

As revealed the availability of data for leachate quality in Navarro is extremely limited, since there are no updated or continuous monitoring data of leachate characteristics, nor exact information about the composition of waste deposited in the Navarro landfill. Additionally, leachate is a very complex waste flow that changes its characteristics (quantity and quality) over time as mentioned before, and investigations made on leachate in other parts of the world have detected more than hundreds of different hazardous substances, including organic and metal-organic compounds, which has to be considered in future landfill risk assessments and in the development of leachate treatment methods (Öman *et al.*, 2007). Likewise, emissions from landfill may prevail for a very long time, often thousands of years or longer.

In a recent study, high levels of heavy metals (exceeding the norms) were found in soil and water resources around the Navarro landfill; most concerning is that the study showed that these contaminants are associated with congenital malformations and cancer diseases (Universidad del Valle, 2009). Consequently, the lack of proper management of generated leachate and also biogas (a public health problem not further revealed in this study) represents high ecological risks, which includes risks for the exposed human population.

Leachate management

As commented earlier, there are different components that can be considered in a management system for landfill leachate, of which some are related to landfill construction aspects such as liners, drainage and collection system, and the final top-sealing. These aspects are important in the view of the quantity of leachate production. The subsequent stage is the adequate handling and disposal of the produced leachate, which can consist of various strategies and treatment technologies.

Current leachate management

The landfill was constructed in phases, where the first cells, today known as the "old hill" and the "hospital hill", were built without impermeable layer and used until 2001 (Valencia, 2005). Consequently, the leachate produced from this area drains uncontrolled to the surroundings. Various studies have proven that this continuous leakage of leachate has generated significant pollution situation in the area with among other a growing contamination plume in groundwater.

The transitory landfill, with more recent cells that was taken into operation from 2002, was built with protection liners and drainage system for the collection of leachate. The leachate that is collected in the drainage system is led to storage ponds. The newer sections of the landfill have been sealed after closure according to established standards, while the older sections are poorly sealed, which contributes to higher infiltration rates and higher leachate production.

The Navarro landfill has a total of seven storage Ponds covering an area of 5,4 ha, which represents a storage volume of approximately 384.000 m^3, see Table 8.11. Considering the estimated leachate inflow to the Ponds of 5 L/s it would result in a retention time of almost 2,5 years. However, this storage capacity is not enough to avoid the discharge of contaminated leachate to recipients, in fact there are reports of unauthorized discharge from the Ponds to the adjacent surface waters.

Table 8.11 Leachate storage ponds characteristics in the Navarro landfill

STORAGE POND	AREA (m^2)	HEIGHT (m)	VOLUME (m^3)
Great pond 1	14.314	8	114.512
Great pond 2	13.800	8	110.400
Great pond 3	12.247	8	98.000
Polish pond	3.828	5	19.000
Pond Cell C		-	600
Pond 5	4.662	4	18.600
Pond 6	5.000	4.6	23.000
Pond 7	-	-	48.000
Total	53.851		432.112

Source: Daza *et al.*, 2010, EMSIRVA (personal communication)

Treatment experiences in Navarro

Over the last decade different strategies to encounter an adequate approach for the treatment and disposal of the leachate produced by the Navarro landfill, including various studies, pilot and full scale projects.

In Table 8.12, a summary of these activities are presented, including the achieved removal efficiency. Some of the applied treatment methods have reached a good efficiency; nevertheless, the general conclusion of the results is that it is advantageous to combine different treatment methods.

At the same time, it is important to state that the conducted studies have been focused on the removal of certain contaminants, while there is no information available on others, e.g. heavy metals.

Table 8.12 Summary of treatment activities employed on the leachate of Navarro landfill

TYPE OF TREATMENT METHODS	SCALE	YEAR	REMOVAL EFFICIENCY (%)		
			COD	BOD	TSS
UASB, sedimentation tank, filter and polishing pond	Pilot scale	2001	<82,1[c]	<82,4[c]	<86,4[c]
Application of PD 1000 (antioxidant made from natural seeds)	Investigation	2001	40[c]	42[c]	72[c]
Anaerobic treatment (Phase separation and UASB)	Investigation	2001	PS <38,4[c] UASB <94,8[c]	-	-
Natural evaporation with recirculation	Full scale	2002	-	-	-
Forced evaporation	Pilot scale	2003	-	-	-
Aerobic and anaerobic treatment	Investigation	2003	Aerobio <50[c]	-	-
Treatment in constructed sub-surface wetland	Investigation	2004	<8,5[a]<95,6[b]	<18,9[a]<90,5[b]	<46,6[a]<78,9[b]
Aeration lagoon, electrolytic flocculation, filtration, settling, sludge recirculation	Full scale	2005	85[c]	97[c]	-
Physico-chemical treatment with coagulants ($FeCl_3$/sulfate and ammonia salts)	Investigation	2005	<44[a] <47[b]	<75[a] <96[b]	-

[a]Old leachate;[b]New leachate;[c]Type of leachate unknown
Source: Adapted from (Valencia, 2005)

Treatment requirements

In the national technical regulation for the water and sanitation sector "RAS - 2000", the guidelines presented in Box 8.1 have been stipulated regarding the management of landfill leachate (Ministerio de Desarrollo Económico, 2000).

Box 8.1 Landfill leachate guidelines according to RAS-2000, Title F
"All contaminated leachate generated from a landfill should receive treatment before its discharge to a water body, superficial or subterranean, using recognized viable technologies. In the treatment process the following aspects should be taken under consideration: *1. Toxicity for microorganism in the case of using biological treatment processes.* *2. Formation of precipitates in tubes, canals, valves, pumps, tanks, and in general in all structures. It should be anticipated that the operation will form these precipitates. It should be considered the possibility to remove the precipitated ions.* *3. Formation of foam. It should be anticipated the form of operation and efficiency that even in the case of its generation the quality of the effluent is guaranteed.* *4. Variation of leachate characteristics with time. It should be anticipated that the physiochemical and biological characteristics of the leachate change significantly during the lifespan of the treatment plant. It should be anticipated the flexibility in operation and efficiency for the whole design period and closure of the landfill.* *5. The process should comply with the effluent quality to guarantee the water uses, which have been assigned for the receiving water body. The quality norms for receiving water body according to water uses are those stipulated in the Decree 1594 of 1984 regulated by 9th Law regarding uses of water and liquid waste or its modification and substitution."*

According to the Decree 1594 of 1984 leachate treatment must show compliance with:
- The quality norm for type of use given to the receiving water body (Art. 37-50)
- Removal efficiency for discharge of liquid residues (Art. 72)

Compared with domestic wastewater, where there is a main focus on the removal of BOD, TSS and microbiological parameters, landfill leachate requires special attention as the content of contaminations is much more complex. Kadle and Wallace (2008) have stated that additional factors that should be taken under consideration are:

1. Removal of considerable amounts of iron.
2. Very high concentrations of ammonia to be removed.
3. Survival of the wetland vegetation.
4. Very small flows, which interact strongly with rainfall and evapotranspiration.
5. Reduction of volatile hydrocarbons (BTEX, etc.).
6. Reduction of trace toxicants (PAHs, PCBs, etc.).
7. Removal and storage of trace metals.
8. Sensitivity and protection of receiving water bodies.

Pre-selection of treatment technology

As mentioned earlier, the complexity of leachate characteristics creates a great challenge in the selection of treatment technology. At the same time the presence of treatment methods that have potential for leachate treatment are significant, with high variations in treatment performance and social, technical and economic requirements. Additionally, the demands for treatment efficiency are dependent on national norms, sensitivity of surrounding ecosystems, and the human usage classification of receiving waters. This combination of components makes the selection process very complex and consequently it essential to employ some kind of decision support system to make use of existing experiences in technology selection.

Model for leachate treatment technology selection using a Decision Support System

Vargas (2007) has developed a decision support system for the selection of the most feasible alternatives of leachate treatment for specific conditions. As its name reveals, this type of system is a tool to create a basis of information for a more sustainable decision making. This

decision support system is capable to generate an initial sequence of alternatives, from the most appropriate to the lowest for leachate treatment; however, it is recommended that further precision of the selection process should be reevaluated for every specific context.

The decision support system developed by Vargas (2007) consists of an algorithm composed by 6 stages as presented in Box 8.2.

Box 8.2 Proposed stages in the Decision Support System (Vargas, 2007).

1st stage: Necessity of the leachate treatment: In conditions where evaporation is higher than precipitation and the landfill and external conditions are favourable, non-treatment management of leachate can be held. Possible solutions: leachate mitigation, natural evaporation, leachate recirculation, and land application. End of DSS. If at least one of the previous conditionals is unfulfilled proceed to 2nd stage.

2nd stage: Technical applicability of leachate treatment technologies based on leachate quality and effluent quality standards: Taken as initial data the influent characteristics of leachate and the effluent standard requirements, the achievement or not of the effluent standards by each leachate treatment technology is determined. The effluent standards are checked for the next seven parameters: COD, BOD, SS, ammonia, chloride, sulfate and metals.

3rd stage: Leachate treatment technology(s) pre-selection: Depending on the number of parameters that reach the effluent standards, a pre-selection of the leachate treatment technology(s) is carried on. The option priorities are the followings, in descending order:

1st priority: Technology with all the parameters achieving the effluent standards

2nd priority: Combination of two technologies: one with the four first parameters achieving the effluent standards, and one with the last three parameters achieving the effluent standards

3rd priority: Combination of two technologies: one with three of the four first parameters achieving the effluent standards, and one with two of the last three parameters achieving the effluent standards

4th priority: Combination of two technologies: one with three of the four first parameters achieving the effluent standards, and one with one of the last three parameters achieving the effluent standards. This combination can be modified depending on each particular case, giving the possibility of a manual pre-selection of combination of two of more technologies.

If no solution is found, move to 6th stage.

4th stage: Selection of technology by Multi-criteria analysis: The preselected leachate treatment options are now evaluated by a multi-criteria analysis.

The applied criteria are:

- Local conditions: climate, hydrology, and land requirement
- Processes: process applicability, simplicity, reliability, and treatment residuals
- Environment and social: soil contamination, air contamination, water contamination, odour-noise, and social acceptance
- Economics: construction cost, operation & maintenance, and sustainability

Each technology has a score for each criterion, and each criterion has a weight. From this a total score of each possible solution is calculated. The list of solutions ordered by priority and by higher scores is presented.

5th stage: Verification of selection using existing experiences: The solution that has a higher priority and higher total score will be analyzed, in order to verify if there is an existing leachate treatment system that presents the same or similar configuration. In case of a positive response, after presenting a scheme of the final solution of leachate treatment technology, the end the DSS is held. In case of a negative response try the same with the other possible solutions. If after checking all possible solutions, there is not a compatibility with an existing treatment system, move to 6th stage.

6th stage (if necessary): Re-evaluation of leachate effluent standard and leachate quality: In case of not finding a solution after 3rd stage or 5th stage, the DSS manages a LOOP process, with a re-evaluation of leachate effluent standard and leachate quality. Evaluating the reduction of the strictness of the effluent standards or the strength of the influent leachate, in order to find a leachate treatment solution, should be held. Pros and cons must be analyzed for aspects such as: effluent discharge and its effect to the environment, sustainability of leachate treatment solution, and costs.

In the following section, the decision support system presented above is used in the pre-selection process of technologies with a potential for leachate treatment of Navarro landfill.

Applying Decision Support System for the pre-selection of leachate treatment in Navarro

Necessity of leachate treatment

This first stage in the decision algorithm defines if leachate treatment is necessary or none-treatment methods are feasible. In the case of Navarro, the necessity for treatment is considered evidently according to the following aspects:

- Precipitation in the area is superior to evaporation, which means that there is a generation of excess water in form of leachate that drains from the landfill (Daza *et al.*, 2010)
- Liquid residues require an adequate treatment before discharge in accordance with the national regulation (Decree 1594 of 1984). Additionally, the specific requirement for treatment installation in the case of Navarro is prescribed in the national policy document CONPES 3624 (MAVDT *et al.*, 2009).
- The intake of the Puerto Mallerino potable water treatment plant is located about 13 km downstream of the Navarro landfill. This water plant serves about 80% of the inhabitants in the city of Cali, hence a comprehensive management of the leachate is considered indispensable to protect public health. Water sampling made in the South Channel before and after the Navarro landfill shows that the landfill has a negative impact on the water quality, which does not comply with the standards to be used as a raw water source for potabilization (EMCALI *et al.*, 2007).

Technical applicability of leachate treatment technologies based on leachate quality and effluent quality standards

The second stage in the model is to test which treatment technologies can achieve the effluents standards stipulated in the regulation. This compliance is dependent on both the influent contamination levels and the treatment efficiency of the technology. The following seven parameters are recommended as indicators: COD, BOD, SS, ammonia, chloride, sulphate and metals.

As the landfill was closed in 2008 no fresh waste has been deposited after this date, which means that the leachate produced in Navarro will tend towards “old” leachate characteristics. In the view of this fact it was considered reasonable that the pre-selection process elaborated in the present study used the “old” leachate as the initial data. However, before proceed to the decision phase new analyses should be made to establish current leachate characteristics and based on this sample data the pre-selection process should be verified.

Table 8.13, shows the contaminant levels for the “old” leachate of Navarro for the available parameters, quality of the recipient, and the corresponding norm for the receiving water. Regarding COD, BOD and SS no values are given in the norm; instead these parameters are prescribed with minimum removal efficiency in treatment. The corresponding values based on these prescribed removal efficiencies are also presented in the table. For BOD and sulphate levels in leachate there are no sample data available. It is important to state that analyses available are taken in 2005 and earlier, which generate space for uncertainty about actual characteristics.

Based on leachate strength, effluent standards and removal efficiency of technologies a first selection can be performed. Vargas (2007) has developed a Decision Support System Matrix (see Appendix 6). This matrix includes the following components:

- Leachate treatment methods (Physical, chemical and biological).
- Removal efficiencies of each technologymethod for: COD, BOD, SS, ammonia, chloride, sulfate and metals. These removal efficiencies are range according to Table 8.14
- Approximate achievable effluent standard of each method for each parameter.

The values for removal efficiency can be found in Table 8.15.

