018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

D5.3.6: Results of applied research programme on natural systems for wastewater treatment and reuse

Diagnosis of the water system in Cali (Colombia)
(within WP 5.3 – Task 3b/g: Development of a master plan for the city of Cali)

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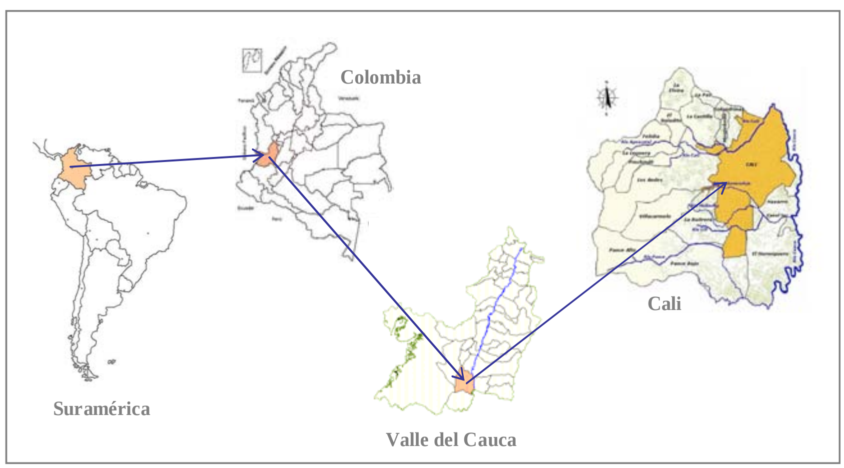
Sustainable Water Improves Tomorrow's Cities' Health SWITCH Project
Study Case: Cali, Colombia

Urban Water Management for the City of Cali
Diagnosis Report





Cali, February, 2008

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ABBREVIATIONS

AC	Asbesto cemento - cement
ACODAL	Asociación Colombiana de Ingenieros - Colombian Association of Sanitary Engineers
ANDI	Asociación Nacional de Empresarios de Colombia - National Association of Colombian Entrepreneurs
ASOCAR	Asociación Colombiana de Autoridades Ambientales
CAR	Corporación Autónoma Regional - Autonomous Regional Corporations
CINARA	Instituto de Investigación y Desarrollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico - Institute for the Research in Water Supply, Sanitation and Water Resources Conservation
CSO	Combined Sewerage Overflow
CRA	Comisión de Regulación de Agua Potable y Saneamiento Básico - Water and Sanitation Regulatory Commission
CRC	Corporación Autónoma Regional del Cauca - Regional Corporation of Cauca
CVC	Corporación Autónoma Regional del Valle del Cauca - Regional Corporation of the Valle del Cauca
DAGMA	Departamento Administrativo de Gestión del Medio Ambiente - Administrative Department for the Management of the Environment
DANE	Departamento Administrativo Nacional de Estadística - National Statistics Department
DAPM	Departamento Administrativo de Planeación Municipal - Municipal Administrative Planning Department
DNP	Direccion Nacional de Planeación - National Planning Directive
DO	Dissolved Oxygen
EEA	European Economic Association
EMCALI	Empresas Municipales de Cali - Cali's Municipal Water Services Company
EMRU	Empresa de Renovación Urbana - Municipal Urban Renovation Company
EMSIRVA	Empresa de Servicios Públicos de Aseo de Cali - Solid Waste Municipal Company
EPSA	Empresa de Energía del Pacifico - Energy of Pacific Company
FIME	Filtración en Multiples Etapas - Multiple stage filtration
FUNDESPAC	Fundación para el Desarrollo Sostenible y la Participación Ciudadana - Sustainable development and citizens participation Foundation
HF	Hierro Fundido - Melted Iron
ICA	Índice de Calidad del Agua - Quality of Water Index
ICAUCA	Índice Fisicoquímico de Calidad del Agua adaptado a las Condiciones del Río Cauca - Physical chemical water quality index adapted to the Cauca river conditions
ICO	Indice de Contaminación - Contamination Index
IDB	Índice de Biodiversidad - Biological Diversity Index
INGESAM.	Ingeniería de Saneamiento Ambiental, Ingenieros Constructores.
IREHISA	Grupo de Investigación en Ingeniería de Recursos Hídricos y Desarrollo de Suelos - Research group for the water resources engineering and soil development
MAVDT	Ministry for the environment, housing and development
m.a.s.l	Meters above the sew level

NGOs	Non-Governmental Organizations
NGP	National Gross Product - Producto Interno Bruto
NUT	Nephelometric Turbidity Units
OMS	Organización Mundial de la Salud - World Health Organization
PAD	Polietileno de Alta Densidad - High Density Polyethylene
PCU	Platinum Cobalt Units - Unidades de Platino y cobalto
PGAM	Plan de Gestión Ambiental Municipio de Santiago de Cali - Municipal Plan for the Management of the Environment
PGIRS	Plan de Gestión Integral de Residuos Sólidos - Plan for the Integrated Management of Solid Waste
PAHO	Panamerican Health Organization
PMC	Proyecto de Modelación del Río Cauca - Modelling of Cauca river Project
POT	Plan de Ordenamiento Territorial - Land Ordering Plan
PS	Pumping Station
PSMV	Plan de Saneamiento y Manejo de Vertimientos - Sanitation and Management of Waste-Discharges plan
PVC	Cloruro de Polivinilo - Poly Vinyl Chloride
RESNATUR	Colombian network for the natural resource and civil society
SDN	North-West Drainage System
SDS	South Drainage System
SDO	East Drainage System
SIGAM	Environmental municipal management system
SSPD	Public services commission
ST	Sólidos Totales - Total solids
TAD	Tiempo de Atención al Daño - Time Spent in the Damages
TOC	Total Organic Carbon
TPA	Tratamiento Primario Avanzado - Primary Advanced Treatment
TSS	Total Suspended Solids - Solidos Suspendidos Totales, SST
TTN	Tubería de Transmisión Norte - Transmission North Pipe
TTO	Transmission Oriental Pipe - Tubería de Transmisión Oriental
TTS	Tubería de Transmisión Sur - Transmission South Pipe
UFC	Unidades de Formadores de Colonia
UFPRAME	Cooperativa de Trabajo Asociado Unidos hacia el Futuro Protegiendo el Medio Ambiente
UNESCO	Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura - United Nations Educational, Scientific and Cultural Organization
USEPA	U.S. Environmental Protection Agency
UV	Luz Ultravioleta
WW	WasteWater
WWTP-C	Wastewater Treatment Plant Cañaveralejo - Planta de Tratamiento de Aguas Residuales de Cañaveralejo
WWTP-Navarro	Wastewater Treatment Plant Navarro - Planta de Tratamiento de Aguas Residuales Navarro
WWTP-Sur	Wastewater Treatment Plant South - Planta de Tratamiento de Aguas Residuales del Sur

Sustainable Water Improves Tomorrow's Cities' Health SWITCH Project

Urban Water Management for the City of Cali
Diagnosis Report

Study Case: Cali, Colombia

1. Introduction

February, 2008

1 INTRODUCTION

This report has been done by CINARA-Universidad del Valle 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.

This document does not only collect information from documents of others institutions of the water and sanitation sector, but also from experiences of different projects developed by Cinara-Universidad del Valle jointly with water and sanitation institutions in the last years. This document shows information from interviews with local experts and includes information about the results of workshops done during 2007 (April 13^{th}, October 4^{th} and November 16^{th} of 2007).

The document shows a global vision of the water management in Cali, which constitute a start point to analyze the water management sustainability and the possibility to propose strategies in the context of the city of Cali as a study case within "*Sustainable Water Improves Tomorrow's Cities' Health*" SWITCH project, with perspectives to become in a demonstration city.

This report includes a general description of the city, its water resources, drinking water supply system, sewerage system, control of the wastewater contamination, solid waste management. In addiction, it presents the institutional aspects related to the water management in the city of Cali and a description of the main future urban expansion areas located to the south of the city.

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2. Municipality of Cali

February, 2008

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2 MUNICIPALITY OF CALI

2.1 GENERAL CHARACTERISTICS

2.1.1 Geographic location

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. Its coordinates of location are: North 92.000N and 116.000N and East 6.000E and 18.000E. Figure 2.1 shows the location of the Valle del Cauca department and the urban area of Cali.

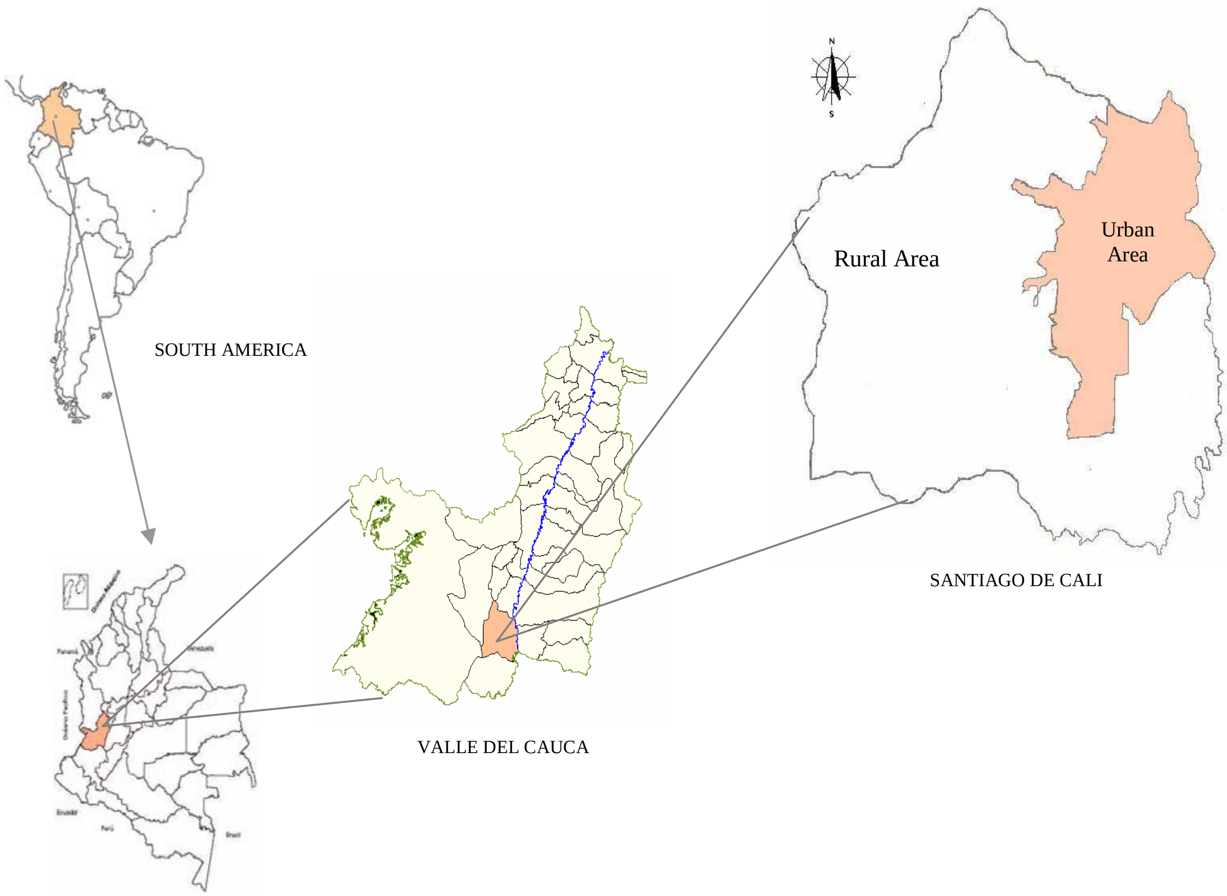

Figure 2.1 Geographic location City of Cali

Figure 2.2 shows that the urban part of the municipality of Cali is composed by two zones: 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 2 areas: Navarro and Cali-Jamundí sectors (EMCALI, 2007).

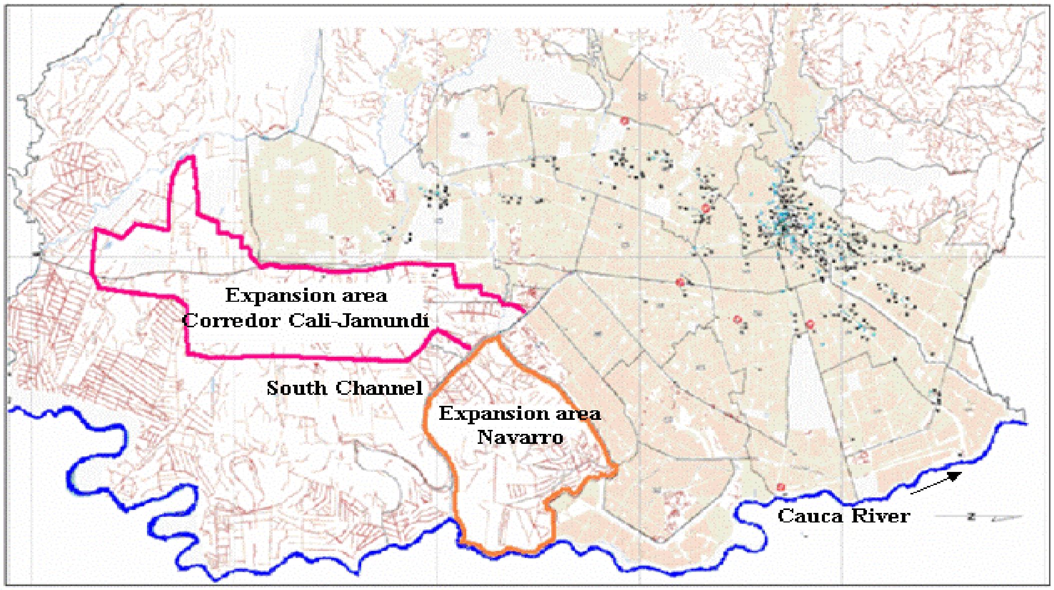

Figure 2.2 Location of existing and future urban areas in the Municipality of Cali

2.1.2 Demography

According to the National statistics department (DANE, 2005a), Cali has a total population of 2075380 inhabitants, from which 979530 are male and 1095850 are female.

Furthermore, according to DAPM (2006), in year 2005, 85% of Cali citizens were located in estratos 1, 2 and 3. Estratos is a way of economically classifying the sectors in the city; Hence estratos 1 and 2 correspond to the most economical stressed groups and estratos 3, 4, 5 and 6 correspond to the economical middle class to the upper class economic groups.

Population in the city has increased mainly by immigration from the rural areas, from the south-west part of the country and from other regions in the country. Table 2.1 shows the growth trend of the population in the municipality of Cali.

Table 2.1 Registered population in the municipality of Cali during period 1912-2005.

Year	Total population	Rate %	Urban Population	% Total urban population	Remaining population	% Total remaining
1912	27747	-	-	-	-	-
1918	45525	7,49	-	-	-	-
1938	101883	4,08	88366	86,7	13517	13,3
1951	284186	7,98	241357	84,9	42829	15,1
1964	637929	6,13	618215	96,9	19714	3,1
1973	991549[a]	4,75	971891	98,0	19658	2,0
1985	1429026[a]	3,05	1402893	98,2	26133	1,8
1993	1847176[a]	3,20	1809054	97,9	38122	2,1
2005	2075380	0,97	2039626	98,3	35754	1,7

[a] with adjustment
(-) Without date
Source: DAPM, 1996 and DANE, 2005a

The increase in the migration trends to the city of Cali, specially from the Pacific coastal area and neighboring departments has produced an additional pressure in the demand of land and public services such as water and sanitation. Figure 2.3 shows the historical immigration-emigration trend from results of census in years 1973, 1993 and 2005. From the census in years 1973 and 1993 it can be seen that Cali used to be a city that welcomed immigrants. The net migration balance (SNM) was positive during those years. In period 2000-2005, the SNM was negative showing that Cali had reduced its availability of receiving immigrants as it did before.

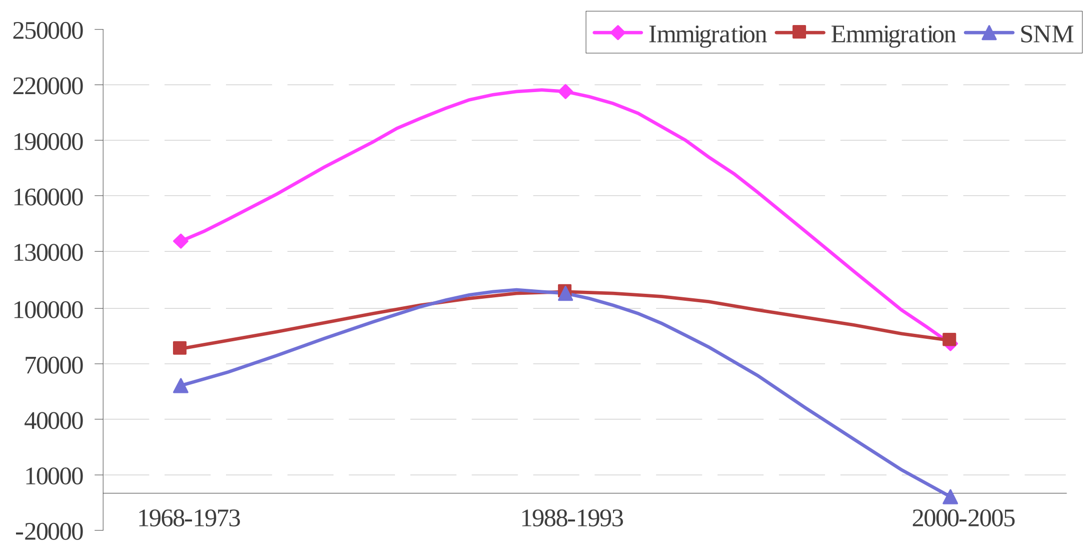

Figure 2.3 Immigration, emigration and net migration balance (SNM) to municipality of Cali, period 1968-2005.
Source: DANE, 2007

People that came from the departments of the Cauca, Chocó, Nariño and Valle, they placed in the low zones of the city in an approximate area of 3000 ha, in the sector called Aguablanca Distric (see Figure 2.4). This zone present an intensive growth of population, going on from 13 neighborhoods in 1981 (28000 inhabitants), to 29 neighborhoods in 1983 (130000 inhabitants) and to 42 neighborhoods in 1985 (167600 inhabitants). The population registered by the DANE (2005) in this sector is 539869 inhabitants, which is equivalent approximately to 26 % of the whole of inhabitants of the city of Cali. When this zone began it is to be inhabited it was completely devoid of public services, nevertheless, at present it is provided with the services of drinkable water and sewerage, with an approximate coverage of 97 % (EMCALI, 2007).

The migration trends towards Cali are mainly caused by violence and internal wars in the country that has caused that people flee their villages looking for more secure dwellings. Between 1985 and 1998, more than 53000 caused-violence immigrants arrived to the city whereas around 16000 caused-violence immigrants arrived between 1999 and 2002.

The number of immigrants from the violence that arrive to Cali shows that the city has become one of the preferred migration urban centers. Currently around 70% of the citizens in Cali are immigrants that were born in other departments of Colombia (URL-1).

Figure 2.4. Immigration from the departments Cauca, Choco, Nariño and Valle del Cauca to Aguablanca Dristrict

2.1.3 Climate

Since Cali is located in a tropical zone, there are not seasons affecting climate. The climate is mostly defined by the mountainous topography and by the elevation above sea level so the weather changes between middle cold and hot temperature (DAPM, 2000). Figure 2.5 shows the temperature and precipitation distribution along the transversal section of the municipality of Cali according to the elevations above sea level.

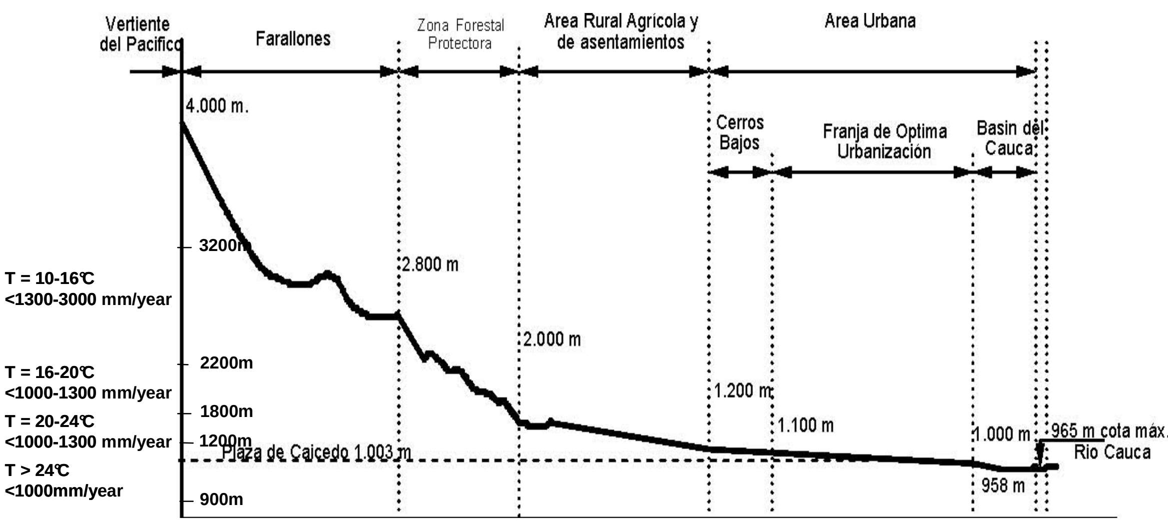

Figure 2.5 Transversal section of the Municipality of Cali and the respective temperatures and precipitations regimes

Source: DAPM, 2002

In the municipality of Cali there are identified four climates based on the air temperature and the spatial distribution of precipitations:

Hot and moderated dry weather: It is mostly present in flat areas such as in the city of Cali with elevation ranging from 900 and 1200 m above sea level and temperatures higher than 24°C. There is lack of frequent precipitations which in average are inferior to 1000 mm/year.

Middle humid weather: It is present in the slope of the hill in the west mountain range with altitudes between 1200 and 1800 m above sea level and temperatures between 20 and 24°C. Precipitations are frequent and well distributed between 1000 and 1300 mm/year.

Cold and moderated humid weather: It is present in altitudes between 1800 and 2200 m above sea level in the east mountain range and presents temperatures between 16 an 20°C. Precipitation is similar to the middle humid weather.

Humid cold weather: It is present in altitudes between 2000 and 3200 m above sea level and presents temperatures between 10 an 16°C. Precipitations are regular and well distributed.

Precipitations in the city vary between 1300 mm/year in the south and 1000 mm/year in the north increasing in the south-west direction. In the mountain areas, precipitations vary between 1300 and 3000 mm/year. Rainy periods occur mainly in the months of March, April, May, October and November. Dry periods correspond to the months of January, February, august and September. December and June are the transition periods (URL-2).

2.2. SOCIOCULTURAL CHARACTERISTICS

2.2.1. Education

In year 2006 Cali registered a gross coverage in education of around 87% (URL-3). 94,9% of the population older than five years are able to read and write. Figure 2.6 shows that people between 6 and 10 years of age are the biggest group attending schools. On the other hand population older than 18 years register a low school attendance percentage (DANE, 2005b).

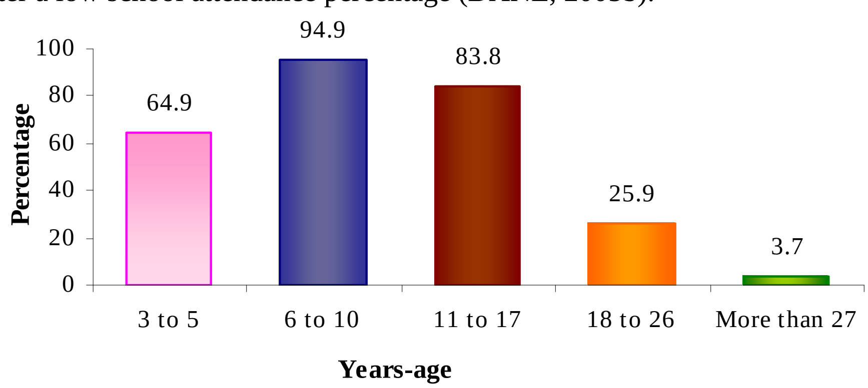

Figure 2.6 Attendance to education centers in Cali
Source: DANE, 2005b

According to Figure 2.7, the percentage of illiterate population that lives in Cali is around 4,8%. 30,9% has reached a basic primary education and 38,1 % secondary education. 9,5% has reached university education and 1,5 have achieved specialized education such as masters and PhDs.

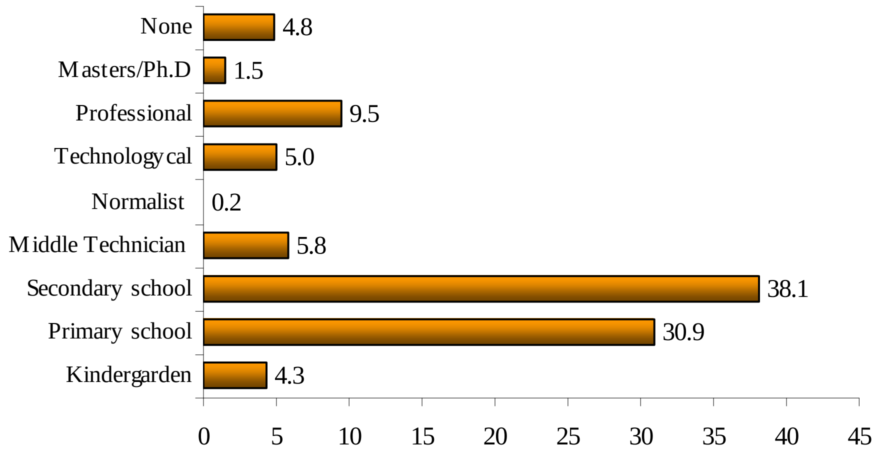

Figure 2.7 Educational level of inhabitants of Cali
Source: DANE, 2005b

2.1.4 Health

Health service

Health coverage in the municipality of Cali is around 75,3% with 40,6% access to priority health services in 2003. According to the Panamerican Health Organization, Cali has been assigned a value of 0,3 in the rank of healthy municipalities (in a scale up to 1.0). The goal for year 2007 was to increase such index to 0,7 (Alcaldía Municipal de Santiago de Cali, 2004).

As stated by DAPM (2004) cited by DAGMA-ASOCAR (2005), the health service infrastructure in the municipality of Cali consists of:

- Two general hospitals
- Two specialized hospitals
- 49 health offices in the urban area
- 23 health offices in the rural area
- 29 health centers
- 28 clinics

Epidemiologic indicators

According to epidemiologic indicators registered in Table 2.2 it can be seen that in Cali, the birth rate is of 20,2% per 1000 inhabitants and in average there are 1,9 children per female. Additionally, the life spam is of 71,9 years for the total population being 76,3 years for women and 69,3 for men.

Table 2.2 Epidemiologic indicators year 2005

Indicator	Colombia	Valle	Cali
Gross birth rate (TBN) per each 1000 inhabitants	22,0	19,4	20,2
Gross dead rate (TBM) per each 1000 inhabitants	5,0	6,0	6,5
Growth rate (TCV) per each 1000 inhabitants	17,0	13,4	13,7
Gross children dead rate (TMI) per each 1000 live-born babies	26,0	20,1	12,0
Pregnancy mortality rate (TMM) per 100.000 live-born babies	130,0	81,0	59,0
Life spam (years)	72,0	71,5	71,9
Fertility global rate (TGF) Average children per female	2,6	2,2	1,9

Source: URL-4

2.2 SOCIECONOMICAL ASPECTS

2.2.1 Non-fulfill Basic needs index NBI

The indicators that evaluate the coverage of the non-fulfill basic needs index are: inadequate dwellings, overpopulated dwellings, dwellings with inadequate public services, dwellings with high economical dependency, dwellings with school-age children which do not attend school.

According to the census in 2005, in the urban area of Cali, 10,9% of the population presented positive non-fulfill basic needs index. At national level the NBI was of 27,6% (DANE, 2005a).

2.2.2 Labor market trend

According to DANE (2005a), in the period between April 2006 and march (2007), the average of un-employed people at national level was 12,1%. Cali presented in the first semester of 2007, an un-employment rate of 12,5%. The sub-employment rate which refers to non formal-employment activities not related to the person professional level registered a rate of 39,9% in the municipality of Cali and 33,2 at national level (URL-5).

2.2.3 National gross product (NGP)

The city of Cali together with the Valle del Cauca department make part of the main economic sectors in Colombia. Cali is considered as an important economical national and international exchange axis. Its proximity to the principal port of Colombia (Buenaventura) and to the Panama channel make of it a key market point in Colombia.

According to DANE in 1995, the NGP annual growth in the Valle del Cauca region was almost the double of the national NGP. In 1997, the Valle del Cauca NGP was inferior to 1%. Afterwards an economical standby in Colombia happened where the NGP reached -4%and since then the NGP in the region of Valle del Cauca has presented high and low trends as it can be seen in Figure 2.8.

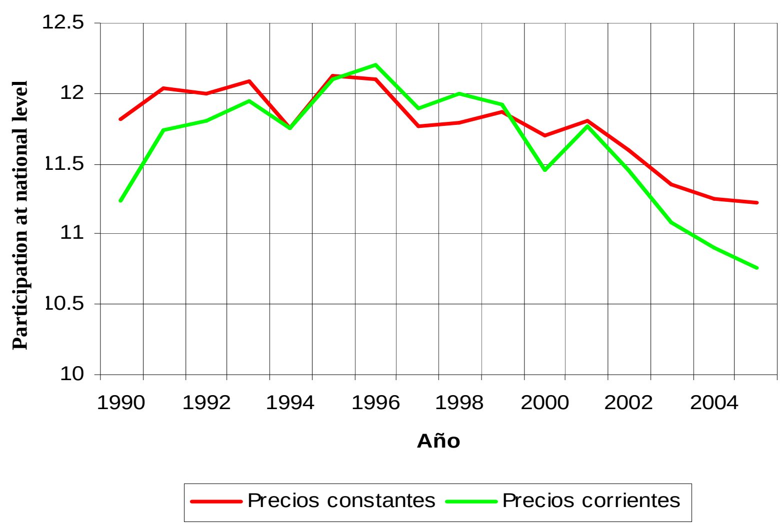

Figure 2.8 Historical percentage of the NGP in the Valle del Cauca in comparison to the national index, constant and current prices

Source: URL-6

2.2.4 Economic sectors

Industrial sector: In the municipality of Cali there are 4857 production units but only the 9,44% of them is dedicated to the industrial sector. In the period of 1990-1996 there were four main industrial areas in the municipality:

- Chemical industry with 22% of the municipal NGP
- Food industry with 19% of the municipal NGP
- Rubber industry with 8% of the municipal NGP
- Paper and press industry with 9% of the municipal NGP

The small industries are located in the residential areas in low and middle class estratos represented mainly by the chemical, paper, rubber and graphic arts industries (DAGMA-ASOCARS, 2005).

Commercial Sector: This sector represents the main economic activity in the municipality with 60,40% of the total market establishments dedicated to commerce. Moreover, this economic sector represent around 36,43% of the employment rate.

