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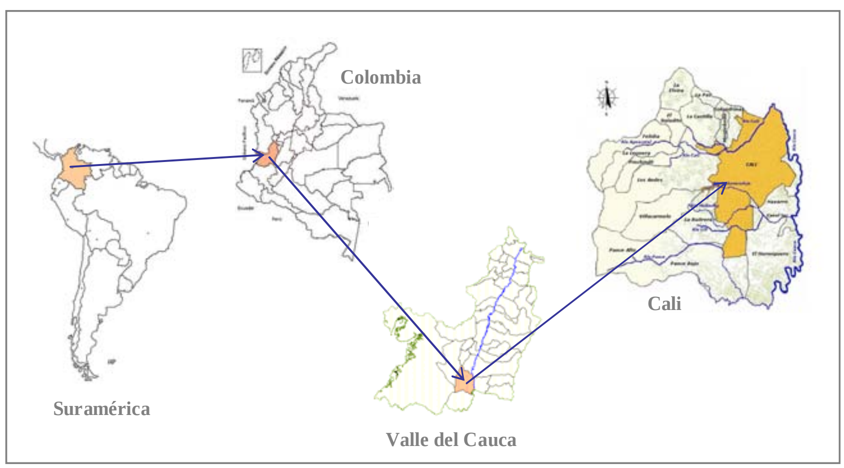
Sustainable Water Improves Tomorrow's Cities' Health SWITCH Project
Study Case: Cali, Colombia

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

5. The Sewerage System of the City of Cali

February, 2008

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5 THE SEWERAGE SYSTEM OF THE CITY OF CALI

5.1 GENERAL DESCRIPTION

The sewage system in Cali is composed of 1) storm and combined water sewers, 2) regulation systems such as the dam of Cañaveralejo and the lagoons of the Pondaje), 3) pumping stations and 4) the Cañaveralejo wastewater treatment plant WWTP-C which will be described in depth in section 6.

Cali's sewage system is a complex system since issues such as illegal connections and wastewater discharges to storm water channels have caused throughout the years that the majority of the sewage system has become mostly combined (see Section 5.5). According to EMCALI, the coverage of the sewage 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). Figure 5.1 shows the areas of drainage of each one of these systems (EMCALI-Universidad del Valle, 2006b).

Through these three drainage systems, Cali directly drains its wastewaters and storm waters through the left margin of the Cauca river using six discharge points: 1) South Channel, 2) Pumping station Puerto Mallarino-Estacion de Bombeo Puerto Mallarino , 3) sludge from drinking water Plant Puerto Mallarino-Lodos Puerto Mallarino ,4) effluent from wastewater treatment plant Cañaveralejo (WWTP-C), 5) pumping stations Paso del Comercio and Floralia- Estaciones de Bombeo Paso del Comercio and Floralia and 6) indirectly through the Cali river via the Collector Margen Izquierda.

5.2 SOUTH DRAINAGE SYSTEM

5.2.1 General overview

This system drains by gravity the South-west part of the city through the main channels which is called South Channel. Its other principal channels are the Cañaveralejo channel (which is the Cañaveralejo River once it has been channeled) and Ferrocarril channel. The drainage system intercepts the rivers Meléndez and Líli. Along its left margin there is a protection dike that joins the Cauca river dike as well. The length of the dike is approximately 8 km. The South Drainage System is the only system that does not count with pumping stations. It completely works by gravity. Figure 5.2 shows the main components of the system.

The final wastewater discharge of this system is the Cauca River. The discharge point is located approx. 5 km upstream the water intake point of the drinking plants of Puerto Mallarino and Cauca river, causing: 1) an increase in the risk of use of the source for the water supply of the city, 2) a greater exigency in the operational capacity of the drinking treatment systems and 3) an increase in the purification costs.

5.2.2 Wastewater collection and transport

The main transport channel of the system is the South Channel whose length is 7730 m and it is coated in its two first sections (3500 m). Its average depth is of 6 m (EMCALI, 2007a).