Table 8.13 Comparison between leachate quality, recipient quality and national effluent norm

PARAMETER	UNIT	"OLD" LEACHATE [a]	Recipient [b] (South channel before Navarro)		Norm for raw water source for potabilization (Decree 1594-1984: Art. 38)	Discharge norm (Decree 1594-1984: Art. 72)
			Summer	Winter		
COD	mgO^2/L	6.269	80	113	-	removal > 80% => *< 1,254 mg/L applied on "old" leachate*
BOD	mgO^2/L	-	41	54	-	removal > 80%
SS	mg/L	198	100	235	-	removal > 80% => *< 40 mg/L applied on "old" leachate*
Ammonia	mg/L	578	-	-	1	-
Chloride	$mgCl^-/L$	2.147	-	-	250	-
Sulphate	mg/L	-	-	-	400	-
Mercury	µg/L	3,21	1	0,9	2	-
Cadmium	mg/L	<0,04	-	-	0,01	-

Source: (Garzon *et al.*, 2005);[b]EMCALI *et al*, 2007

Table 8.14 Estimated removal efficiencies for different leachate treatment methods

Leachate Treatment Methods	Removal efficiency (0-5)						
	COD	BOD	SS	Ammonia	Chloride	Sulphate	Metals
PHYSICAL							
Natural evaporation	1	1	0	2	0	0	3
Filtration	2	2	5	0	0	0	1
Flotation	1	1	2	0	1	0	3
Membrane processes (ultrafiltration - nanofiltration)	3	1	5	2	2	2	3
Reverse osmosis	4	4	5	3	2	2	4
Air stripping	2	2	1	4	1	1	0
CHEMICAL							
Coagulation/precipitation/sedimentation	3	2	5	1	1	2	4
Chemical oxidation	4	3	0	5	1	0	1
Carbon adsorption	3	2	0	2	2	2	1
Ion exchange	2	2	0	3	3	3	4
BIOLOGICAL							
Waste stabilization ponds	4	4	4	3	1	1	1
Constructed wetlands	4	4	4,5	3	1	1	2
Aerated Ponds	4	4	4	2	1	1	1
Leachate recirculation	2	3	3	3	0	0	0
Conventional activated sludge	4	4.5	4,5	4	0	0	0
Land treatment (slow rate)	4,5	4.5	4,5	4	1	1	1
Activated sludge with extended aeration	4,5	5	4,5	4	0	0	0
Membrane Bioreactor (MBR)	4	5	5	5	3	1	1
Sequencing batch reactor (SBR)	4,5	5	4,5	4	0	0	1
Trickling filter	3	4	4	2	0	0	0
Rotating biological contactors	3	4	4	2	0	0	0
Powdered activated carbon treatment (PACT)	3	4	3	1	1	1	1
Anaerobic treatment process	4	4	4	2	1	1	1

Source: (Vargas, 2007)

Table 8.15 Removal efficiencies for the classification of leachate treatment methods

0	None	0 %
1	very low	0 – 20 %
2	Low	20 – 40 %
3	Medium	40 – 60 %
4	High	60 – 80 %
5	very high	80 – 100 %

Pre-selection of potential leachate treatment technologies

The approximate achievable effluent is compared to the required effluent standards. For each technology a verification is made if the effluent standard can be achieved or not, then receiving a YES or NO, respectively. According to the number of YES and NO received (as described in Box 8.2) a first selection of potential leachate technologies is made (see Appendix 6)

This matrix analysis resulted in 12 potential technologies, see Table 8.16, which needs to be applied combined in pairs (see Appendix 6).

Table 8.16 Pre-selected treatment technologies

1. Reverse osmosis	7. Conventional activated sludge
2. Coagulation/precipitation/sedimentation	8. Land treatment (slow rate)
3. Ion exchange	9. Activated sludge with extended aeration
4. Waste stabilization ponds	10. Membrane Bioreactor (MBR)
5. Constructed wetlands	11. Sequencing batch reactor (SBR)
6. Aerated Ponds	12. Anaerobic treatment process

Selection of technology by multi-criteria analysis

The next stage in the Decision Support System is to apply a multi-criteria analysis on the pre-selected technologies, including the criteria: local conditions, process performance, environmental, social and economic aspects (see Box 8.2).

Each technology has a score for each criterion, and each criterion has a weight, in relation with its relevance, and where the total sum of all the weights is equal to 100; while the technologies receives a score from 1 (less favourable) to 10 (most favourable) for each criterion. Priorities differ in different contexts, hence specific consideration is taken for developing and developed countries, see Figure 8.25.

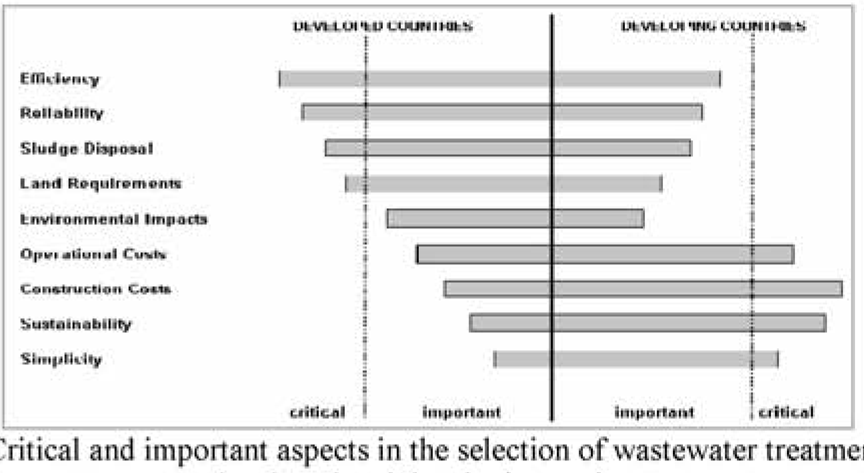


Figure 8.25 Critical and important aspects in the selection of wastewater treatment systems in developed and developing regions

Source: (Vargas, 2007)

To obtain the total score the following equation was used:

$S_j = \Sigma\, w_i * r_{ij}$

where: r_{ij} = score for alternative j in regard to criterion i
W_i = weight for criterion i
S_j = score for alternative j

The result of the evaluation, applying weights and calculating the scores, is displayed in Appendix 6 while the final scores are presented in the Figure 8.26. The result shows that in general the technologies employing natural treatment systems receive higher score, while more complicated or advanced systems get less, which are to be expected in a developing country context. Waste stabilization ponds and constructed wetlands are the technologies that receive highest score in the comparison.

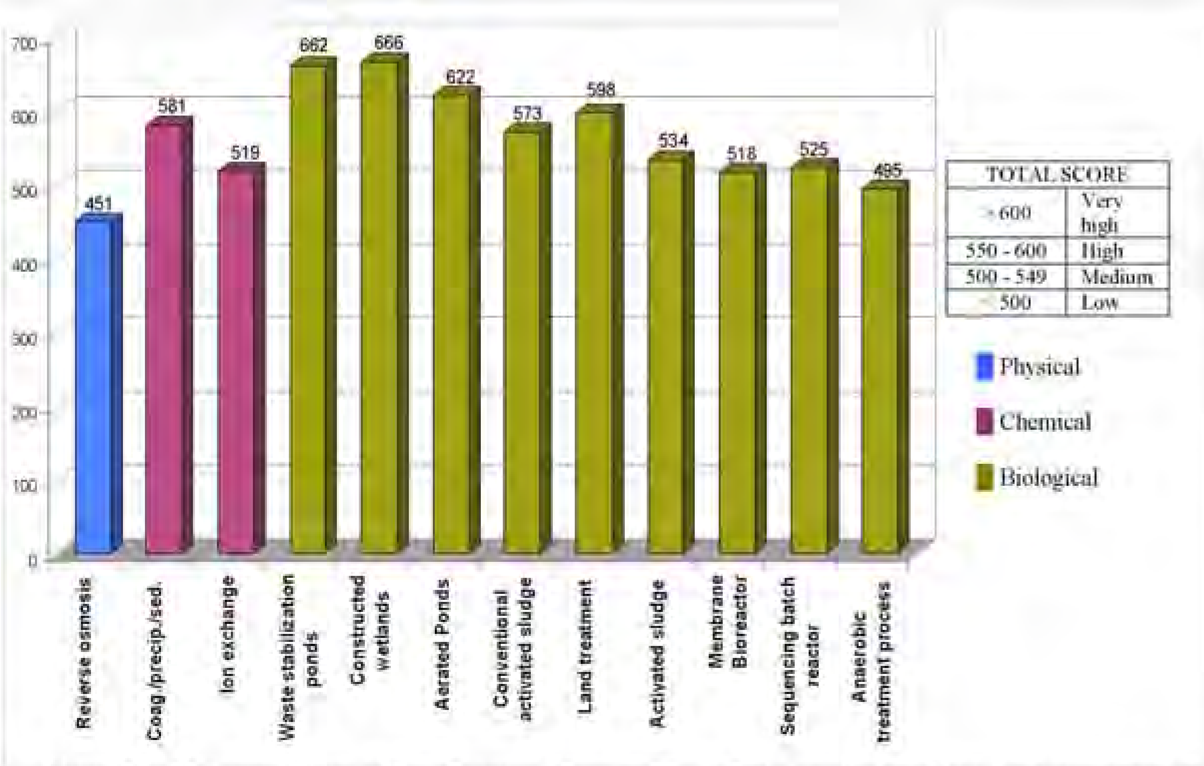


Figure 8.26 Comparison of total scores from multi-criteria analysis of leachate treatment technologies

With the aim to generate a better overview of the result from the multi-criteria analysis and to include the different combinations of treatment technologies a summary table was generated, which presents the sequence of solutions with their priority and total score sequence, see Appendix 6.

According to the objective of the SWITCH project technologies using natural treatment technology is desired. At the same time the biological treatment methods (constructed wetland, waste stabilization ponds and aerated ponds) received the highest score in the multi criteria analysis. Consequently, these technologies have been chosen as the SWITCH alternative. The treatment scheme that was selected includes: *anaerobic pond, aerated pond, constructed wetland and polishing pond*, as presented in Figure 8.27.

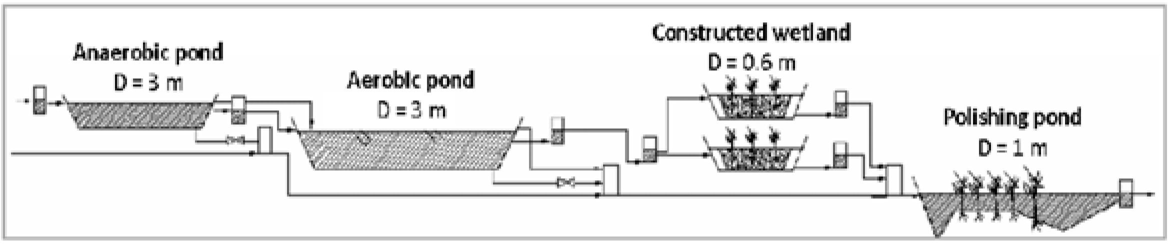


Figure 8.27 Leachate treatment scheme selected
Source: Adapted from Maehlum (1995)

Verification of the selection using existing experiences

The final stage in the decision support system consists of the comparison of the result from the multi-criteria analyses with existing experiences on leachate treatment systems. The purpose is to verify if there are any existing treatment systems with the same or similar configuration, which can prove that the selected treatment system has been tested and proved to be feasible and efficient.

The configuration selected is similar to a plant that has been implemented and operated in Norway during many years, which has shown very significant removal efficiencies; COD 97%, BOD 91%, TOC 71%, N-tot 83%, P-tot 88%, Fe 88%, and E.coli 95% (Vargas, 2007). Additionally, there are several local experiences in the Valle de Cauca Department with good result using natural methods for the treatment of wastewater, which shows that the technology is accepted and has a good potential for leachate treatment in the context of Cali (Corrales *et al.*, 2000).

8.5.2 Conventional solution

8.5.2.1 Description

A proposal for the leachate management is currently being under consideration by the regional environmental authorities, CVC. The proposal was elaborated by the consultancy firm Hidrosuelos, which was contracted by former municipal waste company, EMSIRVA, which is under liquidation. The SWITCH Project has been able to take part of an overview of the proposal, however exact details of their proposal was not available at the moment of generating the present study. Consequently, the characteristics of wastewater quality and flows have not been adjusted according to new findings; moreover, the technology choice has been used for the conventional alternative in this comparison study, while exact design parameters have been adapted to international experiences. The main technology selected by the consultant is *Reverse Osmosis - RO*, however the pre-treatment option was not clearly specified or was considered unnecessary.

In the case of Navarro landfill it is considered important to implement an efficient pre-treatment prior to the reverse osmosis stage, as the water will have variation in its composition depending on the source (storage ponds, new or old landfill leachate, contaminated superficial water bodies or groundwater) and its quality not can be assured. Moreover, a majority of the reviewed worldwide experiences of reverse osmosis have some form of pre-treatment (Renou *et al.*, 2008; Vargas, 2007).

The first technology option -or pre-treatment in this case- for the conventional alternative is *Conventional Activated Sludge - CAS*, which was selected based on the same decision support system used for the natural treatment system, where this system received the highest score among the conventional systems in the multi-criteria analysis. Furthermore, this is also the technology considered for the secondary treatment in the WWTP-Cañaveralejo, which makes it an alternative with acceptance among both politicians and technicians in the municipality. The second technology option, which will be combined with the CAS, is *Reversed Osmosis - RO*, since it is the main option under consideration by the authorities.

The average removal efficiency for the CAS/RO technology option is presented in Table 8.17, which is based on international experiences (Renou *et al.*, 2008; Vargas, 2007). However, COD and metal removal efficiencies above 98-99% have been reported from some plants using RO (Renou *et al.*, 2008).

Table 8.17 Estimated removal efficiencies of selected conventional alternative

TREATMENT SYSTEM	COD (%)	BOD (%)	TSS (%)	Ammonia (%)	Metals (%)
Conventional Activated Sludge + Reversed Osmosis	95	94	98	85	70

8.5.2.2 Initial investment costs

For the estimation of costs for the conventional activated sludge and reversed osmosis treatment systems data mainly from US-EPA (1995) have been used; however, it is important to state that a pre-design of the conventional alternative not has been performed. Consequently, only the specific leachate flow (3 L/s) has been used to set the plant size and establish the approximate cost implications, based on international experiences. The estimated removal efficiency and cost estimations are presented in Table 8.18

Table 8.18 Estimated initial cost for the conventional treatment system

TREATMENT SYSTEM	INITIAL INVESTMENT COSTS (Euro)
Conventional Activated Sludge	€518.400
Reverse Osmosis	€84.915
TOTAL	€603.300

8.5.2.3 Operation & maintenance costs

The operation and maintenance costs have been calculated in the same manner as the initial cost, using international guidelines and experience (see Table 8.19), resulting in an annual O&M cost of € 104.265 Euro.