Services Sector: According to the economic census, 30,16% of the establishments in Cali are dedicated to the delivery of services. This sector is the main source of employment with 47,01% of the employment rate.

Figure 2.9 shows the distribution in percentage of the commercial establishments in Cali according to their production sectors being the commerce and service delivery sectors the main economic activities.

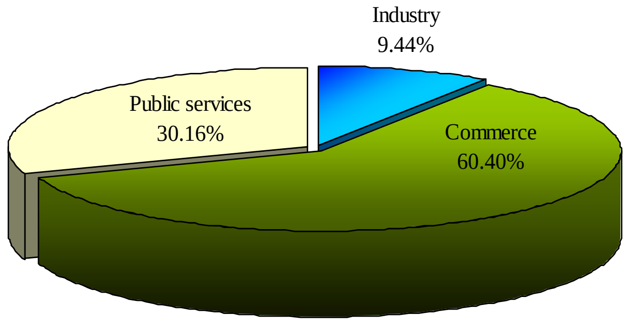

Figure 2.9 Distribution of the economical establishments in the municipality of Cali, census 2005
Source: DANE, 2005b.

As stated by the Economical census for Cali-Yumbo in 2005, the service delivery sector represents the main source of employment in the municipality of Cali as it is shown in Figure 2.10 where 47 % of the hired personal belongs to this sector. The commercial sector presents a significant percentage of employed personal as well.

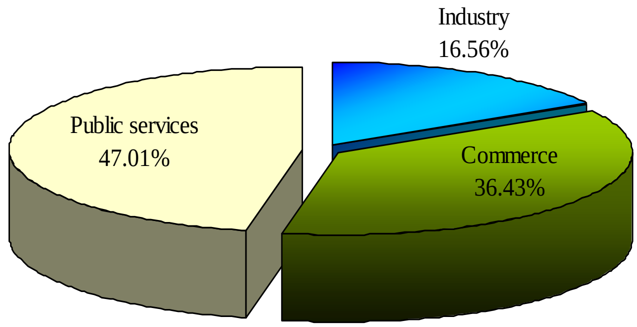

Figure 2.10 Distribution of employed personal based on the economical sector, 2005.
Source: DANE, 2005b.

2.3 PUBLIC SERVICES

2.3.1 Water supply system

EMCALI is the company responsible for the delivery of water supply, sewerage and energy services in Cali. The current drinking water coverage in Cali is 97% according to the technical planning department of EMCALI (2007). The drinking water distribution system in the city is supplied by: a) Puerto Mallarino plant with an average production of 6,6 m^3/s, b) Río Cauca plant with an average production of 2,5 m^3/s, c) Río Cali plant with an average production of 1,80 m^3/s and d) La Reforma plant with an average production of 1 m^3/s. Recently EMCALI has started operation of a smaller plant called la Ribera with a production of 0,030 m^3/s.

Puerto Mallarino plant which uses Cauca river as its water source treats and supplies around 76% of the drinking water demand in the city.

Chapter 4 explains in detail the drinking water supply system in the city of Cali together with the plants description, demand and consumption and main environmental issues associated to drinking water supply.

2.3.2 Sewerage system

According to EMCALI, the coverage of the sewerage system to September, 2007 is 94,8%. Following the land topography, the sewage system in Cali is divided in three drainage systems: the South Drainage System (SDS), North-West Drainage system (SDN) and East Drainage System (SDO).

Through these three drainage systems, Cali directly drains its wastewaters and storm waters to Cauca river. The only way of control of wastewater contamination in the city of Cali is made through the use of the wastewater treatment plant of Cañaveralejo (WWTP-C) which receives around 56% of the total wastewater produced in the city.

Chapters 4 and 5 explain in detail the sewerage system of the city together with the operation and efficiency of the WWTP-C and the main environmental issues surrounding these systems.

2.3.3 Electric energy

EMCALI is the responsible for providing the electric energy service to the municipalities of Cali and Yumbo. The company is the owner of the distribution infrastructure and together with EPSA (Energy company of the Pacific) own the energy sub-stations which are connected to the electric energy national network (URL-6).

2.3.4 Telecommunications

EMCALI is the principal enterprise of the service of telephony with 85 % of the local market. The telephone offices and the equipments of transmission are connected by an extensive network of optical fiber. At present (2007) EMCALI has approximately 510000 users. Other companies on the market of public telephony are UNITEL, Telecom, and ERT. The city has a disposition of 115400 lines.

There are three operators of mobile telephony, all with national coverage and with technology GSM, Comcel (of Mobile America); Movistar (of Telephone) and Tigo (of the ETB, EPM Telecommunications and Millicom International of Luxembourg), (URL-6).

2.3.5 Solid waste collection and disposal

The company responsible for the collection, transport and disposal of the solid waste produced in the municipality of Cali is EMSIRVA. The approximate 1800 ton/day of waste produced in the city are collected and transported to the disposal site of Navarro which is located in the area of Navarro in the south-east part of the city of Cali. Navarro is not considered as a proper land fill so currently the environmental authority CVC has stated that the disposal site needs to be closed and new alternatives of solid waste disposal need to be found.

Chapter 7 explains in detail the situation of the city of Cali regarding solid waste management, transport and disposal.

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3. Water Resources

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3 WATER RESOURCES

3.1 GENERAL OVERVIEW

The water network in the municipality of Cali, including Cali city has a sufficient amount of water to satisfy the necessities of the different urban, agricultural, industrial and recreational sectors. As it is shown in Figure 3.1, the dense hydrographic network of the municipality is conformed by the Pance, Meléndez, Lilí, Cañaveralejo, Cali, Aguacatal and Cauca River, which determine the centers of urbanization and economic development of the city of Cali (DAGMA - Universidad del Valle, 2007).

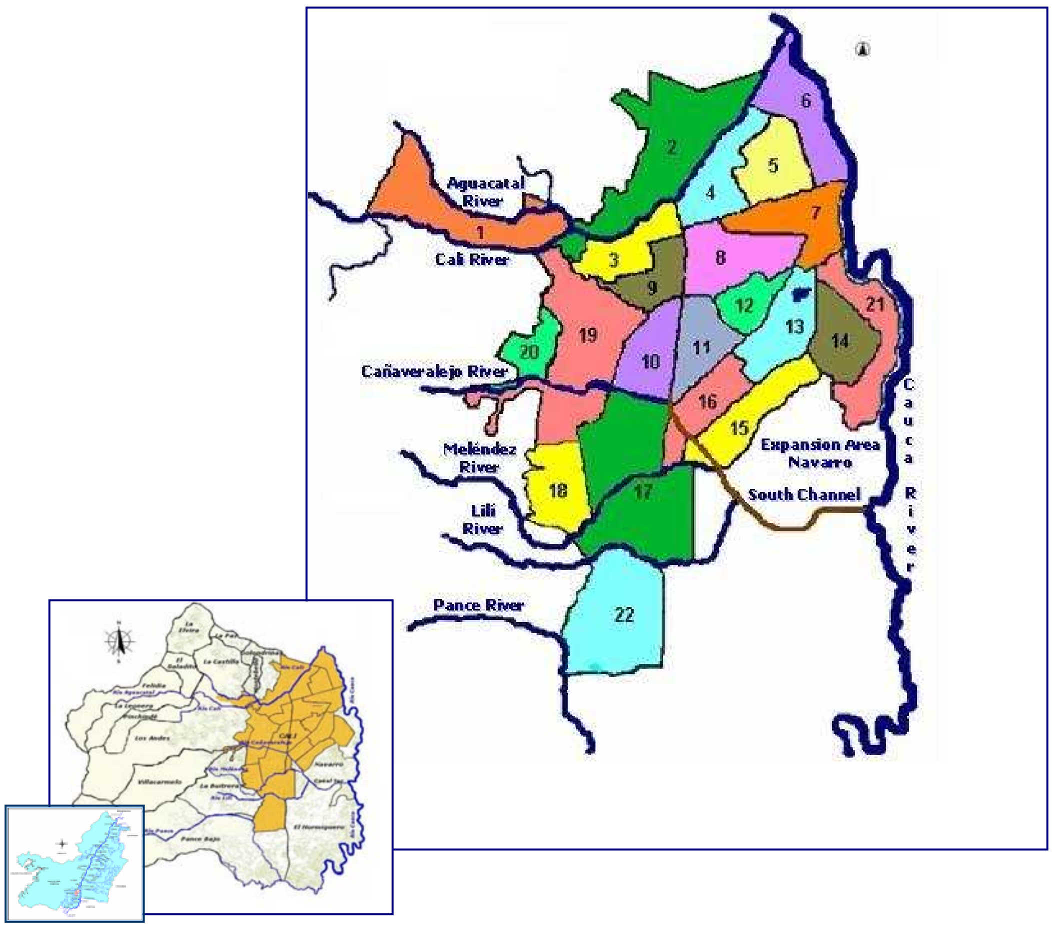

Figure 3.1. Urban area of the municipality of Cali and its seven rivers.
Source: DAGMA - Universidad del Valle, 2007

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 basins' areas are located at 1200 m above sea level in the highest part of the municipality where the majority of rain events occur (DAPM, 2000). The network of drainage of the seven rivers Cali has an overall of 757,56 km (CVC, 1996 cited by DAPM, 2000).

These rivers haven been affected in their composition and characteristics along its way through the urban area of Cali. The main characteristics affected are: river bank area, margins, route, quality and quantity of water. Some of these rivers have become also part of the drainage system of Cali being

receptors of the domestic and industrial wastewater produced in the city: 1) Cañaveralejo, Meléndez and Líli rivers discharge to the South Channel in the south drainage area of Cali; 2) Aguacatal river meets Cali river, which finally discharges to Cauca river after collecting wastewater discharges from the Collector Margen izquierdo in the North-west drainage area

Following, a description is made of the main characteristics of the geographical valley of the Cauca river basin, the quantity and quality conditions of the Cauca river and the others tributaries rivers that form the water network in the city of Cali.

3.2 GEOGRAPHICAL VALLEY OF THE CAUCA RIVER

The Cauca river is the second most important water source in Colombia. It is born in the Colombian mountain range (Macizo Colombiano). It surrounds the moorland of Sotará and has a length of 1350 km which crosses Colombia from the south to the north until meeting the Magdalena river (Figure 3.2). Cauca's river basin is extended along the Central and Western Mountain ranges with an approximated area of 63300 km^2.

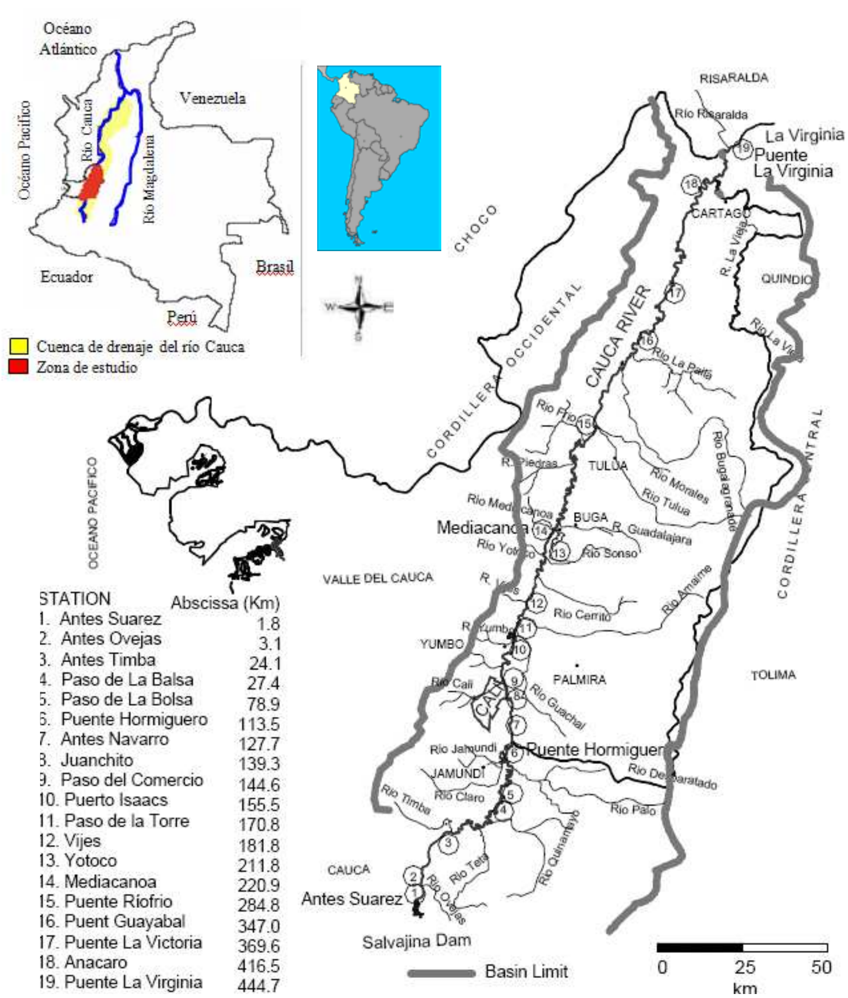

Figure 3.2 Cauca River general location, including its total river basin, geographical drainage valley with its monitoring stations.

The river crosses Colombia from south to north through the departments of the Cauca, Valle del Cauca, Quindío, Risaralda, Caldas, Antioquia, Cordoba, Sucre and the Bolivar. Along its river basin more than 10 million people live, who represent approximately 25 % of the Colombian population. Along Cauca river basin, there is located the sugar cane crops and the Colombian sugar industry, part of the coffee zone, the zones of mining and farming development of de department of Antioquia and an important sector of the manufacturing industry of the country (Velez et al., 2006).

The Cauca's river basin is divided and classified in three sections: high Cauca, medium Cauca and low Cauca (see Figure 3.3). High Cauca extents from its source through the Cauca and Valle del Cauca departments until the municipality of La Virginia (located in the department of Risaralda) with a length of 445 km. The High Cauca is called Cauca's geographical valley. Medium Cauca extents from the municipality of La Virginia until the municipality of Tarazá in the department of Antioquia with a length of 400 km. Low Cauca extents from Tarazá until it meets Magdalena river with a length of 260 km (CVC - Universidad del Valle, 2007a).

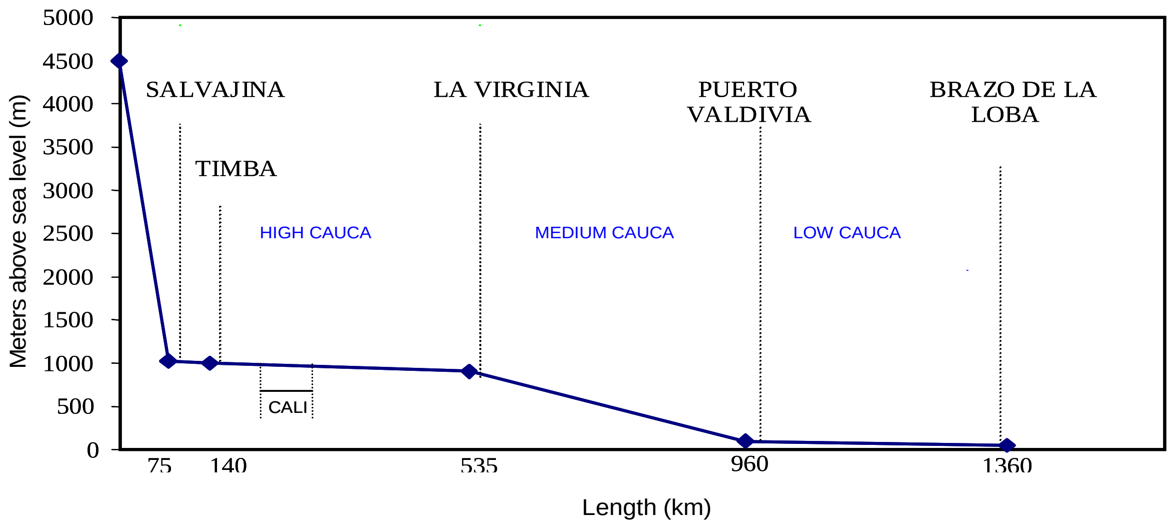

Figure 3.3 Cauca river basin general classification
Source: CVC-Universidad del Valle, 2007a

The Cauca's river geographical valley is considered as one of the most fertile areas in Colombia which is the base for an important part of the Colombian economy. Along the valley many important economic industries are located such as coffee, mining, agriculture and sugar cane production (CVC-Universidad del Valle, 2007a).

The Cauca River flows for 445 km in its geographical valley and descends from a height of 1000 meters to 900 m above sea level. The geographical valley covers an area of 317595 ha and it is located between the dam of Salvajina and the municipality of La Virginia (see Figure 3.2) crossing the departments of Cauca and Valle del Cauca. This stretch of the river has an average width of 105 m, which at its highest level can fluctuate between 80 m in the high part of its course (Salvajina – La Balsa) to 150 m in the lowest part (Anacaro – La Virginia). The depth at its highest level can vary between 3,5 and 8,0 m (Velez et al., 2003). There are 40 tributaries between Salvajina and la Virginia with strong slopes and considerable short-lasting spates. Figure 3.4, Figure 3.5 and Figure 3.6 show the complete geographical valley from Salvajina – La Virginia divided in three sections.

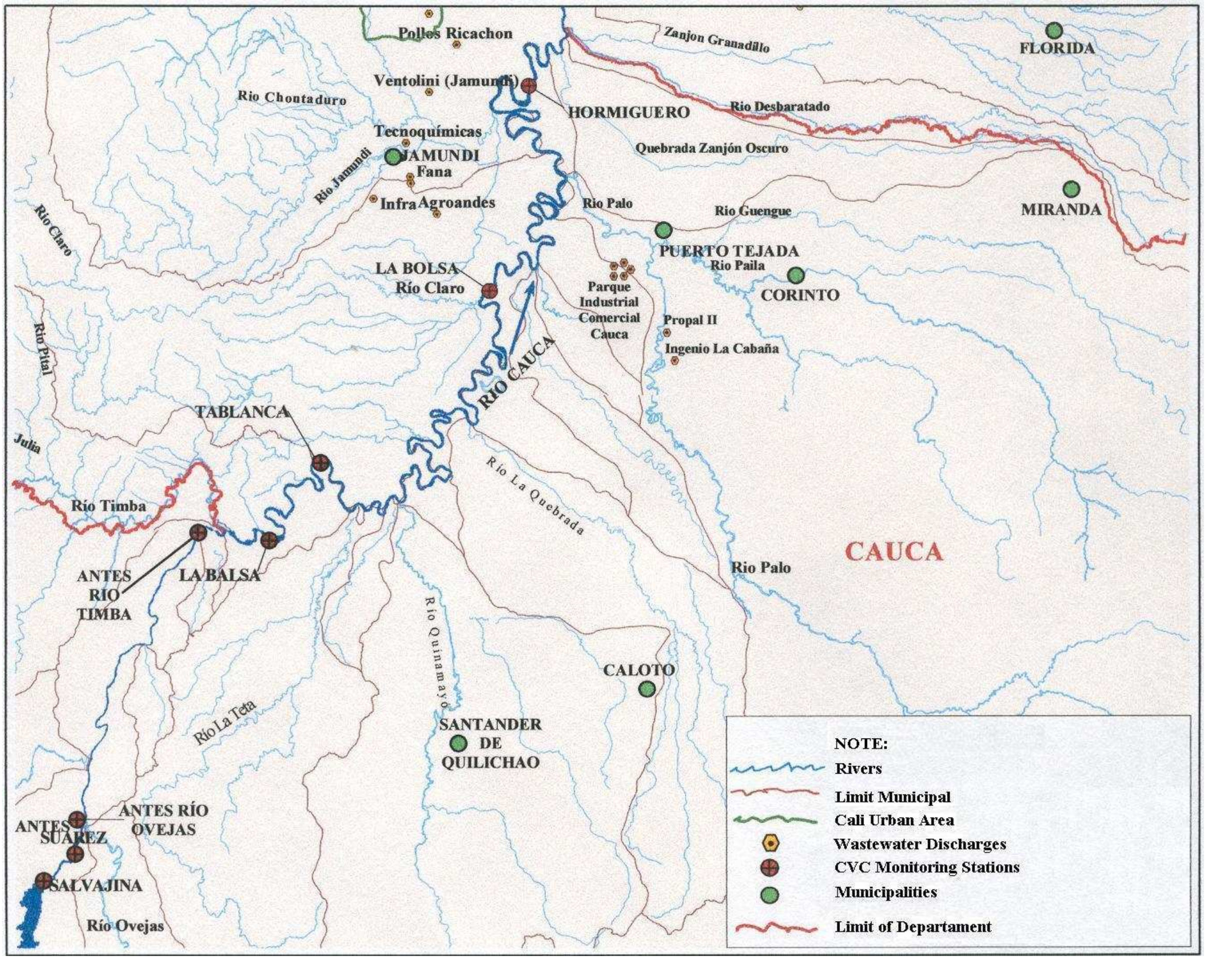

Figure 3.4 Main tributaries, industrial discharges and municipalities along Cauca's river geographic Valley. Section: Salvajina– Hormiguero

Figure 3.4 shows the first section Salvajina– Hormiguero, Figure 3.5 shows the middle section Hormiguero – Mediacanoa and Figure 3.6 shows the last section Mediacanoa – La Virginia . The Figures show in addition to the tributary rivers, the municipalities and the main industrial discharges around the geographic valley.

As mentioned before, the geographical valley crosses the departments of Cauca and Valle del Cauca. The stations antes de Suarez (at the level of Salvajina dam) to Timba are located in the department of Cauca The stations from Timba to Anacaro are located in the department of the Valle del Cauca and the station La Virginia is located in the department of the Risaralda.

In the Cauca river between the dam of Salvajina and the station La Virginia, there are located 19 monitoring stations which serve the CVC (Corporación Autónoma regional del Valle-environmental authority) to carry out systematic monitoring to control the quality and quantity of the river. Annex 3.1 describes the monitoring goals, quality parameters measured and the monitoring frequency.

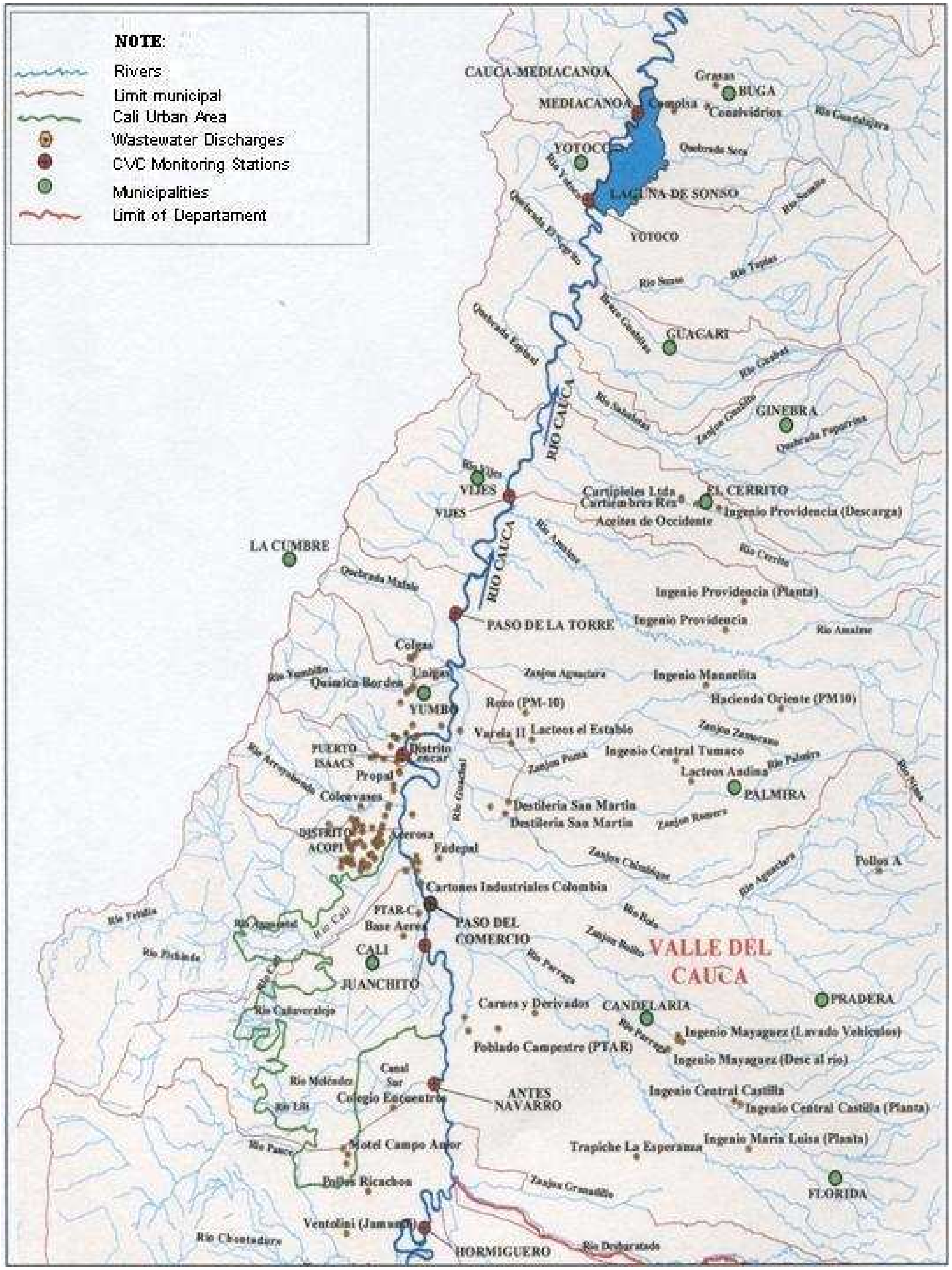

Figure 3.5 Main tributaries, industrial discharges and municipalities along Cauca's river geographic Valley. Section: Hormiguero – Mediacanoa

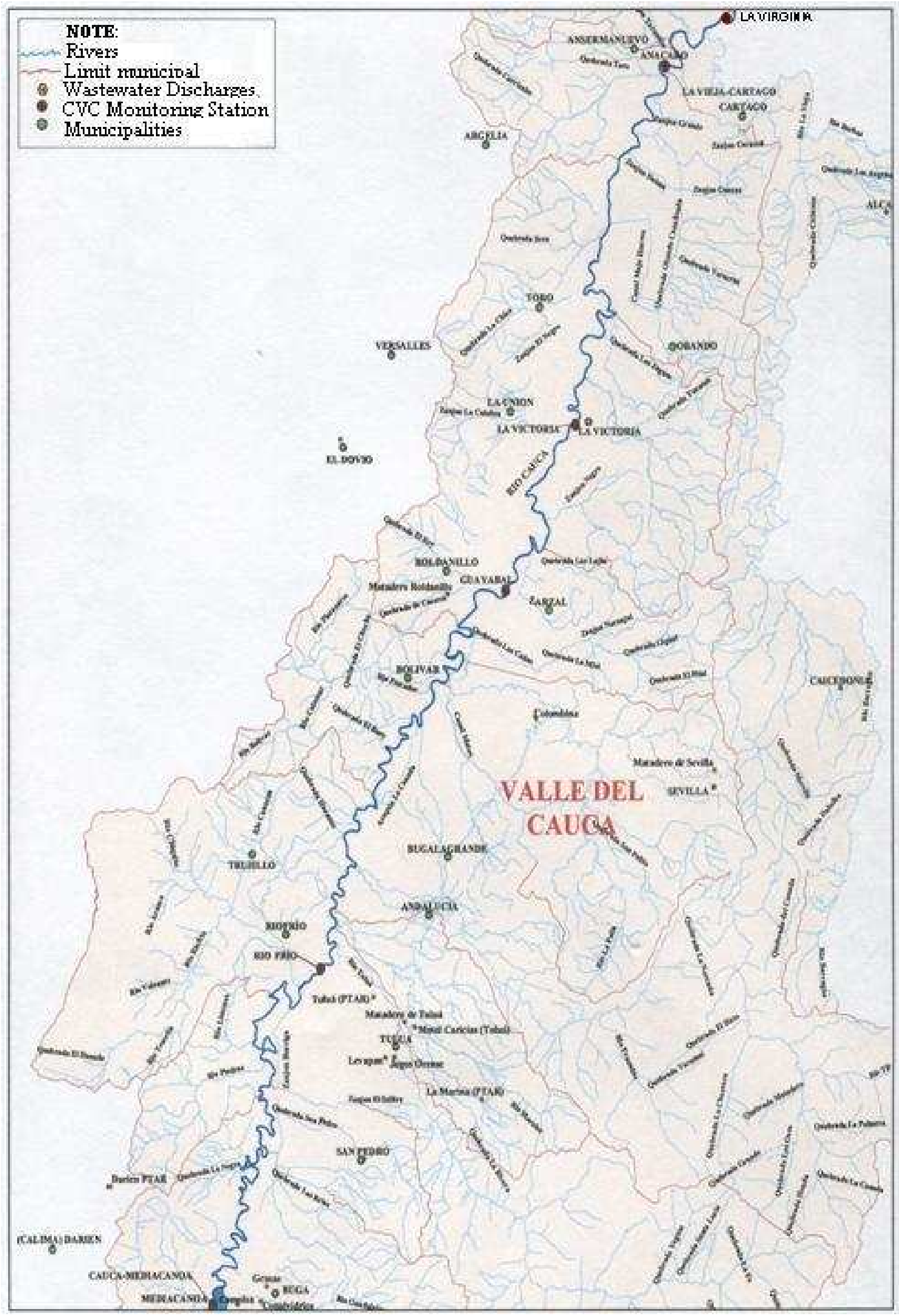

Figure 3.6 Main tributaries, industrial discharges and municipalities along Cauca's river geographic Valley. Section: Mediacanoa – La Virginia.

3.2.1 Land uses

The geographical valley is located mainly along the departments of Cauca and Valle del Cauca. The Cauca river basin in the Cauca department has an area of 739480 ha which represents 24,2% of the area of the department. According to the land use defined by CRC (Corporación Autónoma Regional del Cauca – environmental authority), the land uses are mainly for commercial crops of pine, coffee, plantain, flowers, cassava, and beans among others. The mining sector is also present exploiting bauxite. There is also small scale fish activities, cattle breeding and agriculture exploitation by indigenous groups. The paper and sugar industries play important roles in the land use. Gold and coal exploitation is a relevant activity which has impacted natural resources (EMCALI- Universidad del Valle, 2006).

The Cauca river basin in the Valle del Cauca department is manly used for cattle breeding in green areas which correspond to 38,6% of the land use, followed by sugar cane crops with 17% and other agriculture activities with 14%.
Table 3.1 shows the main land uses.

Table 3.1 Land uses in the geographical river basin in the Valle del Cauca department

Land use	Area (ha)	Area (%)
Green areas	414474,5	38,6
Sugar cane crops	184954,5	17,2
Natural virgin forests	157439,5	14,7
Permanent crops*	150547,1	14,0
Rastrojo (type of grass)	61218,3	5,7
Moorland vegetation	44465	4,1
Urban areas	24468,8	2,3
Cultivated forests	12463,9	1,2
Guadua forest	7527,9	0,7
Water bodies	6111,5	0,6
Infrastructure	6735,9	0,6
Semi-permanent crops	2425	0,2
Mining	1054	0,1
Total	1073885,9	100

Source: CVC-Universidad del Valle, 2004.
Note: *Permanent crops: fruits trees, grapes, coffee, cacao, melon, cotton, plantain and pumpkin
**Semi permanent crops: sorgo, soy, corn and rice

However, sugar cane crops and its industrial process have impacted the quality and quantity of the water resource mainly by 1) groundwater depletion when it is used in irrigation and 2) river pollution by chemical products used in the process (CVC – Universidad del Valle, 2004).