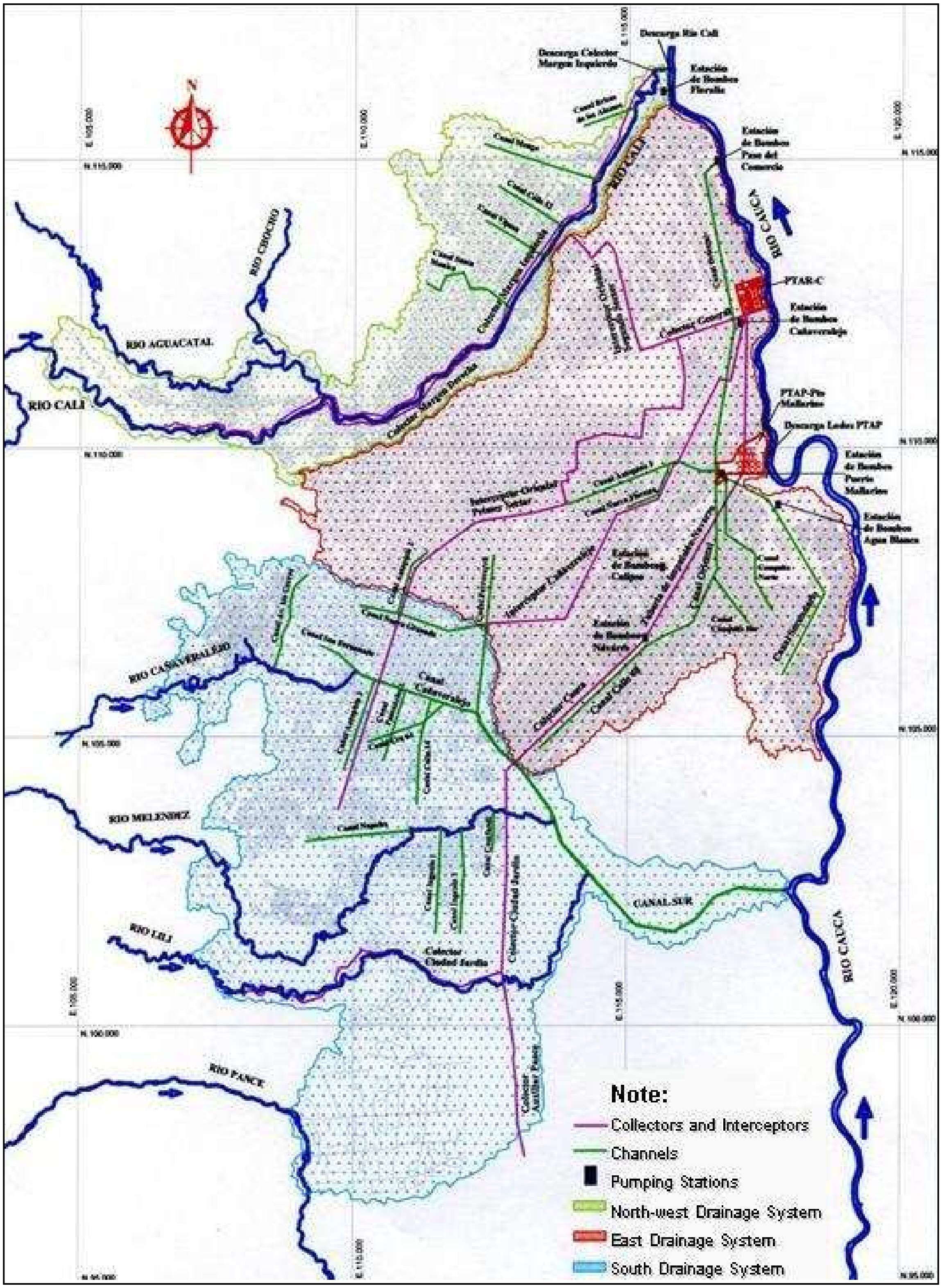

Figure 5.1 Drainage systems in City of Cali.
Source: EMCALI-Universidad del Valle, 2006b