Table 8.19 Estimated annual operation and maintenance cost for the conventional treatment system

TREATMENT SYSTEM	OPERATION AND MAINTENANCE COSTS (Euro/year)
Conventional Activated Sludge	€38.880
Reverse Osmosis	€65.385
TOTAL	€ 104.265

8.5.3 Solution with SWITCH approach

8.5.3.1 Description

The result of the pre-design of the selected treatment system, including anaerobic pond, secondary facultative pond, constructed wetland and polishing pond is presented in Table 8.20. The pre-design and calculations of the natural treatment systems were made using methodologies presented by (EPA, 2000; Kadlec *et al.*, 1996; Madera *et al.*, 2003b; Peña, 2002).

Table 8.20 Design parameters of natural treatment system for leachate

TREATMENT TECHNOLOGIES	Flow (Q) (L/s)	HRT (days)	Area (ha)	Depth (m)	Length (m)	Width (m)
Anaerobic pond	3	15,4	0,13	3	60	22,2
Aerated pond		12	0,10	3	56	19
Constructed wetland		1,1	0,12	1	40	31
Polishing pond		6,0	0,15	1	45	16,8
	TOTAL:	*34,5*	*0,5*			

A principal design criterion has been to achieve the quality objective set by the environmental metropolitan authority, DAGMA, for the South Channel with a BOD ≤15 mg/L and TSS ≤25 mg/L (Resolution 376 of 11th December 2006). The conventional anaerobic pond was designed using a volumetric BOD loading rate of <350 g/m^3/d, while the aerated pond was dimensioned with a retention time of 12 days. To permit a safe deposition or reuse of the effluent regarding pathogenic organism, the polishing pond was designed to reach levels recommended by the World Health Organization for unrestricted irrigation, regarding the removal of *Escherichia coli.*

The removal efficiency of the leachate treatment system is presented in Table 8.21. The parameters presented have been calculated using the methodologies mentioned earlier, except the removal efficiencies of COD and Metals, which have been adopted partly from literature and also previous studies conducted in the Navarro Landfill (Valencia, 2005; Vargas, 2007).

Table 8.21 Estimated removal efficiencies of selected natural treatment system

Treatment system	COD (%)	BOD (%)	TSS (%)	Ammonia (%)	Metals (%)	E. Coli (%)
Anaerobic pond + Aerated pond + CW + Polishing pond	90	99,7	98,6	61	65	99,99

8.5.3.2 Initial investment costs

For the estimation of construction cost for the natural treatment system, the following main items have been considered: land acquisition, excavation, impermeabilization, filter material, aerators, pipe systems and pump stations, taking into account costs for installation and movement of material. The purpose of this exercise is to give a general idea of the cost implications to build the plant and to be able to make a fair comparison with the conventional alternative, see Table 8.22. The cost calculations are based on real project experiences in Colombia (Cinara *et al.*, 2008a). The initial investment cost for the solution with SWITCH approach is € 186.483 Euros.

Table 8.22 Estimated initial cost for the natural treatment system

TREATMENT SYSTEM	INITIAL INVESTMENT COSTS (Euro)
Anaerobic pond	€ 16.486
Aerated pond	€ 59.279
Constructed wetland	€ 60.411
Polishing pond	€ 24.775
Pipes, pumps and other equipment	€ 25.532
TOTAL	€186.483

8.5.3.3 Operation & maintenance costs

The operation and maintenance costs have been estimated taking into account the (WHO, 2006), recommendation, which consider the annual O&M costs as 5% of the total construction costs; in addition the energy cost for the aerators of the aerated pond system has been added (see Table 8.23). The estimated costs for the O&M are €30.695 Euros.

Table 8.23 Estimated annual operation and maintenance cost for the natural treatment system

COST ITEM	OPERATION AND MAINTENANCE COSTS (Euro/year)
General O&M (5% of construction cost)	€ 9.324
Energy cost for aeration	€ 21.371
TOTAL	€ 30.695

8.5.4 Comparison of solutions

8.5.4.1 NPV analysis

In the following item a comparative analysis is presented between the proposed SWITCH and the Conventional Alternative. The first part compares the qualitative and quantitative benefits of the two alternatives and the second part is a cost analysis comparing the alternatives regarding net present value in a 30-year period.

<u>Environmental and socio-economic benefits</u>

Taking advantage of the multi-criteria analysis made in the pre-selection phase, the results regarding technical, socio-economic and environmental aspects are compared, see Table 8.24. These results clearly show that leachate treatment with natural systems has high potentials, for the local conditions prevailing in Cali. The scores presented in the table are average values of the analysis of each technology forming part of each alternative.

Table 8.24 Comparison of scoring result from the multi-criteria analyses of the alternative with a SWITCH and conventional approach, respectively

LEACHATE TREATMENT METHODS	LOCAL CONDITIONS Climate, hydrology, land requirement (weight 16)	PROCESSES Process application, Simplicity, reliability, residuals (weight 29)	ENVIRONMENT & SOCIAL Soil, air and water contamination, odour/noise, social accept. (weight 35)	ECONOMICS Const. cost, O&M, sust. (weight 20)	Total points (classification)
<u>SWITCH Alt:</u> Anaerobic pond + Aerated pond + CW + Polishing pond	97	203	210	140	650 (very high)
<u>Conventional Alt:</u> Conventional Activated Sludge + Reversed Osmosis	86	152	161	114	512 (medium)

When studying the estimated removal efficiencies it was found that the two compared alternatives will generate similar results, see Figure 8.28. In the case of ammonia the conventional alternative is expected to achieve superior removal efficiency than the SWITCH alternative. If a higher removal efficiency of ammonia is desired it is possible to consider aeration of the constructed wetland stage, which has proven to be efficient to enhance the removal (Jamieson *et al.*, 2003).

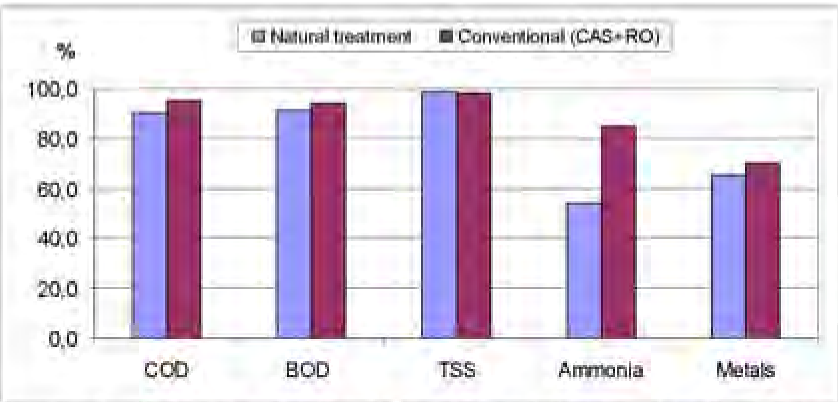


Figure 8.28 Removal efficiencies for the SWITCH and Conventional treatment alternatives

Regarding the identification of benefits, the ones considered equal or shared between the two options have not been included in the analysis. For example, as the estimated removal efficiencies of the two solutions are very similar, the benefits regarding contaminant removal or reduction of discharge have not been included. Although, in this case study removal of contaminants is the most important benefit of a treatment plant, this parameter has not been included. The identified benefits for the comparison of leachate treatment alternatives are presented below:

A pre-evaluation was made to determine the added value of performing a cost-benefit analysis. In this analysis the method for cost estimation was considered, see Table 8.25, where it was determined that four out of six parameters, can roughly be included in the O&M. The potential of carbon credits due to avoided greenhouse gas emission (GGE) was calculated, giving a yearly credit of €215 in favour of the SWITCH alternative, which only represents 1% of the annual O&M cost. Since the majority of the benefits are represented in the O&M and the benefit that is not included (GGE) generate a very moderate value; it is not considered feasible to do a cost-benefit analysis as the added benefits are negligible, consequently only a cost analyses is made for the comparison of the two alternatives.

Table 8.25 Benefits with corresponding methods for cost estimation.

TYPE OF BENEFIT	BENEFIT	COST ESTIMATION
Environmental	Reduced consumption of chemicals	Included in O&M
	Reduced greenhouse gas emissions from air compressors	Calculation of carbon credits
	Reduced production of toxic sludge	Included in O&M
	Generation of new green areas/ecosystems	Not calculated
Economic	Reduced treatment cost	Included in O&M
	Reduced cost for sludge management	Included in O&M

As the benefit for the generation of new green area/ecosystem not will be included in the cost analyses, it is worth mention that the solution with SWITCH approach has potentials in this sense, as the option includes the construction of ponds and wetlands, instead of concrete constructions as the conventional solution. Hence, new green areas and ecosystems will be implemented that will enhance the environmental conditions in the area. The production of toxic sludge is another issue that is worth analyse further, according to (Renou *et al.*, 2008) the high sludge production is one of the major drawbacks for reverse osmosis.

Additionally, two other strategies should be taken into consideration to mitigate negative impacts of the leachate management. The first is the possibility to use the biogas generated in the landfill to run motors for energy generation, to avoid additional electricity consumption. Moreover, a possible reuse of treated leachate in controlled and monitored irrigation should also be considered, since it reduces discharges to water bodies; for example the adjacent sugar cane cultivation has a potential for this reuse in irrigation.

Cost analyses

Based on the benefits identified in the previous section the costs were analyzed. The pure economic costs representing the use of land, manpower initial investment were taken into consideration. Furthermore the Net Present Value (NPV) was calculated to estimate the operation and maintenance costs for a period of 30 years. The total costs divided in initial investment and O&M are presented in Figure 8.29.

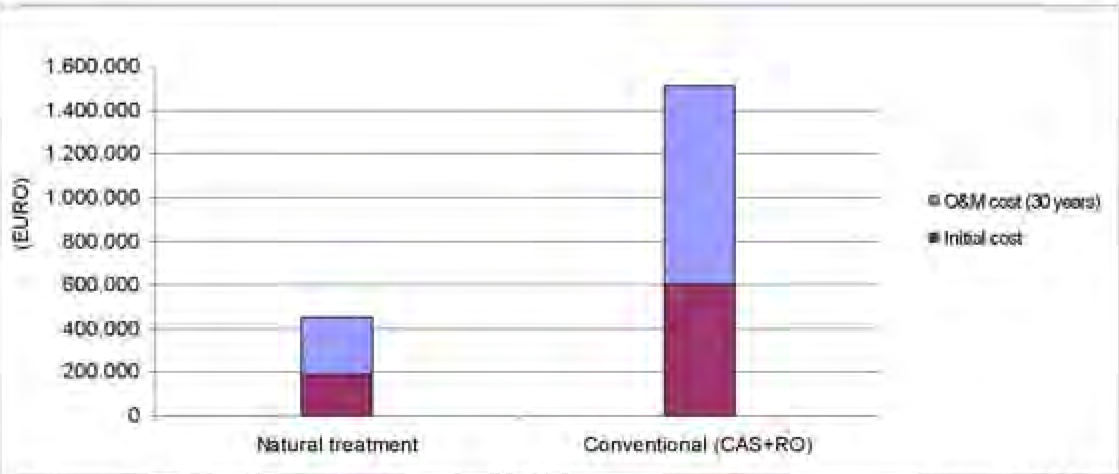


Figure 8.29 Total costs including initial investment and net present value of O&M

The result of the cost comparison shows that the initial cost and the NPV value of O&M-cost are significantly lower for the option with a SWITCH approach than the conventional one. Additionally, including the economic discount for benefits in the case of the SWITCH option the advantage is further enhanced. If the total costs over the 30 years are compared, including O&M it gives a total of *€454.545* for the SWITCH option compared to *€1.513.877* for the Conventional option.

8.5.4.2 Other considerations

It is important to state that only a handful of contamination parameters have been considered in this pre-study analysis, while in fact the leachate is a very complex waste that changes its characteristics (quantity and quality) over time. Investigations made on leachate have detected

more than hundreds of different hazardous substances, including organic and metal-organic compounds, which should be considered in future landfill risk assessments and in the development of leachate treatment methods (Öman *et al.*, 2007). In this sense, recent investigations on constructed wetlands have shown very promising results of potential heavy metal remediation through their plants, of which some are native species in Colombia (Hernández-Allica *et al.*, 2008).

As treatment with natural methods is a very attractive alternative, taken into consideration both technical and socio-economic aspects as shown in the present study, a possible strategy could be to develop the leachate treatment project in phases. The first phase would include the construction of a treatment plant applying natural methods according to the proposal with a SWITCH approach. When this natural leachate treatment plant is in operation a full performance evaluation would be conducted to verify the removal efficiency. If the removal efficiency of contaminants (including complex ones) not is adequate, a physical treatment step would be implemented, e.g. reverse osmosis. In this way, the decision about investment in advanced treatment is made based on the actual needs, and in this case the natural treatment will function as a thorough pre-treatment that will facilitate the function and maintenance of the membrane technology. Furthermore, the combination with natural treatment methods will help to keep cost down and ensure that the system is more resilient to operation failures.

8.6 CASE STUDY 4 – STRATEGIES IN RURAL AREA

8.6.1 Description of study area

The area under consideration in this section is the rural area of the Cañaveralejo river water basin with dispersed population or just small nucleated settlements, where agricultural or forestry activities can be found both on a household and larger production scale. In accordance with this, the peri-urban area (la Sirena and el Mango) that formally belongs to the rural districts according to the Territorial Ordinance Plan (POT) of Cali Municipality, is not included here, this topic will be treating in chapter 8.8.

The rural area of the Cañaveralejo river basin covers a small part of the rural districts of Los Andes, Villacarmelo and La Buitrera. The rural area has an altitude span from about 1.000 until 1.800 meters above sea level. The highest part of the basin is included in a corridor of forest reserve; still this area and the surrounding areas are only partly covered with forests as the area is severely affected by deforestation. The rural area is intervened by cattle grazing, small scale cultivation, and some forestry activities. The majority of the farms are using conventional agricultural methods, which include the use of chemical fertilizers and pesticides (CVC, 2010b)

Furthermore, there are still some coal mining activities in a limited sector of the basin. The carbon sources left in the area are scarce and of low quality, hence the mines are small scale and ran in a rudimentary manner without any legal permits (SSPM, 2010). (see Figure 8.30 and Figure 8.31). However, there are many out-phased mines that have been exploited but left unsealed and with significant remaining impacts on the environment, including degraded soils with erosion problems and leachate production from disposed material. The old mining shafts also pose a risk for land collapses and slides. Apart from dissolved solids, the contaminants generated in the carbon mining are characterized by high acidity, sulphates and metals such as iron, manganese and aluminum.