The destination of forests and hill areas for cattle breeding (38,6%) has generated an ecological imbalance caused by deforestation, degradation and change in the land use. Table 3.2 shows the different erosion levels along the Cauca river basin. Erosion has impacted quality and quantity on the water resource mainly in winter season when the dragging of sediments is more sever causing an increase in the sediments, turbidity and color of surface waters. Hence, the uses of the resources may be limiting human consumption, and crop and agriculture when the sediments may clog the used systems and the soil permeability (CVC-Universidad del Valle, 2004).

Table 3.2 Soil erosion levels in the Cauca river basin

Level	Area	
	(ha)	(%)
Highly severe	29323,9	2,7
Severe	151387	14,1
Moderated	331711,4	31
Low	65296,3	6,1
Natural**	139199,7	13
Not studied*	20200,9	1,9
Flat area	333416,6	31,2
Total	1070535,8	100

Source: CVC – Universidad del Valle, 2004
Note: *high zones in Riofrío, Piedras, Pescador, Jamundí, Claro and Timba river
**Forests without and apparent lost in land use

3.2.2 Water uses

The main water uses in the department of Cauca are in the agricultural sector, industrial production, human consumption and energy generation.

Cauca River has been used for fishing, recreation, energy generation, riverbed matter extraction, human consumption, irrigation and industry. It is also used as a receiving source for solid residues and dumping of industrial and domestic residual water, which has caused deterioration in water quality.

In the department of the Valle del Cauca, the Cauca river and its tributary rivers are used as water source for three important sectors in the region namely agriculture, domestic and industrial use. Figure 3.7 show the water quantity and used percentages for these different sectors. The sectors that more use the river as drinking water source are the domestic and agriculture sectors. It is observed that the agricultural use of the Cauca River basin as irrigation is the predominant one in the Department of Valle del Cauca (86%), being mainly used in the irrigation of the sugar cane and in the crops of the district of irrigation located in the north of the Department.

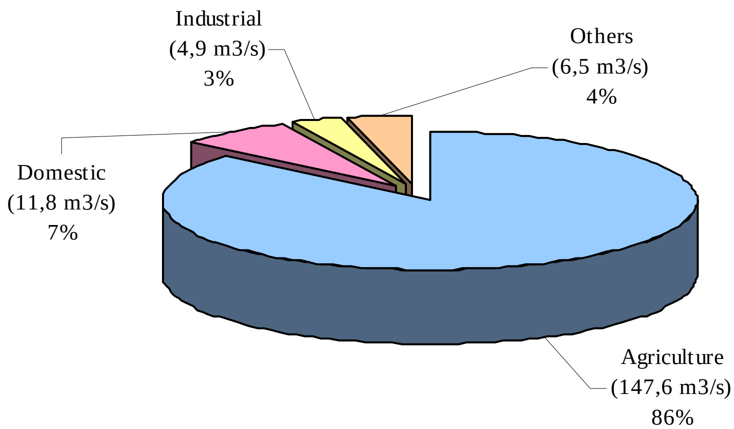

Figure 3.7 Water use of the Cauca river basin in the Valle del Cauca department
Source: CVC- Universidad del Valle, 2004

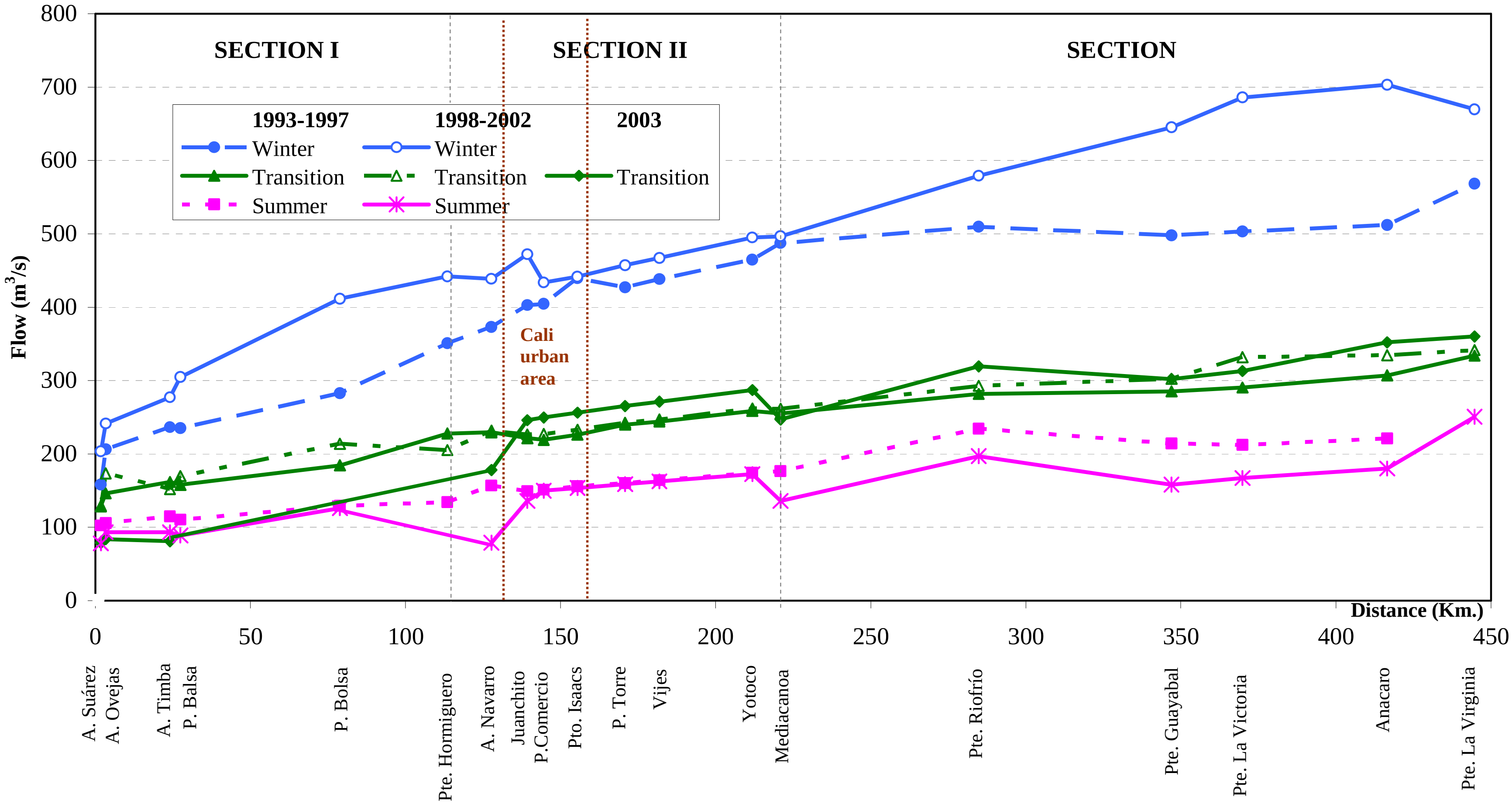

Figure 3.8 Historic Flow profile in Cauca River. Periods 1993 – 1997, 1998 – 2002 and 2003 Section: Salvajina – La Virginia. Conditions: Winter – Transition – Summer

Source: CVC-Universidad del Valle, 2004

3.2.3 Cauca river water quantity

Figure 3.8 shows the average flows of Cauca River during the periods 1993-1997, 1998-2002 and year 2003 during summer, winter and transition season (between summer and winter); between the Suárez and La Virginia stations.

Period 1998-2002 and 1993-1997 present the biggest flows during winter-transition season and summer season respectively. Also, an increasing flow trend is seen in this sector. Table 3.3 shows the resume of the flow ranges registered in the mentioned seasons.

Table 3.3 Flow ranges measured in the Cauca river. Periods 1993-2003

Period	Winter (m^3/s)	Transition (m^3/s)	Summer (m^3/s)
1993-1997	158-548	129-334	103-251
1998-2002	204-670	140-341	97-234
2003		81-360	80-251

Source: CVC-Universidad del Valle, 2004

3.2.4 Water quality

To describe the waster quality of Cauca river along it geographical valley, following , it is presented the historical analysis of the DO concentrations registered by the CVC, in the samplings made in the 19 stations on the Cauca's river geographical valley, section Salvajina-La Virginia. Such monitorings where made during the periods 1993 – 1997, 1998 – 2002 and year 2003 (see Figure 3.9). For the understanding of the DO profile, three main sections were defined: Salvajina-Puerto Hormiguero, Hormiguero-Mediacanoa, Mediacanoa-La Virginia.

Section Salvajina – Puente Hormiguero. In general for the evaluated periods it is observed that the levels of DO in the stations Antes Suarez and Antes Ovejas, located after the course of Cauca River by the Salvajina dam, are lower that the reported DO in the stations located downstream these two stations, phenomenon that can be associated with the increase of the dissolved organic matter in the dam, which generates an increase in the BOD and therefore a diminution in the DO levels.

The recovery of the levels of DO in the River after the station Antes Ovejas is associated to the self aeration of the river, due to the topographical conditions of the river basin in this section, where slopes of near 0,11 % appear. In this first section the River also presents its best concentrations not only by the self purification but also by the few wastewater discharges registered in this zone in comparison with other sections. Additionally, it is seen that the average DO measured along the years is near the oxygen saturation for this area (7,4 mg/l) (Velez et al., 2003) except for the years 1993-1997 in the summer condition.

Section Puente Hormiguero – Mediacanoa. As it is shown in Figure 3.9 the DO presents a noticeable decrease in its concentrations throughout the stations located in this section, situation that reflects the impacts that undergoes Cauca River when receiving the discharges from the collectors of waste water and storm water from the City of Cali, the waste waters of the industrial zone of the municipality of Yumbo, as well as the discharges of some tributary rivers affected by industrial and domestic wastewaters of the different municipalities and industries located throughout its route. In summer the most critical condition appears, with lowest levels of DO around 1,0 mg/l between the stations Paso de La Torre and Yotoco, this is a recorded average value but in general lower values are presented reaching cero (Velez et al., 2006). This behavior can be associated with the diminution in the capacity of dilution of the River at this time and to its high degree of pollution present in this section. Moreover, the average DO measured along the years is far from being around the oxygen saturation value for this area (7,4 mg/l).

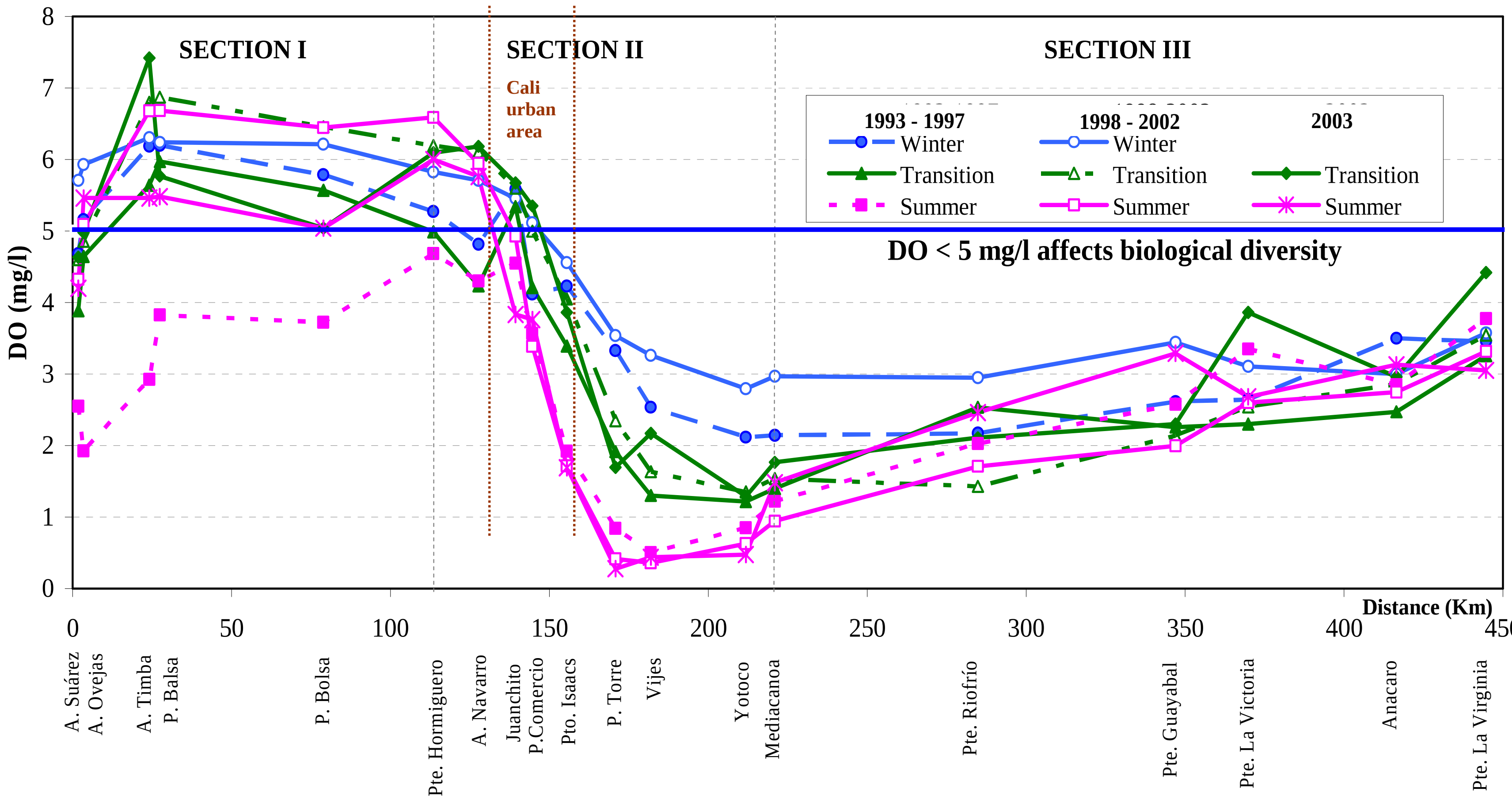

Figure 3.9 Historic DO profile in Cauca River. . Periods 1993 – 1997, 1998 – 2002 and 2003 Section: Salvajina – La Virginia. Conditions: Winter – Transition – Summer

Source: CVC-Universidad del Valle, 2004

Mediacanoa – La Virginia. According to Figure 3.9 in this section the DO for periods 1993 – 1997, 1998 – 2002 and year 2003, present a slight increase in its concentrations, changing from inferior values of 2 mg/l for summer in the Mediacanoa station, to 3 mg/l in the station Puente Virginia during the three defined climatologic conditions. Although the River shows a recovery as far as the presented DO concentrations, levels continue being critical in terms of the minimum requirements recommended by UNESCO (1996) to guarantee the diversity of aquatic biota (5 mg/l) and for reaching the value of oxygen saturation of 7,4 mg/l. This situation in this section is associated to the discharges from the tributary Rivers like: Riofrío, Tuluá, Morales, the Paila and La Vieja, which present a deterioration in their quality due to the wastewater discharges from different municipalities and some sugar cane crops located in the area. The gradual recovery that the Cauca River presents in this section is mainly due to the increase in the flow volumes which improves the capacity of dilution of the River (CVC-Universidad del Valle, 2004).

Physical chemical water quality index adapted to the Cauca river conditions

During the project of modeling of the Cauca river (PMC), and adaptation of a water quality index for the potential use of water bodies as sources for human consumption was carried out (ICAUCA) to evaluate Cauca river. This adaptation was made based on the most widely used national and international standards according to the environment conditions present in the Cauca river basin. Annex 3.2 shows a summarized description of the methodology and parameters used to adapt the ICAUCA index. In addition, the Annex 3.2 shows the water quality classification for human consumptions according to ICAUCA values. The ICAUCA index showed that neither of the monitored stations along Cauca river presents an optimum water quality. In the section Salvajina – Puente Hormiguero (before Cali), the river reports the highest ICAUCA values, classifying the water between good and acceptable (see Figure 3.10).

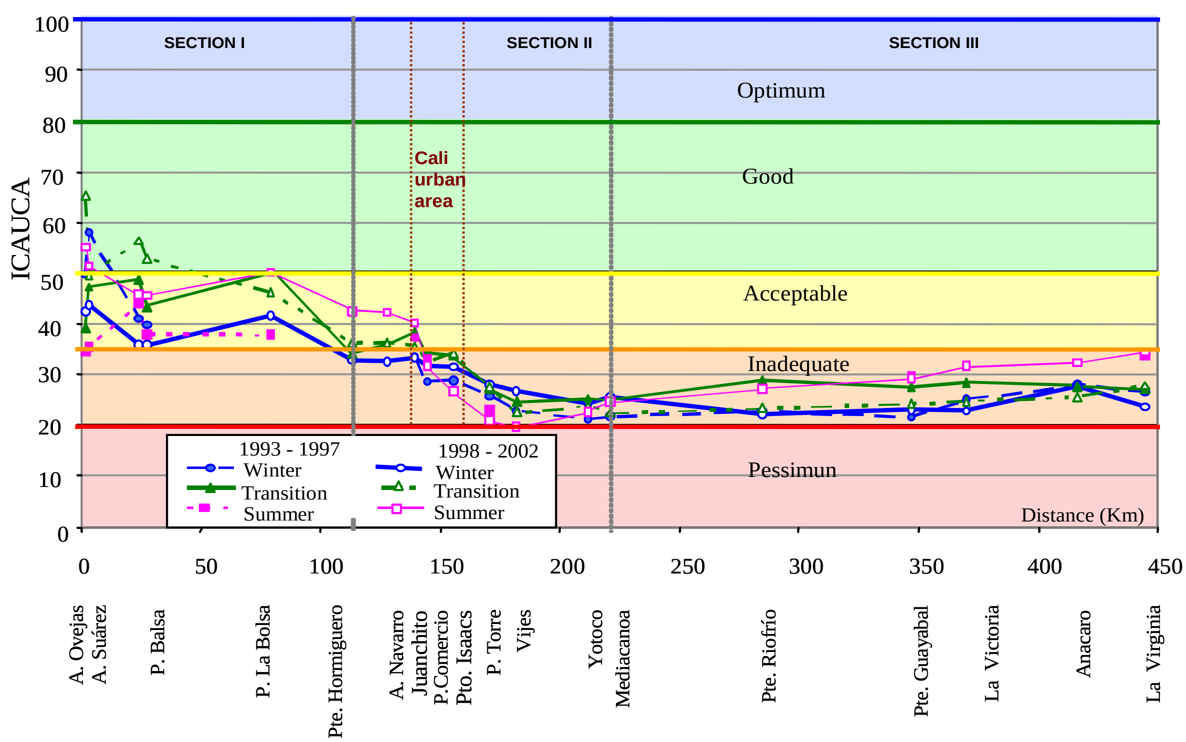

Figure 3.10 Water quality in Cauca River according to ICAUCA index. Period 1993 – 1997 and 1998 – 2002. Winter, transition and summer season.
Source: Patiño et al., 2005

However, at the end of this section the quality decreases to an inadequate water quality in both winter and summer season. This progressive decrease in the water quality is associated to the impacts generated by the tributary rivers when finally discharging to Cauca River. The water quality in the section Puente Hormiguero – Mediacanoa (including Cali's discharges) decreases from acceptable to inadequate in the beginning to inadequate and bad at the end of the section, being the worst index at the Paso de la Torre and Vijes stations (Patiño et al., 2005).

In the section Mediacanoa – La Virginia, the water in the majority of the stations is classified as inadequate water quality showing a slight recovery at the end of the section, in the Anacaro and La Virginia stations (Patiño et al., 2005).

Effects of the operation of the Salvajina dam in the Cauca river

The dam of Salvajina, that began operating in the beginning of 1985, constitutes one of the most important systems of regulation of the Cauca River. This Project had as main purpose the recovery of the agricultural operation on the flat territories of the geographic valley of the Cauca River, which corresponds to 130000 ha. In the past this area was periodically affected by floods caused by the overflow of the Cauca River and its tributary rivers. As secondary purpose of the dam were considered 1) the production of hydroelectric energy with a capacity of 270 MW and 2) the decrease of the pollution of the Cauca River by the increase in its minimum volume of 70 to m^3/s to 130 m^3/s (Galvis, 1988 mentioned by CVC-Universidad del Valle, 2007b) and the discharge of 250 Mm^3 in dry periods. The dam is located in the South-west, North latitude 2º 56' and east 76º 42' and on the height 1100 m above sea level. The average rain is 2522 mm and an average temperature of 23ºC. In the
Table 3.4 the main characteristics of the dam and in the Figure 3.11 a picture of Salvajina dam are shown.

Table 3.4 General characteristics of the dam

Characteristic	Measure
Intake area (km^2)	3960
Total length (km)	32
Average width (km)	1,2
Total area (ha)	2124
Average depth (m)	36,4
Maximum depth (m)	140
Total capacity (Mm^3)	908,6
Usage volume (Mm^3)	753

Source: adapted from CVC-Universidad del Valle, 2007b

Figure 3.11 Salvajina dam

From its initial operation, the regulating effect of the dam has introduced changes in the volume regime in Cauca river that can be possibly reflected in the quality of the water of the Cauca River, added to the changes caused by the progressive deterioration of the main source of development in the Region. The modification of some of the components that define the regime of volumes (magnitude, frequency, duration, and rate of variation) has changed the space and temporary distribution of the flow, which causes alterations in the structure, the composition and the operation of the fluvial ecosystem.

With relation to the hydrologic regime the changes were as expected: an increase in the volumes during the Post-Salvajina period (1985-2005), during the condition of summer and a decrease in the flow during the condition of winter. As far as the quality of the water, the levels of DO registered for the condition of summer do not present significant differences between the periods Pre-Salvajina (1980 – 1984), and Post-Salvajina (1985 – 2005).

The hourly volume variability originated by the operation of the dam of Salvajina causes hourly variations in the quality of water that cannot be visualized and be quantified base on the daily information. Following, the DO trend measured in years 2003 and 2005 in the stations La Balsa and Hormiguero is shown which better reflect the hourly changes in the quality of Cauca's river water caused by the operation of the Salvajina dam, considering the climatic conditions of winter and summer. In the station Balsa certain tendencies are observed that can be related to some of the following processes:

- The maximum levels of DO appear at noon (12:00 h) when the solar brightness and the temperature are maximum whereas the minimum concentrations happen at midnight (00:00 h) when the solar brightness is null and the temperature is minimum. This variation in DO can be associated with the photosynthetic activity in the sector of Balsa caused by the presence of seaweed of the dam of Salvajina (CVC – Universidad de Valle, 2007b).
- The dilution of the polluting load as a result of the volume increase takes place, which generates an increase in the dissolved oxygen levels. This effect is seen in the curve's changes in the hours following the release of the volumes in Salvajina.
- The fast release of the bigger water volumes from the dam can produce a reduction in the dissolved oxygen levels due to the increase in the speeds of the flow that produce the dragging of materials on the bed of the river and the settlement of sediments "phenomenon of washing of the river basin" (CVC – Universidad de Valle, 2007b).
- The capacity of self-recovery of the river diminishes, since the concentration of DO in the water coming from Salvajina is lower than the one in Cauca River in this section until La balsa station

Wastewater discharges

There are 40 tributaries between Salvajina and La Virginia, with a strong slope and considerable short-lasting spates. From the total organic discharges to the Cauca River, 59% is discharged by means of these tributaries (145 ton/day BOD in 1999). The most critical tributary rivers in terms of BOD load discharge are: Tuluá, Guachal, La Paila, La Vieja, Palo and Cali (Velez et al., 2003).

Regarding wastewater discharges to the river, the CVC has been periodically controlling and monitoring the wastewater discharges from around 200 industries located in the geographical river basin, whose wastewaters are discharged to the Cauca River and its tributaries. Figure 3.12 shows the BOD loads discharged to the Cauca river basin in the section Salvajina –La Virginia during 1979 to 2003. Figure 3.12 shows that sectors like the sugar cane production, paper industry and coffee production have reduced their polluting contribution to the Cauca River.

In year 1979 the sugar production industry spilled near 100 ton/day of BOD load to the river causing great impacts in the quality of the water resource and affecting the aquatic ecosystems. Nevertheless for the years 2001 and 2003, this same production sector reduced its polluting load to approximately 5 BOD ton/day.

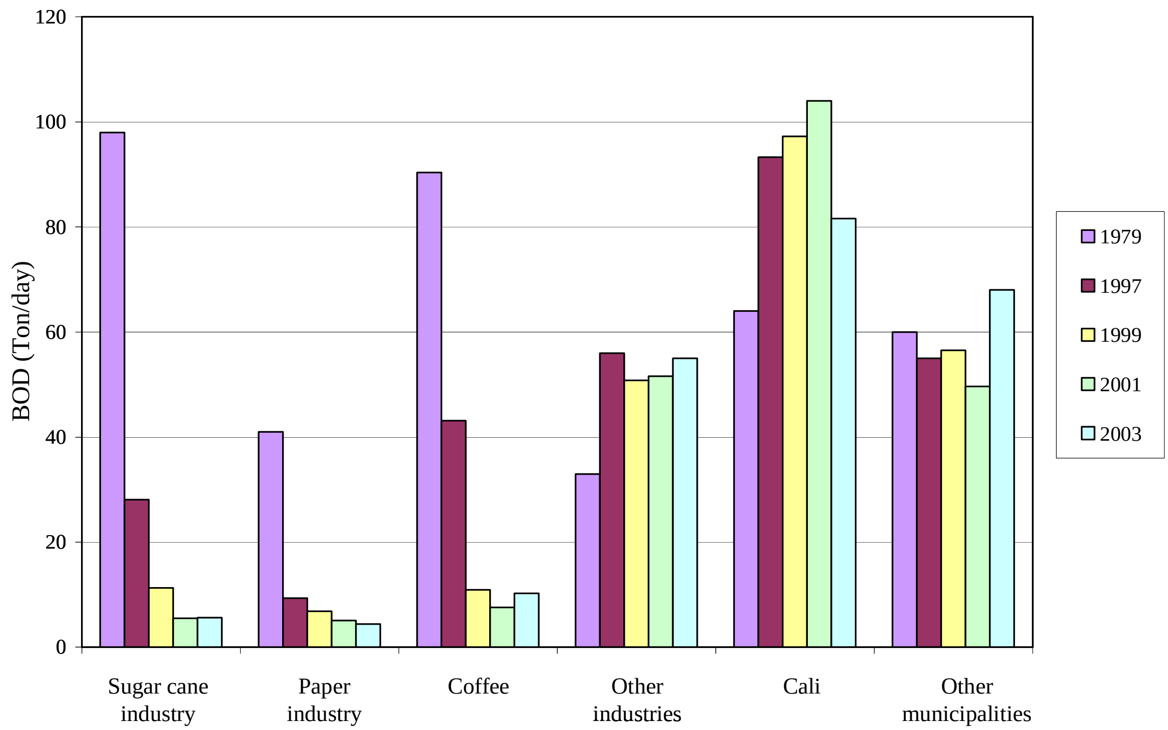

Figure 3.12 BOD load discharged to Cauca river. Section: Salvajina – La Virginia. Period: 1979 – 2003.
Source: CVC, 2003 cited by CVC-Universidad del Valle, 2004.

A similar behavior presents the paper industry and coffee sectors, when their contribution was of 40 and 90 BOD load ton/day respectively in 1979. These two industries along with the sugar cane one are the three productive sectors of greater impact on the quality of the water of the Cauca River. However, during the years 2001 and 2003 these sectors had reduced their polluting load in near 90% (CVC-Universidad del Valle, 2004).

Although, from Figure 3.12 it can be seen a decrease in the average industrial load discharges to Cauca river, there is no monitored evidence regarding the operation of the industrial treatment systems and sporadically it had been found specific discharge points with high pollution loads.

Likewise, the municipal wastewater load discharges have increased during the years, as a result of the growth of the population, the development of the industries within the cities and the low implementation of systems of wastewater treatment. Only for the case of the municipality of Cali in year 2003, a reduction in the contribution of BOD load is observed, associated with the beginning of the Wastewater Treatment Plant of Cañaveralejo (WWTP-C) which started operation at the end of year 2002 (CVC-Universidad del Valle, 2004).

Discharges from Cauca department

Cauca river in the Cauca department from its source to the sector located near Desbaratado river (in the border with the Valle del Cauca department) receives in average a BOD load of 20,86 ton/day (see Figure 3.13) being the municipal sector the highest contributor with a 68% of the total BOD_5

load. The river in its course through the department receives indirect or direct pollution from the nearby municipalities as well.

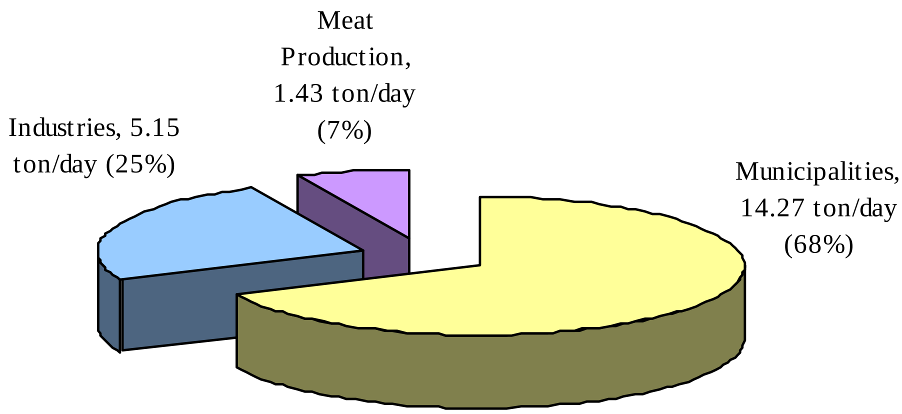

Figure 3.13 BOD load discharges in the Cauca river basin by the different commercial, industrial and domestic sectors in the Cauca department
Source: EMCALI-Universidad del Valle, 2006.

Cauca department has deficiencies regarding the management of wastewater in general. This situation is the main cause of problems related to respiratory deficiencies, water body's pollution, landscape deterioration and higher costs in the drinking water treatment (EMCALI –Universidad del Valle, 2006).

The river basin in the Cauca department receives high industrial wastewater contributions mainly from the paper and sugar cane industry (around 4,44 ton/day) which corresponds to 86,4% of the total industrial discharge to the river basin. However, after law Páez[1] was implemented, around 65% of the new industries created use now dry production and the remaining 35% has implemented wastewater treatment plants as clean production technologies which has helped lowering the impact from the new industries on receiving waters to around 469 kg/day (which corresponds to around 9,1% of the total load discharged to the river).

Regarding the discharges from the tributary rivers to Cauca river in the Cauca department, states that 47,1% of the total load (9,8 BOD ton/day) is discharged by the rivers located after Salvajina dam namely Palo, Zanjón Oscuro, Quinamayó and Ovejas rivers (EMCALI – Universidad del Valle, 2006).