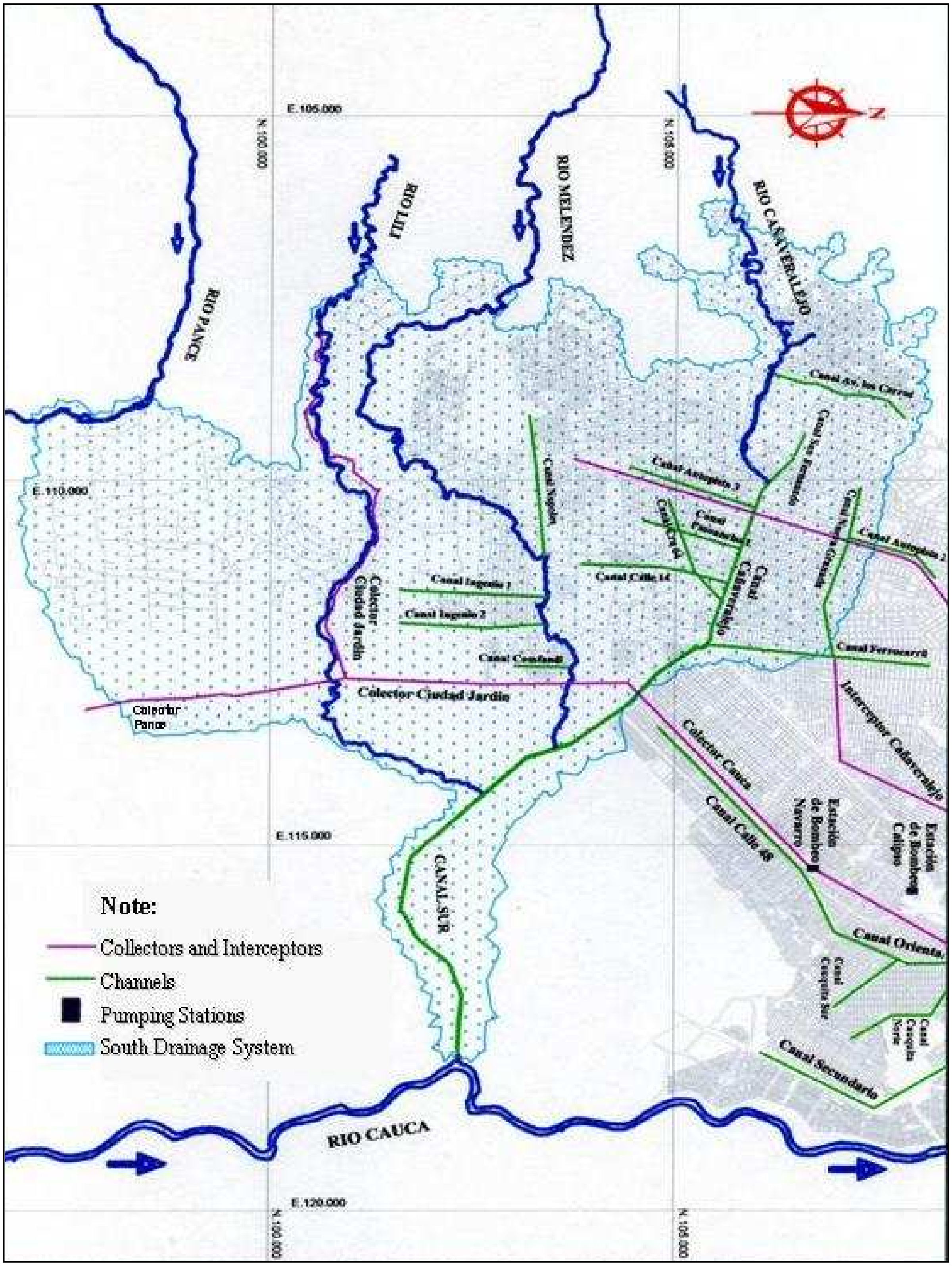

Figure 5.2 South drainage system and its main components
Source: EMCALI-Universidad del Valle, 2006b

Wastewater discharge: The South Channel conveys all wastewater collected in the South Drainage System to finally discharge it to Cauca river. Figure 5.3 shows the South Channel near its final discharge to Cauca river. Figure 5.4 shows the South Channel discharge point to Cauca river.