Figure 8.30 Coal mining activity in the La Bandera Hill
Source: (Martinez, 2007)

Figure 8.31 Mining intervention in the stream of "Quebrada Jinetes"
Source: (MANOV *et al.*, 2007).

The area has dispersed settlements and some few nucleated settlements. Based on population density maps (DAPM, 2000), it can be estimated that the rural area under consideration here, which covers an area of approximately 1.700 ha, has about 1.100 households. According to officials from the authorities working in the area (CVC, 2010c,d,e; SSPM, 2010) the households in the area have individual or community based water supply systems, while the management of wastewater is mainly handled on an individual level, an exception is the settlement "Altos de los mangos" which has a community based sewerage and newly built wastewater treatment plant.

There are three principal ways to manage the water supply in the rural area, where the predominant is through community based systems, followed by individual supply using springs and streams, while superficial wells and rainwater harvesting are more uncommon sources (Table 8.26). The most common water use is for domestic purposes (95,6%), while agricultural and animal raising activities just covers a few percent of the use (3,9%); however, this data considers the number of users and not the actual volume of water consumed in each activity. The quality of these services, regarding availability of water, shows that there is a significant vulnerable group who lacks permanent water supply (35,3%).

Table 8.26 Water supply, uses and availability in the rural districts of Cañaveralejo river basin

DESCRIPTION	LOS ANDES (%)	VILLACARMELO (%)	LA BUITRERA (%)	AVERAGE (%)
Water supply				
Community based	38,3	67,5	85,2	63,6
Superficial well	0,6	0	0,5	0,4
Spring	40,1	30,9	13,0	28,0
Stream	20,5	1,1	1,2	7,6
Rainwater	0,6	0,5	0,2	0,4
Water uses				
Domestic	-	93,3	98,1	95,6
Agricultural	-	4,8	1,0	2,9
Animal raising	-	1,4	0,5	1,0
Recreational	-	0,5	0,2	0,4
Industrial	-	0	0,2	0,1
Water availability				
Permanent	-	84,3	45,2	64,7
Limited	-	13,8	24,3	19,1
Periodically	-	0,5	12,2	6,4
Sporadically	-	1,4	18,3	9,8

Adapted from (UMATA, 2005)

There is no specific information available on the sanitation coverage in the area delimited by the water basin, however, (UMATA, 2005) has made an inventory of the three rural districts where the basin is incrusted, see Table 8.27. According to these figures an average has been calculated for the entire area (including Los Andes, Villacarmelo and La Buitrera) for the different sanitation solutions with the following result: 79,9% infiltration pit, 14,3% community sewerage, 0,4% biodigester, 0,8% grease trap, 1,5% discharging directly to water bodies, and 3% discharging directly to open-air without prior treatment.

Table 8.27 Sanitation solutions in the rural districts

SANITATION SOLUTION	LOS ANDES (%)	VILLACARMELO (%)	LA BUITRERA (%)	AVERAGE (%)
Infiltration pit	77,3	79,7	82,8	79,9
Sewerage	21,0	11,7	10,2	14,3
Biodigester	-	-	1,3	0,4
Grease trap	-	-	2,3	0,8
Discharge directly to water body	1,5	1,2	1,8	1,5
Discharge to open-air	0,2	7,2	1,6	3,0

Adapted from (UMATA, 2005)

Regarding the management of solid waste, about 80 to 93% of the rural population has access to collection service, according to the information obtained in an inventory of the rural districts Villacarmelo and Buitrera (UMATA, 2005). Other common ways of handling solid waste in the rural households in the area are through incineration, composting and burying; but unfortunately it is also common to deposit the waste in the nature without any precautions.

Regarding to problems of the Cañaveralejo river basin, the river system is severely affected by contamination as it enters the urban area. Another major issue is the high water peaks occurring during rain events and particularly low flows in the dry period. In the following section these main problems will be discussed briefly.

The majority of the households in the rural area have individual water based sanitation solutions, employing infiltration pits. However, these systems do not offer an actual treatment of the wastewater; consequently the wastewater drains to the subsoil and contributes to the contamination of groundwater and surface water. Additionally, it can be estimated that about 5% of the households discharge their wastewater directly to the soil or to water bodies without prior treatment.

Other sources for contamination are the animal breeding activities and the use of chemical fertilizers and pesticides in the agriculture, which contribute both to point and non-point pollution. For example, the conventional cultivations of tomatoes that can be found in the area require the application of high doses of agro-chemicals (CVC, 2010d).

Furthermore, the deforestation, cattle grazing and mining activities in the area are the main causes to severe erosion, which increase the level of suspended solids in the river.

The deficiency of solid waste service and the lack of environmental consciousness among the rural population generate an inadequate waste management, which is another factor deteriorating the quality and the aesthetics of the water resource.

Regarding the issue of high and low water peaks in the river system (generating flooding and water scarcity, respectively) this can partly be explained on a natural cause as the upper-middle water basin has a quick hydrological response, due to high slopes in a limited area,

which is reflected in the moderate to high potential torrential (CVC, 2001; HIDROINGENIERIA LTDA *et al.*, 2000; Mayorquin *et al.*, 1997).

However, the high degree of deforestation and lack of buffer zones along the river system implies that these high and low peaks are significantly enhanced.

8.6.2 Strategic lines

Considering the key problems mentioned above, the following conceptual strategies or alternatives have been proposed for the rural area in the Cañaveralejo river basin, divided in three main themes: water and sanitation, agriculture and forestry, and mining. As the purpose is to present feasible options with high potentials for the recuperation of the water basin, alternatives based on strategies proposed by the authorities are also included, which is clearly indicated in the text.

Water and sanitation

It is considered indispensable to set the overall goals for the strategies to be developed for each theme, in a way to coordinate and reinforce the actions to be implemented. For the water and sanitation component in the rural area the following principal objectives are proposed in the SWITCH context.

Goals for rural water and sanitation

- Guarantee ecological flow levels in the river system.
- Optimization of water use, including reduced potable water consumption among others.
- 100% sanitation coverage: access to adequate wastewater and human exereta management.
- Potentialize the reuse of treated wastewater and human exereta

In Table 8.28 the main strategies for rural water and sanitation developed by the authorities working in the area, including strategies that are implemented, under implementation or projected, are briefly presented.

Table 8.28 Rural water and sanitation strategies -implemented, under implementation and projected- by the authorities

CVC *regional environment authority*	▪ The CVC, is responsible for the permission process of water and sanitation in the rural area, and employ the following procedures (CVC, personal comunication 2010): ▪ The ones who are to use the water from the Cañaveralejo river or from its tributaries needs to obtain a concession from the CVC, which are assigned considering the flow patterns in the dry season. ▪ Likewise, for the construction of new houses the CVC requests a technical report with design of system for wastewater, which should include a study of topography and perculation capacity. The systems implemented in the Cañaveralejo river basin are conventional, including septic tanks, anaerobic filtres and with disposal in a infiltration system, or in some specific cases through a storage tank with cloration for reuse. The CVC conducts a visit to verify the conditions for the generation of permission, gives education on O&M during construction, and when the in operation performs regular visits to control the function.
SSPM *municipal public health secretariat*	▪ The SSPM has programs to provide water and sanitation services, as a way to protect the public health. ▪ Regarding water supply they technically and financially supports the construction of community based systems, that later are operated by the community. The rural area of the river basin has various examples of community based water supply systems implemented by SSPM. ▪ In the case of wastewater, SSPM, supports both community based systems in nucleated settlements and individual on-site systems in dispersed settlements. In the Cañaveralejo river basin, they have only been involved in community based systems, for example in the "Luisa" and "Alto de los mangos" settlements where system with septic tanks, anaerobic filters and subsuperficial wetlands were implemented. However, SSPM is planning to support the implementation of individual systems in the future.

Source: (CVC, 2010d,e; SSPM, 2010; Vargas, 2007)

It is considered that the strategies elaborated by the authorities partly will contribute to mitigate negative impacts generated in the rural water and sanitation sector. However, to optimize the efforts and to ensure the long-term sustainability of the implemented activities it is considered necessary to develop the following proposed strategic lines with a SWITCH approach:

Water balance of river system

Carry out a study of the water balance and the capacity of supply and demand in the water basin. According to Vargas (CVC, 2010c,d,e) there is a deficiency in the information on the superficial sources in the basin related to the process of evaluating new water concessions.

Water and sanitation diagnosis

Conduct a detailed inventory of the water and sanitation situation in the rural area of the Cañaveralejo river basin, to establish the magnitude of negative impacts and the needs associated to improved services. Although there are data about the water and sanitation services for rural districts developed by the municipal authorities (UMATA, 2005), this information is not specific to the Cañaveralejo river basin.

Alternative water and sanitation solutions

Promote water and sanitation alternatives that contribute to an improved sustainability. Regarding the sources for water use; the potential to use rainwater harvesting and groundwater as an alternative supply source should be analysed. In the case of management of wastewater and human excreta, alternative technologies such as natural treatment (e.g. constructed wetlands) and dry sanitation systems that permits reuse of treated subproducts should be included in the technology selection process. In this sense, it is important to promote reuse of wastewater and treated excreta in agricultural or reforestation activities.

Program for increased coverage

Perform campaigns to increase the coverage of adequate water and sanitation services. It is considered indispensable with a close collaboration between CVC and SSPM to confront the challenge.

Agriculture and forestry

The following objectives have been proposed for the agriculture and forestry theme.

Goals for agriculture and forestry

- Increase of forest protection strips along the water bodies, a minimum of 30 metres as stipulated in the municipal Territorial Ordinance Plan (POT).
- Reduction and control of erosion and land use degradation.
- Reduction of agro-chemical use.
- *Guarantee ecological flow levels in the river system*
- *Optimization of water use, including reduced potable water consumption among others.*
- *100% sanitation coverage; access to adequate wastewater and human excreta management*
- *Reuse of treated wastewater and human excreta*

In Table 8.29 a brief presentation of the main strategies for agriculture and forestry developed by of the authorities working in the area, including strategies that are implemented, under implementation or projected.

Table 8.29 Agricultural and forestry strategies -implemented, under implementation and projected- by the authorities

AUTHORITY	STRATEGIES
CVC *regional environment authority*	▪ The activities of CVC can be catagorized in three main strategic lines for the agriculture and forestry sector: ▪ *Forestry repopulation project*: Is a project where landowners who are interested in the implementation of a reforestation or recuperation program of the forest protection strips within their territory. The CVC gives the technical assistance, the trees and their transport, the fertilizers, the enclosure, and furthermore the pay the landowners for this activity, and every third months the landowner receives a subsidy for the maintenance of the forest cultivation during the first three years. In the area within the 30 metres protection zone along the river, protective species are planted, in the area outside the buffer zone protective/productive species like bamboo are planted, and thereafter productive species like eucalyptus, pines, and cypress. The purpose with this strategy is that the productive species can generate income for landowners in the future. It is important to mention that the budget for the implementation of this strategy is limited. ▪ *Green market project:* Small agricultural units interested in organic farming, can receive support from CVC, as they do not use chemical products. The cultivations include lettuce, papaya, among other. The organic produce is distributed to supermarkets in the city and according to the CVC their support to the project is complete. ▪ *Conservation and restauration projects:* Additionally, the CVC is participating in different conservation projects and formulation of management plans for strategic ecosystems, water springs, ecological buffer zones. One of the programs is the environmental recuperation and restauration of the "La Bandera" hill.
Municipal government	▪ The Municipal Unit for Technical Agricultural Assistance - UMATA and the Municipal rural development council are participating in a agro-ecoturistic program lead by the Andeen Environmental Cooperative -Ecooambiental- directed to 600 environmental service providers and community leaders in 12 of the rural communities in the municipality of Cali, including Los Andes, La Buitrera and Villa carmelo. The aim of their participation is to strengthen the environmental and land-use friendly practices in the rural area.

Source: (CVC, 2010c)

The authorities associated with the agriculture and forestry sector are implementing strategies with high potentials to improve the basin management and the sustainability of the activities developed in the Cañaveralejo river basin, although the scale of the implementation of these strategies is still limited. Consequently, with the strategies developed by the authorities as a base the following strategic lines are proposed:

Reforestation campaign program

Applying the approach of the CVC "Forestry repopulation project" described in Table 8.29, increasing the outreach activities, to reach new land owners. Important to seek for new financial opportunities, such as the new national planning policy CONPES 3624, which aims for the recuperation of the Cauca River with funds destined for reforestation.

Promotion of organic agriculture

Develop and promote the effort of green market developed by CVC. Find ways to generate new markets, including the international, to increase the demand. Encounter economic incentives or mechanism for the transfer from conventional to organic agriculture.

River basin conservation projects

Take advantage of new alliances with institutions working for the improvement of the river basin to formulate broad and long-term conservation project proposals.

Mining

The following objectives have been proposed for the improvement of the mining sector.

Goals for mining sector

- Only mining activities that have environmental permits in operation
- All sub products generated in the mining activities must be managed to minimize environmental impacts.
- Closed mines must be adequately sealed and the area revegetated.

In Table 8.30 a brief presentation of the main strategies for the mining sector developed by the authorities working in the area, including strategies that are implemented, under implementation or projected.

Table 8.30 Mining sector strategies -implemented, under implementation and projected- by the authorities

AUTHORITY	STRATEGIES
CVC *regional-environment authority* / INGEOMINAS	CVC is the authority who has the responsibility regarding the environmental component in the concession process for new mining prospects. However, according to representatives of CVC, it is not common practice that they participate in the process and conduct the corresponding environmental evaluations. Together with INGEOMINAS, which is the authority responsibility for the generation of permissions for mining activities, CVC conducted a campaign to close illegal and abandoned mines in the area around the La Bandera hill. 104 mines were closed and sealed; however, simultaneously about 30 new illegal mines were taking into operation.

Source: (CVC, 2010d)

The authorities with jurisdiction over the mining activities have implemented some punctual actions to mitigate the problems related to the mining. However these actions have not showed a significant result; wherefore the following strategies are proposed to increase the potential for success of future actions:

Include environmental evaluation in all mining activities

It should be standard and an obligation for the environmental authorities to be involved in all new mining project application and a basic requirement to always conduct an environmental evaluation.