Discharges from the Valle del Cauca department

In Figure 3.14, the contribution of BOD load in 2006 by the industrial and municipal sector, (monitored by the CVC to the industries, Cali and other municipalities) is shown. In the Figure, Cali is the municipal sector that contributes the most with BOD load (38%).

[1] The law Páez (law 218 of 1995) regulated the generation of economical incentives to create industries in the department of Cauca, at present there are an industrial complex in the south of this department.

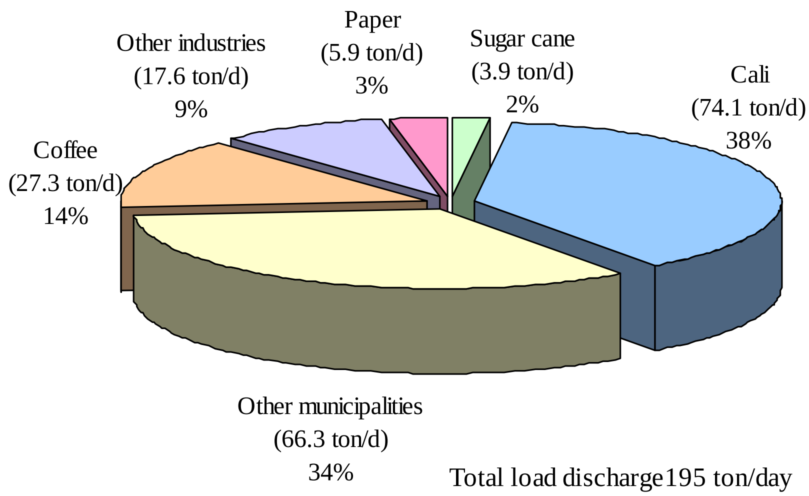

Figure 3.14 BOD load discharges to Cauca river basin in the Valle del Cauca department, year 2006
Source: EMCALI-Universidad del Valle 2006

3.3 RIVERS OF THE CITY OF CALI

3.3.1 Cauca River

The Cauca river enters Cali, from the mouth of the Jamundí river (South municipal limit with the municipality of Jamundí) and crosses approximately 30 km until it arrives at the mouth of the Cali river, that is the North limit of the city. In this section, it receives the discharges from Líli, Meléndez, Cañaveralejo and Cali rivers. The Cauca river is the main water source for approximately one million and half of inhabitants of the city of Cali (EMCALI – Universidad del Valle, 2006). The area of influence of Cali is located between the stations Hormiguero and Mediacanoa.

In Cali, Cauca river acts as the final discharge site for the wastewater produced in the city and in its rural area. From Hormiguero to Mediacanoa the progressive deterioration of the water quality is associated to the wastewater discharges from the domestic and industrial sector, mining exploitation, deforestation process and solid waste discharges from nearby municipalities.

Following a description of water quality of the sub-sections of Cauca river upstream, along and downstream to Cali.
Section from Hormiguero to Before the South Channel (upstream to Cali): A slight decrease in the dissolved oxygen levels is registered. This decrease is possibly associated, among other factors, to the accumulative effect of the domestic and industrial wastewater discharges in the Desbaratado river, the stream Zanjón Oscuro and water discharges from Palo and Jamundí rivers, located upstream Hormiguero.

Section Before the South Channel – Puerto Isaacs (along Cali): There is a considerable decrease in the concentrations of the dissolved oxygen as a result of the water discharges of the station before the South Channel and the discharges before Puerto Isaacs, which correspond to wastewaters from Cali that are spilled through the systems of drainage and channels. According to the results of the monitoring campaign in 2006 (EMCALI – Universidad del Valle, 2006), the average BOD polluting load discharged by the system of drainage of the city was 116,4 ton/day when the wastewater treatment plant of Cañaveralejo (WWTP-C) was operating without addition of

chemicals (Ferric chloride). The greatest contribution of BOD and COD load was the WWTP-C effluent with a percentage around 46%. In addition to the wastewater discharges of the drainage system of Cali, in this section the Cauca river receives industrial wastewaters discharges as well such as the paper industry and oil industry.

In this section, the south drainage system of the city discharges its wastewater to Cauca river which is contaminated by leachate coming from Navarro disposal site. This discharge occurs 4 kilometers upstream the water intake of drinking plants of Puerto Mallarino and Rio Cauca which deliver approximately 77% of the total drinking water to the city of Cali. The polluted discharges from the south drainage system threaten the treatment and delivery of drinking water to the city. According to the records of operation from the plants from year 2000 to 2007 the number of shutdowns in the plants has increased as follows: from 10 to 28 shutdowns per year in Puerto Mallarino and from 10 to 24 shutdowns per year in Rio Cauca plant (EMCALI, 2007b).

In the Section between Puerto Isaacs – Mediacanoa (downstream to Cali): The most critical point in the river appears in the Station Paso de la Torre, which presented anaerobic conditions, which are seen by the changes that take place in the water, such as the deterioration of the aesthetic aspect, dark coloration, floating substances and bad odors by the H_2S liberated. This condition appears as a cumulative response of the river influenced by the wastewater discharges of Cali, added to the domestic and industrial wastewater discharges of the municipalities of Palmira and Yumbo through the rivers Yumbo and Guachal. Although in this section the lowest DO concentration was recorded, after the station Paso de la Torre there was observed a recovery tendency, registering a slight increase in the DO concentrations.

The total load discharged to the Cauca river in the section Hormiguero- Mediacanoa during the four days of monitoring campaign in 2006 was 197,8 BOD ton/day; 404,2 COD ton/day and 228,4 TSS ton/day discharged by tributary rivers and the sewage system Cali. Regarding the origin of these discharges 40% arrive through the four tributary rivers and the other 60% was contributed by the city of Cali (EMCALI-Universidad del Valle, 2006).

Presence of hazardous substances. In the section Hormiguero-Mediacanoa there has been also found a potential risk of pollution in the water due to presence of hazardous substances such as high concentrations of phenolic compounds, some metals and organic matter (EMCALI- Universidad del Valle, 2006).

Figure 3.15 the diagram of boxes show the variation in the lead concentration which is similar in the stations Hormiguero and Before South Channel, the mean value for both stations is over the value recommended in Decree 1594 of 1984 (0.05 mg/l) (criteria of water quality for human consumption after conventional treatment). At the level of water intake in the station before Puerto Mallarino, the lead concentrations stay below the permissible limits.

In Table 3.5 the minimums, maximums and averages values of the concentrations of phenol compounds are shown (EMCALI-Universidad del Valle, 2006). In this Table it is possible to observe that the average total concentrations of phenols are above the limit established in Decree 1594 of 1984 of the Ministry of Health (that is of 2,0 µg/l). This means that there is a risk of by product formation from the disinfection with chlorine in the case of using the water as source for drinking water production.

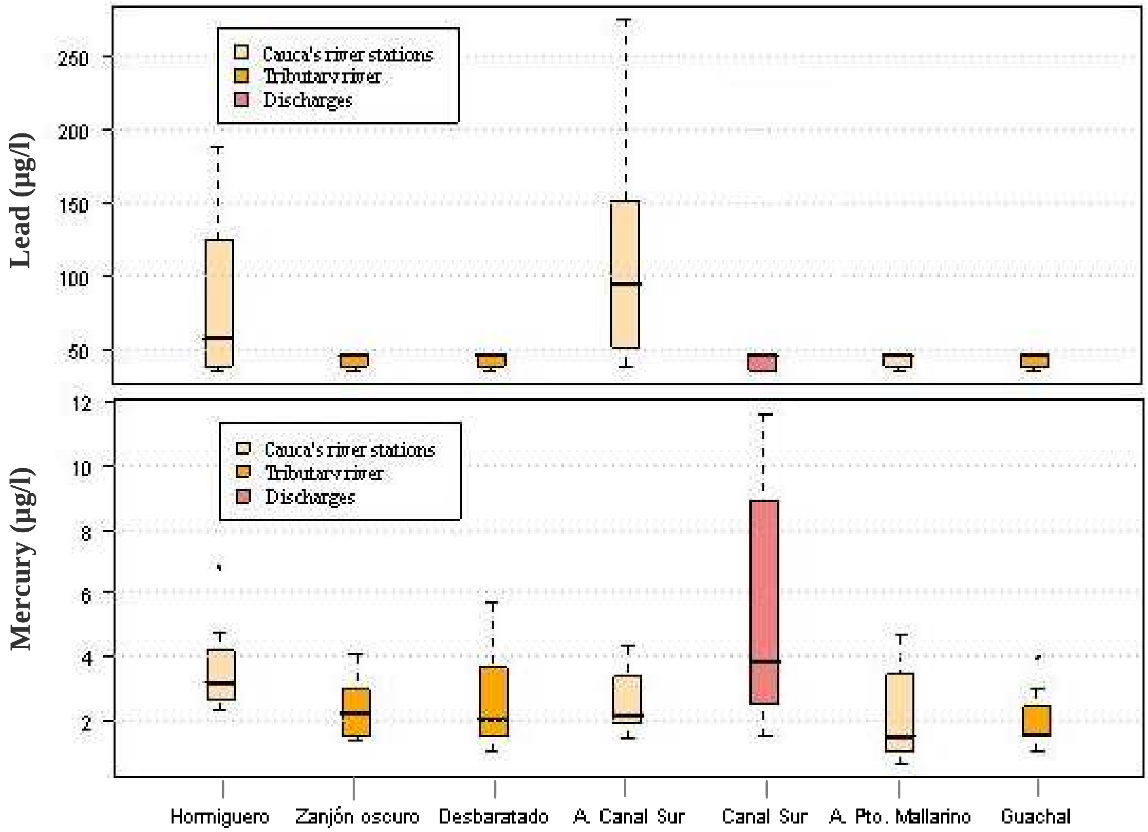

Figure 3.15 Boxes diagram presenting concentration of hazardous substance in the Cauca river: lead and Mercury in the period July 11-15, 2006
Source: EMCALI – Universidad del Valle, 2006

Table 3.5 Minimum, maximum and average phenols concentration in three stations of Cauca river and the tributaries before intake Pto. Mallarino

Parameters	Charact.	Cauca river			Tributaries				Decree 1594 – 1984
		Hormiguero	Before South channel	Before intake Pto. Mallarino	Zanjón Oscuro	Desbaratado river	Guachal river	Canal Sur	
Total phenols (µg/l)	Minimum	<1,00	<1,00	<1,00	<1,00	<1,00	<1,00	<1,00	<2,0
	Maximum	57,4	39,51	14,53	78,54	39,76	78,54	56,9	
	Average	20,06	12,53	4,42	19,87	18,81	19,87	12,78	
Penta-chlorine-phenol (µg/l)	Minimum	<0,35	<0,35	<0,35	<0,35	<0,35	<0,35	<0,86	<2,0
	Maximum	<0,35	<0,35	0,91	5,77	1,06	0,49	3,59	
	Average	<0,35	<0,35	0,42	1,09	0,47	0,37	1,49	
2,4,6 Tri-chlorine-phenol (µg/l)	Minimum	<0,86	<0,86	<0,86	<0,86	<0,86	<0,86	<0,86	<2,0
	Maximum	<0,86	<0,86	<0,86	<0,86	<0,86	0,87	3,59	
	Average	<0,86	<0,86	<0,86	<0,86	<0,86	0,86	1,49	

Source: EMCALI- Universidad del Valle, 2006.

3.3.2 Cañaveralejo River

The Cañaveralejo river is born in the slope of The Farallones of Cali at 1800 meters above sea level. The Farallones are the tallest rock formations in the West mountain range. The river limits the Northwest with the hydrographic river basin of the Cali river, on the South west with the Meléndez river basin on the east with the urban border. The Cañaveralejo river basin has an estimated area of 2882 ha and it is divided in three geomorphologic units: high, medium and low river basin, that go from the level 1800 above sea level (in the countryside of Cali) to the discharge in the South Channel, crossing an approximated length of 9 km.

Land use. The high part of the river basin (river source 1880 above sea level- La Sirena sector 1005 m.a.s.l) is characterized by the presence of forest areas with natural vegetation. This part has presence of small scale crops, low level of deforestation and cattle breeding activities.

The middle part of the river basin (La Sirena sector 1005 m.a.s.l- Cañaveralejo dam 988 m.a.s.l) is characterized by a displacement of the vegetation cover due to construction activities that is located in the protection area of the river basin. This area has been highly affected by charcoal mining activities, deforestation, cattle activities and uncontrolled urbanization activities.

The low part of the river basin (Cañaveralejo dam 988 m.a.s.l – South channel discharge 955 m.a.s.l) is characterized by being completely urbanized with a shortage of green areas (DAGMA-Universidad del Valle, 2004).

Water use. In the urban zone of Cali the only water use directly from the river is for gardening as irrigation for aesthetic purposes (DAGMA, Universidad del Valle, 2004). The river, in addition, is used as waste water receiver. In the urban section it gathers the discharges from drainage channels and water from nearby streams, which present a high degree of pollution.

Water quality

The Cañaveralejo River receives high domestic waste water volumes present in the storm water channels. It also presents changes in the hydraulic conditions of its river bed, which are reflected in the low slope (0,5%) and in the canalization of the river until its river mouth in the South Channel. These conditions make difficult the recovery of the river (DAGMA-Universidad del Valle, 2004).

Around the urban periphery of Cali, the Dissolved Oxygen concentrations existing in the river limit the life of the aquatic species (UNESCO, 1996), besides to inhibit their use for the agricultural preservation of the flora and fauna, recreation, activities and for human consumption, as it is established in Decree 1594 of 1984 (DAGMA-Universidad del Valle, 2004).

Along its course the river receives high polluting discharges from tributary rivers and adjacent towns so that when the river discharges to the South channel the DO oscillates around 1.0 mg/l in both summer and winter season Figure 3.16, Figure 3.17, and Figure 3.18 show the BOD and TSS discharges measured in different monitoring points and their direct relation to DO, respectively.

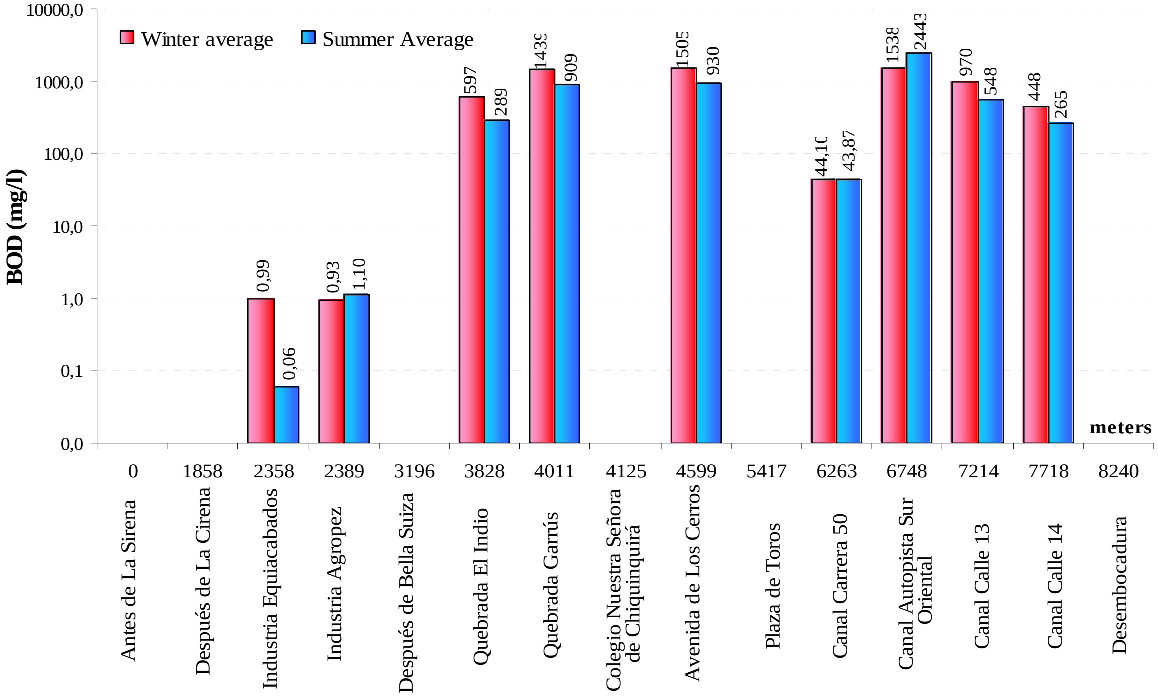

Figure 3.16 BOD load discharges along Cañaveralejo river
Source: DAGMA - Universidad del Valle, 2004.

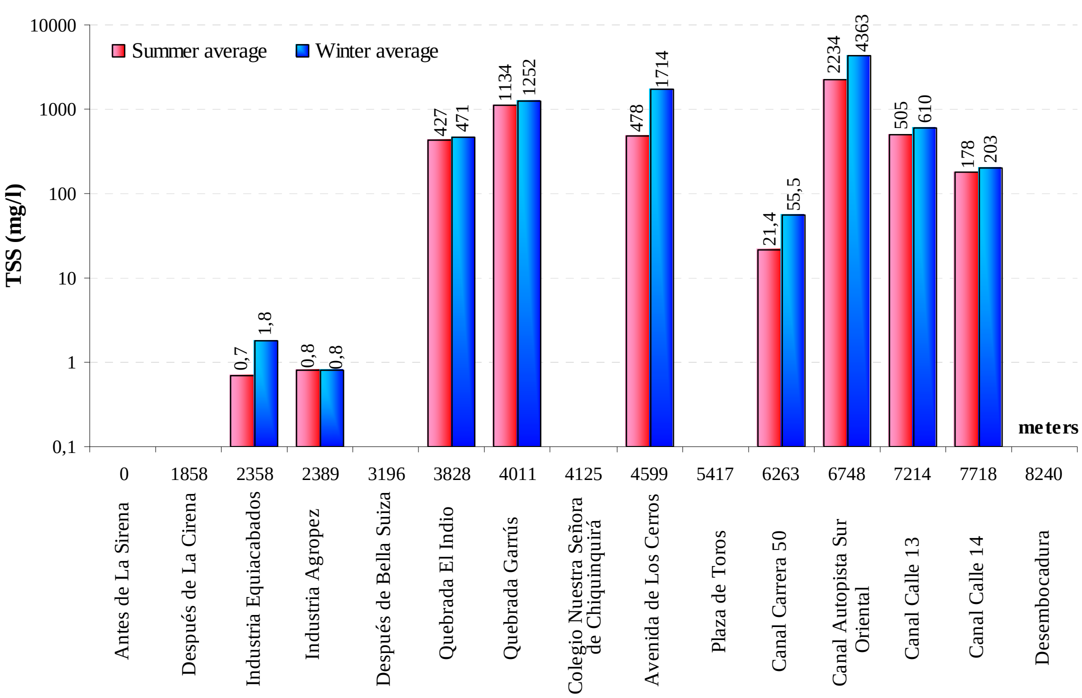

Figure 3.17 TSS load discharges along Cañaveralejo river.
Source: DAGMA - Universidad del Valle, 2004.

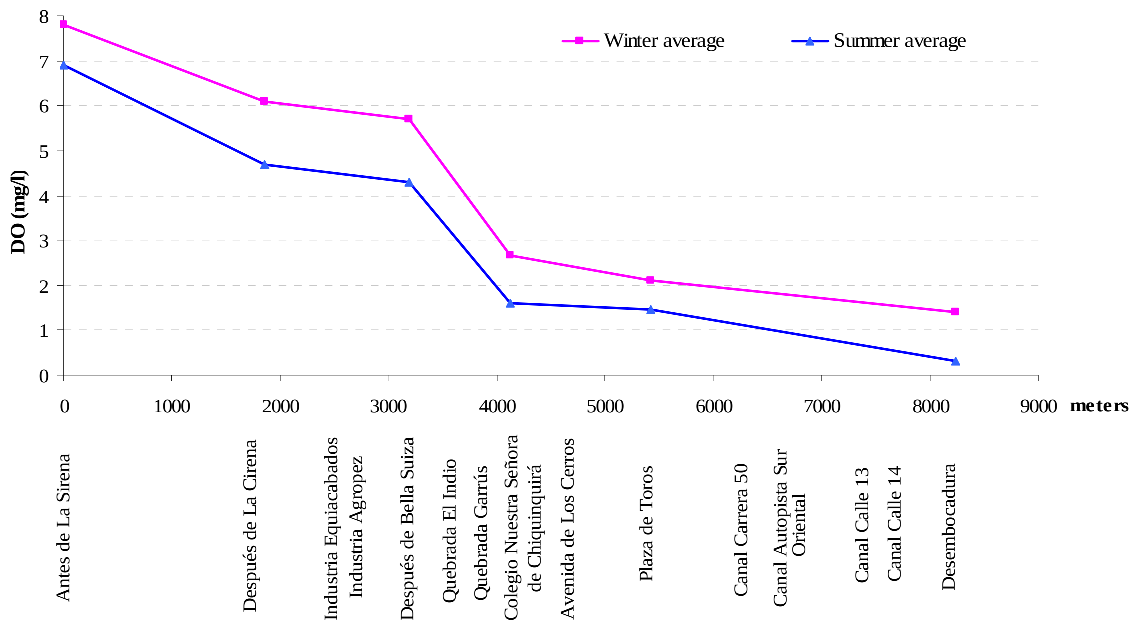

Figure 3.18 Dissolved oxygen in the Cañaveralejo river as result of polluting BOD and TSS discharges.
Source: DAGMA - Universidad del Valle, 2004.

Index ICA-NSF for the quality of water applied to Cañaveralejo river. The ICA-NSF is an index that considers the potential use of water bodies as sources for human consumption (a more detailed explanation of the index and its classification parameters is found in Annex 3.2, Table A3.2-2). Using this index in the Cañaveralejo River (Figure 3.19), it was seen that the river presents three different sections depending on the characteristics of water during winter and summer seasons.

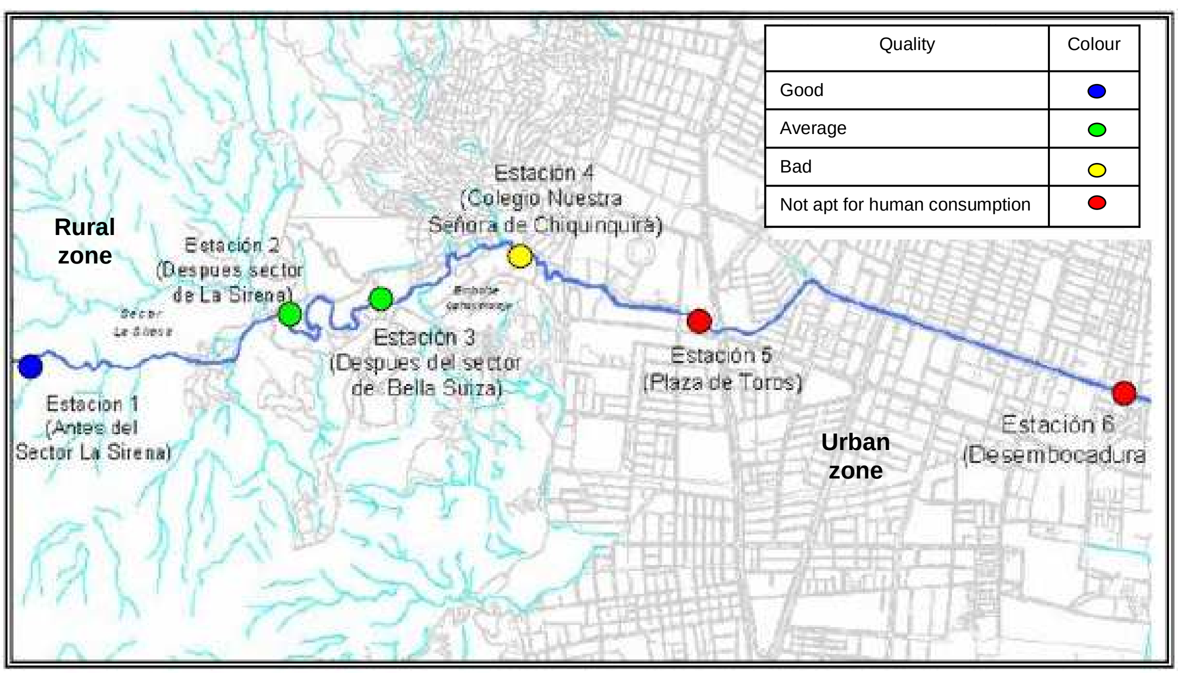

Figure 3.19 Map of the quality of water of the Cañaveralejo river based on ICA-NSF index.
Source: DAGMA-Universidad del Valle, 2004

The first part (before La Sirena – after Bella Suiza) the river is classified as of good quality to end up as of average quality. The second sector (after Bella Suiza to Colegio Nuestra Señora del Chiquinquirá), the river is characterized by an average quality ending up as of bad quality. Finally, the last sector from Colegio Nuestra Señora del Chiquinquirá to Desembocadura (discharge to south channel) is characterized by the high decline in quality so that is not considered as for human consumption (DAGMA - Universidad del Valle, 2004).

3.3.3 Meléndez River

The Meléndez river is born in the Western Mountain range at a level of 2800 meters above sea level inside the Natural National Park the Farallones of Cali. It has an approximated length of 25 km and it is located between the river basins of the rivers Cañaveralejo and Líli. The river basin has an estimated area of 3832 ha

Water use. The river supplies water to the drinking water system "La Reforma" which provides water by gravity to the zones in the slope of the mountain. Also, the river has been used like irrigation and recreation source. In addition, it is part of the relevant landscaping component of the city (DAGMA - Universidad del Valle, 2004).

Land use. The main land uses in the river basin of Meléndez river are described in Table 3.6.

Table 3.6 Land uses in Meléndez river basin, year 2000

Use	Area (ha)	%
Natural virgin forests	2325,6	63,3
Cultivated forest	28,8	0,8
Mining	20,4	0,6
Natural grass	894,4	24,4
Rastrojo (type of grass)	264,4	7,2
Infrastructure	63,2	1,7
Suburban area	29,6	0,8
Urban area	46,2	1,3
Total	3672,7	100

Source: CVC, 2004a

Water quality

In 2003, the flow of the river entering the city was 121 l/s and in its discharge point was 294,5 l/s (DAGMA, 2003). This river presents water shortages problems, which affects the operation on the drinking plant La Reforma which uses it as its water resource. The average capacity of La Reforma plant is 0,4m^3/s in spite of the Fact of having a design capacity of 1.0m^3/s. The Meléndez river, before the sector of the Choclona, presents water source characteristics of good quality. The area is characterized by very steep zones that allow the formation of turbulent flows in the river which enhances the self-purification and self aeration process.

77,6% of the houses and 82,6% of the establishments that are in the medium and low river basin of the Meléndez river, discharge their waste waters to the river, directly and indirectly using hoses or small pipes, or by means of the infiltration from black holes and septic tanks. According to DAGMA, (2003), Meléndez river receives a polluting discharge of 145 BOD kg/day, 401COD kg/day and 156 TSS kg/day.

Figure 3.20 shows the DO profile along the river and its direct influence by polluting BOD and TSS discharges shown in Figure 3.21 and Figure 3.22 respectively. It is observed that the wastewater

discharges from the pigs breeding sector (Marranera Meléndez), Nápoles channel and Canal Valle del Líli (drainage channels) contribute significantly with BOD and TSS loads (DAGMA-Universidad del Valle, 2004). When the river meets the south channel the DO concentrations oscillate around 2,0 mg/l.

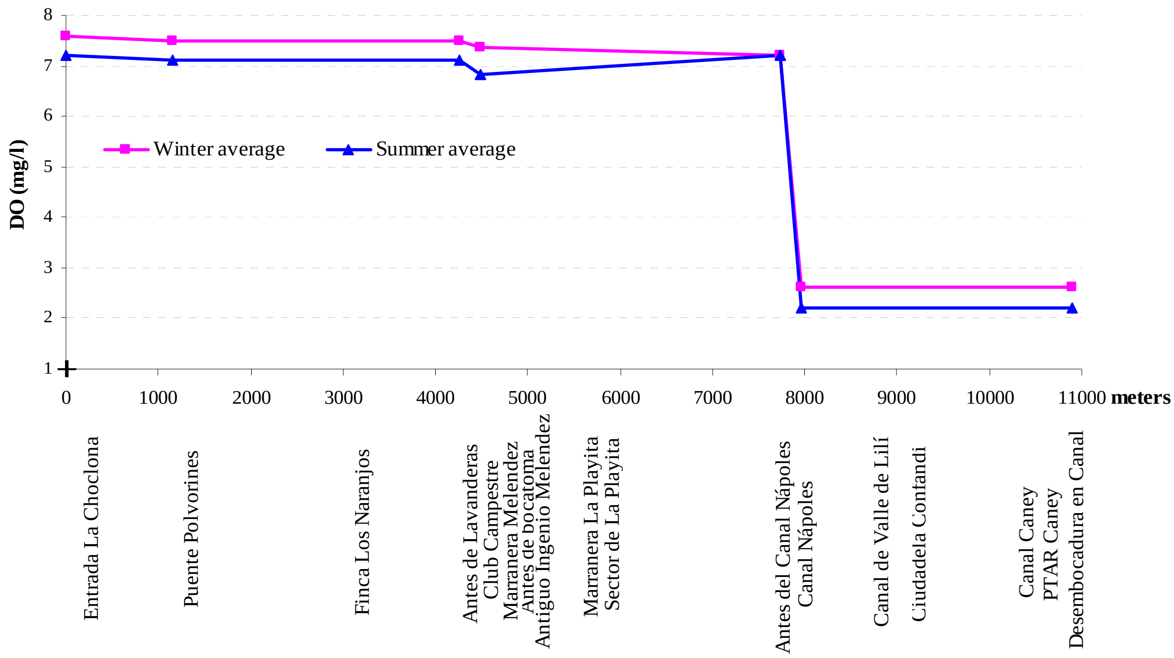

Figure 3.20 Dissolved oxygen along Meléndez river.
Source: Adapted from DAGMA-Universidad del Valle, 2004.