Figure 5.3 South Channel nearby its discharge point to Cauca river

Figure 5.4 South Channel discharge point to Cauca river

Currently, there are illegal connections and deviated sanitary collectors' connections that discharge to the rivers and channels from the drainage system. Such situation has generated the presence of wastewater in the system and an increasing deterioration of Cauca river's water (see more detailed information in section 5.5).

5.2.3 Systems of regulation

In the South System is located the dam of Cañaveralejo. The Cañaveralejo dam is an artificial system of regulation whose aim is to buffer the flow peaks that appear during winter season in the Cañaveralejo River and hence avoid flood events in nearby zones. It covers an area of 78492 m^2.

5.3 NORTH-WEST DRAINAGE SYSTEM

5.3.1 General overview

The system is composed mainly by the sanitary and storm water collectors Margen Izquierda and Margen derecha, and Guaduales pumping station which through a network of channels discharge first to Cali river and pumping station Floralia and finally to Cauca river. The approximated total length of channels in the system is 15170 m. There are no regulation systems in this drainage system (see Figure 5.5).

5.3.2 Wastewater collection and transport

The main collector of the system is the collector Margen Izquierda which is located parallel to Cali river. Its total length is 12 km. During its course, it receives the wastewater from the north-east part of the city and from collector Margen Derecho. Collector Margen Izquierda finally discharges to Cali River approximately 800 m before Cali river discharges to Cauca River (EMCALI-Universidad del Valle, 2006b). However, on 2003 this collector collapsed and the discharge point moved approximately 1000 m upstream the original discharge point (See Figure 5.6 and Figure 5.7).