Mining closure program integrated in protection plans

To strengthen the control of the closure and sealing actions, these actions should if possible be integrated in environmental protection and conservations plans, which should ensure that management and control plans are developed for the area, the access to the area is limited and preferably supervised.

Social programs to create new income generating activities

In general, for the families involved in the mining activities, there are no alternative activities available for the generation of income. Consequently, new alternative employments and income generating activities should be promoted.

Strengthen the environmental protection spirit of communities

In addition to the above mentioned strategies, environmental capacity building should be given to the communities to create an appropriation of the nature resources, which will increase the respect and motivation to protect the ecological values around the communities.

8.7 CASE STUDY 5 – STRATEGIES FOR INCOMPLETE DEVELOPMENT SETTLEMENTS

8.7.1 Description of study area

Sub-normal assets are those settlements that do not have a complete development (as defined by Decree 0419 dated May 24, 1999 from the Municipality of Cali). These settlements are a result of Cali's demographic growth, and the different migration trends caused by the caused by the unbalanced and improvised occupation of the municipality's "free" terrains (DAPM, 2000). These settlements are mainly characterized as a cluster of human beings under diverse circumstances, who have to solve their habitat in a rapid manner, without measuring the risks that may threat their own survival, in conditions under the poverty line. Catalogued as illegal settlements, they lack the proper water and basic sanitation services, which they usually obtain in a fraudulent way (EMCALI, 2007).

Migration towards Cali started in the decade of the 40's (Secretaria de Vivienda Social *et al.*, 2010). However, an accelerated growth occurs in the 60's, caused by massive displacement of people towards the large cities, as a product of the violence and insecure conditions in the rural areas. Back then, settlements originated in invasions and pirate urban developments started and began to grow, due to a deficit in housing for the poor population (CVC, 2008). In Cali, the displaced population went to the foothill areas, where it is difficult to implement the public services infrastructure (EMCALI *et al.*, 1996). The main areas occupied were Siloé, Terrón Colorado, Lleras Camargo, etc.; on the other hand, settlers also went to low and floodable land, such as Cristóbal Colón, Villanueva, Villacolombia, La Isla, among others. With the desiccation of land in the eastern side of the city, the settlements growth was promoted (CVC, 2008). The city of Cali, due to its strategic position in Colombia's south-western Pacific area, is an attractive city that welcomes all, having many economic perspectives. For this reason, many neighborhoods have been created in invasion processes of river protected areas, green areas, or government terrains (Secretaria de Vivienda Social *et al.*, 2010).

Colombia is one of the most affected countries regarding poverty problems. According to a recent Poverty Mission, 49,2% of its population is poor and 14,7% live in misery conditions. In general, the homeless inhabitants of these incomplete development settlements have low economic resources, as well as a low education level, demonstrating a high incidence of unsatisfied basic needs (Secretaria de Vivienda Social *et al.*, 2010).

The negative environmental impact of Cali's urban development is constantly increasing common, due to the drastic change of land use caused by the lack of knowledge of their natural characteristics. Currently, the foothills of Cali have settlements which include urban districts 1, 2, 3, 18, 19 and 20. Additionally, the crest of the Cauca River's flood protection walls shows a consolidated strip of subnormal settlements, affecting the safety of the entire population. The western and north-eastern limits of the city have become spontaneous settlers, bringing problems related to their location (CVC, 2008).

Considering the magnitude of this problem, the Municipal Planning Department in 1987 established the existence of 67.051 inhabitants and 12.448 households in invasions and sub-normal settlements located in the foothills of Cali. According to a study made in 2010 by the Social Housing Secretariat – Special Housing Fund and the government of the city of Cali, there are 14.024 households in incomplete development settlements, out of which 919 are in rural areas and 13.105 are in urban areas.

The Figure 8.32 shows the distribution of housing settlements located in the municipality of Cali, including urban districts (1 to 21) and rural area.

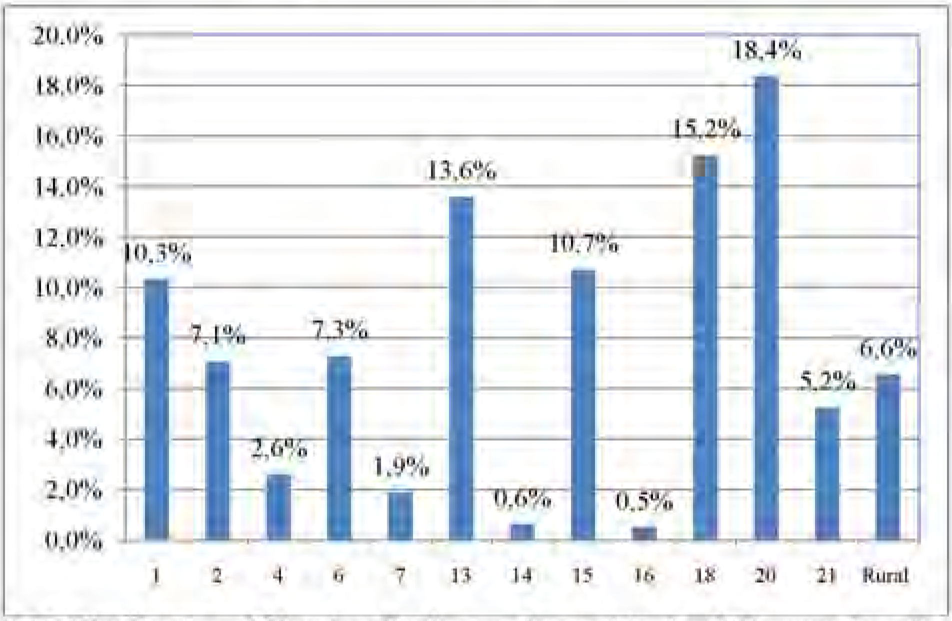


Figure 8.32 Distribution of Housing Settlement located in the different urban districts of Municipality of Cali

Source: (Secretaria de Vivienda Social *et al.*, 2010)

As a consequence of the increasing poverty conditions and the high demographic growth, the population looks for places to settle, where the lots, rentals and services have a low cost, without considering the topographic and bio-physical characteristics of the site. Some of these areas are located in natural reserves or river protection strips (Cali, Cañaveralejo, Aguacatal, Lili, Meléndez, Pance and the Cauca River), generating deforestation, destruction of native species, with the development of activities such as animal husbandry and small scale agriculture, which completely affect the areas and the land use. The settlements with incomplete development in the foothills are located in an area classified as vulnerable to any anthropical activity, a situation that is worsen because most of its households have been constructed without the required structures to avoid possible land slides, representing a risk for the settlers, which is caused by uncontrolled and unplanned development of the urban infrastructure, but also improper soil management during mining activities, a lack of

infrastructure to manage water runoff, and the loss of vegetation coverage, among others (CVC, 2008)

On the other hand, these settlements cause the contamination of water sources due to direct solid waste and wastewater disposal to water bodies and channels. The Sanitation and Waste Disposal Management Plan (PSMV) determined the Southern Canal as the most affected system since it receives 57% of the total direct waste disposals of the cities, with approximately 59 invasions, followed by the Oriental Canal, with 40% and 138 invasions, and the outstanding 3% in the North-western Canal, with 11 invasions (CVC, 2008).

In terms of territorial planning (DAPM, 2010), the municipality of Cali defined some deferred regime areas. Part of the Cañaveralejo River (upper and middle section) crosses one of these areas that surrounds part of the limits of urban districts 18, 19 and 20 (see Figure 8.33). The deferred regime areas initially were proposed as urban expansion areas. However, CVC, the corresponding environmental authority, did not approve to this use, only the Cali-Jamundi corridor was accepted as urban expansion area at this point. Basically, the areas were considered deferred regime and not urban expansion areas because they had information gaps. This denomination implies that such areas do not have a defined usage. However, and in accordance to the Municipal Planning Department (Geologist Andrés Prieto, personnal communication), these gaps have currently been overcome and therefore, the soil usage trend in this areas is rural, but the final soil use agreement has not been made.

The above mentioned problem has caused that part of the deferred regime area crossed by the Cañaveralejo River does not have regulations for new developments or for the legalization of the existing developments. Probably the lack of governance has promoted the creation of incomplete development settlements in the area, not allowing action due to the lack of regulations. Another factor, that restrings these developments in the area and their legalization process is the fact that it would promote population growth in the area of the Cañaveralejo River, generating an entrance vector towards the forest reserve and national park; a scenario that is not desired for the Municipality of Cali. This is a problem that not only involves the municipal planning department, but also the Ministry of Environment, Housing and Territorial Development (MAVDT). According to Plan for Territorial Ordinance (POT) 2000, rural lands are those that are not fit for urban use due to opportunity reasons or their use for agricultural, animal husbandry, forestry, natural resources exploitation and related activities. The decision to convert these areas into deferred regime implies the limitation of the consolidation possibilities of these informal settlements.

Particularly in the Cañaveralejo River Basin there are several settlements that do not have basic water and sanitation infrastructures; some located near La Sirena, in La Buitrera, called La Sirena- El Edén Upper Sector, La Sirena – El Edén Lower Sector, San Agustín, Los Arrayanes and Bella Suiza, among others.According to a report by the Secretariat of Social Housing of the government of the municipality of Cali, the Upper and Lower Sector of El Edén, Los Arrayanes and San Agustín have 33, 56, 119, and 131 households, respectivelyParadoxically, Los Arrayanes represents a high seismic risk because it is located in a geological fault that throughout the years has distributed, becoming more risky. In general, the Cañaveralejo River area of influence has a medium threat level (see Figure 8.33).

The public service infrastructure in the upper and middle part of the basin depends on sectors having their own water supply systems, such as La Sirena and La Luisa, and with respect to their sanitation, depend on organizations such as EMCALI, the Municipal Secretariat of

Public Health and DAGMA, who will jointly make an effort (economic support) to construct a collector in the zone in order to solve the problem of direct disposal of wastewater into the Cañaveralejo River. The mentioned collector will cross the rural zone, entering the urban perimeter to collect wastewater coming from La Sirena and El Mango sectors, to finalize in the Venezuela collector which is connected to the Cañaveralejo WWTP. The extension of the Venezuela Collector solves the problem of direct disposal of waste into the Cañaveralejo River of legal communities not having this treatment system. However, this collector does not cover settlements with incomplete development such as San Agustin and Los Arrayanes, which contaminate nearby creeks such as Gallinazal and San Agustín, which finally feed the Cañaveralejo River.

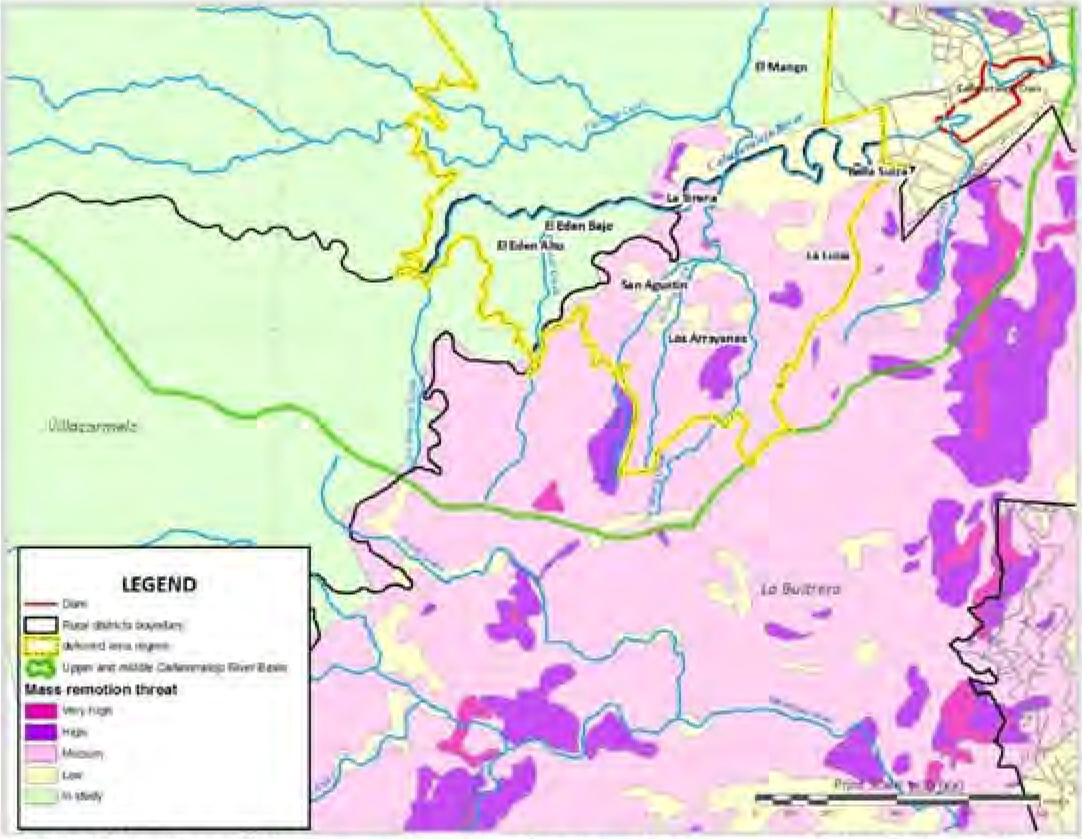


Figure 8.33 Location of the Incomplete Development Settlements of the Cañaveralejo River Basin

8.7.2 Strategic lines

Strategic lines to be prioritized have been proposed in order to solve problems generated by incomplete development settlements located in the Cañaveralejo River Basin. Considering the risks in the basin due to floods and that most of the area is at medium risk due to mass removal, but there are also some high risk areas for mass removal and therefore, it is of highest concern to relocate some settlements, trying to prioritize better and safer living standards for its inhabitants, as well as protecting the environment and avoiding settlements in natural parks or forest reserves.

In spite of the fact that there exist a clear need for settlement eviction and/or relocation municipal policies do not exist, this situation must become a priority. Following are the strategic guidelines developed, which will depend on the legalization of the settlements:

Land appropriation

The appropriation of land by the Municipality for the re-location of the inhabitants in settlements with incomplete development that due to their characteristics cannot be legalized. Of all the invaded land of the Cañaveralejo River Basin, only a few belongs to the municipality, while most of the terrains belong or have belonged to landlords that have abandoned them. As a result, most owners are not known due to the abandonment and the scarce law control over the land and its owners. Action in this respect is required, since in Colombia invading land is a crime since 1997.