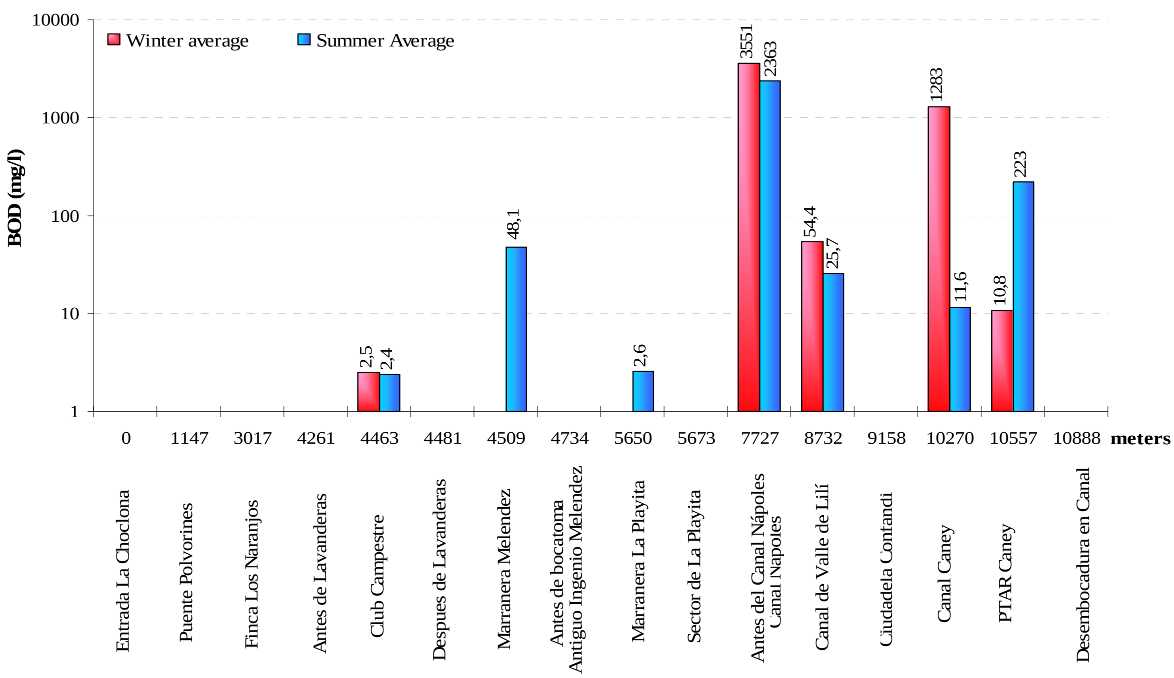

Figure 3.21 BOD load discharges along Meléndez river.
Source: Adapted from DAGMA-Universidad del Valle, 2004.

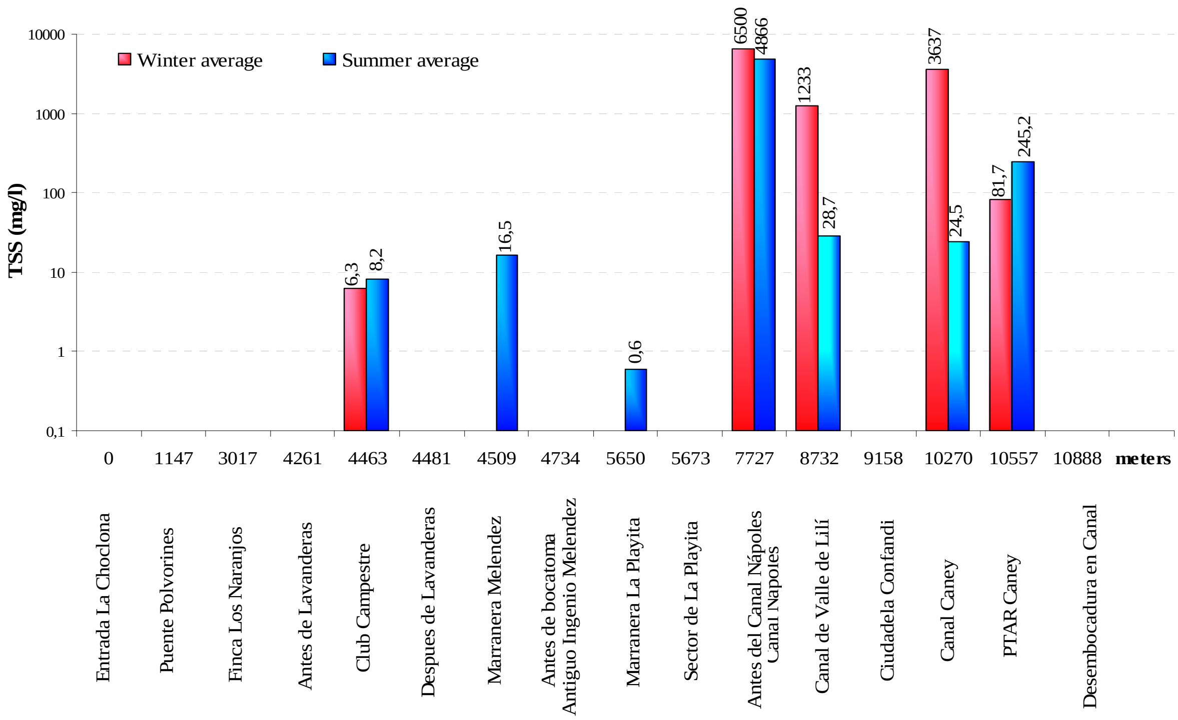

Figure 3.22 TSS load discharges along Meléndez river
Source: Adapted from DAGMA-Universidad del Valle, 2004

Index ICA-NSF for the quality of water applied to Meléndez River. According to the ICA index the river presents three different sections depending on the characteristics of water during winter and summer seasons. The first part is formed by the stations before La Choclona – before Lavanderas where the river is being classified as of good quality. The second sector before Lavanderas to before Napoles channel, the river is characterized by an average quality. Finally, the last sector from before Napoles channel to discharge to south channel is characterized by a bad water quality (See Figure 3.23).

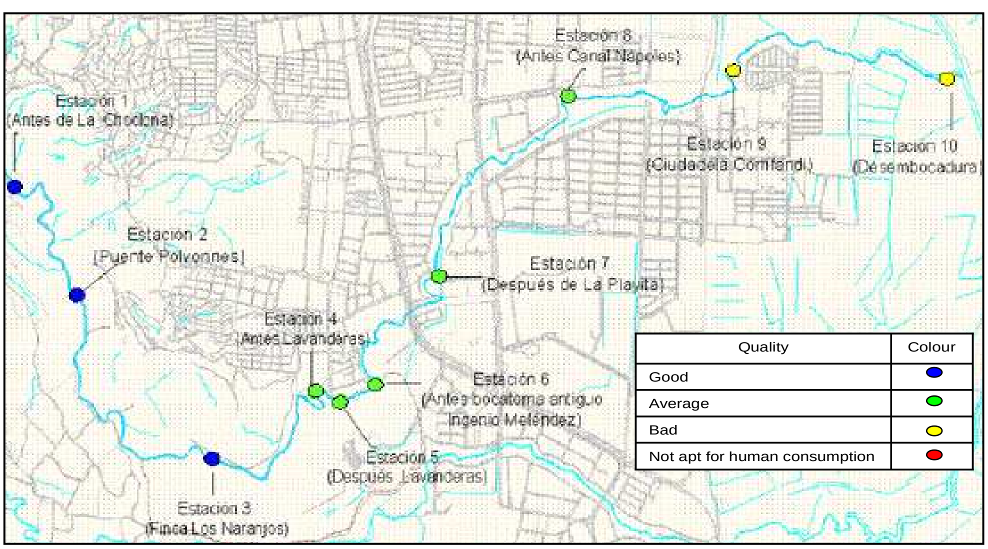

Figure 3.23 Map showing the quality of water of the Meléndez river based on ICA-NSF index.
Source: DAGMA-Universi dad del Valle, 2004

3.3.4 Líli River

It has a length of 15 km and a river basin of 1667 ha of extension. Its natural course was altered and deviated to the South channel, where its condition of river disappears to be replaced by a wastewater / storm water channel.

Land use. The majority of Líli river basin (34%) consists of natural grass out of which 30% is located between the urban and sub-urban area. The basin is influenced by mining activities and sugar cane crops located around the area (CVC, 2004b).
Table 3.7 shows the land uses in the river basin.

Table 3.7 Land uses in Líli river basin, year 2000

Land use	Area (ha)	%
Forests	466,5	19
Sugar cane crops	84,3	3
Infrastructure	70,4	3
Natural grass	864,3	34
Mining	92,4	4
Rastrojos (type of grass)	177,9	7
Suburban area	48,6	2
Urban area	702,6	28
Total	2506,9	100

Source: CVC, 2004b

Water use. It is used for human consumption before the city. The highest consumption is by the town La Buitrera. It is also used for the sugar cane crops as irrigation and for the feeding of cattle (DAGMA, 1997).

Water Quality

According to DAGMA (2003), the Líli river present an average flow of 597 l/s in its discharge point to the south channel. The Líli river basin has been divided in three parts: high, medium and low. Next, the characteristics of each one of them are described (DAGMA, 1997):

- In its highest part where the river is born there are affected sectors in the river by the mining operation. Severe erosion is detected by the presence of 11 coalmines.
- In the medium part the river undergoes polluting effects by the disposal of rubbish dragged and deposited during the crescents and by the wastewaters generated in the houses bordering the river basin. Nevertheless, the factor of greater incidence in the deterioration of its waters constitutes the original discharges from the mines that present a pH acid.
- The low part of the river basin until the South Channel is affected by slums that produce wastewater discharges and pollution. In this sector the river is transformed into a channel without any possibility of vegetation that can provide support and feeding to the aquatic organisms.

Biological diversity index (IDB) and the quality index (ICA) for the quality of water applied to Líli River. For the evaluation of the quality of the Líli river the IDB and ICA-NSF were used. A more detailed description of the index is found in Annex 3.2. In its course the river presented a IDB value of 1,7 which indicates that the water is average polluted whereas the ICA-NSF value was 52 which indicates a medium water quality. In the discharge point to the south channel, the IDB was 0,1 and ICA-NSF was 48, classifying the water as very polluted and of bad quality (DAPM, 2000)

3.3.5 Cali River

The river basin is located in the Northwest part of the municipality. The river is born in the Western Mountain range in the National Park Natural The Farallones, approximately at the 4000 m level above sea level. The river basin has a surface of 12352 ha. The Cali River crosses the city of Cali in the West east sense crossing 16 km (DAGMA - Universidad del Valle, 2007).

Land use. Around 69% of the total river basin area consists of natural forests which are reflected in the fact that more than 50% of the area is located inside the National Natural Park The Farallones (CVC, 2004c). Table 3.8 shows the land uses in Cali's river basin.

Table 3.8 Land uses in Cali river basin, year 2000

Use	Area (ha)	%
Natural forest	8175,2	68,6
Cultivated forest	52	0,4
Permanent crops*	184,6	1,5
Transitory crops**	234,1	2
Green grass	1980	16,6
Infrastructure	103,9	0,9
Rastrojos	744	6,2
Moor vegetation	141,6	1,2
Sub-urban area	3,5	0,03
Urban area	301,4	2,5
Total	11920	100

*coffee, plantain ** vegetables and corn
Source: CVC, 2004c.

Water use. The waters of the river are used mainly for the water supply of the city of Cali, by means of the drinking Plant Cali River, whose maximum capacity of production is 2,5 m^3/s. At the moment the water intake is done from the bottom of the plant with an average volume of 1,8 m^3/s (CVC, 2004c). Additionally, the Cali river is used for energy generation (Cidral-EPSA Plant), animal consumption (zoo of Cali), landscaping and like receiver of liquid and solid waste discharges (DAGMA, Universidad del Valle, 2007). In the last years, the shores of the river had been recovered and marginal collectors have been constructed to avoid the pollution of the source and to deviate waste waters towards the treatment plant before being discharged to the Cauca River (CVC-Universidad del Valle, 2004).

Water Quality

In 2003, the flow of the river entering the city was 3900 l/s (winter season) and in its discharge point to Cauca river was 6700 l/s (DAGMA, 2003). During summer time the flow can decrease to around 10 l/s (DAGMA, 1997). The parameters of BOD and COD quality in winter and summer, showed an increasing trend throughout the route of the river due to the wastewater discharges from the domestic areas in the urban zone of Cali. In the last section of the river until its discharge to Cauca river the concentrations are increased by the discharges of the industrial sector from the municipality of Yumbo), the Collector Margen Izquierdo (domestic wastewater from Cali).

Around Cali river basin, activities of deforestation, erosion are present mainly in the high part of the river basin. Such has contributed to a decrease in the natural section of the river, changes in the natural river course which added to the lack of maintenance of the drainage structure in the city and accumulation of sediments in the drainage networks has caused overflow of the river. A direct

critical consequence has been the increase in flood events along the river basin of Cali river. (Delgado et al., 2005).

In summer, it is observed that after the Intercontinental Hotel discharge the DO diminishes reaching lower values up to 1 mgO_2/l. The high polluting loads discharged to the river mainly in their last section, generate anoxic conditions producing anaerobic reactions that trigger bad odors. Before its discharge to the Cauca river, the Cali river (in dry periods) does not fulfill the minimum level of DO (4 mgO_2/l) established in Decree 1594 of 1984 for the destination of the water body to the conservation of flora and fauna

The loads of BOD and COD present little variation with respect to the climatic condition. On the contrary, the TSS load is greater in winter than in summer, which would be associated to the storm water contribution that produces the dragging of particulate material. According to the monitoring campaign made in August of 2006 during summer, the highest contribution of load in terms of BOD and TSS was the collector Margen Izquierdo (urban wastewater from Cali) which presented values of 15759,4 kg/day and 14025,4 kg/day, respectively.

The high discharge from this collector is directly related to its great tributary area of 1109,55 ha, corresponding to its own area of 965,62 ha and to the one of the Collector Margen derecha of 143,93 ha. Other important discharges in terms of load to the river are the industrial wastewater from the municipality of Yumbo, the Aguacatal river, the different domestic waste water discharges along the river (DAGMA-Universidad del Valle, 2007).

Index ICA-NSF for the quality of water applied to Cali River. The ICA-NSF presented medium quality when the river enters the urban area, possibly caused by the wastewater discharges of the settlements located in the high part of the river bank. After that, the quality of the water along the urban area is of bad quality.

During the summer conditions, in the river mouth, the water reaches a very poor quality classification, indicating the effect caused by slums areas located around its margins and the industrial wastewater discharges from the industries in Yumbo municipality located 800 m upstream the final discharge of Cali river to Cauca river (CVC - Universidad del Valle, 2004) (See Figure 3.24, in which the blue color means good quality, green average quality, yellow bad quality and red is not apt for human consumption).

3.3.6 Aguacatal River

During its course it receives the contribution of several water streams, wastewater discharges from nearby quarries, coalmines and most of the waste waters of the nearby municipalities. The Aguacatal River after crossing the urban area of Cali for approximately 6 km meets the Cali River. The Aguacatal river basin has an approximate area of 6179 ha.

Land uses. The high part of the river basin (Alto Aguacatal –La Playita Sector) is characterized by farm dwellings with pigs breeding fed by the river water. In the Playita sector there are located to the right margin dwellings under high risk of landslide.

The middle part of the river basin (La Playita Sector– El Choclo creek’s mouth) is characterized by an area of forests which is protected but that is under risk of extinction due to the high level on uncontrolled urbanization to the right margin of the river. The vegetation green layer is poor with presence only of rastrojo (type of grass) at the banks of the river. The low part of the river basin (El choclo creek’s mouth –Aguacatal river mouth) is characterized by a forest protected zone at both sides of the river bank and presence of buildings for residential use. The land uses were described according to (DAGMA, 1997).

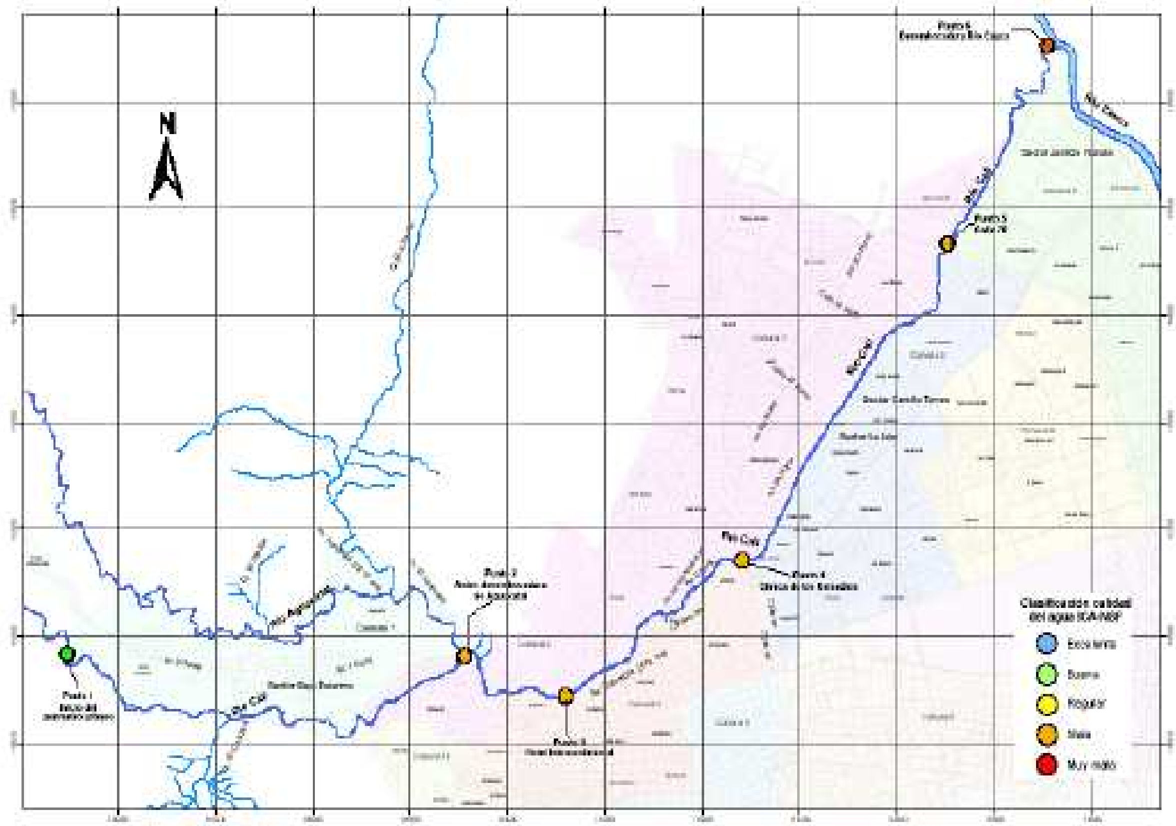

Figure 3.24 Map showing the quality of water of the Cali river based on ICA-NSF index.
Source: DAGMA-Universidad del Valle, 2007

Water use. In the Cali urban zone, the Aguacatal river is used for clothes washing, for aesthetic and landscape aims (lake of the club "the Shore"), for extraction of construction material (rocks) and as wastewater disposal and solid waste.

Water quality

According to DAGMA, Universidad del Valle (2007) the Aguacatal river basin has the lowest flow of all seven river basins with an average flow of 0,59 m^3/s. The river in the urban zone, presents also slums that generate as much deterioration in the slope as in the water quality, due to the wastewater discharges (DAPM. 2000 mentioned by EMCALI, 2007a).

According to the monitoring campaign made in August of 2006 during summer, the highest contribution of load in terms of BOD and TSS was the Chocho river, which presented values of 83.95 kg/day and 772.9 kg/day, respectively (DAGMA-Universidad del Valle, 2007).

Index ICA-NSF for the quality of water applied to Aguacatal River. The ICA-NSF index showed that when the river enters the urban area is of medium quality, possibly caused by the wastewater discharges of the settlements located in the high part of the river bank. Following, the water finally reaches “bad quality” in its discharge point to Cali River (DAGMA - Universidad del Valle, 2007) (see Figure 3.25, in which the blue color means good quality, green average quality, yellow bad quality and red is not apt for human consumption).

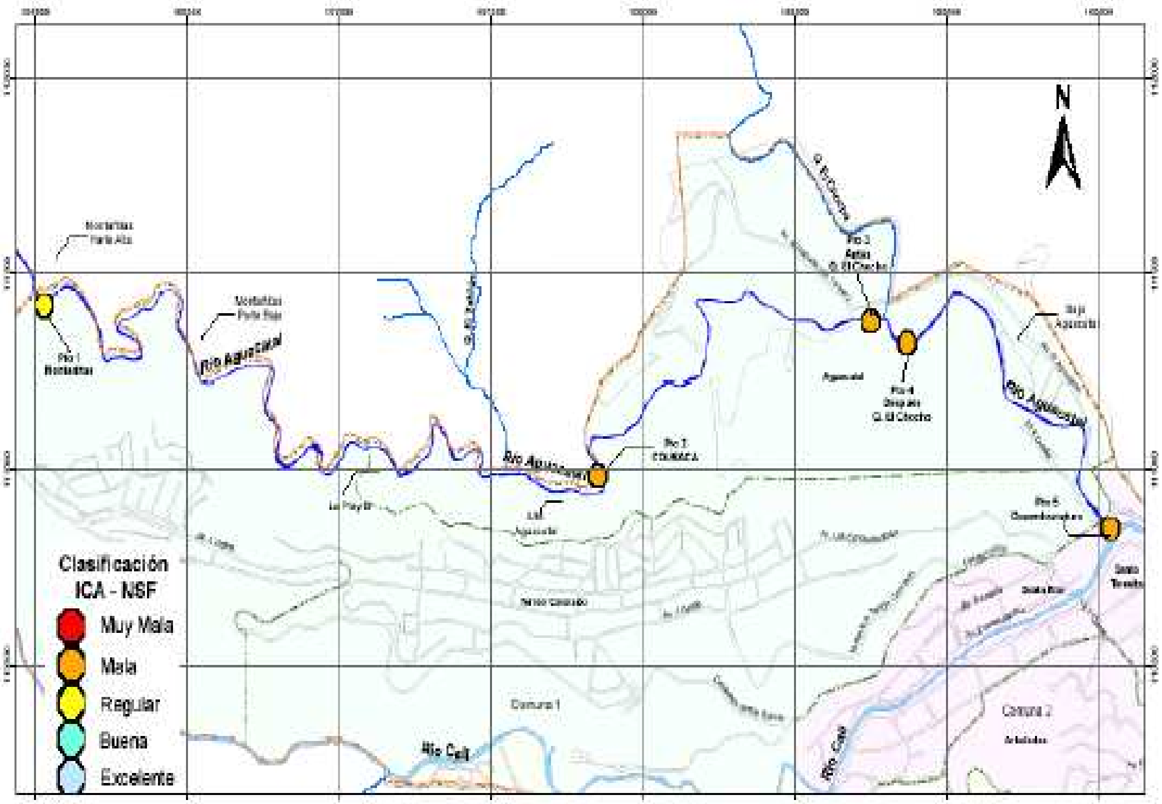

Figure 3.25 Map showing the quality of water of Aguacatal river based on ICA-NSF index.
Source: DAGMA - Universidad del Valle, 2007

3.3.7 Pance River

The river basin is located in the South-west mountainous area of Cali with an area of 8975 ha. It is born in the Pance mountain, at level of the national natural park The Farallones at 4200 m above sea level. It crosses the municipalities of Pance and la Voragine and finally discharges in Jamundí river (EMCALI, 2007a).

Land use. The high part of the river basin (the river source- La Vorágine sector) is characterized by agriculture crops. There is land dedicated the extensive cattle breeding. At small scale there are also corn, beans, coffee and plantain crops.

The middle part of the river basin (La Vorágine sector – Soccer Club Deportivo Cali) is characterized by the biggest concentration of agriculture activities and commercial activities focused on tourism. Around the populated areas there are fish and forest activities.

The low part of the river basin (Club del Deportivo Cali–river mouth) is characterized by construction of lots and educational centers. There is also extensive cattle breeding activities. This are corresponds to the expansion urban area of the city of Cali (DMP, 2004).

Water use. Pance river is the last natural source for recreational purposes of the inhabitants of the municipality of Cali. Hence, its social function is extremely important.

Water Quality

According to DAGMA (1997) Pance is the river with biggest average flow of approximately 2,59 m^3/s. It is the only river that presents crystalline water and less contaminated reason why it is used as the only recreation source in the city. In Pance's river bank, the highest presence of vegetation and ethnic animal species is found (DAGMA, 1997).

Index ICA-CETESB for the quality of water applied to Pance River. The ICA- CETESB is an index that considers the potential use of water bodies as sources for human consumption. More information regarding this index can be found in Annex A 3.2, Table A 3.2-4. The index classified the waters in Pance river as good quality during the two monitoring campaigns carried out by CVC in 2006.

3.4 GROUND WATER IN THE CITY OF CALI

The ground water constitutes an important resource that contributes considerably to supply the seasonal and spatial water deficit in the Valley of the Cauca and specifically in Cali, becoming an alternative source of water supply for the municipality of Cali. The quality of the underground water in the municipality of Cali is classified in general terms as good, being 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' infiltration by lack of sewage systems (DAGMA, 2000).

DAGMA (2000) characterized the ground water in Cali according to the river basins of the Cali rivers. This methodology allows the evaluation of the specific physical and chemical characteristics of ground waters depending on factors such as climate, geology and entropic action. Table 3.9, shows the ground water characteristics according to the river basins.

Table 3.9 Characteristics of the groundwater in the eight sub-river basins in the urban area of Cali.

River basin	Length (km)	Area (km^2)	Transmisivity (m^2/day)	Flow (m^3/year)
Pance	2	10,0	30	328.000
Lilí river	2	5,0	70	511.000
Meléndez river	2	7,5	36	438.000
Other*	4,5	16,5	30	949000
Cañaveralejo	1,6	5,3	35	245.280
Cali river	5	34,0	60	1.314.000
Cauca river	18	36,0	150	7.884.000
Total available ground water flow				11.304.280

Note: * corresponds to "Chorros" and "San Fernando" water streams
Source: DAGMA, 2000.

The estimation of the groundwater volume of each river basin, registered in Table 3.9, is centered in the fact of using only the water that drains the highest part of the aquifer (between 15 and 60 m), not including the water storage. The calculated annual flow volumes are the maximums estimated for extraction. exceeding these values would produce an over-exploitation of the aquifer causing its definitive exhaustion and possible bad effects on the ground, since it has happened in many parts of the world.

To the year 2000 the use of the highest aquifer in the city of Cali (approx 300 wells) reached a volume of 8 millions of m^3/year, which is equivalent to a 75% of the technically allowed usage

volume without interfering with the water storage. This means that still it can be counted on an additional volume of 25% within the volumes technically available.

According to the group for underground water from DAGMA, at August 2007 there has been identified 475 underground wells in the city of Cali out of which 44 are used by the industry, 235 are used for car washing by the gas stations, 59 are used for irrigation, 9 are used for human consumption among other uses.

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Sustainable Water Improves Tomorrow's Cities' Health
SWITCH Project

Study Case: Cali, Colombia
Water Resources

ANNEXES
Cauca River: Water Quality

February, 2008

A3.1 CAUCA RIVER: WATER QUALITY MONITORINGS

In the year of 1969 the CVC initiated the measurements of the quality of the water in the tributary rivers and industries that contributed with high loads of pollutants to the Cauca river. In that same year the controlled monitoring of the final sewage system's discharges in the city of Cali began as well (Galvis et al., 2001). As of 1980, the CVC began a program of systematic monitoring, fixing sampling points in 19 stations located along the Cauca River, which continue working as far as today. The sampling plan of the Cauca River and its tributary rivers oriented to the finding of strategies of control and management of the water resource, setting out the following objectives:

- To estimate the space and temporary evolution of the quality of the water in the Cauca River and its tributary ones.
- To evaluate the impact of the strategies for the control of the contamination of the Cauca River and its tributary rivers.
- To obtain data for the planning and decision making of the polluter pays policy.
- To propose schemes of sampling with intentions of calibration in simulation models.

Base on these objectives, the CVC carries out the sampling monitoring campaigns in the stations on the Cauca River, tributary rivers, the industries and the municipalities considering different water quality parameters as it is point out in Table A3.1-1 The site and the frequency of sampling appears in Table A3.1-2

Table A3.1-1 Water quality parameters monitored by the CVC

Type	Parameter	Unit	Station	Tributary rivers	Municipality of Cali	Other Municipalities	Industries
Hydraulic	Flow	m^3/s	X	X	X	X	X
Physical-chemical	Temperature	^oC	X	X	X		
	pH	Unit	X	X			X
	DO	mg/l	X	X	X		
	Total solids	mg/l	X	X	X		
	Dissolved solids	mg/l	X	X			
	Suspended solids	mg/l	X	X		X	X
	Turbidity	UNT	X	X	X		
	Color	UC	X	X	X		
	conductivity	Mmhos/cm	X	X			
	Total hardness	mg/l	X	X			
	Magnesium hardness	mg/l	X	X			
	Calcium hardness	mg/l	X	X			
	Alkalinity Total	mg/l	X	X			
	Phenol alkalinity	mg/l		X			
Organics	BOD	mg/l	X	X	X	X	X
	COD	mg/l	X	X	X		X

Table A3.1-1 Water quality parameters monitored by the CVC, cont.

Type	Parameter	Unit	Station	Tributary rivers	Municipality of Cali	Other Municipalities	Industries
Nutrients	Total	mg/l	X	X			
	Organic Nitrogen	mg/l	X	X			
	Ammoniac Nitrogen	mg/l	X	X			
	Nitrates	mg/l	X	X	X		
	Nitrite	mg/l	X	X	X		
	Total phosphorous	mg/l P	X	X			
	phosphate	mg/l PO4	X	X			
Ions	Total	mg/l Na	X	X			
	Dissolved sodium	mg/l Na	X				
	Total Potassium	mg/l K	X	X			
	Dissolved potassium	mg/l K	X				
	Calcium	mg/l	X	X			
	Magnesium	mg/l	X	X			
	Carbonate	mg/l	X	X			
	Bicarbonate	mg/l	X	X			
	Chloride	mg/l	X	X			
	Sulphate	mg/l	X	X	X		
Inorganic	Sulphate	mg/l	X				
	Sílice	mg/l	X				
	Fluoride	mg/l	X				
	Cyanide	mg/l	X				
Metals	Aluminum	mg/l Al	X	X			X
	Cadmium Total	mg/l Cd	X	X	X		X
	Chromium Total	mg/l Cr	X	X	X		X
	Dissolved chromium	mg/l Cr	X				X
	Copper	mg/l Cu	X	X	X		X
	Iron Total	mg/l Fe	X	X	X		X
	Dissolved	mg/l Fe	X				X
	Mercury	mg/l Hg	X	X			X
	Manganese	mg/l Mn	X	X	X		X
	Manganese Dissolved	mg/l Mn	X				X

Table A3.1-1 Water quality parameters monitored by the CVC, cont.

Type	Parameter	Unit	Station	Tributary rivers	Municipality of Cali	Other Municipalities	Industries
Metals	Total Nickel	mg/l Ni	X	X	X		X
	Nickel Dissolved	mg/l Ni	X				X
	Lead Total	mg/l Pb	X	X	X		X
	Dissolved	mg/l Pb	X				X
	Zinc total	mg/l Zn	X	X	X		X
	Zinc	mg/l Zn	X				X
Microbiologic	Coliforms	NMP/100	X	X	X		
	Coliforms	NMP/100	X	X	X		
Pesticides		p.p.m	X				

Source: CVC-Universidad del Valle, 2001

Table A3.1-2.Site and frequency of sampling carried out by CVC.