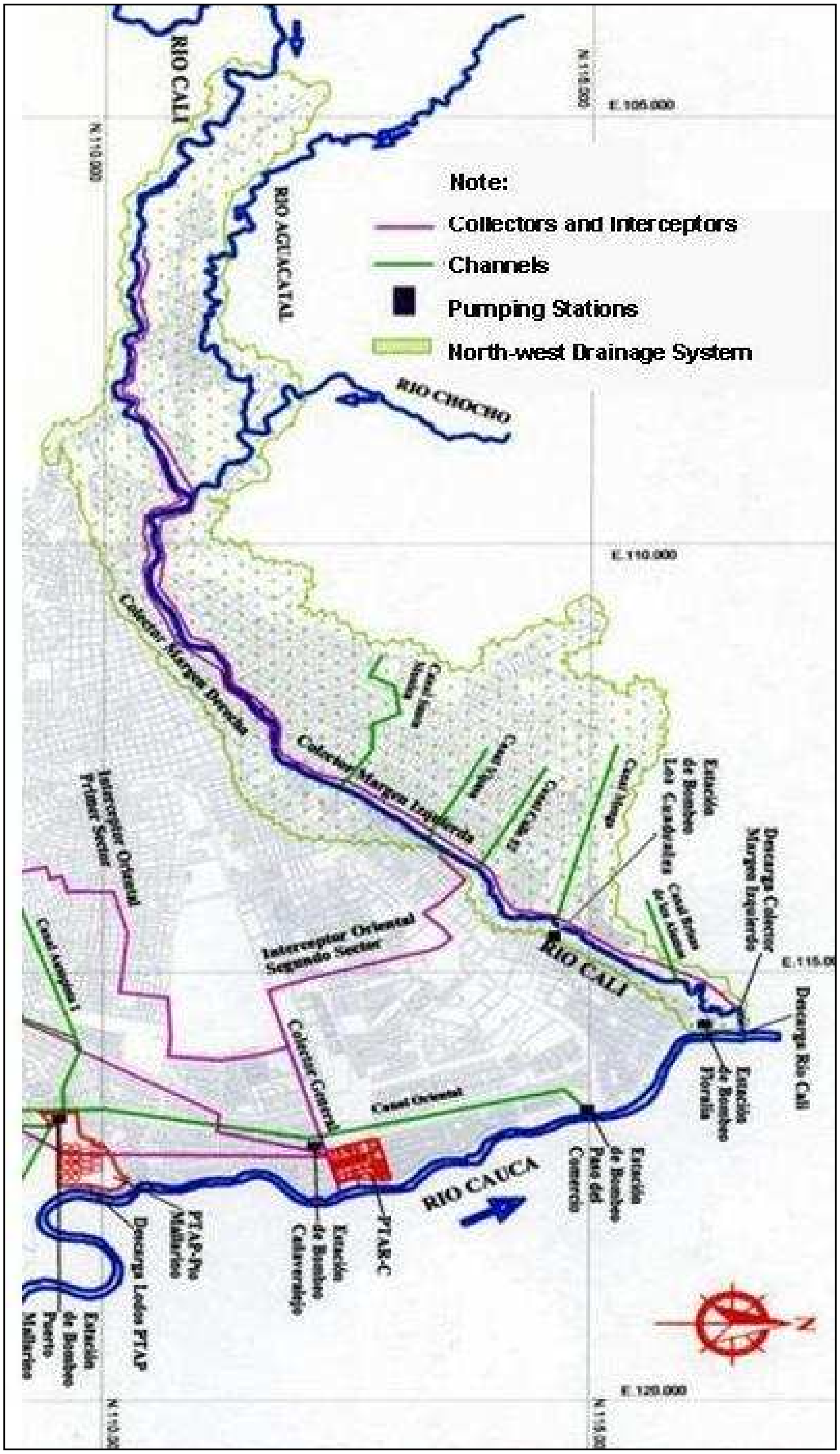

Figure 5.5 North-west Drainage System and its main components
Source: EMCALI-Universidad del Valle, 2006b

Figure 5.6 Collector Margen Izquierda discharge point, before collapsing in 2003.

Figure 5.7 Collector Margen Izquierda discharge point, after collapsing in 2003.

Wastewater discharge: The Margen Izquierda collector conveys and transport wastewater directly to Cauca river. This collector transports around 10% of the total wastewater produced by the city of Cali. The other discharge point is the Floralia pumping station which pumps around 2% of the total wastewater produced in the city to Cauca river (EMCALI, 2007a).

Since December 16th, 2007 are operating the works of construction made for convey and transport the wastewater from the Marginales collectors up to the wastewater treatment plant of Cañaveralejo (WWTP-C), with the main purpose of reduce the polluting discharges made directly to the Cauca river from Floralia pumping station and take advantage of the capacity of the plant and increasing the flow to treat in approximately 850 l/s.

The work of construction has two stretches, the first one with a diameter of 36" and 380 m of length, which go from the Margen Izquierda collector up to the Floralia pumping station; the second one is the impulsion line of 33" of diameter and 4300 m, which initiates at the Floralia pumping station up to the wastewater treatment plant of Cañaveralejo (WWTP-C).

5.3.3 Pumping stations

Pumping station Floralia

It is located on the north-east side of the city near the confluence of the Cauca and Cali rivers. It drains an important part of the right margin of the Cali River, including part of wastewaters of the nearby districts. It was designed to evacuate storm water from the low zones of the sector (see Figure 5.8).

This station has four pumps in parallel (see Figure 5.9), each one with a volume of 250 l/s. In addition the station counts with a system of four auxiliary pumps with a capacity of 2500 l/s, available for storm water events (EMCALI-Universidad del Valle 2006b).

Currently, this pumping station receives the wastewaters of the Marginales collectors from the Cali river; from here the wastewater are transported up to the wastewater treatment plant - Cañaveralejo (WWTP-C) through the impulsion line, as was mentioned before.

Figure 5.8 Discharge point from Floralia pumping station to Cauca River

Figure 5.9 Pumping station Floralia

Pumping station Guaduales

It is located in the right margin of the Cali river, in the Guaduales sector. It is a storm water station and counts with and installed capacity of $8m^3/s$. It operates only one month per year.