Consolidation of settlements

Considering the trend of converting this area into rural land use, a strategy for these settlements would be to consolidate only the older areas that have an infrastructure that may be upgraded and/or used and if they can be connected to existing public services in nearby areas, without significant additional costs. It is also important to ensure the monitoring of these zones, controlling their population growth in order to avoid subsequent environmental impact. Settlers must have a sense of belonging and not allow new occupation of perimeter areas. Complete or concentrated occupancy cannot be promoted, but community parcels can be used in associative enterprises or cooperatives, to exploit the land guaranteeing rural usage, low occupation density and water supply and sanitation solutions with alternative technologies. However, these programs demand strong and broad institution+al support in order to obtain good results.

Re-composition of settlement

Identification of sites within the informal settlement that do not present erosion problems or are located close to riverbeds, in order to concentrate the settlers in those areas.Likewise, the use of the new available areas created by the intra-relocation can be used as public space, endowed with what the actual settlements lack: construction of parks, sports and recreation areas and others, in order to improve the surroundings.

Relocation of settlements

Relocation processes are complex due to their social and economic implications, but must be initiated because many settlements are at imminent risk. Also, the lack of basic water and sanitation infrastructure affects the living standards of the settlers. The participation of the municipal government is fundamental as executing entity; firstly, due to the acquisition of funds and secondly, due to the need of organizational capacity needed for this type of actions. However, work should start with specific cases that can be used as pilot experiences to be replicated in other sectors affected by similar problems.

Environmental education

Through capacity building it is necessary that the inhabitants in settlements with incomplete development are made aware of the environmental problems that they generate by contaminating water resources and the risks that this is generating regarding the spreading of diseases. Given the displacement conditions, in the case of illegal occupancy of terrains, it should be a basic requirement that the households implement temporary water and sanitation solutions that are affordable and contribute to improve their living standards.

8.7.2.1 Development of Strategic Lines

The developed strategies within the SWITCH context and their application in settlements with incomplete development in the Cañaveralejo River Basin are shown in Figure 8.34.

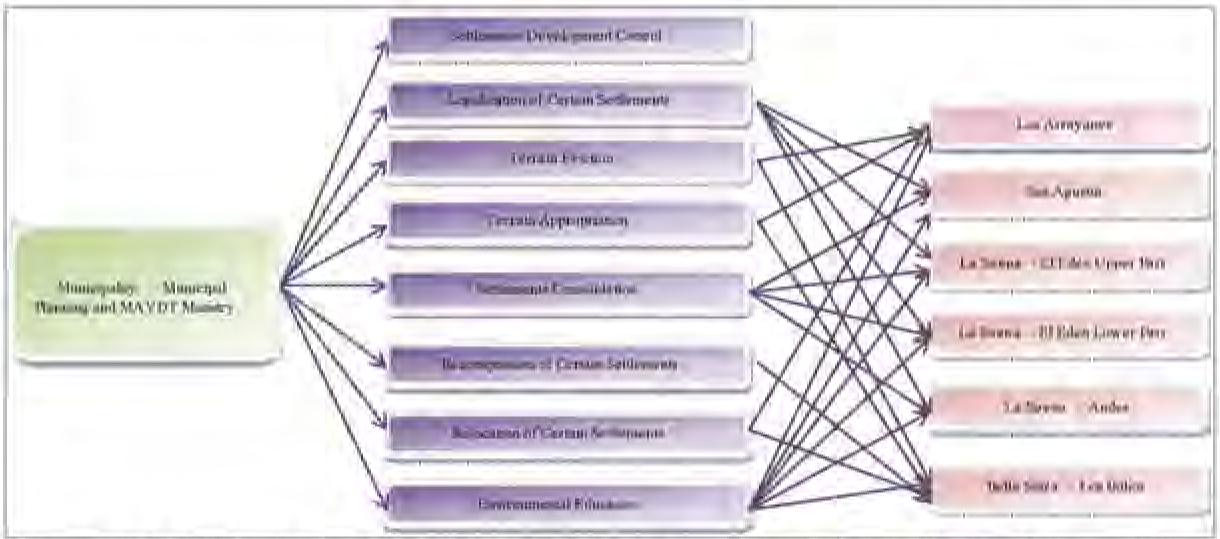


Figure 8.34 Strategies for incomplete development settlements located in the Cañaveralejo River Basin

The municipal government should take the lead to implement control in the development of these settlements in order to guarantee better living standards and opportunities to its people, achieving a decrease in migration phenomena resulting in illegal occupation. Likewise, there is a strong need of community environmental awareness raising and capacity building, since it is desired that the inhabitants strive for the environmental protection and are aware that unorganized settlements cause deterioration of ecosystems and river system.

According to the information displayed in Figure 8.34, San Agustin and the tree settlements next to La Sirena: El Edén Upper Sector, El Edén Lower Sector, and Andes could be legalized and consolidated since they are urbanistically connected to La Sirena sector and have local water supply services. Los Arrayanes is recommended to be relocated as it is situated in an area with high risk caused by mass removal. New land needs to be acquired by the municipal government to be able to relocate those settlers. The lower parts of the Bella Suiza - Los Búhos also requires relocated, especially the area within the Cañaveralejo River protection margin and also due to the fact that their management of wastewater has not been settled and consequently the area is contaminating the river. The connection of that area to the existing municipal sewage network is difficult because the area is at an altitude lower than the collector; the low location also generates flooding and wastewater backflow to the houses. Hence it is important with relocation of this peri-urban settlement to recover the river protection margin, as well as the reforestation of the zone. The implementation of these strategies requires a development of a standardization procedure, but without doubt, the options presented within the SWITCH Project context are guidelines that will help improve current problems and were jointly discussed with experts in the matter, such as Geologist Andres Prieto, from the Municipal Planning Department.

9 CONCLUSIONS

- In WWTP-C drainage system, two solutions for reduction of pollution discharged by Cañaveralejo wastewater treatment plant to Cauca River were analysed, a conventional solution and a solution with SWITCH approach. The conventional solution consists in complement the primary treatment with a secondary treatment. The secondary treatment selected is activated sludge in the modality of contact stabilization, and effluent treated will be discharged to Cauca River.

  The solution with SWITCH approach consists in: 1) a strategy for pollution prevention and minimisation in the household composed by a flushing toilet of 2,3 L and rainwater harvesting system, 2) the complementation of primary treatment with activated sludge as secondary treatment, and 3) the reuse of effluent treated in sugar cane irrigation.

  The comparison of these solutions was carried out through of cost-benefit analysis. Even though the solution with SWITCH approach has many environmental advantages compared with conventional solution, the cost-benefit analysis shows as result that solution with SWITCH approach is not feasible because the costs are greater that benefits.

- Regarding the south expansion area, also two solutions were analysed such as the WWTP-C drainage system. The conventional solution consists in conventional water management in households (without pollution prevention and minimisation), transport wastewater produced in the zone to WWTP-C complemented with activated sludge, as secondary treatment, and the effluent treated will be discharge on Cauca River.

  The solution with SWITCH approach consists in the application of pollution prevention and minimisation in expansion area households, and treatment with natural system and reuse of effluent treated in sugar cane irrigation. The pollution prevention and minimisation strategy selected is composed by: 1) a flushing toilet of 2,3 L and tap high efficient in kitchen, handbasin, and shower, 2) rainwater harvesting system for households and multifamily buildings, and 3) greywater reuse system for households and multifamily buildings. The wastewater treatment systems proposed is integrated by high rate anaerobic pond + secondary facultative pond + rock filter.

  The analysis of the pollution prevention and minimisation alternatives considering aspects as: economical, technical, social, and environmental, shows that is feasible the implementation of low consumption devices, rainwater harvesting systems, and greywater reuse systems. The implementation of these strategies involve a disminution of impact of this area about water resources related to less consumption of drinking water, and reduction of pollution load. Also represents economical benefits, since the analysis with the relation cost-benefit shows savings in tariff, and in the reduction of initial investment in drinking water network, sewer system, and pumping stations. This strategy complemented with decentralized system for wastewater treatment using natural methods is feasible compared with transport the wastewater to WWTP-C.

- The application of solution with SWITCH approach is influenced by several factors according with the local context evaluated, stand out as important factor the poblacional densification. In terms of initial investment, for the WWTP-C drainage system, the strategy of pollution prevention and minimisation had a lower impact that implementation of effluent reuse in agricultural proposes.

  The effluent reuse in agricultural irrigation in the WWTP-C drainage system and south expansion area presents different behavior due the temporality and spatial effects of climatological phenomenon. In case of WWTP-C drainage system, the agricultural plan shows that effluent treated is a favorable strategy due to little precipitation in the 97% of year; contrary to south expansion area where precipitation regime is major.

- In the South Drainage System, four geographical areas can be distinguished with specific characteristics and as a result with different needs regarding water management: the rural upper and middle Lili-Meléndez-Cañaveralejo river basins; the peri-urban area with a mixture of rural and urban conditions; the consolidated urban area corresponding mainly to residential and commercial development, but also includes some industries; and finally, the rural area in the lower basin with the out-phased Navarro landfill.

  In the upper-middle basin -among other affected by deforestation, erosion-generating cattle grazing and informal mining activities together with the lack of wastewater treatment from household- the proposed alternatives are aiming to strengthen and complement ongoing program from corresponding authorities; since the implemented activities still have not generated significant results regarding quality and quantity parameters of the rivers. In this sense, to increase the long-term sustainability it is indispensable to develop strategies such as: promotion of improved sanitation through the inclusion of additional treatment steps preferably using natural methods that facilitate reuse; formulation of a broad inter-institutional reforesting program backed-up with new financing opportunities within the recent CONPES 3624 (Upper Cauca River basin restoration plan); and for the illegal mining it is necessary to complement the closure actions with social programs to create alternative income-generating activities for the population.

- Regarding the peri-urban area of Cañaveralejo study area, especially two issues are considered significant for the negative impact that these have on the river systems: the first is the large number of informal settlements located within the river protection area or in high-slope areas with severe erosion and vulnerability for landslides; and the second is the general discharge of wastewater directly to creeks and rivers from both formal and informal settlements. The present initiatives to find solutions to the informal settlements are almost inexistent and most institutions are not taking actions as they consider it a problem for the municipal government to solve. Since, the informal settlements require a combination of social and technical approaches, a strong inter-institutional collaboration should be initiated including strategies such as: development control to avoid expansion of informal settlements, legalization and consolidation of safe settlements and relocation of

unsafe, and a general environmental education to strengthen the awareness and appropriation of natural resources.

- In the consolidated area of Cañaveralejo study area, which is densely built with impermeable surfaces, an important strategy developed in this study has been to regain the retention capacity for rainwater and restore basic river characteristics in concrete-lined river channel sections. The retention of rainwater has two principle purposes in this case: to avoid flooding within the city and to reduce the inflow of stormwater to the wastewater sewerage system in areas with combined system. Initially two types of Sustainable Urban Drainage Systems (SUDS) where considered: infiltration basins -taking advantage of existing football fields- and installation of pervious pavement. The first results show that SUDS have the potential to retain large volume of water; in this case the two systems had the capacity to retain a complete 10 year-rain for the limited areas under consideration. Furthermore, the proposed removal of concrete-lining and widening of intervened river channels would increase the flow capacity in the system, and also show high potential to support autopurification and enhance the green environment of the city.

- Finally, the leachate management from the Navarro landfill is an environmental issue of great importance for Cali that still has not been resolved; regardless of the risks that this situation constantly pose for a majority of the population of the city, who are dependant of the potable water production taking water downstream the landfill. In the comparison study between conventional and natural leachate treatment methods, both showed similar results regarding removal efficiencies for basic contamination parameters (BOD, COD, and TSS) considered in the national effluent norms, while the economic implication of the two options differs significantly; the cost (NPV for 30 years) for natural methods is about 30% compared to the conventional system. However, considering that the landfill leachate is a complex of both organic and inorganic contaminants it is recommended to consider complement the natural treatment with an advanced filtration step, such as reverse osmosis or membrane filtration.

10 REFERENCES

Abbassi, B. and Baz, I. A. (2008). "Integrated Wastewater Management: A Review." In: Efficient Management of Wastewater, I. A. Baz, R. Otterpohl, y C. Wendland, eds., Springer Berlin Heidelberg, 29-40.

Alarcon, M. T. (2010). "Elementos Ambientales Determinantes." SITM-MIO. Universidad del Valle, Cali, Colombia, 42.

Ayers, R. and Wescot, D. (1987). "La calidad del agua en la agricultura. Estudio FAO riego y drenaje 29.1. Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO)."

Ballard, B. W., Bray, R., Jefferles, C., Kellagher, R., Martin, P. and Shaffer, P. (2007). "The SUDS Manual." CIRIA, Classic House, London, 606.

Bernhardt, E. and Palmer, M. (2007). "Freshwater Biology." (52), 738–751.

Birks, R. and Hills, S. (2007). "Characterisation of Indicator Organisms and Pathogens in Domestic Greywater for Recycling." Environmental Monitoring and Assessment, 129(1), 61-69.

Brent, R. (2006). Applied cost-benefit analysis, Second Edition Ed., Edward Elgar Publishing limited, Cheltenham.

Caicedo, A. (2010). "Marco de la Ecologico de la cuenca del río Cañaveralejo. Cali ciudad de las aguas. Documento en preparación." Colegio IDEAS, Cali.

Cámara de Comercio de Cali, Cámara de Comercio de Bogotá, El País, Casa Editorial El Tiempo and Fundación Alvaralice and Fundación Corona. (2008). "Evaluación de la Calidad de Vida en Cali 2008. Primer año de la Administración de Jorge Iván Ospina."

Castro, D., Rodríguez, J., Rodríguez, J. and Ballestero, F. (2005). "Sistemas Urbanos De Drenaje Sostenible (SUDS)." In: Interciencia, Interciencia, Caracas, 6.

CENICAÑA. (2004). "Avances técnicos para la programación y el manejo del riego en caña de azúcar." 66.

CEPIS, OPS and OMS. (2001). "Guía de diseño para captación de agua lluvia." Lima-Perú.

Cereve, Tauw BV, Chalmers University of Technology, Technical University of Denmark, Middlesex University, National Technical University of Athens, DHI Hydroinform, Sieker GmbH, Water Pollution Unit at Laboratoire Central des Ponts et Chaussees and Lulea University of Technology. (2010). "DayWater "Adaptive Decision Support System for Stormwater Pollution Control"" *http://daywater.in2p3.fr/EN/gfx/bmp/performances/Performance28.pdf*.