Sampling point		Frequency
Cauca river	19 stations located along the river	Three months
Tributary rivers	41 rivers, out of which 30 are Cauca river tributaries	Three months
Industries	CVC controls around 200 industries in the Valle del Cauca department	Six months
Municipalities	Municipal wastewater discharges in the municipalities of Valle del Cauca department	Six months

Source: CVC-Universidad del Valle, 2001

A3.2 WATER QUALITY INDEXES

***ICAUCA index*:** To formulate ICAUCA index, the water quality index (ICA) and contamination index (ICO) were adapted. After a sensitivity analysis from this two indexes applied to the conditions of Cauca river to be used in the agriculture, human consumption and fish sector, the criteria selected to adapt the ICAUCA index river was:

1. Dissolved oxygen
2. Feacal coliforms
3. Turbidity
4. BOD
5. Suspended solids
6. Color
7. Total solids
8. pH
9. Total phosphorous
10. Total Nitrogen

Considering the river as a source for human consumption prior to conventional treatment, the ICAUCA index was classified as shown in Table A3.2-1

Table A3.2-1 ICAUCA index for the classification to be used as human consumption

Value ICAUCA	Water classification
80-100	Optimum quality
50-80	Good quality
35-50	Acceptable quality
20-35	Inadequate quality
0-20	Bad quality

Source: Patiño et al., 2005

***ICA index from National Sanitation Foundation (ICA-NSF)*:** Brown et al. (1970) supported by the National Sanitation Foundation, proponed the ICA-NSF index for the quality of water

The physical and chemical parameters used to evaluate the river based on the ICA-NSF were

1. Biological oxygen demand (BOD mg/l)
2. Dissolved oxygen (% de saturation oxygen)
3. pH
4. Turbidity (Turb, in UNT)
5. Phosphates (PO_4^{-3}, mg/l)
6. Nitrates (NO_3^{-2}, mg/l)
7. Temperature (T)
8. Feacal coliforms (Coli. F, NMP/100 ml)
9. Total solids (ST, en mg/l)

To classify the river water swing ICA-NSF there are classification ranges based on the characteristics of water to be used as human source. The classification is presented in Table A3.2-2

Table A3.2-2 ICA-NSF index for classification of the water resource to be used as water consumption

ICA index	Water classification
90-100	Excellent quality
70-90	Good quality
50-70	Medium quality
25-50	Bad quality
0-2	Very bad quality

Source: CVC, Universidad del Valle, 2004

Diversity Index Shannon Weaver**:** The diversity index classifies water intended to be used for human consumption based on the parameters in Table A3.2-3

Table A3.2-3 Water quality classification according Shannon Weaver diversity index (H')

Shannon index (H')	Water classification
0.0-1.5	Very polluted
1.6-3.0	Average polluted
3.1-5.0	Very clean

Source: Roldán (1992) cited by CVC, Universidad del Valle, 2004

CETESB water index. The technical agency for environmental sanitation in Brasil (Compañía de Tecnología de Saneamiento Ambiental de Brasil) – CETESB (2002), proposed a modification of the ICA-NSF index to be adjust to the conditions of the river basins in Sao Paulo. The ICA-CETESB is defined by the following parameters:

1. Dissolved oxygen
2. Feacal coliforms
3. Turbidity
4. BOD
5. Color
6. Total solids
7. pH
8. Total phosphorous
9. Total Nitrogen

The CETESB classification is shown in Table A3.2-4

Table A3.2-4 Water classification according to the ICA -CESTESB (2002)

CESTESB index	Water classification
79-100	Excellent quality
51-79	Good quality
36-51	Medium quality
19-36	Bad quality
0-19	Very bad quality

Source: CETESB (2002) cited by CVC, Universidad del Valle, 2004

Sustainable Water Improves Tomorrow's Cities' Health SWITCH Project

Urban Water Management for the City of Cali
Diagnosis report

Study Case: Cali, Colombia

4. Drinking Water Supply

February, 2008

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4 DRINKING WATER SUPPLY IN CALI

4.1 DRINKING WATER SOURCES

The water sources for the five drinking water plants in the city of Cali are Cauca, Cali, Meléndez and Pance river. Table 4.1 shows the five drinking water plants and their respective water source.

Table 4.1 Water sources and drinking water plants in the city of Cali

Water source	Drinking water plant
Cauca river	Puerto Mallarino
	Río Cauca
Cali river	Río Cali
Meléndez river	La Reforma
Pance river	La Ribera

Cauca river, which supplies two of the five plants: Puerto Mallarino and Río Cauca, presented a flow variation between 80 and 251 m^3/s during summer season in 2003 (CVC, Universidad del Valle, 2004). During year 2006, the minimum daily flow during dry conditions was 106 m^3/s and the maximum daily flow during rainy season was 651 m^3/s (EMCALI, 2006 cited by Vasco, 2006). This flow trend contrast Cali and Meléndez flows, which during summer season do not count with sufficient amount of water to keep up the drinking water production capacity of the plants they supply. Rio Cali and La Reforma drinking water plants supply 19% and 5% of the total consumption of the city, reaching specially the highest parts of the city. Table 4.2 shows the minimum, maximum and average daily flows for Cauca, Cali and Meléndez rivers during year 2006.

Table 4.2 Cauca, Cali and Meléndez river flows, year 2006

Source	Minimum daily flow dry season (m^3/s)	Maximum daily flow rainy season (m^3/s)	Average daily flow (m^3/s)
Cauca river	106	651	264
Cali river	1,52	22,22	4,76
Meléndez river	0,39	3,00	1,23

Source: EMCALI, 2006 cited by Vasco, 2006

According to the report from the Technical Planning Department from EMCALI, in September 2007, the maximum available flow for the rivers Cali and Meléndez are below the installed capacity of the drinking plants they supply. This situation has caused that the drinking water production from Río Cauca and Puerto Mallarino plants, supplied by Cauca river, increase so that they can cope with the water demand in the city. Table 4.3 shows a comparison between the river flows and the drinking water treatment capacity of the plants they supply.

Table 4.3 Comparison between the rivers available flows and the drinking water plants capacities

Plant	Source	Rivers maximum available flow (m^3/s)	Treatment capacity (m^3/s)
Río Cali	Cali river	0,80	1,80
Río Cauca	Cauca river	2,50	2,50
Puerto Mallarino		6,60	6,60
La Reforma	Meléndez river	0,30	1,00
Total		**10,20**	**11,90**

Source: EMCALI, 2007a. Technical Planning Department

In year 2004, EMCALI bought drinking water plant La Ribera which is uses Pance river as its water source. This plant supplies the drinking water network of an area located in the south of the city which is called La Ribera as well. The drinking water network counts with a water reservoir of capacity 5000 m^3 and a treated water flow of approximately 0,014 m^3/s. As of today, there is no documented information regarding flows and water quality from this system only that there is iron and manganese presence coming from the mines located in the high river basin.

One of the aspects that has influenced the quality and quantity of the rivers in the city is related to the continue migration of people which settle in an unorganized way without following the regular urbanization process. Such situation has caused deforestation in the river basins specially in Cali and Melendez rivers which is reflected in the low flows which are under the treatment capacity of the plants they supply.

Water quality

Concerning the quality of the water sources for drinking water, Cauca river, which is the main source for 77% of the total Cali’s population, has been suffering a continue water deterioration and has become the main concern of the environmental authorities, water supply company and the community.

According to the results from the monitoring campaign carried out in July, 2006 (EMCALI, Universidad del Valle, 2006) there is a high risk of use when using Cauca’s river water as drinking water source. Such risk is related to the following parameters: DO, TOC, COD, feacal coliforms, mercury and total phenols since they all exceed the limit values for water quality established by RAS 2000, decree 1594 -1984 and OMS, 2004. In this regard there were concentrations of TOC and COD of 6,55 mg/l and 3,39 mg/l respectively which although lower than values recommended in literature (10 mg/l y 8 mg/l respectively) can affect the different drinking water treatment processes, requiring high chlorine doses and increase trihalomethanes potential risk formation (Arboleda, 2000 cited by EMCALI - Universidad del Valle, 2006).

Likewise there are recorded average concentrations before Puerto Mallarino water intake of 42,88 μg/l lead, 2,19 μg/l mercury, 0,01 mg/l de total cyanide, <0,001 mg/l chromium (VI) , < 0,03 mg/l copper and total phenols of 12,78 μg/l.

The main problem related to water quality in Cali and Meléndez rivers is the increased concentration of solids during winter time which causes many times the shutdown of the drinking water plants supplied by these rivers. Contamination of these rivers is mainly produced during their course through the urban city where several industrial, domestic and agriculture wastewater are spilled into them. In the drinking water plants the following standard measurements are carried out: Temperature (ºC), Turbidity (UNT), Color (Und), pH (Und), Total Alkalinity (ppm. $CaCO_3$) and residual chlorine (ppm. Cl_2). Table 4.4 shows the maximum, minimum and average values of these parameters.

Raw water characterization in the plants indicate presence of maximum turbidity peaks changing from 2460 UNT to 6000 UNT. The value of 6000 UNT was the highest registered in the Río Cali plant in year 2006. When the turbidity levels exceed the treatment limits, it is not possible to treat the water since water under such conditions would cause operation failures in the treatment units in the plant.

Table 4.4 Minimum, maximum and average concentrations of the different water quality parameters measured in the drinking water plants, 2006

Parameters	Raw water			Treated water		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Río Cali Plant						
Temperature (° C)	23,20	16,00	19,00	23,30	17,00	19,63
Turbidity (U.N.T.)	600	1,00	53,75	5,50	0,20	0,72
Color (Un)	250	3,90	39,49	5,60	0,20	1,50
pH (Un)	8,40	6,80	-	9,00	5,80	-
Total Alcalinity (ppm. $CaCO_3$)	60,00	12,00	36,93	53,00	12,00	36,12
Free residual chlorine (ppm. Cl_2)	-	-	-	1,90	1,00	1,33
Río Cauca Plant						
Temperature (° C)	25,20	20,00	22,38	27,00	20,40	22,63
Turbidity (U.N.T.)	2460	14,00	131,14	6,30	0,44	0,84
Color (Un)	400	40,0	236,28	10,00	0,70	1,23
pH (Un)	9,00	5,00	-	9,30	4,80	-
Total Alkalinity (ppm. $CaCO_3$)	31,30	17,00	23,65	31,40	11,40	20,65
Free residual chlorine (ppm. Cl_2)	-	-	-	2,50	1,10	1,58
Puerto Mallarino Plant						
Temperature (° C)	25,20	20,00	22,38	27,00	20,40	22,63
Turbidity (U.N.T.)	2700	21,00	148,26	3,20	0,20	0,57
Color (Un)	734	26,00	92,74	6,10	0,20	1,64
pH (Un)	7,50	6,50	-	9,60	4,60	-
Total Alkalinity (ppm. $CaC0_3$)	36,30	14,40	24,60	38,10	1,00	21,59
Free residual chlorine (ppm. Cl_2)	-	-	-	2,30	1,00	1,50
La Reforma Plant						
Temperature (° C)	24,60	17,20	19,58	24,80	17,60	21,07
Turbidity (U.N.T.)	500	0,75	36,30	5,00	0,10	0,40
Color (Un)	400	0,40	50,02	20,00	0,00	0,21
pH (Un)	7,90	6,40	-	9,70	6,50	-
Total Alkalinity (ppm. $CaCO_3$)	30,00	11,00	22,32	35,00	14,00	24,14
Free residual chlorine (ppm. Cl_2)	-	-	-	*	0,40	1,05

Source: EMCALI 2006a
(-) not applicable
*Without date

Figure 4.1 shows the maximum turbidity values recorded in the four drinking water plants. The highest values correspond to the ones recorded in Río Cauca and Puerto Mallarino plants, whereas La Reforma plant presents the lowest values with Meléndez river. The likely reason for the lowest turbidity values in this river is that the water intake is performed in the high part of the river basin where human activities have not yet deteriorated water quality.

4.2 TREATMENT PLANTS

Location

Figure 4.2 shows the location of the plants Río Cali, Río Cauca, Puerto Mallarino, La Reforma and La Ribera with their respective area of influence. As it can be seen from the Figure, Puerto Mallarino and Río Cauca supply 77% of the city through the transmission North, East and South

pipes (TTN, TTO, TTS) which exit from Puerto Mallarino and North and South exits (SN, SS) to Cauca river.

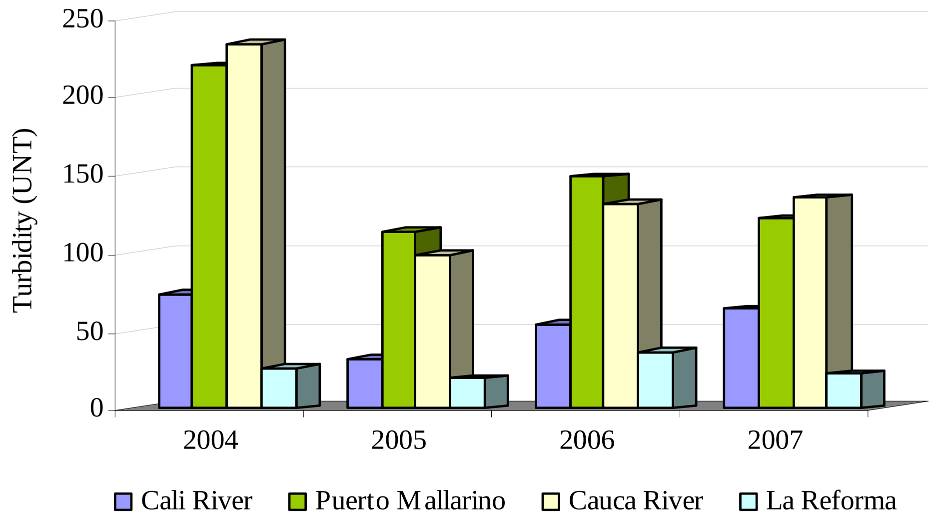

Figure 4.1 Maximum turbidity values in raw water arriving to the four drinking water plants in Cali.
Source: Adapted by EMCALI 2006a

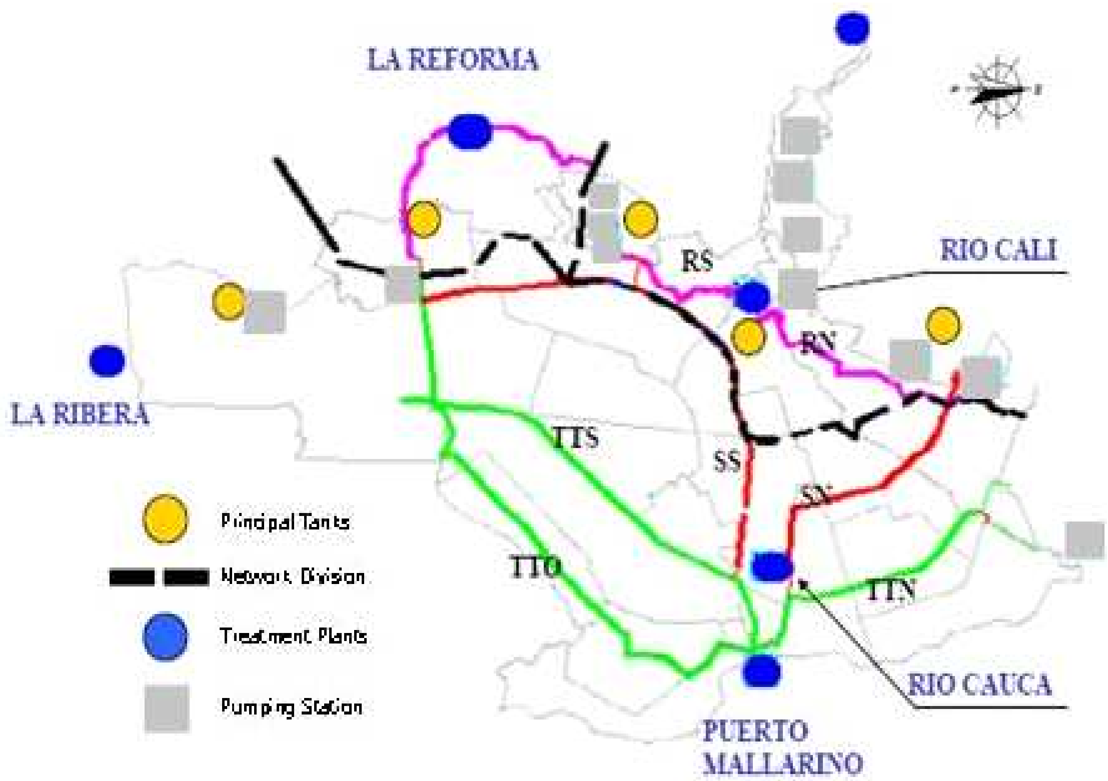

Figure 4.2 Location of Cali's drinking water plants
Source: EMCALI-Universidad del Valle, 2007

Río Cali plant's supply area is the North-East and center of the city through the pipes center, south, north and normal (RS, RN). This influence area corresponds to the highest part of the city regarding topography. La Reforma plant supplies the neighborhoods located in the slope of the hills in the South-east part of the city.

La Ribera plant, located in the south part of the city in the Pance district, supplies the drinking water network named Pance.

Following, the most important characteristics of the five drinking plants are described.

Río Cali: Its water source is Cali river. The plant was put in operation in the year 1930. It has a production capacity of 1,80 m^3/s to serve 420000 people living in the old part of the city. It is a conventional plant that works by gravity. It is composed by the following structures:

- Three types of water intake: sideway, bottom and inverted siphon type. The last one takes the settled water from the Chidral energy generation plant.
- One grit removal.
- One wire of rapid mixture whit addition of liquid aluminum sulfate, type B.
- Thirty six mechanic flocculation chambers.
- Three sedimentation tanks which are conventional at around 2/3 of the length and the last third of the length consist in parallel plates.
- Twenty filters, out of which 12 work at decline rate and the remaining eight work at constant rate.
- Chlorine disinfection.
- Four storage tanks with capacity of 40000 m^3.
- Five gravity exits: "Refuerzos Norte, Sur, Centro, Nacional, La Normal", and one pumping exit called Bellavista.

Figure 4.3 Río Cali treatment plant

Río Cauca: Its water source is Cauca river. The plant was put in operation in the year 1958 with a production capacity of 1,0 m^3/s increased to 2,5 m^3/s in 1968. It is a compact plant composed by:

- A lateral water intake of capacity 2,76 m^3/s.
- One grit removal chamber.
- One raw water pumping station.
- 6 Six reactors for rapid mixture with addition of aluminum sulfate and flocculation and sedimentation processes.

- 32 filters at constant rate.
- Chlorine disinfection.
- Two storage tanks.
- One drinking water pumping station to the distribution network.
- 7 Seven pumping stations with a total installed capacity of 2,5 m^3/s.

Figure 4.4 Río Cauca treatment plant

Puerto Mallarino: It started operation in 1978. It is located at North-east part of the city. Its water source is Cauca river. It has an installed capacity of 6,6 m^3/s and supplies approximately 53% of the total water demand in Cali. The plant was designed and constructed using complete cycle technology and it is composed by the following units:

- One raw water pumping station with 6 raw water pumps.
- Activated carbon addition in the impulsion pipes.
- Grit chamber with four containers.
- Two rapid mix chambers, where chlorine is added (pre-treatment) and liquid aluminum sulfate is added as well ($Al_2(SO_4)_3$) type B.
- 4 Four reactors compact type where water is flocculated and settled.
- 24 filters at decline rate (descendent flow).
- Chlorine disinfection.
- Chlorine contact tank with capacity of 24000m^3. In the exit, $Ca(OH)_2$ is added to adjust pH (8,5-9,0 units).
- One drinking water pumping station to the distribution network, composed by 6 pumps with capacity of 1,1m^3/s each.

Figure 4.5 Puerto Mallarino treatment plant

La Reforma: It is located in the rural district of Villa Carmelo in the city of Cali at a level of 1300 above sea. It is supplied by Meléndez river and has an installed capacity of 1,0m^3/s. The plant supplies by gravity the slope hill area of the city. It is compact type that can operate at complete cycle or direct filtration depending on the turbidity of the incoming raw water. It is composed by the following units:

- One double water intake (bottom and side).
- One grit chamber with two compartments.
- One rapid mix chamber, where chlorine is added
- 4 flocculation units composed by three chambers each.
- 4 high rate sedimentation units.
- Rapid gravity filters with sand and anthracite beds, decline rate and a filter back wash system.
- One storage tank where gas chlorine is added.
- Two water distribution exits: Lines Nápoles y Siloé.

Figure 4.6 La Reforma treatment plant

La Ribera: It is located in the middle part of Pance river basin. The water intake is performed by means of a side intake design to catch 30,0 l/s from Pance river. The plant was bought by EMCALI in year 2004 and supplies the dwellings from La Ribera urbanization. The plant has a technology with multiple stage filtration. The system is composed by:

- Deviation channel.
- Regulation pond with an approx. Volume of 10000 m^3.
- Entry channel.
- Two pre-filters with ascend flow. Sand bed of thickness 1,20 m and five gravel layers.
- Two slow sand filters. Sand bed of thickness 1,25 m and 0,20 m gravel layer, 0,05 m thick sand and 1,00 m fine sand.
- Two storage tanks.
- Chlorine disinfection

Figure 4.7 La Ribera treatment plant

Table 4.5 shows a summary of the design parameters and characteristics of the four plants that supply the drinking water demand in Cali.

Table 4.5 Drinking water plants characteristics

Plant	Río Cali	Río Cauca	Puerto Mallarino	La Reforma
Initial operation year	1930	1958	1978	1993
Technology	Conventional	Compact	Complete cycle	Conventional
Installed capacity (m^3/s)	1,80	2,50	6,60	1,00
Average production (m^3/s)[1]	1,23	1,77	4,11	0,41
Plant shutdowns (hours/year)[2]	11,3	37	35	19,6
Sludge production (ton/month)[3]	17,9	30,7	67,8	2,3
Cost treated m^3 ($\$/m^3$)[4]	39,6	97,14	51,8	31,2

Source:
1.Production information, December 2006, EMCALI
2. Production year 2005, EMCALI.
3. Sludge production year 2003, EMCALI
4. Production costs year 2006, EMCALI. Río Cali and Río Cauca plant, production costs - September 2007. Costs without expenses of personnel.

Regarding chemical consumption, Table 4.6 shows the total consumption during the last three years in Puerto Mallarino and Río Cauca plants. In the table, it can be seen that the chemical most used is aluminum sulfate used in the coagulation process and the second most used is Calcium hydroxide used to regulate pH. The main cost in the drinking water treatment is the consumption of chemicals.

Table 4.6 Chemical consumption in Puerto Mallarino and Río Cauca plants. Period 2004-2006.

Plant	Puerto Mallarino					Río Cauca			
Year	Aluminum sulfate (kg)	Calcium (kg)	Chlorine (kg)	Activated carbon (kg)	Polymer (kg)	Aluminum sulfate (kg)	Calcium (kg)	Chlorine (kg)	Activated carbon (kg)
2004	3.177.112	1.008.100	818.454	102.600	0	1.444.711	367.000	298.731	55.869
2005	3.043.862	1.101.850	986.796	158.581	101.172	1.059.475	268.952	220.275	45.417
2006	3.779.481	1.447.550	1.001.725	131.522	47.257	1.240.179	336.944	247.467	123.983

Source: EMCALI, 2006.

Table 4.7 shows the chemicals consumption in Río Cali and la Reforma plants during the period January –May, 2007.

Table 4.7 Chemical consumption in Río Cali and La Reforma plants period January – May, 2007

Plant	Río Cali				La Reforma			
Month	Calcium (kg)	Chlorine (kg)	Aluminum sulfate (kg)	Activated carbon (kg)	Calcium (kg)	Chlorine (kg)	Aluminu m sulfate (kg)	Activated carbon (kg)
January	19,98	8,16	80,66	20	5,20	1,81	10,09	0
February	17,25	6,34	76,13	0	4,40	1,81	12,09	0
March	19,15	9,07	112,69	20	5,35	907	13,29	40
April	18,30	8,16	95,77	20	5,35	2,72	11,54	0
May	16,43	9,07	99,99	40	5,10	907	12,63	0

Source: EMCALI, 2007b

Annex 4.1 describes the sludge quality coming from the drinking water process in the different plants. The Annex shows as well the volume and sludge characterization produced in Puerto Mallarino plant.

4.3 DRINKING WATER DISTRIBUTION

4.3.1 General description

The current drinking water coverage in Cali is 97% (Technical planning department, EMCALI, 2007). The drinking water distribution system in the city is supplied by Puerto Mallarino, Río Cauca, Río Cali and La Reforma plants. Figure 4.8 shows the water distribution network scheme.

The distribution network is divided depending on the type of service: High network (pumped system), low network (gravity system) and Reforma. Additionally, there is the Ribera water supply system which covers the communities located in the Pance area. Figure 4.9 shows the low and high network distribution systems.

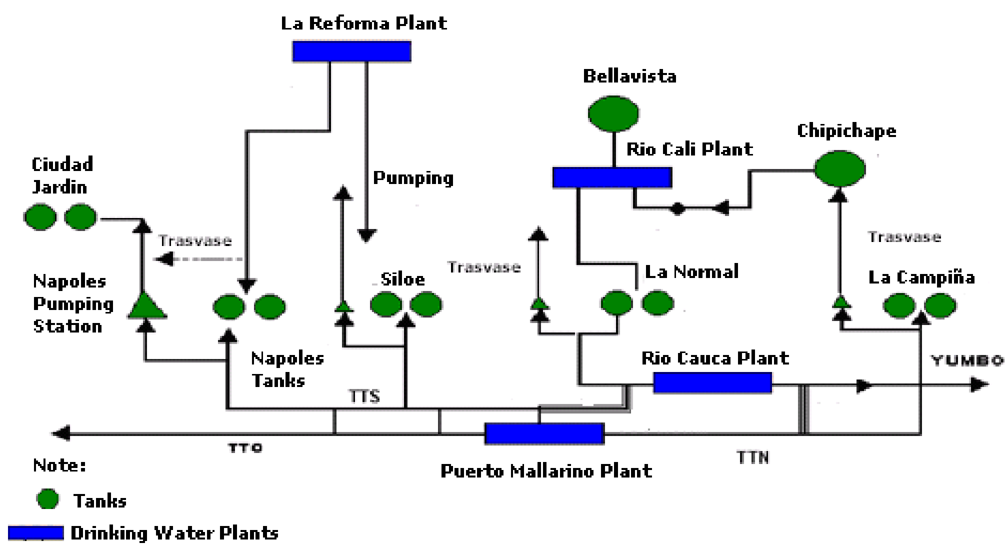

Figure 4.8 Drinking water distribution network scheme in the city of Cali.
Source: EMCALI , 2007b.

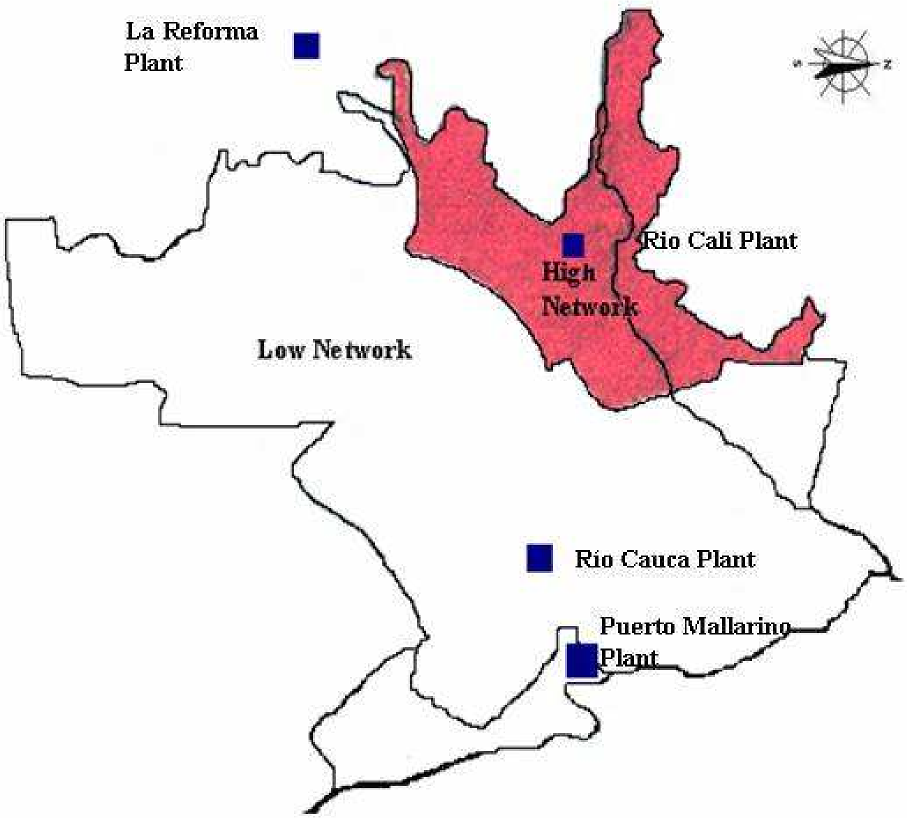

Figure 4.9 High and low distribution networks in Cali.
Source: Vasco, 2006

Table 4.8 briefly describes the distribution network in the city, considering the water source and the population covered.

Table 4.8 General description of the water distribution network in Cali

Source	Drinking water plant	Design flow (m^3/s)	Current flow, 2007 (m^3/s)	Network	Percentage covered population
Cauca river	Puerto Mallarino	6,60	4,20	Low	77% of the population located in the flat area of Cali and a sector located in the flat area of the municipality of Yumbo
	Rio Cauca	2,50	1,80		
Cali river	Rio Cali	1,80	1,50	High	17,1% of the population located in the slope hill (north-west and center of Cali)
Meléndez river	La Reforma	1,00	0,45	Reforma	5,7% of the population located in the slope hill (south-west of Cali)

Source: Adapted from EMCALI-Universidad del Valle, 2007

Table 4.9 shows the course and diameters followed in the low network in Cali.

Table 4.9 Description of pipes and their trajectory in the low distribution network in Cali

Plant	Network	Description
Puerto Mallarino	Transmission North pipe (TTN)	Supplies the north of the city with a pipe diameter of 56" until Cali-Yumbo highway where the diameter are reduced from 24" to 12" until Puerto Isaac pumping station in Yumbo.
	Transmission South pipe (TTS)	Supplies the south of the city with a pipe diameter of 56". Supplies Napoles tanks.
	Transmission east pipe (TTO)	Supplies the east part of the city. It crosses Aguablanca district wit pipe diameter of 36" until the hospital Valle del Líli.
Río Cauca	South exit	Meets a deviation of TTS and supplies Napoles pumping station.
	North exit	Feeds the tanks located in La Campiña neighborhood with a pipe diameter of 30". Exits with a diameter of 24".

Source: Adapted from EMCALI– Universidad del Valle, 2007

4.3.2 Age of the pipes

The total length of the distribution network in Cali is 2703 km. The diameters of the pipes vary between 25,4 and 1422 mm made of different materials such as: melted iron (HF), cement (AC), steel, PVC, high density polyethylene (PAD) and ductile iron. In Figure 4.10 shows the distribution in percentage of the diameters and materials used in Cali's distribution network and Table 4.10 shows the approximate age of the pipes in the system.