5.4 EAST DRAINAGE SYSTEM

5.4.1 General overview

The principal components of the East System are the General and Cauca collectors, Oriental and Cañaveralejo interceptors, Cañaveralejo, Navarro and Aguablanca pumping stations and the wastewater treatment plant of Cañaveralejo (WWTP-C), see Figure 5.10. The channel system is mainly composed by Oriental, Secundary and Cauquita Norte channels and the Paso del Comercio and Puerto Mallarino pumping stations. The lagoons of Pondaje and Charco Azul make part of the regulating system of this system as well.

5.4.2 Wastewater collection and transport

The General or Central collector is the principal collector of the system. It works by gravity and receives the wastewater coming from Oriental interceptor, other secondary interceptors and Cañaveralejo interceptor through Cañaveralejo pumping station. The general collector is connected to the line influent of the WWTP-C and counts with a by-pass system to the Cauca river, which is used in season of rains.

Wastewater discharge: The East Drainage System has the following final discharge points: i) Paso del Comercio pumping station which pumps around 2% (169 l/s) of the total wastewater to Cauca river, ii) Puerto Mallarino pumping station which pumps around 5% (322 l/s) of the total wastewater and iii) the effluent from the WWTP-C which discharges around 56% (3810 l/s) of the total wastewater produced in the city (EMCALI, 2007a).