Cinara. (2007). "Lineamientos para el diseño y administración de sistemas de abastecimiento de Agua bajo el enfoque de usos múltiples - Usos múltiples del Agua como estrategia para enfrentar la pobreza." Universidad del Valle, Cali.

Cinara and Universidad del Valle. (2008a). "Diseño del Sistema de Tratamiento para las Aguas Residuales Domesticas - Memoria Técnica de diseño." In: Proyecto de Construccion de Vivienda Productiva "Nashira", Cali, Colombia.

Cinara and Universidad del Valle. (2008b). "Urban Water Management for the City of Cali - Diagnosis Report." Universidad del Valle, Cali.

Colegio IDEAS. (2010). "Personal communication of Dr. Jahuira." Cali, Colombia.

COLPOZOS. (2010a). "Comunicación personal acerca de costos de sistemas de bombeo.", Cali.

COLPOZOS. (2010b). "Costos de sistemas de bombeo." Cali.

Congreso de Colombia. (1997). "Ley 373 de 1997. Programa para el uso eficiente y ahorro del agua." Congreso de Colombia, ed., Bogotá D.C., Colombia. .

Consejería de Medio Ambiente. (2009). "Medio Ambiente recupera el río Guadalete a su paso por Arcos de la Frontera para el uso público de sus vecinos." *http://www.juntadeandalucia.es/medioambiente*, Junta de Andalucía,.

Corrales, D. and Montenegro, F. (2000). "Experiencias de Acuavalle S.A.E.S.P. en la operación y mantenimiento de lagunas de estabilización " In: Conferencia latinoamericana en lagunas de estabilización y reuso, CINARA, Santiago de Cali, Colombia

CVC. (1984). "Decreto 1594 de 1984. Mediante el cual se fijan las normas que deben cumplirse para realizar los vertimientos líquidos a cuerpos de agua."

CVC. (2001). "Sistema de Información Geográfica de la Unidad de Manejo de Cuencas Cali- Meléndez - Pance - Aguacatal." CVC, Cali, Colombia, 180.

CVC. (2004). "Proyecto de distribución de agua del río Cauca." CVC, ed., Cali.

CVC. (2007). "Balance Oferta - Demanda de Agua superficial Cuenca del Río Cañaveralejo." Dirección Técnica Ambiental, Cali, Colombia, 8.

CVC. (2008). "SOS por el Valle del Cauca Síntesis Ambiental Urbana Municipio de Cali." CVC, Cali, Colombia, 32.

CVC. (2009). "Acuerdo No. 008 de 2008 Por el cual se fija la tarifa de la tasa por uso del agua." Cali.

CVC. (2010a). "Bases de datos de usuarios del recurso hídrico en el Valle del Cauca." Cali.

CVC. (2010b). "Personal communication for Eng. Arango." Cali, Colombia.

CVC. (2010c). "Personal communication for Eng. Carmona." Cali, Colombia.

CVC. (2010d). "Personal communication of Eng. Navia." Cali, Colombia.

CVC. (2010e). "personal communication of Eng. Vargas." Cali, Colombia.

CVC and Universidad del Tolima. (2008a). "Caracterización de los bosques naturales y zonificación de las tierras forestales en las cuencas hidrográficas de los ríos, Estudio de los bosques naturales." In: Convenio interaministrativo CVC No. 083 de 2007, Cali, Colombia.

Christova-Boal, D. (1995). "Installation and evaluation of domestic greywater reuse systems," Victoria University of Technology, Australia.

DAGMA. (2004). "Inventario del sector industrial de la ciudad de Cali." Cali.

DAGMA. (2009). "Monitoreo y caracterización de los vertimientos puntuales y calidad de Agua del recurso hídrico del municipio de Santiago de Cali en los rios Aguacatal, Cali, Melendez, Cañaveralejo y Cauca." Santiago de Cali.

DAGMA. (2010). "Personal Communication of Eng. Gisella Arizabaleta." Cali, Colombia.

DAGMA and ASOCARS. (2005). "Plan de Gestión Ambiental Municipio de Santiago de Cali."

DAGMA and CRPML. (2010). "Implementación de Sistemas de Mejoramiento Ambiental Empresarial en Santiago de Cali." DAGMA, Departamento Administrativo de Gestión del Medio Ambiente, Cali.

DAGMA, CVC, Universidad del Valle and ACODAL. (2004a). "Informe ejecutivo, Identificación de vertimientos puntuales y tomas de agua en los cauces de los río Meléndez, Cañaveralejo y quebradas afluentes en el perímetro urbano del municipio de Santiago de Cali." Cali, Colombia.

DAGMA and Universidad del Valle. (2004b). "Informe Final, Río Cañaveralejo, Identificación de vertimientos puntuales y tomas de agua en los cauces de los ríos meléndez, cañaveralejo y quebradas afluentes en el perímetro urbano del municipio de Santiago de Cali." In: convenio interadministrativo 010 de 2003 DAGMA – Universidad del Valle." Cali, Colombia.

DAGMA and Universidad del Valle. (2007). "Identificación de la Situación Ambiental de la Cuenca Hidrográfica del Río Cali, Zona Urbana de Santiago de Cali." Cali.

Dallas, S., Scheffe, B. and Ho, G. (2004). "Reedbeds for greywater treatment--case study in Santa Elena-Monteverde, Costa Rica, Central America." Ecological Engineering, 23(1), 55-61.

DANE. (2005). "Censo General Nivel Nacional." República de Colombia, Colombia.

DANE. (2010). "Indice de costos de la construcción de vivienda - ICCV." *http://www.dane.gov.co/daneweb_V09/index.php?option=com_content&view=article&id=89&Itemid=57*.

DAPM. (2000). "Plan de ordenamiento territorial de la ciudad de Santiago de Cali.".

DAPM. (2008). "Cali en cifras." Departamento Administrativo de Planeación Alcaldía de Santiago de Cali, ed., Impresora Feriva S.A., Cali.

DAPM. (2009). "Cali en Cifras 2009." DAPM, Cali, Colombia, 190.

DAPM. (2010). "Revisión de planes parciales aprobados y formulados en la zona de expansión de Cali.".

DAPM and Alcaldía de Santiago de Cali. (2000). "Acuerdo 069 de octubre 26 de 2000, Plan de ordenamiento territorial del municipio de Santiago de Cali." Cali, Colombia, 231.

Doorenbos, J. and Pruitt, W. (1977). "Guidelines for predicting crop water requirements. Rome: FAO, 1977. 179p." Irrigation and Drainage, Paper, 24.

El Pais. (2009). "Alerta por lagunas de lixiviados en Navarro." In: Edicion de Junio 21.

EMCALI. (2006). "Reporte Ejecutivo de Operación Planta de Tratamiento de Aguas Residuales de Cañaveralejo - Resumen Año 2006."

EMCALI. (2007). "Plan de Saneamiento y Manejo de Vertimientos 2007 - 2016." Unidad Estrategica de Negocios de Acueducto y Alcantarillado, ed., Emcali, Cali, Colombia, 324.

EMCALI. (2010a). "Personal communication for Eng. Jesús A. Soto." Cali, Colombia.

EMCALI. (2010b). "Personal Communication of Eng. Emilio Corrales." Cali, Colombia.

EMCALI and ANGEL & RODRIGUEZ. (1995). "Invesitgaciones, estudios y diseños del colector sanitario margen izquierda rio Cañaveralejo y del colector Venezuela, Informe Final." In: Contrato No. GAA-DP-317-94-ALC, Cali, Colombia.

EMCALI and Consorcio Ingesam-Hidroccidente. (2009). "Estudios y diseños de las redes de acueducto y alcantarillado de la primera etapa de expansión del corredor Cali-Jamundí." Cali, Colombia.

EMCALI and Hidroccidente. (2006a). "Estudio de Alternativas de Dotación de Los Servicios Públicos de Acueducto, Alcantarillado y Complementario de Alcantarillado En La Zona de Expansión de La Ciudad de Cali Denominada “Corredor Cali-Jamundí”." Cali, Colombia.

EMCALI and UNIVALLE. (2006b). "Informe de Campaña de Monitoreo y Caracterización de los Vertimientos de la Ciudad de Cali y de la Calidad del Agua del Río Cauca en el Tramo Hormiguero - Mediacanoa." Empresas Municipales de Cali (EMCALI), Universidad del Valle (UNIVALLE), Cali, Colombia.

EMCALI and Universidad del Valle. (1996). "Diagnostico participativo para el mejoramiento del sistema de transporte, recolección y tratamiento de Aguas Residuales, Localidad: La Sirena." Cali, Colombia.

EPA. (2000). "Folleto informativo de tecnología de aguas residuales. Humedales de flujo subsuperficial."

FAO. (1999). "Wastewater treatment and use in agriculture." Wastewater treatment and use in agriculture. (30 de Abril, 2010).

FDE. (2007). "River Restoration Fact Sheet: Costs of Retaining Rodman Reservoir vs. Restoring the Ocklawaha River."

Forero, R. and Franco, D. M. (2003). "Estudio hidrológico e hidrodinámico del sistema de drenaje pluvial de la zona suroccidental en Santiago de Cali mediante la simulación numérica," Pregado, Universidad del Valle, Cali, Colombia.

Foster, S., Hirata, R., Gomes, D., D'ELIA, M. and París, M. (2003). Protección de la calidad del agua subterránea, Banco Mundial.

Galvis, A., Cardona, D. and Aponte, A. (2007). "Technology selection for pollution control and wastewater impact reduction in Buga, Colombia." In: SWITCH Scientific Meeting.

Garzon, A. and Lara, J. A. (2005). "Diseño De Un Humedal Artificial Para El Tratamiento De Escorrentias Urbanas." In: 48 Congreso De ACODAL. Saneamiento Y Amabiente: Politicas, Educación, Tecnologia y Negocios Santa Marta, Colombia, 4.

GBA. (2010). "*http://globizall.com/econnovation.*" (March, 2010).

Ghisi, E. and Ferreira, D. (2007). "Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil." Building and environment, 42, 10.

Gikas, P. and Tchobanoglous, G. (2009). "The role of satellite and decentralized strategies in water resources management." Journal of Environmental Management, 90(1), 144-152.

Gleick, P. (2000). "The World's Water 2000-2001: The Biennial Report on Freshwater Resources." Island Press, Washington, D.C.

Gobernación del Valle del Cauca. (2008). "Plan de Desarrollo Departamental 2008-2011." Cali.

Goldschmid, U. (2007). "Living river Liesing – Is rehabilitation of a heavily modified waterbody in an urban environment possible? Results of a LIFEProject." Presentation in the River Restoration Centre's 8th annual network conference.

Google maps. (2010). "Cali, Coliseo del Pueblo." *http://maps.google.es/* (Octubre 01, 2010).

Gori, R. and Rosso, D. (2009). "Effects of Biosolids Carbon Sequestration on Energy Footprint at Wastewater Treatment Plants." In: Mitigation in the water sector & potential synergies with the energy sector, Internationa Water Association - IWA, Copenhagen.

Gourbesville, P. (2008). "Integrated River Basin Management, ICT and DSS: Challenges and Needs." Physics and Chemistry of the Earth 33, 9.

Gross, A., Kaplan, D. and Baker, K. (2007). "Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB)." Ecological Engineering, 31(2), 107-114.

Helmreich, B. and Horn, H. (2009). "Opportunities in rainwater harvesting." Desalination, 248, 18.

Hernández-Allica, J., Becerril, J. M. and Garbisu, C. (2008). "Assessment of the phytoextraction potential of high biomass crop plants, Environmental Pollution." Environmental pollution, 152, 8.

HIDROINGENIERIA LTDA and DAGMA. (2000). "Estudio de Caudal Ecológico, Balance Hídrico, Indicador Ambientales e Inventario del Recurso Hídrico en los ríos Cali, Aguacatal, Cañaveralejo y Melendez del Munícipio de Santiago de Cali. Plan del Río - Informe final Documento Técnico Río Aguacatal." DAGMA, Cali, Colombia.

HIPERAGUAS and EMCALI. (2007). "Diseño de la Sectorización de la Red de Acueducto y Optimización del Servicio de alcantarillado Mediante la Implementación del Modelo de Simulación Hidráulico. Contrato Nº 300-GAA-CC-452-2005, Evaluación de Estructuras de Separación. V1." E, Cali, Colombia, 44.

Holguín, M. (2003). "Diseño de acueducto, alcantarillado, plantas PTAP y PTAR para las veredas "La Carolina", "Andes Bajo", "Corral de Piedra" y "El Mango", corregimiento "Los Andes", Municipio de Santiago de Cali." Secretaria de Salud Pública Municipal de Santiago de Cali, Area de Inversiones, Cali, Colombia.

Jamieson, T., Stratton, G., Gordon, R. and Madani, A. (2003). "The use of aeration to enhance ammonia nitrogen removal in constructed wetlands." Canadian Biosys. Engi, 45, 1.9-1.14.

Jiménez, B., Mara, D., Carr, R. and Brissaud, F. (2010). "Wastewater Treatment for Pathogen Removal and Nutrient Conservation: Suitable Systems for Use in Developing Countries." Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries, 149.

Jiménez, P. N. (2005). "Elementos Históricos y Urbanos en la Generación de Desastres por Inundaciones y Deslizamientos en Cali, 1950 -2000," Pregrado, Universidad del Valle, Cali, Colombia.

Kadlec, R. H. and Knight, R. L. (1996). Treatment Wetlands, McGraw Hill.

Kelly, F. (2001). "Restoration of Urban Streams. Practical Evaluation of Options for 319(h) Funded Projects." USDA-NRCS.

Li, F., Wichmann, K. and Otterpohl, R. (2009). "Review of the technological approaches for grey water treatment and reuses." Science of the Total Environment, 407, 11.

Liu, S., Butler, D., Memon, F. A., Makropoulos, C., Avery, L. and Jefferson, B. (2010). "Impacts of residence time during storage on potential of water saving for grey water recycling system." Water Research, 44(1), 267-277.

Londoño, C. C. and Balanta, R. (2001). "Comparacion estructural y economica de tanques en ferrocemento y en concreto reforzado," Universidad del Valle, Cali-Colombia.