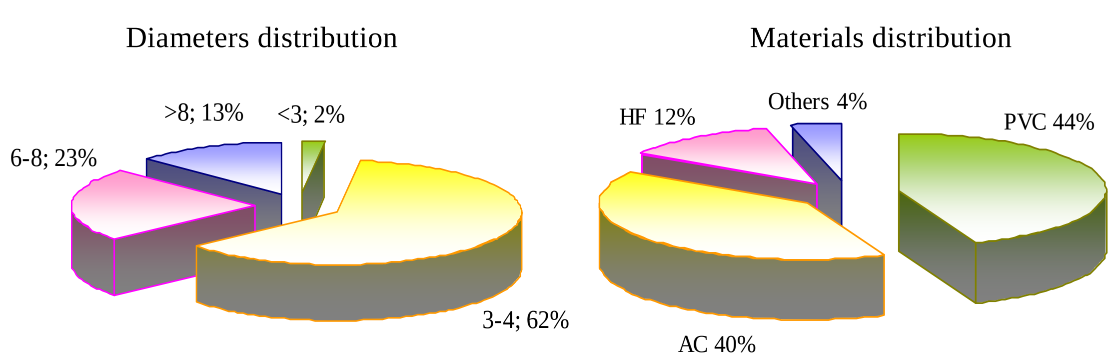

Figure 4.10 Distribution of the diameters and materials used in Cali's distribution network.
Source : EMCALI, 2006 cited by EMCALI-Universidad del Valle, 2007

Table 4.10 Age of pipes in the distribution network in Cali

Material	Material distribution (%)	Installation date	Average age (years)
PVC	43,28	1982 – 2005	12
Cement	39,98	1956 – 1992	31
Iron	12,39	1942 – 1962	53
Pre-enforced concrete	2,03	1960 – 1997	27
Ductile iron	0,82	1994 – 2005	6
Steel	1,31	1964 – 1982	32
Polyethylene high density	0,19	2005	

Source: EMCALI 2006 cited by Vasco 2006

4.3.3 Storage tanks and pumping stations

Table 4.11 shows the information regarding the storage tanks in the city.

Table 4.11 Principal tanks in the distribution network in Cali.

Tank	Water source
La Campiña	North exit and TTN
La Normal	Water from the high
Siloé	La Reforma plant through a pipe of 24’’diameter. In dry season, low network puma water to these tanks
Nápoles	TTS
C. Jardín	Compensation tank located in pilot area Nápoles – Ciudad Jardín

Source: Adapted from EMCALI

The pumping stations corresponds to the sectors of Nápoles, Menga alto and bajo, Bellavista 1 and 2, Siloé tanks, La Normal tanks, Yumbo and Terrón Colorado (EMCALI, 2006 cited by EMCALI-Universidad del Valle, 2007).

Table 4.12 and Table 4.13 show the pumping stations and the storage tanks in the high and low networks with their respective capacities.

Table 4.12 Pumping stations and storage tanks in the high network

Pumping station		Tank		
Name	Capacity (m^3/ h)	Location	No.	Volume (m^3)
Bella vista	420	Río Cali plant	4	40
Cristales	58	Bella vista pumping	2	2,5
Terron Colorado 1	430	Terron Colorado pumping	4	2,69
Terron Colorado 2	202	Menga pumping	2	2
Terron Colorado 3	111	Cristales pumping	1	120
Terron Colorado 4	43	Norte 1 pumping	3	3,2
Aguacatal	54		-	-
Siloé Antiguo	-		-	-
Menga Antiguo	129		-	-
Menga Nuevo	40		-	-
Norte 1	-		-	-
Total	1487	Total	16	50,51

Source: URL-1

Table 4.13 Pumping stations and storage tanks in the low network

Pumping station		Tank		
Name	Capacity (m^3/ h)	Location	No.	Volume (m^3)
Siloé 1	576	Siloé (La Nave)	2	24
Siloé 2	396	Normal	2	30
Siloé 3	396	Campiña	2	32,5
La Normal	630	Ciudad Jardín	2	8,5
Nápoles	1446	Yumbo	2	4
Los Chorros	90	Norte II	4	1141
Yumbo 1	-	Siloé 1	1	480
Yumbo 2	-	Siloé 2	1	990
Norte II E	-	Siloé 3	1	450
Total	3534	Total	17	102061

Source: Adapted from EMCALI– Universidad del Valle, 2007

4.3.4 Damages in the distribution networks

In Figure 4.11 it can be seen that the number of damages has decreased with time due to replacement of pipes in the networks and general maintenance.

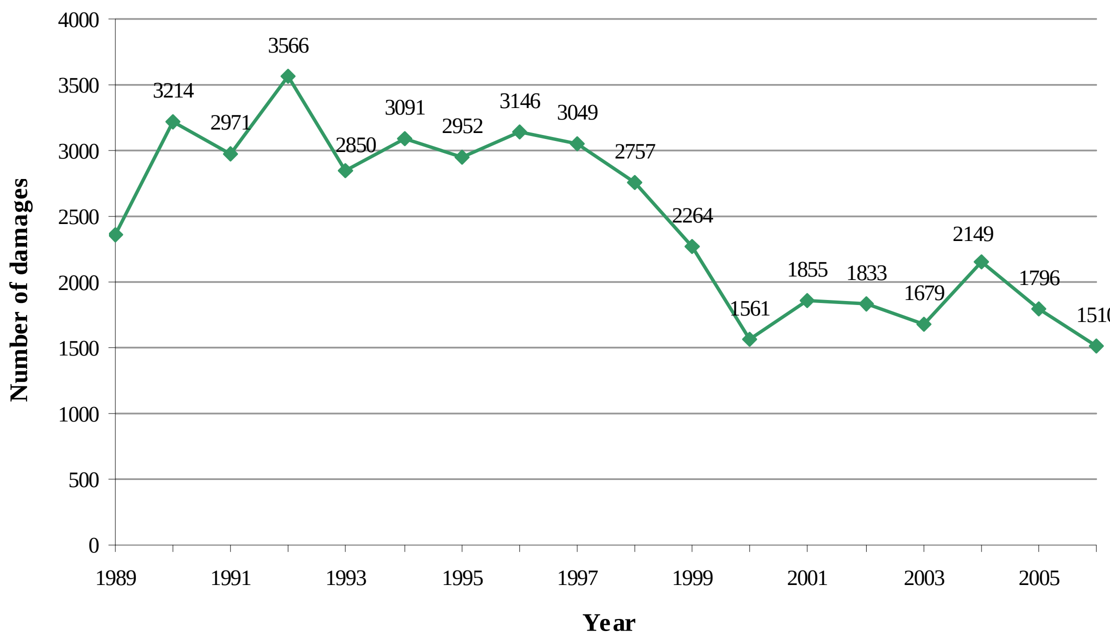

Figure 4.11 Number of registered damages during the period 1989-2006
Source: EMCALI, 2006b

According to Figure 4.12, the cemented pipes are the ones that registered the bigger number of damages followed by PVC and iron pipes. In the cemented pipes is more likely to find damages since this type of pipes constitute 40% of the total pipes in the network. However, cemented pipes are more likely to suffer damages than PVC pipes (which constitute 44% of the total pipes) since PVC material is stronger. In year 2006, PVC pipes registered 198 damages in comparison to cemented pipes with 1106 damages.

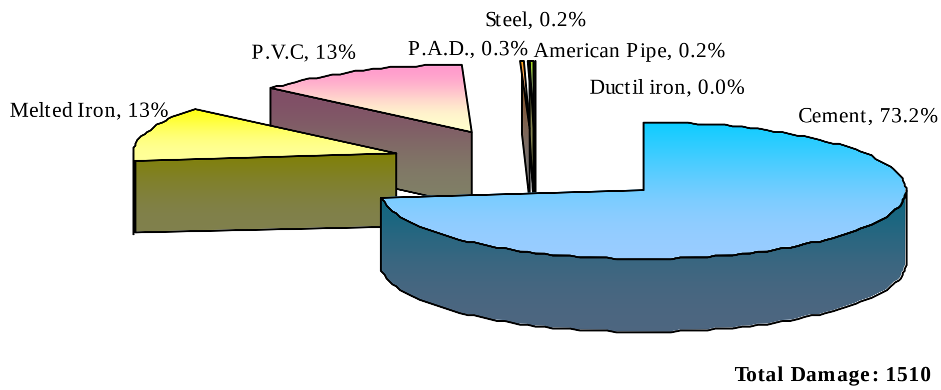

Figure 4.12 Damages classified by material, year 2006
Source: EMCALI, 2006b

4.3.5 Service interruptions

Figure 4.13 registers the total number of hours when the distribution network services were stopped and the average time spent in the damages (TAD) during years 1998 and 2007.
The interruption of the service is made only in the area where the damage was presented with an approximated duration of 12 hours based in the reports from the last years. The time spent in damages has decreased in the past years showing an improvement in the efficiency in time reparation. In this way the time of interruption in the delivery of water has decreased as well. However, due to the high number of damages registered in the networks, the interruption time is still to long; for instance in 2006 the total number of hours of cancellation of the system was 19616 hours.

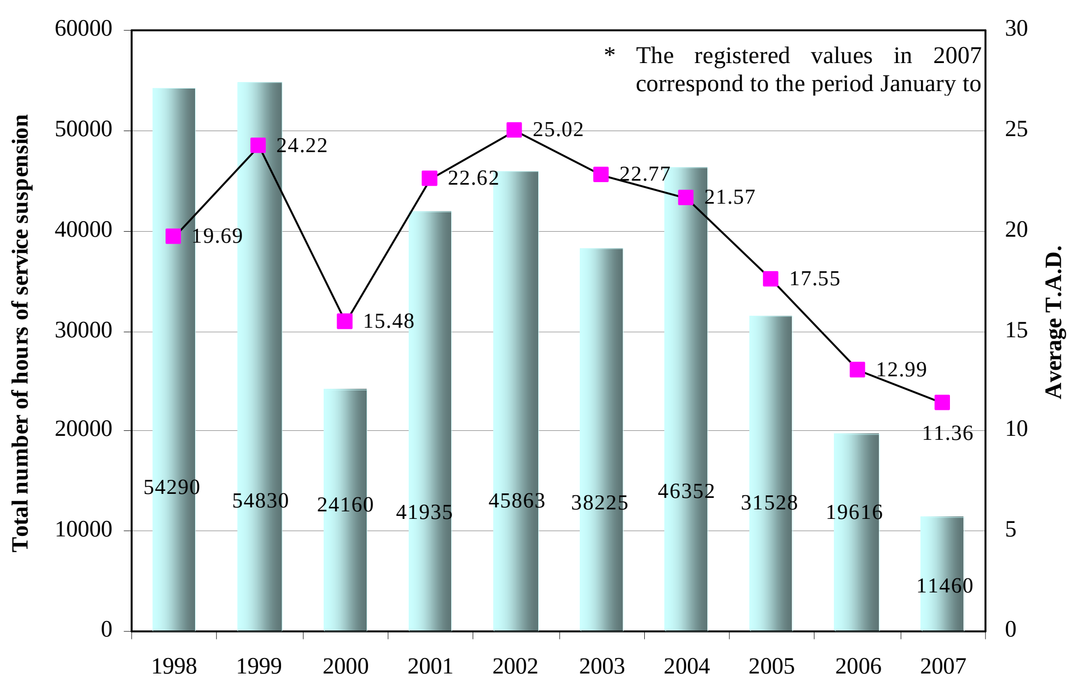

Figure 4.13 Total number of hours of interruption of the delivery of drinking water based on the affected area and the time spent repairing the damages (TAD). Period 1998-2007
Source: EMCALI, 2007c

4.3.6 Water losses

The unaccounted for water index has been kept constant throughout the years with average values reaching 40%. As it is shown in Table 4.14 in year 2003, 86'161822 m^3 of the total produced water were not charged which indicates presence of illegal connections mainly in slum areas. Such amount of water lost (not charged) represents great economic losses for the drinking water company in charged, in this case EMCALI.

Table 4.14 Volume of unaccounted for water in Cali. Period 1997-2003.

Year	Total volume of supplied water (m^3/year)	Volume of water according to payments (m^3/year)	Volume of water not paid (m^3/year)	Average un-accounted for water index (%)
1997	209.506.839	147.316.543	62.190.296	29,63
1998	212.724.360	142.176.023	70.548.337	33,16
1999	195.809.566	132.836.212	62.973.354	32,14
2000	199.005.765	130.774.290	68.231.475	34,26
2001	212.230.029	130.074.944	82.155.085	38,63
2002	223.595.369	132.516.378	91.078.991	40,72
2003	219.475.452	133.313.630	86.161.822	39,25

Source: EMCALI, 2003.

According to EMCALI, for the year 2007 until July the unaccounted for water index has reached an average of 39,98%. Figure 4.14 shows the percentages of un-accounted for water during the period 1997- 2005.

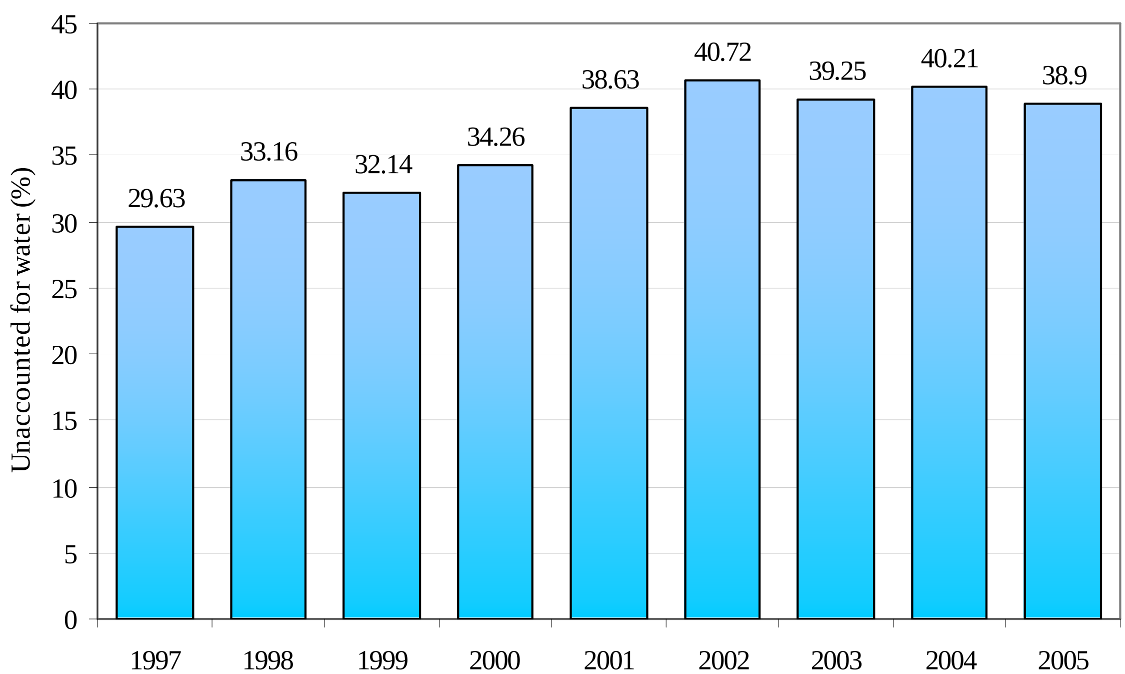

Figure 4.14 Unaccounted for water index in percentage, period 1997 - 2005

Source: EMCALI, 2007b

4.3.7 Water quality in the network

The water production department in EMCALI counts with a central lab where water quality control is carried out daily. In the lab, physical-chemical and bacteriologic analysis are made to water samples taken in different parts of the city (Vasco, 2006).

After a study carried out by EMCALI-Universidad del Valle (2007), that analyzed possible ways to reduce the toxicity risk in the water network supplied by Cauca river, it was found that the high network presents problems associated to presence of particulate material which influences the turbidity, total solids and real color in the water. Such problem may be related to the age of pipes which are older than 36 years.

There are also chlorine concentrations above 1 mg/l recorded in the monitoring control stations in the distribution network which can influence formation of by-products in the network and increase the risk of chemical contamination in the water (EMCALI-Universidad del Valle, 2007). More discussion about contamination of drinking networks will be discussed in Section 4.4.3.

4.4 MAIN ENVIRONMENTAL PROBLEMS ASOCIATED TO DRINKING WATER SUPPLY

4.4.1 Deterioration of the water supply sources in the city of Cali

The water supply sources in the city of Cali present a progressive quality deterioration mainly due to deforestation, to presence of slums located in the protection area of the river basins and to the discharge of wastewater. The contamination of the rivers threaten the supply of drinking water being the biggest affected source Cauca river to which the next section 4.4.2 will be devoted.

Due to the contamination of the water supply sources, the drinking water plants present higher operation and treatment requirements and as a consequence an increment in the treatment costs. When there are pollution peaks, EMCALI suspends the intake of raw water. As it can be seen in Figure 4.15 the drinking water plants that present higher operation-time stops are Rio Cauca and Puerto Mallarino which are supplied by Cauca river.

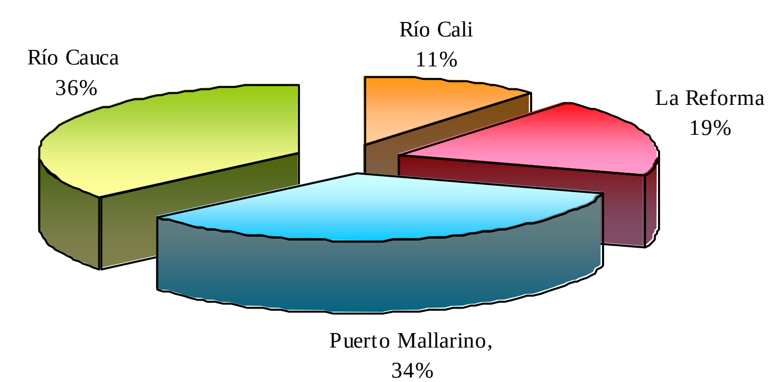

Figure 4.15 Percentage of time that the drinking water plants were shutdown due to high pollution concentration in the water sources in year 2005.
Source, Vasco, 2006

4.4.2 Contamination of Cauca river and its effects in water supply

The city of Cali depends 77% on the Cauca river for the drinking water provision. The deterioration of the quality of this source is threatening the safe provision of water to the population, when the risk is increased as much as the acute and chronic point beyond the capacity of treatment of the Río Cauca and Puerto Mallarino plants.

The two most important sources of contamination upstream the water intake of Puerto Mallarino Plant are the south channel and the Navarro disposal site which discharge wastewater and pollution around 5 km upstream the Puerto Mallarino water intake. As an example, the level of contamination of Cauca river is reflected in the oxygen curve recorded in the water intake point of the plant in March, 2007 shown in Figure 4.15, where it can be seen the sudden oxygen decrease in the river.

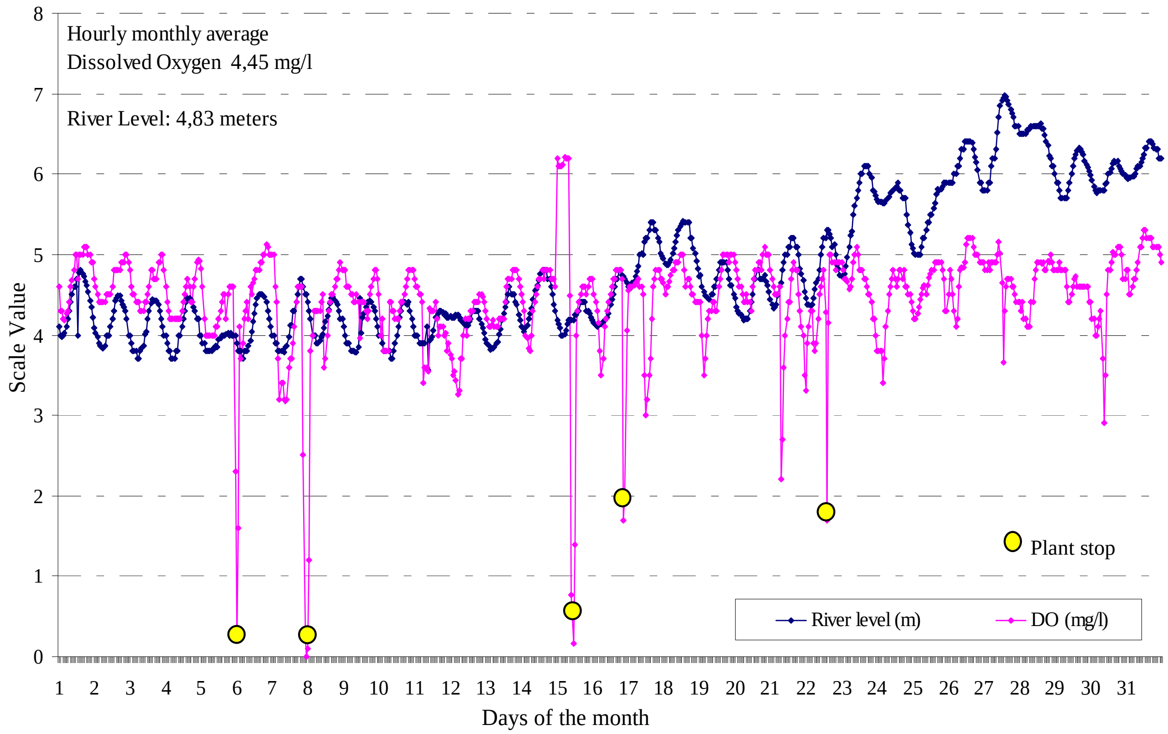

Figure 4.16 Dissolved Oxygen (DO) and water levels of the Cauca River in the water intake point of Puerto Mallarino Plant, March 2007
Source: EMCALI, 2007d. Daily report of DO and water levels recorded in Puerto Mallarino Plant

When the DO levels in the water intake point reaches values lower than 2 mgO_2/l, EMCALI suspends the raw water intake. Figure 4.17 shows an example of the low DO levels in the water intake in Cauca river registered in a day in March, 2007. The low DO levels caused the stopping of operations in the Puerto Mallarino plant during a period of around three hours.

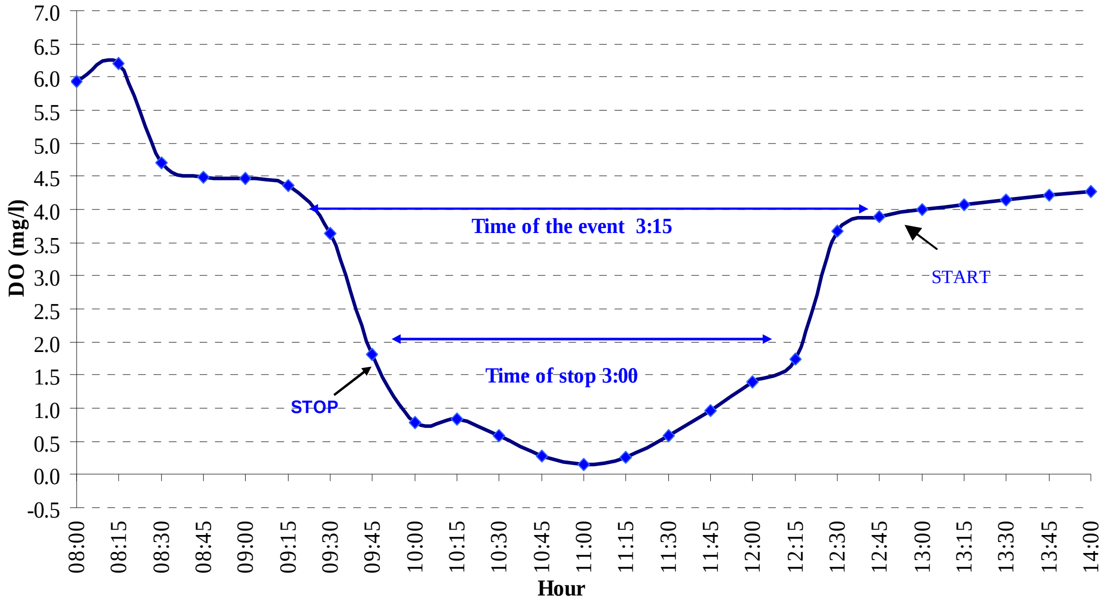

Figure 4.17 DO profile that causes the cease of activities in the drinking plant Puerto Mallarino in March 15, 2007 from hours 9:45 to 12:45 pm.

Source: EMCALI, 2007d. Daily report of DO and water levels recorded in Puerto Mallarino Plant, 2007

Likewise, Figure 4.18 shows the number of times that the Puerto Mallarino and Rio Cauca plants were stopped due to high contaminating levels in Cauca river since the year 2000 to 2006. The number of time that the plant was left out operation has increased during the years.

The total number of hours that the Puerto Mallarino plant was out of operation in the period 2000-2006 was 342 hours and 11 minutes.

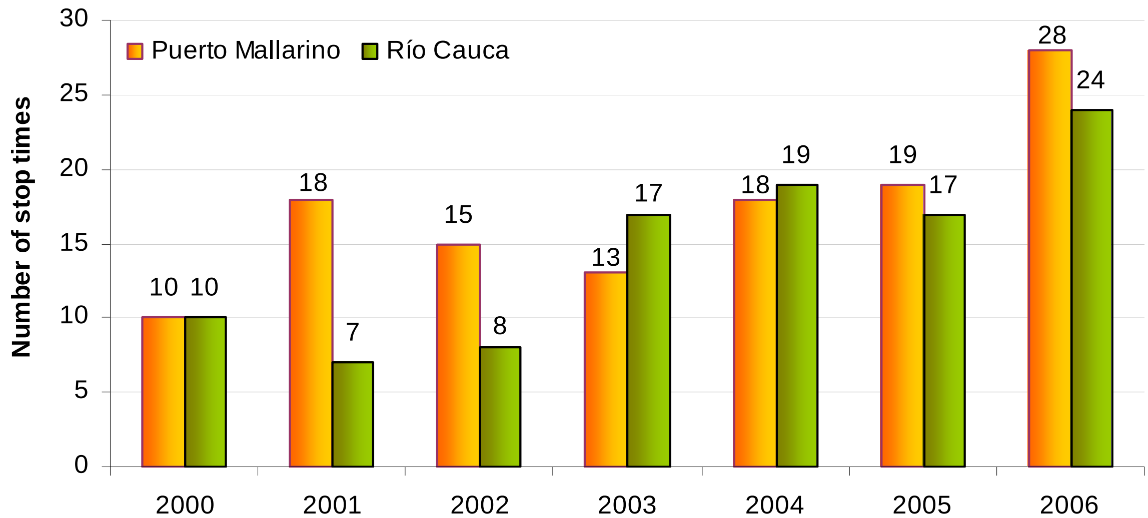

Figure 4.18 Times Puerto Mallarino and Rio Cauca plants were put out of operation, 2000 to

Source: Data reports given directly by Rio Cauca plant years 2000-2006 and EMCALI-Universidad del Valle, 2007

Figure 4.19 shows the causes of the shutdown of the plant. It can be seen that around 60% of the times was due to the high polluting levels in the river, followed by shortages in the electric power.

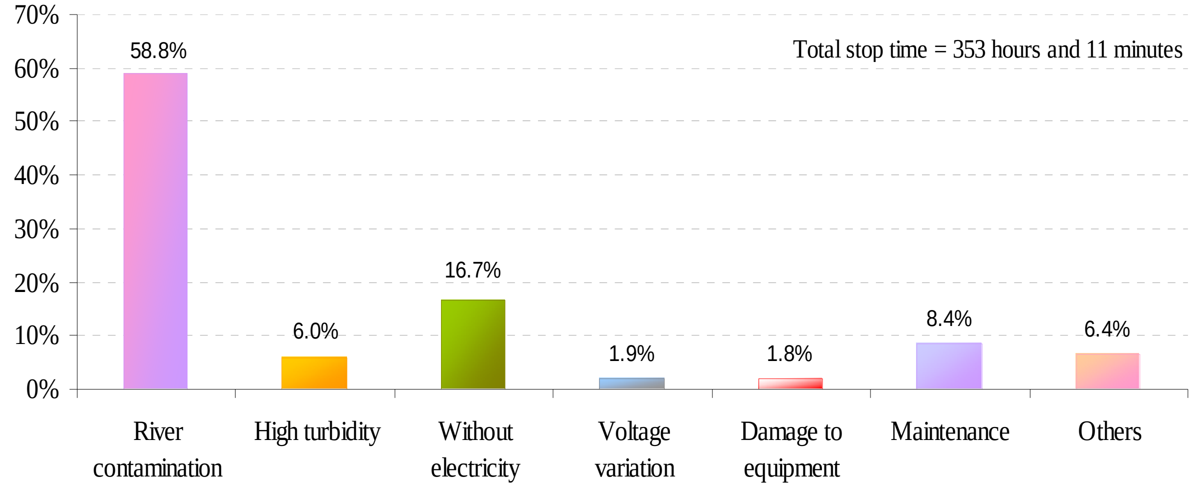

Figure 4.19 Percentage distribution of the time that Puerto Mallarino was shutdown and the likely causes of it. Periods 2000-2006.
Source: EMCALI-Universidad del Valle, 2007

Each time that the drinking water plant is stopped, more than one million people are left out without water since the plants are stopped suddenly when the DO concentrations measured in the water intake are low. Additionally there is not system in place that alerts when the plant will be likely stopped. Hence, there is no time to inform people that the plants will be stopped so that the community can take the adequate prevention measurements.

Additional to the problems surrounding the operational shutdowns by contamination of the Cauca river, it has been also found a potential risk of contamination in the water due to the high concentrations of phenol compounds, some metals and organic matter, which cause by-products formation as a result of the disinfection process when treating water (EMCALI- Universidad del Valle, 2006). In Figure 4.20 the diagram of boxes and wires found in the monitoring campaign carried out by EMCALI-Universidad del Valle in 2006 show the variation in the lead concentration which is similar in the stations Hormiguero and Before South Channel, the mean value for both stations is over the value recommended in National Norm, Decree 1594 of 1984 (0,05 mg/l) (criteria of water quality for human consumption after conventional treatment). At the level of water intake in the station before Puerto Mallarino, the lead concentrations stay below the permissible limits.

Moreover, in Table 4.15 the minimums, maximums and averages values of the concentrations of phenol compounds are shown monitored in 2006. In this Table it is possible to observe that the average total concentrations of phenols are above the limit established in National Norm, Decree 1594 of 1984 of the Ministry of Health (that is of 2,0 µg/l). This means that there is a risk of by-product formation from the disinfection with chlorine. or penta-chlorine-phenoles and 2,4,6 tri-chloride-phenol the values stay below the norm. Nevertheless, the wastewater discharge from the South Channel presents the maximum values (3,59 µg/l) and average (1,49 µg/l) in concentration of 2,4,6 tri-chloride-phenol. In spite of this at the level of water intake in Puerto Mallarino, the concentration of these parameters is below the limit for the use of the resource as human consumption.