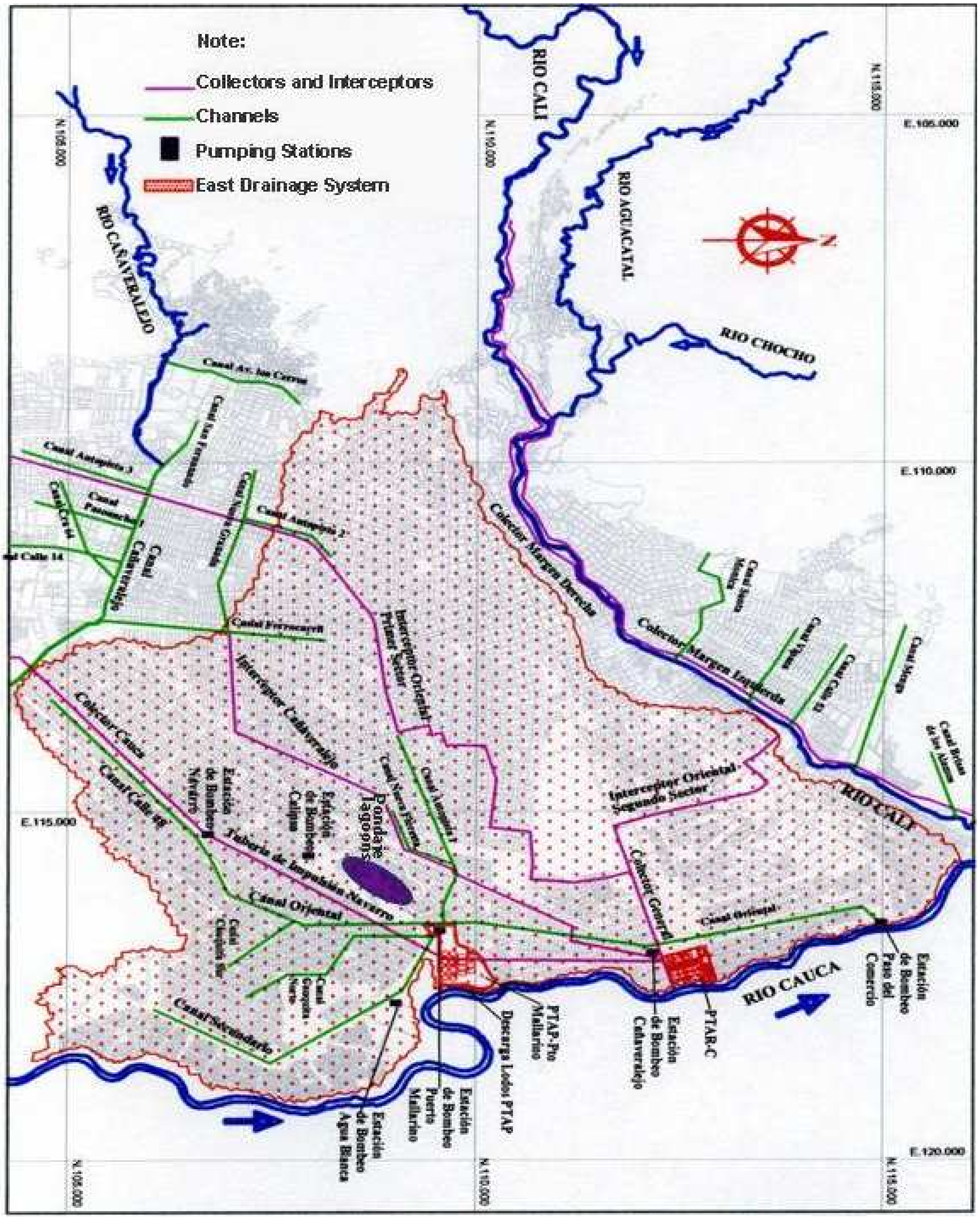

Figure 5.10 East Drainage System and its main components
Source: EMCALI-Universidad del Valle, 2006b

5.4.3 Systems of regulation

It consists of an artificial wetland constructed in the 60`s for the regulation of the storm water in the city and for the regulation of the frequent flood events presented in this area of the city. It is composed by two lagoons, one denominated the Pondaje (South) and the other Charco azul (North).

The ponds finally discharge to the Oriental medio channel. Due to presence of illegal slums in the area, the lagoons have lost their initial hydraulic capacity (EMCALI, 2007a). Table 5.1 shows a comparison between the Pondaje lagoons design operation parameters and the design capacity in year 2000.

Table 5.1 Comparison between design and characteristics in year 2000 Pondaje lagoons.

Characteristics	Design (1959)	At year 2000
Área (ha)	31	25 (80% of the original area)
Storage capacity (m^3)	620000	265000 (42% of the original)
Inhabitants living nearby the lagoons	250 (year 1969)	61000 (comuna 13) and 4889 people living in the lagoon protected area.

Source: Quantum, 2000

These regulation lagoons were designed to serve as dams lowering hygrograms peaks so that the maximum pumping flows could be decreased and a reduction in the costs of operation of the pumping stations could be reached as well. Nevertheless, according to Quantum (2000), the function of the lagoons in 2000 was minimal due to:

- Presence of wastewater in the storm water channels that discharge to the lagoons (wastewater flow measured in year 2000 was 320 l/s).
- Direct waste water disposal from illegal slums located around both lagoons
- Disposition of garbage and solid waste in the channels that discharge to the lagoons and inside the lagoons as well, (volume of debris found was 203024 m^3).
- Presence of sediments and vegetation inside the lagoons (volume of measured sediments was 152000 m^3 and vegetation 133462 m^3) in year 2000.
- Dissolved oxygen in the lagoon was cero and there was no presence of aquatic life.

In addition, Quantum (2000) found that the areas of the lagoons that were not being occupied by illegal slums (inside and outside) were used as sport fields, due to the high amount of sediments and vegetations present in the lagoons (see Figure 5.11, Figure 5.12 and Figure 5.13).

Figure 5.11 Pondaje lagoons in 1982.
Source : Quatum (2000).

Figure 5.12 Lagoons El Pondaje and Charco Azul in 2004
Source: Contraloría de Cali, (2005).

Figure 5.13 Pondaje Lagoons in 2000
Source: Quatum (2000).

5.4.4 Pumping stations

Wastewater

Table 5.2 shows the pumping stations of East Drainage System, which the biggest station is Navarro, that impels wastewater to WWTP-C.