Madera, C. A., Peña, M. R. and Van Ginneken, M. (2003a). "Humedales de Flujo Subsuperficial: Una Alternativa Natural para el Tratamiento de Aguas Residuales Domésticas en Zonas Tropicales." Ingeniería y competitividad, 5, 27-35.

Madera, C. A., Silva, J. P. and Peña, M. R. (2003b). "Sistemas combinados de tratamiento de agua residuales basados en tanque séptico – filtro anaerobio – humedales: una alternativa sostenible en pequeñas comunidades en países tropicales." In: AGUA 2003-Seminario internacional sobre Métodos Naturales para el Tratamiento de Aguas Residuales, Cartagena, Colombia.

Manga, J., Logreira, N. and Serrait, J. (2001). "Reuso de aguas residuales: Un recurso hídrico disponible." Barranuilla, Colombia, 12–21.

MANOV, Analisis Ambiental and EMCALI. (2007). "Diseño de estructuras de retención de sólidos y desarenadores en las quebradas guarruz y el Indio, Consultoria para establecer las estrategias y elaborar los diseños de las estructuras hidráulicas requeridas, que disminuyan el impacto de la contaminación del sistema de drenaje sur en las aguas captadas para las plantas de puerto mallarino y río Cauca." In: Contrato N° 300-GAA-CC-133-2006, Cali, Colombia.

Mara, D. (2003). Domestic Wastewater Treatment in developing countries, Earthscan Book. UK. ISBN 1-84407-020-4. Ed.

Mara, D. D. (1987). "Waste Stabilization Ponds: Problems and controversies." Water Quality International, 1, 20-22.

Mara, D. D. (2006). "Constructed Wetlands are not a Viable Alternative or Addition to Waste Stabilization Ponds,." In: 7th IWA Specialist conference on waste stabilization ponds, Bankok, Thailand.

Mara, D. D. and Johnson, M. L. (2007). "Waste stabilization ponds and rock filters: solutions for small communities." Water Science and Technology, 55(7), 103−107.

Mara, D. D., Pearson, H. W., Oragui, J. I., Arridge, A. and Silva, S. A. (2001). "Development of a new approach to waste stabilization pond design." Tropical public health engineering research monograph, 12.

Martínez, F. (2007). "Curso de conservación y manejo de suelos y aguas, Practica de construcción de trinchos con llantas como estrategia de recuperación de suelos erosionados en los cerros tutelares de Cali. Colombia." Universidad del Valle, Cali, Colombia.

Materon, H. (1997). Obras hidráulicas rurales, Universidad del Valle, Cali-Colombia.

MAVDT. (2003). "Determinación de la tarifa mínima por concepto de tasa retributiva. Decreto 3100."

MAVDT and MHCP. (2009). "CONPES 3624 - Programa para el saneamiento, manejo y recuperación ambiental de la cuenca alta del Río Cauca." Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Ministerio de Hacienda y Crédito Público.

Mayorquín, R. and Astrid, J. (1997). "Evaluación de Diferentes Métodos para Determinar máximos en las Cuencas de los Ríos Cali, Pichindé, Cañaveralejo, Meñendez y Lili," Pregrado, Universidad del Valle, Cali, Colombia.

Metcalf & Eddy. (1995). Ingeniería de aguas residuales, McGraw Hill Ed., España.

Metcalf & Eddy (2003). Wastewater Engineering - Treatment and Reuse, Fourth Edition Ed., McGraw-Hill, New York.

Ministerio de Agricultura y Desarrollo Rural. (2009). "Evaluación Departamental de Costos de Producción de Caña de Azucar por Hectárea." Cali, Colombia.

Ministerio de Desarrollo Económico. (2000). "Reglamento Técnico del Sector de Agua Potable y Saneamiento Basico: RAS – 2000. Seccion II - Título F. Sistemas de Aseo Urbano." Bogotá.

Miranda, J. J. (2001). Gestión de proyectos, Cuarta Ed., MM Editores, Colombia.

Montajes e Ingenieria LTDA. (2004). "Cálculos diseño planta de tratamiento de aguas residuales." Cali, Colombia.

Morel, A., Schertenielb, R. and Zürbrugg, C. (2003). Alternative Environmental Sanitation Approaches in Developing Countries.

Moscoso, J., Egocheaga, L., Ugaz, R. and Tréllez, E. (2002a). "Guía para la formulación de proyectos de Sistemas Integrados de Tratamiento y Uso de Aguas Residuales Domésticas."

Moscoso, J. and Young, L. E. (2002b). "Sistemas integrados de tratamiento y uso de aguas residuales en América Latina: realidad y potencial." 360,589.

Nascimento, N., Sperling, M., Vieira, L., Silva, A., Seidl, M. and Vieira, P. d. C. (2008). "Urban Stormwater Management Projects in Belo Horizonte." Federal University of Minas Gerais - Graduate Programme on Sanitation, Environment and Water Resources, Belo Horizonte, MG - Brazil.

National SUDS Working Group. (2004). "Interim Code of Practice for Sustainable Drainage Systems." National SUDS Working Group, London.

Nhapi, I. and Gijzen, H. J. (2005). "A 3-step strategic approach to sustainable wastewater management." Water SA, 31, 133-140.

Novotny, V. (2003). Water Quality - Diffuse pollution and watershed managment, Second Edition Ed., John Wiley & Sons, Inc., New York

Oakley, S. (2005). "Lagunas de Estabilizacion en Honduras. Manual de Diseño, Construcción, Operación y Mantenimiento, Monitoreo y sostenibilidad." FHIS/USAID/RRAS-CA. Junio 2005: 212. *http://www. rrasca. org/pdf/laguna. pdf.*

Ochoa, M. d. P. (2007). "Estudio preliminar de caracterización y cuantificación de las aguas grises en una residencia de Bogotá. Universidad de Los Andes." Bogotá, Colombia.

Öman, C. and Junestedt, C. (2007). "Swedish Environmental Research Institute. Chemical characterization of landfill leachates - 400 parameters and compounds."

Osorio, P. (2003). "Sistemas de tratamiento de aguas residuales domésticas empleados por la CVC en el sector rural del Departamento del Valle del Cauca." In: Seminario Internacional sobre Métodos Naturales para el tratamiento de Aguas Residuales, Cali, Colombia.

Otterpohl, R., Halalsheh, M., Al , I., Kramer, A., Tamrabet, L., Kribaa, M. and Mara, D. (2008). "The 2006 WHO Guidelines for Wastewater and Greywater Use in Agriculture: A Practical Interpretation." In: Efficient Management of Wastewater, Efficient Management of Wastewater.

Palmer, M., Bernhardt, E. and Allan, J. (2005). "Standards for ecologically successful river restoration." Journal of Applied Ecology, 42, 208 -217.

Peña, M. R. (2002). "Advanced primary treatment of domestic wastewater in tropical countries development of high-rate anaerobic ponds," University of Leeds, Leeds.

Peña, M. R. (2008). "Informe técnico final – Proyecto "Modelación de los mecanismos involucrados en la transformación y remoción de nutrientes y materia orgánica en humedales subsuperficiales para el tratamiento de aguas residuales domesticas." Programa Nacional de Biotecnología, COLCIENCIAS, Bogotá, Colombia.

Peña, M. R. and Mara, D. (2004). "Waste Stabilisation Ponds." ICR International Water and Sanitation Centre, The Netherlands.

Perales, S. and Domenech, I. (2007). "Los Sistemas Urbanos De Drenaje Sostenible: Una Alternativa A La Gestión Del Agua De Lluvia." In: V Congreso Nacional de la Ingeniería Civil (5°. 2007. Sevilla) Colegio De Ingeniería De Caminos, Canales y Puertos, Sevilla, 15.

Podraza, P. (2007). "River restoration in Urban Areas. Presentation in Rivers for the Life of Towns."

Proexport Cali and Cámara de Comercio de Cali. (2005). "Dinámica empresarial Cali - Valle del Cauca." Cali.

Punmia, B. C. and Ashok, J. (1998). Wastewater Engineering, Laxmi Publications, New Delhi.

Reed, S., Crites, R. and Middlebrooks, E. (1995). Natural systems for waste management and treatment, McGraw-Hill, New York.

Renou, S., Givaudan, J., Poulain, S., Dirassouyan, F. and Moulin, P. (2008). "Landfill leachate treatment: Review and opportunity." Journal of Hazardous Materials, 150, 468-493.

Ridderstolpe, P. (2004). "Introduction to Greywater Management." Stockholm Environment Institute, Stockholm.

Romero, C. (1997). Análisis de las decisiones multicriterio, Isdefe, Madrid, España.

Romero, J. A. (2004). Tratamiento de aguas residuales: Teoría y principio de diseño, Tercera Ed., Escuela Colombiana de Ingeniería, Bogotá, Colombia.

Romero, J. A. (2005). "Lagunas de estabilización de aguas residuales, Escuela Colombiana de Ingeniería." Bogotá, Colombia.

Schneiderman, E., Steenhuis, T., Thongs, D., Easton, Z., Zion, M., Neal, A., Mendoza, G. and Todd Walter, M. (2007). "Incorporating variable source area hydrology into a curve number based watershed model." Hydrological Processes, 21(25), 3420-3430.

Secretaria de Salud Municipal. (2009). "Agua potable y saneamiento basico rural." Alcaldía de Cali, Cali.

Secretaria de Vivienda Social and Fondo Especial de Vivienda. (2010). "Asentamientos humanos de desarrollo incompleto existentes en el Municipio de Santiago de Cali." A. Zambrano, ed., Cali, Colombia.

Siebel, M. A. and Gijzen, H. J. (2002). "Application of Cleaner Production Concepts in Urban Water Management." In: Environmental Technology and Management Seminar. , I. T. B. E. E. Department, ed., Indonesia.

Silva, J. (2008). "Reuso del efluente de la planta de tratamiento de agua residuales de Cañaveralejo PTAR-C en el riego de Caña de azúcar," Tesis de maestría, Universidad del Valle, Cali.

Silva, J., Torres, P. and Madera, C. (2008). "Domestic wastewater reuse in agriculture. A review." Agronomía Colombiana, 26, 347-359.

Sokolov, A. and Chapman, T. (1981). "Métodos de cálculo del balance hídrico." Guía internacional de métodos de investigación (versión en Español). Instituto de Hidrología de España-UNESCO.

SSPM. (2010). "Communication Personal of Eng. Alvaro Loaiza." Cali, Colombia.

Suarez, B., Paola, D., Zea, C. and Amparo, D. (2003). "Selección de tecnología para el tratamiento de aguas residuales domésticas por métodos naturales: una metodología con énfasis en aspectos tecnológico."

SUI. (2009). "Consumos facturados en m3 por municipio reportados por Emcali." *http://reportes.sui.gov.co/fabricaReportes/frameSet.jsp?idreporte=acu_com_107*.

The River Restoration Centre. (2002). "Manual of River Restoration Techniques."

UK Environment Agency. (2006). "Diffuse pollution and the Water Framework Directive." London.

UMATA. (2005). "Mapas sociales de los corregimientos del municipio de Cali." Alcaldía Municipal de Santiago de Cali, Cali.

UNESCO-IHE and European Comission. (2007). "Sustainable Water Management Improves Tomorrow's Cities Health (SWITCH), European Comission."

Universidad del Valle - Cinara. (2008). "Urban Water Management for the City of Cali - Diagnosis Report." Universidad del Valle, Cali.

Universidad del Valle. (2009a). "Estudio de evaluación para el tratamiento del efluente de la PTAR Cañaveralejo a través de dos opciones secundarias convencionales-Fase 2." EIDENAR, Cali.

Universidad del Valle. (2009b). "Wastewater Management Framework for the city of Cali, Colombia, A paradigm shift in the wastewater pollution control." Universidad del Valle & UNESCO - IHE.

Universidad del Valle. (2010a). "Conceptual Framework for the Decontamination and Recuperation of Water Resources in the Municipality of Cali, "Master Plan"." Universidad del Valle, UNESCO - IHE, Cali, Colombia.

Universidad del Valle. (2010b). "Estudio de evaluación para el tratamiento del efluente de la PTAR Cañaveralejo a través de dos opciones secundarias convencionales - Fase 3." EIDENAR/Univalle, Cali.

Universidad del Valle and CEDETES. (2007). "La situación de Salud en Santiago de Cali, Una mirada desde la salud pública." Cali, Colombia.

Universidad del Valle and Cinara. (2009). "Wastewater Management Framework for the city of Cali, Colombia. "A paradigm shift in the wastewater pollution control"." Santiago de Cali.

Universidad del Valle, CINARA and CORPOCALDAS. (2005). "Informe Auto Depuración de Corrientes de Alta Montaña: Quebrada Tasajo."

Universidad del Valle and EMCALI. (2008). "Estudio de evaluación para el tratamiento del efluente de la PTAR Cañaveralejo a través de dos opciones secundarias convencionales-Fase 2." EIDENAR, Cali.

US EPA. (1994). "Polluted." Seattle.

Valencia, A. (2005). "Estudio comparativo de dos coagulantes para el tratamiento del lixiviado del vertedero de Navarro." Bachelor Thesis, Universidad del Valle, Cali, Colombia.

Valentín, G. M. (2006). Curos Hidrología Urbana, Distribuidora Alfambra de Papelería, S.L Ed., Flumen, Barcelona, España.

Vargas, J. (2007). "Decision Support System for Leachate Treatment Technologies," UNESCO-IHE Institute for Water Education, Delft, The Netherlands.

Vasquez, N. (2009). "Evaluación a escala piloto del sistema de lodos activados en las modalidades de estabilización por contacto y convencional como alternativa de tratamiento secundario para el agua residual doméstica de la ciudad de Cali ", Universidad del Valle, Cali.

Walsh, R., Feminella, C. and Groffman, M. (2005). "The urban stream syndrome: current knowledge and the search for a cure." Journal of the North American Benthological Society, 24(706–723).

WHO. (2006). Guidelines for the safe use of wastewater, excreta and greywater, WHO, France.

Woods-Ballard, B., Kellagher, R., C Jefferles, P. M., Bray, R. and Shaffer, P. (2007). "The SUDS Manual." CIRIA, London, 606.

Wright, A. and Bendell, B. (2005). "Mersey Basin Campaign: a partnership approach to river basin management." IWA - Water Intelligence Online, UK.

Zeng, G., Jiang, R., Huang, G., Xu, M. and Li, J. (2007). "Optimization of wastewater treatment alternative selection by hierarchy grey relational analysis." Journal of environmental management, 82, 9.