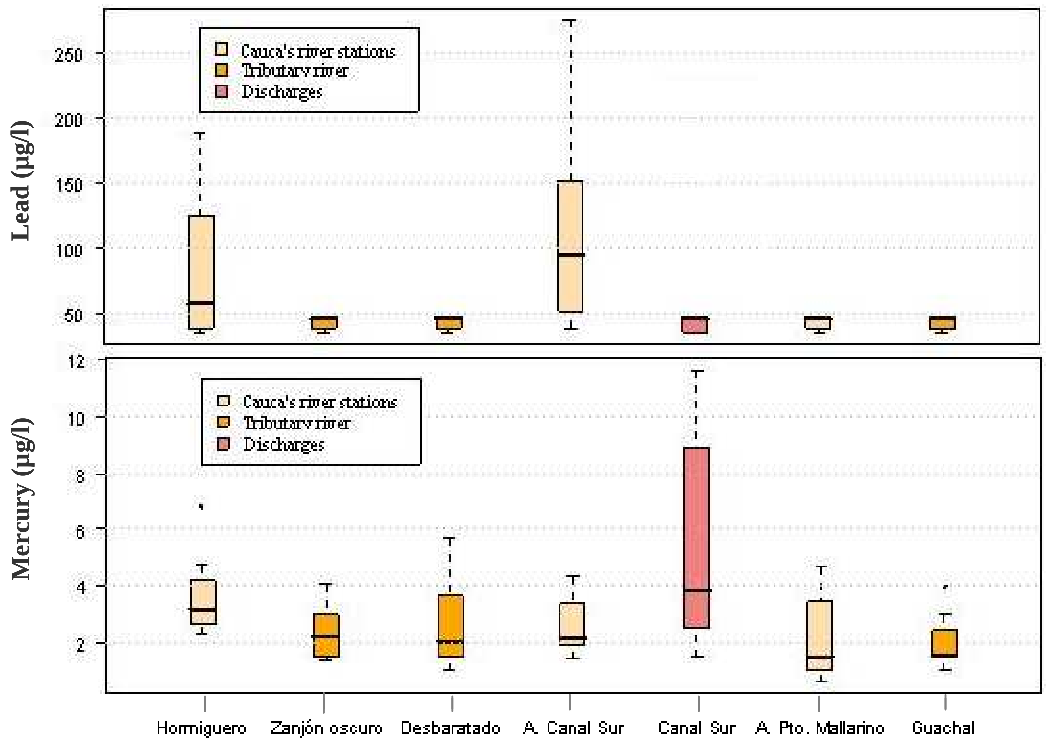

Figure 4.20 Boxes diagram presenting concentrations of hazardous substances in Cauca river: lead and Mercury. Monitoring campaign, july 11-15, 2006

Source: EMCALI-Universidad del Valle, 2007

Table 4.15 Phenols concentrations. Monitoring campaign, july 11-15, 2006

Parameters	Charact.	Cauca river			Tributaries				Decree 1594 , 1984
		Hormiguero	Before South channel	Before intake Pto Mallarino	Zanjón Oscuro	Desbaratado river	Guachal river	South channel	
Total phenols (µg/l)	Minimum	<1,00	<1,00	<1,00	<1,00	<1,00	<1,00	<1,00	<2,0
	Maximum	57,4	39,51	14,53	78,54	39,76	78,54	56,9	
	Average	20,06	12,53	4,42	19,87	18,81	19,87	12,78	
Penta-chlorine-phenol (µg/l)	Minimum	<0,35	<0,35	<0,35	<0,35	<0,35	<0,35	<0,86	<2,0
	Maximum	<0,35	<0,35	0,91	5,77	1,06	0,49	3,59	
	Average	<0,35	<0,35	0,42	1,09	0,47	0,37	1,49	
2,4,6 Tri-chlorine-phenol (µg/l)	Minimum	<0,86	<0,86	<0,86	<0,86	<0,86	<0,86	<0,86	<2,0
	Maximum	<0,86	<0,86	<0,86	<0,86	<0,86	0,87	3,59	
	Average	<0,86	<0,86	<0,86	<0,86	<0,86	0,86	1,49	

Source: EMCALI- Universidad del Valle, 2006

4.4.3 Risk of contamination of the water distribution networks

In the last years the number of complaints of the users about the deterioration of the physical quality of the water has increased. In addition in a daily basis there are registered between 5 and 7 damages in the networks, which increases the risk of contamination of the water in the networks during the repairs. This situation constitutes a problem for EMCALI since the potential risk for the public health to which the users are exposed is unknown. Due to the lack of studies on formation of bio-films, presence of microorganisms and the accumulation of physic-chemical substances in the internal walls of the distribution networks, recently, a study of the microbiological characterization of the interior of the pipes of the low network of distribution of Cali was made (Muñoz, 2007). In this study the microbiological quality of the source and the effluent of the existing conventional treatment system in Puerto Mallarino was characterized obtaining the following results:

The quality of the water of the Cauca River presents a high level of microbiological risk. The type of pathogenic bacteria more found in the raw water were: *the Klebsiella pneuminiae, Citrobacter freudnii, Entrobacter aglomerans, Klebsiella Oxytoca and Proteus mirabilis* that represent the group of the entro-bacteriacea. Belonging to this group the bacteria must be inactivated in the system of treatment and networks during the repairs, since these organisms grow within bio-films. In Table 4.16 and Table 4.17 the data of quality parameters for raw water and treated water appears.

Table 4.16 Row water quality description – Cauca river (Period 14/08/2003-13/05/2004).

Parameter	E. Coli	Total Coliforms	Heterotrophic bacteria	Temperature	pH	TOC	Phosphates	Total iron	Total manganese
	(UFC/ml)	(UFC/ml)	(UFC/ml)	(ºC)	(un)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Max	$2.1x10^6$	$8.8x10^6$	$2.96x10^7$	25	7,6	9,0	1,11	9,4	1,8
Min	$1.1x10^4$	$2.5x10^4$	$5.5x10^4$	23	6,5	1,37	0,02	2,5	0,04
Average				24		3,97	0,21	5,7	0,3
Percentile 95%						6,96	0,54		

Source: Adapted from Muñoz, (2007)

According to the COT, phosphates and heterotrophic bacteria concentrations were found in the evaluated period and the effluent from Mallarino plant show a potential re-growth and multiplication of microorganisms inside the networks walls (see Table 4.17).

In the internal walls of the distribution pipes, tanks and valves, it was found presence of total coliformes, with maximum values of 5 log units UFC/cm^2, whereas the heterotrophic bacteria registered maximum values of 10 log units UFC/cm^2 (Muñoz, 2007).

Table 4.17 Effluent water quality description – Cauca River (Period 14/08/2003-13/05/2004).

Parameter	E. Coli	Total Coliformes	Heterotrophic bacteria	Temperature	pH	TOC	Phosphates	Total iron
	(UFC/ml)	(UFC/ml)	(UFC/ml)	(ºC)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Max	0	0	80	26	3.7	0.17	0.08	0.098
Min	0	0	0	23	0.7	0.01	0.06	0.015
Average				24	1.9	0.08	0.07	0.06
Percentile 95%			22		3.0	0.16		

Source: Adapted from Muñoz, (2007)

The results also indicated the formation of bio-film inside the distribution pipes walls which depend on the temperature variation, total iron inside the walls and the distance of the sampling point to the effluent of the drinking plant as well as the age and material of the pipe.

As it is shown in Table 4.18, in the water column of the distribution network, it was found presence of heterotrophic bacteria in two sampling points with values of 177 and 92 UFC/100ml. The presence of such bacteria can be associated to the distance to the treatment plant and the pipe material.

In neither of the water column sampling points, there was record of feacal and total coliformes and the values for the physical-chemical parameters were found inside the standard range (decree 475-1984). In the PVC and cement pipes, 5 sampling points showed TOC values between 2,1-2,9mg/l which are higher than the ones recommended by USEPA (2,0 mg/l inside the network) which shows that more maintenance and higher control in the water source are needed.

The obtained results in the study from Muñoz (2007), indicate that EMCALI must study more in depth the development of bio-films so that it can be controlled and the potential risk health by contamination on the distribution networks can be prevented.

Table 4.18 Microbiologic and physical-chemical quality in the water column according to material type.

Microbiologic parameter	Mean value		
	AC (cement)	PVC	AC/HF[1]
E. Coli (UFC/100ml)	0	0	0
Total Coliformes (UFC/100ml)	0	0	0
Heterotrophic bacteria (UFC/100cm^3)	92*	0	177*
Physical-chemical parameter	Average value (Standard deviation)		
Residual chlorine (mg/l)	0,92(+0,26)	0,89(+0,32)	0,86(+0,41)
pH (Und) Min-Max	6,5-7,9	7,5-7,8	7,1-7,7
TOC(NPOC mg/l)	1,5(+0,66)	1,75(+0,83)	1,8(+0,87)
Phosphates (mg/l)	0,16(+0,24)	0,17(+0,14)	0,18(+0,20)
Magnesium (mg/l)	0,06(+0,04)	0,08(+0,08)	0,06(+0,01)
Total Iron (mg/l)	0,13(+0,16)	0,11(+0,14)	0,19(+0,26)
Aluminum (mg/l)	0,05(+0,02)	0,03(+0,02)	0,05(+0,03)
Temperature (ºC)	27(+2,74)	29	27(+0,28)
Number of data	12	9	3

Source: Muñoz, 2007.
1. AC/HF Sector where the pipe is made of iron and cement
(*) maximum values

4.5 ALTERNATIVES TO GUARANTEE THE DRINKING WATER SUPPLY IN CALI

Reservoir

In order to guarantee the supply of drinking water to Cali, using as source of supplying the river Cauca, EMCALI proposes the construction of a water reservoir near the plant, that allows the storage of a sufficient volume of water to supply the Puerto Mallarino plant during the peaks of pollution in the river. Figure 4.21 shows the location of this reservoir, that it will allow to store next to 80000 m^3 of raw water in an area of 6 ha (URL-2).

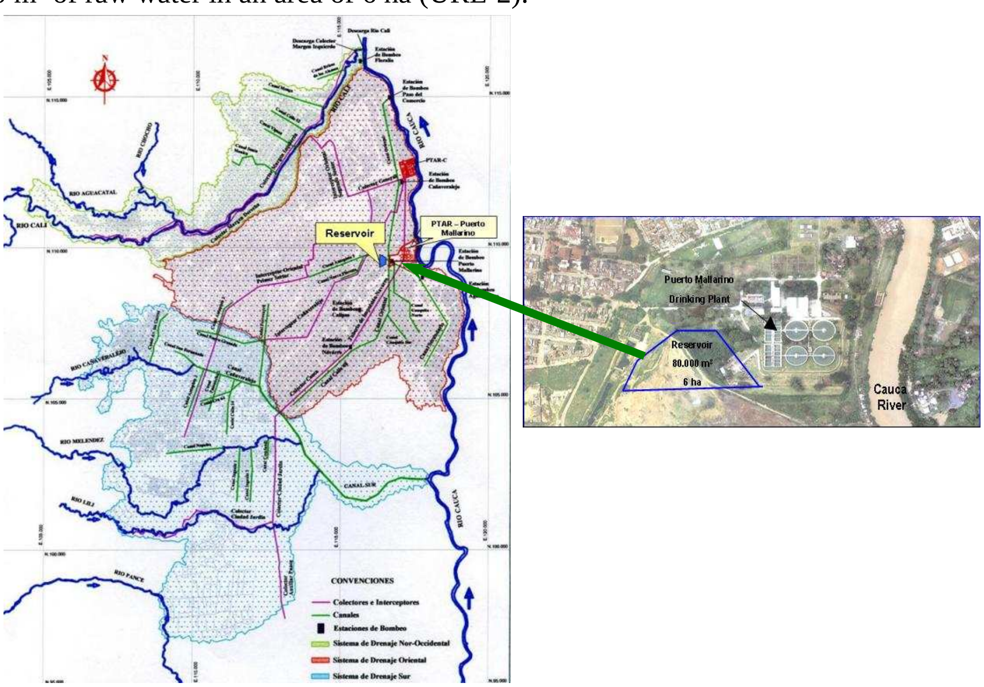

Figure 4.21 Location of the reservoir
Source: EMCALI, 2007.

Figure 4.22. shows the diagram as there would stay working the intake water and the plant of treatment of Puerto Mallarino with the operation of the reservoir.

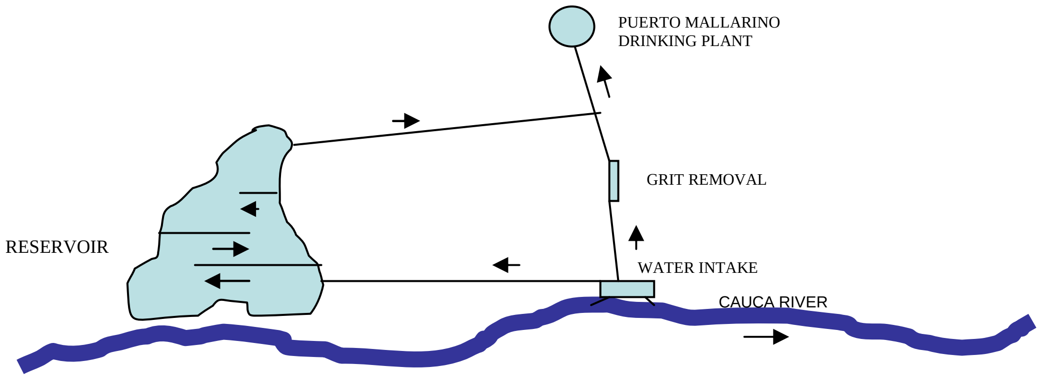

Figure 4.22 Diagram of operation way of Puerto Mallarino plant with the construction of the reservoir.
Source: EMCALI, 2007.

Relocation of the water intake of Puerto Mallarino Plant

Another alternative is to locate the water intake of Puerto Mallarino plant in the Paso de la Bolsa Station and transport the raw water up to the Puerto Mallarino Plant, where the treatment would be realized. Figure 4.23, shows the different possible rutes for transport the raw water up to the plant.

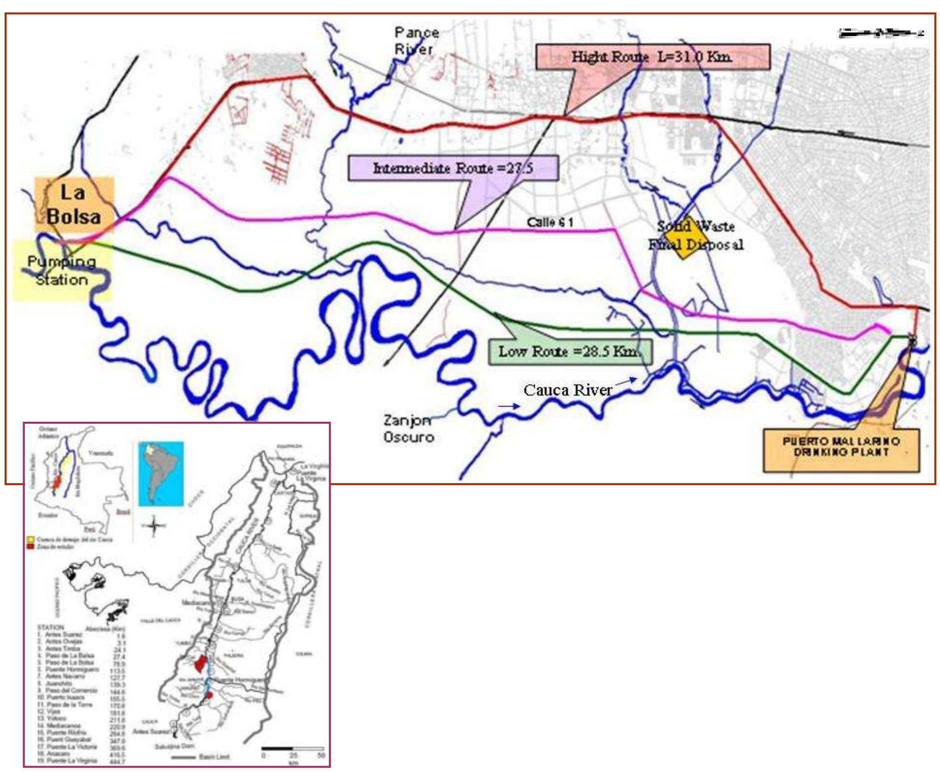

Figure 4.23 Different possible rutes for transport the raw water from Paso de la Bolsa up to the Puerto mallarino plant.
Source: EMCALI, 2007

Proposals for location of place for water intake and water drinking plant

The Municipal Enterprises of Cali, EMCALI, also have studied alternatives related with the locating of water intake and drinking water plant of the Cauca river, in a place located upstream the south channel discharge. In this way it is sought to resist the possible pollution by leachate from the infiltration to the south channel. The places where it proposes of water intake and drinking water plant of the Cauca river are shown in Table 4.19 and in the Figure 4.24

Table 4.19 Alternatives for guarantee the drinking water supply from the Cauca river

Alternative	Regulate flow (m^3/s)	Water Intake		Conduction Line	Treatment plant	
		Place	m.a.s.l	Length (km)	Place	m.a.s.l
1	6,30	Salvajina	1102	67.6	Pance	1015
2	6,30	La Bolsa	955	17.8	La Bolsa	970
3	6,30	La Balsa	975	41.2	Pance	1015

Source: EMCALI, 2007.

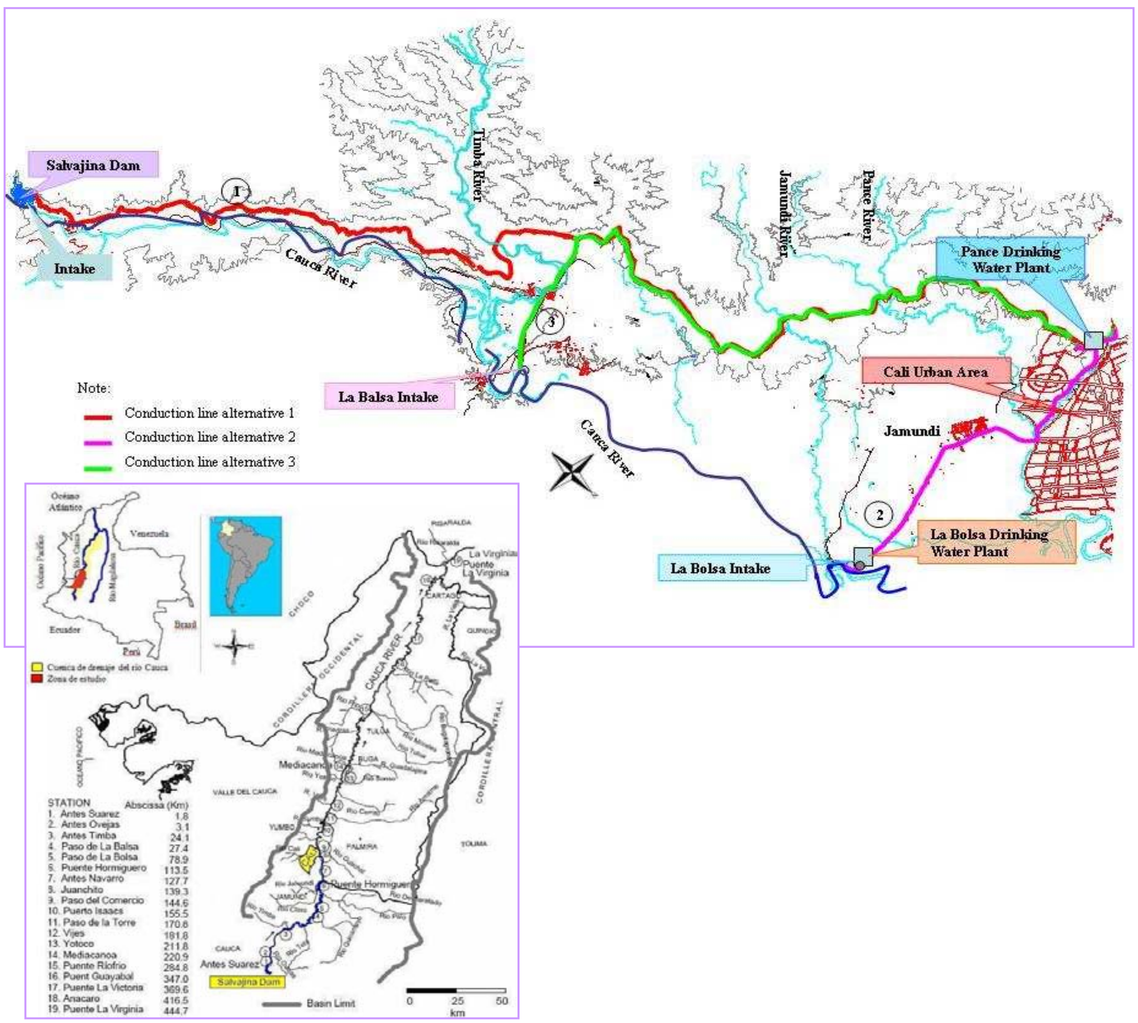

Figure 4.24 Alternatives for guarantee the drinking water supply from the Cauca river
Source: EMCALI, 2007.

Futures sources for water supply in Cali

Medium-term (to 5 years), it considers to optimize the sources of hillside, such as the rivers Cali, Meléndez and Pance. For example, for the Cali river, the proposal is built a dam with a useful volume of $10{,}8x10^6$ m^3, with a regulation flow of 3,53 m^3/s and from this place to transport the raw water up to the La Reforma y Rio Cali plants. Figure 4.25, shows the location of the dam and the conduction line up to the La Reforma plant.

Additionally other sources of water supply for Cali has been individuated such as river Pance, Cali, Melendez, Timba, Claro and Jamundí in the south of the country and river Naya, Yurumanguím, Anchicaya, Dagua and Calima in the Pacific coast.

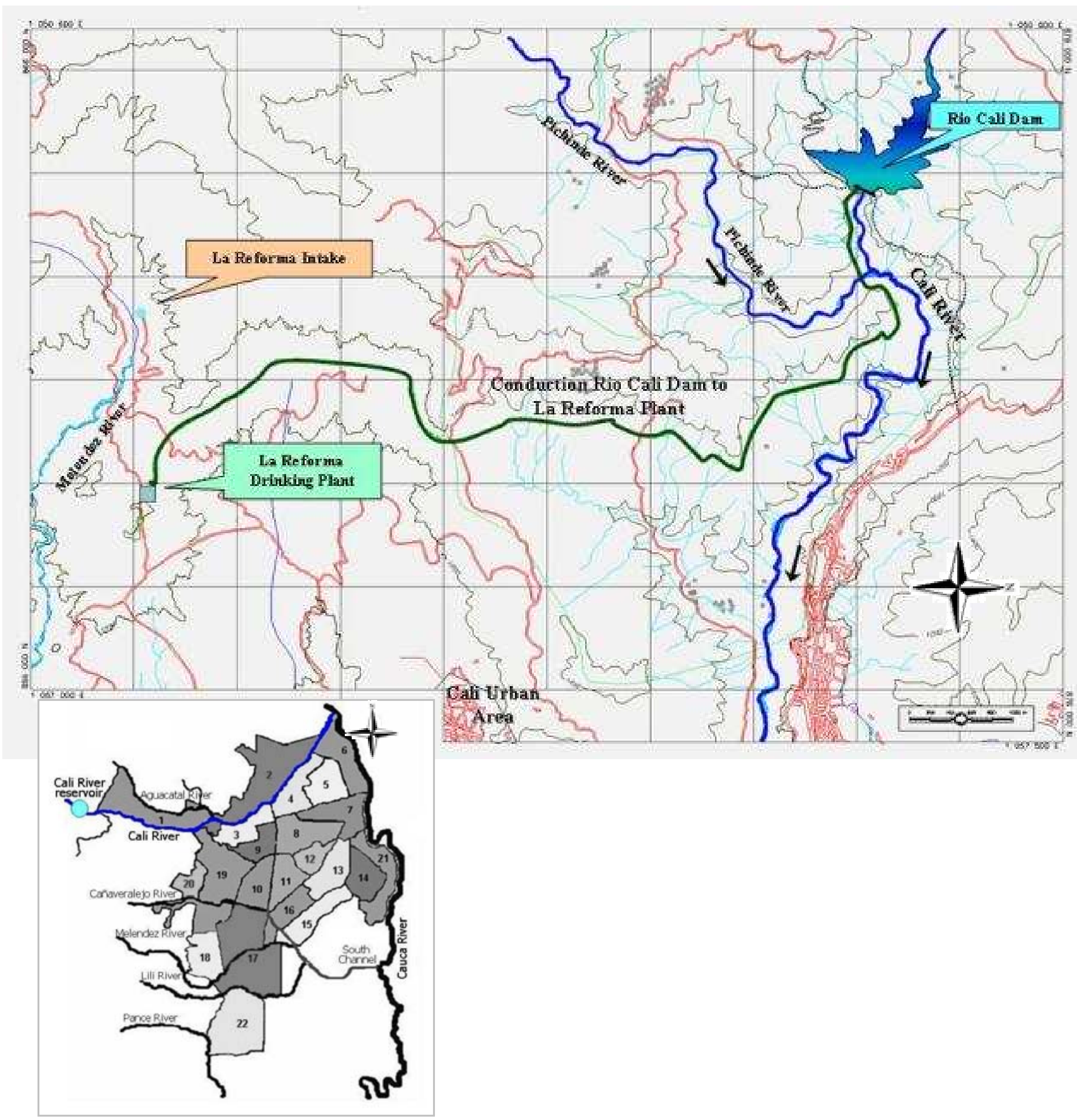

Figure 4.25 Location of the Cali river dam and conduction line up to La Reforma plant
Source: EMCALI, 2007.

4.6 PRESPECTIVES OF THE DISTRIBUTION NETWORK OF CALI

The Municipal Enterprises of Cali, EMCALI, it hired to the Consortium Hiperaguas, to make the modeling of the distribution network. The targets of this project are the follow:

1. Update of the Technical Register of the system of water distribution of EMCALI through a SIG (System of Geographical Information).

2. Hydraulic modeling of existing networks of water distribution system with hydraulic calibration.

3. Calibration of water quality for the distribution system of drinking water (Residual Chlorine) and design of the system of disinfection.

4. Design of the division of the distribution system network.

5. Analysis of future stages of modeling for the distribution system.

The modeling of the distribution system was realized by the program INFOWATER, which uses the software ArcGis. With the calibrated model of the distribution network, it hopes to obtained information related with: the possibilities of the service, expansion of the distribution network in future zones, operational analysis of the system, and with the map of pressures to identify the points to diminish the un-accounted for water index. This project at present is in execution, for that reason the model is not applying yet.

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Sustainable Water Improves Tomorrow's Cities' Health
SWITCH Project

Study Case: Cali, Colombia
Water Resources

ANNEX
Characterization of Sludge

February, 2008

A4.1 CHARACTERIZATION OF SLUDGE

Table A4.1.-1 Characterization in mg/l of sludge produced during the washing of the treatment units. Period 2004-2005

Parameter	Unit	LA REFORMA			RÍO CALI			RÍO CAUCA			PUERTO MALLARINO		
		Aver	Min	Max	Aver	Min	Max	Aver	Min	Max	Aver	Min	Max
pH	Units	7,1	6,7	7,4	6,5	6,3	7,1	6,0	5,7	6,8	6,2	5	7,1
Volatile suspended solids	mg/l	306,0											
Settled solids	mg/l	299	1	920	601	100	980	521	25	1000	391	6	915
Oil and fats	mg/l		<10	83			40		<10	160		<10	148
BOD	mg/l		<3,7	338		<3,7	755		<3,7	1286		<3,7	468
COD	mg/l	709	17	1883	3339,1	282	11920	3153,6	134	18025	2222,4	32	7500
Total phenols	mg/l		<0,0084	0,049		<0,0084	0,086		<0,0084	0,1728		<0,0084	8061
Total cyanide	mg/l		<0,009	<0,658		<0,001	0,002					<0,009	0,538
Cadmium	mg/l	<0,003			<0,033							<0,005	<0,033
Chromium	mg/l	<0,257				<0,257	1,067		<0,043	<0,257		<0,043	0,466
Lead	mg/l	<0,658			<0,658				<0,110	<0,658		<0,110	0,312
Nickel	mg/l	<0,189				<0,183	4680		<0,031	0,04		<0,031	1,21
Copper	mg/l	0,2	0,184	0,311	2,0	0,084	5,62	0,2	0,03	0,315		<0,06	0,87
Silver	mg/l	<0,071			<0,071				<0,071	0,071		<0,012	0,02
Zinc	mg/l	0,3	0,118	0,385	1,7	0,095	4,09		<0,005	2,64	1,8	0,069	3,98
Iron	mg/l	169,0			832,5	0,13	2097	164,5	81	248	0,4	0,341	0,366
Mercury	mg/l		<0,00017	<0,0004		<0,00017	0,006		<0,00017	0,0017		<0,00017	0,007

Source: records from drinking water plants, EMCALI

Table A4.1-2. Characterization of Sludge produced in Puerto Mallarino plant

Parameter	Minimum	Maximum	Average
Flow (m^3/s)	0,013	1,580	0,247
pH	6,10	8,00	7,37
Temperature (ºC)	23	23	23
Conductivity (µS/cm)	96	1510	142
BOD(mg/l)	62	1100	297,56
COD (mg/l)	119,04	2544	664,08
SST (mg/l)	47	2993	909,29
Feacal coliforms	$5{,}90^{E+05}$	$1{,}04E^{+06}$	$8{,}31^{E+05}$

Source: EMCALI-Universidad del Valle, 2006

Table A4.1-2 shows the characterization of the sludge produced in Puerto Mallarino plant according to the monitoring campaign carried out in July 11 to 15, 2006 (EMCALI, Universidad del Valle, 2006). The maximum recorded values are registered possibly during the back wash of filters and grit chambers.

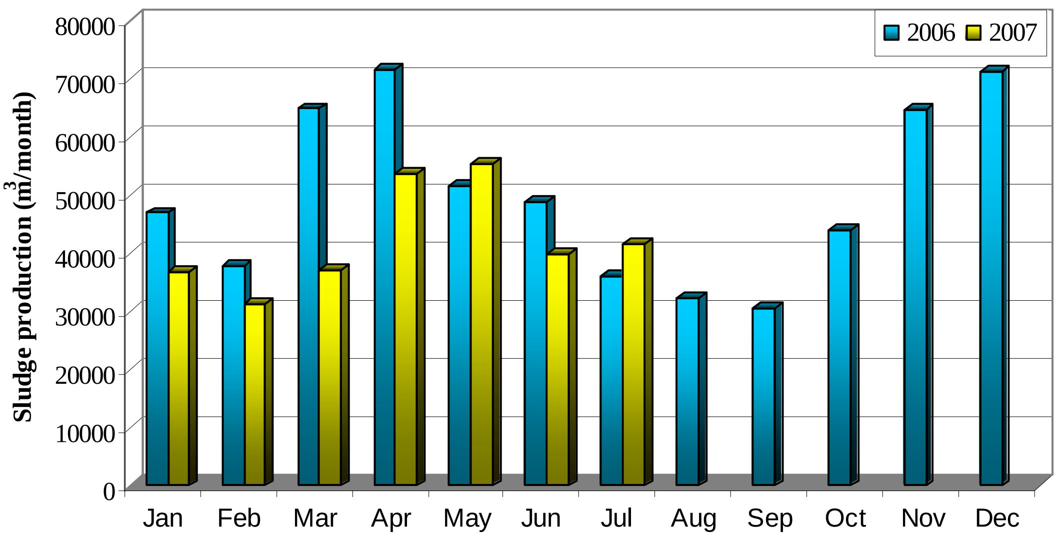

Figure A4.1-1 Sludge volume produced in Puerto Mallarino plant. Period 2006-2007

Source: EMCALI, 2007d. Reports from the plant.

In the monitoring camping it was seen that there are single sludge discharges with high contamination loads from which, the possible impacts on Cauca's river water quality are still unknown.