Table 5.2 Pumping Stations of the East Drainage System

Pumping Station	Installed Capacity (m^3/s)	Receives wastewater from:	Impels wastewater until:
Navarro	8,0	The Cauca Collector	The WWTP-C
Aguablanca	2,8	An ample sector of Aguablanca	The WWTP-C
Cañaveralejo	6,5	Cañaveralejo Interceptor	The WWTP-C

Source: EMCALI, 2007a

Combined and storm waters:

Paso del Comercio. It was initially designed for the evacuation of storm water coming from Oriental Channel. However, as it was mentioned before, due to illegal connections from the sanitary collectors in the city, at the moment a combined water volume is pumped from the Comunas or districts 13, 16, 15 and 6 (see Figure 5.14).

Pumping station Puerto Mallarino. It was originally designed to evacuate storm water; however it pumps wastewater as well as consequence of illegal connections (see Figure 5.15). It receives water coming from Cauquita Norte and Secundario Channel. The system is composed by 5 pumps. Each one has a capacity of 3,6 m^3/s. The total pumping capacity is 18 m^3/s.

Pumping station Calipso: It drains directly some neighborhoods located in the North-west part of the city. It is located in the South and it receives waters from Calle 72I collector. It pumps wastewater to Navarro pumping station, which pumps wastewater to WWTP-C and the Pondaje Lagoons. It has an installed wastewater pumping capacity of capacity 0,7 m^3/s and a storm water pumping capacity of 3,5 m^3/s (EMCALI, 2007a).

Figure 5.14 Exit channel from pumping station Paso del Comercio.

Figure 5.15 Discharge point Pumping station Puerto Mallarino

5.5 MAIN ENVIRONMENTAL PROBLEMS IN THE DRAINAGE SYSTEM OF CALI

5.5.1 General view in the three drainage systems

As it was mentioned before, the drainage system of Cali presents many problems starting from 1) presence of wastewater in the storm water channels, 2) the inadequate disposal of solid waste that cause clogging of channels, 3) presence of sediments in channels, 4) poor conditions of structures of the drainage systems such as Combined Sewer Overflows (CSOs), 5) presence of slums and 6) the presence of hazardous substances specially in the South Drainage System, coming mainly from the industrial discharges and leachate from Navarro disposal site. The drainage system in the most critical conditions is the South Drainage System due too to the presence of wastewaters. Following, the problems mentioned above will be explained for the three drainage systems in general. Afterwards, being the most critical the South Drainage System, its problems will be described in more detail in section 5.5.8.

5.5.2 Presence of wastewater in the channels

The presence of wastewater in the storm water channels is mainly caused by:

- Illegal connections installed directly by house owners and slum dwellers
- Presence of slums which directly deposit wastewater into the channels
- illegal connections from the commercial sector
- Clogging of the CSOs due to failures in the sewage system or lack of maintenance
- CSOs shortage
- Lack of interceptor structures and of sewage networks , specially in slum areas
- Lack of sewerage capacity as well as lack of maintenance of the sewage networks

According to the EMCALI’s technical planning department, in 2006 the percentage of wastewater in the channels of the three drainage systems was: 28% presence in the North-west System, 16% in the East System and 56% in the South System, being the South System the most critical one (EMCALI, 2007a). Figure 5.16 shows a spilling of waste waster to a storm water channel.

Figure 5.16. Waste water spilling to a storm water channel in the north-west drainage area

5.5.3 Inadequate solid waste and debris disposal into the channels

The presence of solid waste and debris in the storm water channels and in the drainage structures is mainly caused by:

- Presence of slums which directly deposit their rubbish into the channels and the drainage systems. According to Cali’s planning municipal, in 2004 the number of slums in the city was 23239.
- Unavailability of official debris disposal sites and solid waste transfer stations
- Lack of “city culture” and community spirit to care for their city
- Lack of knowledge and education from the community regarding the proper use of channels and drainage structures, see Figure 5.17, Figure 5.18 Figure 5.19.

Figure 5.17 Solid waste in the secondary channel (North-west System)

Figure 5.18 Solid waste and debris in the canal oriental (North-west System)

Figure 5.19 Solid waste the channels from the East System.

According to EMCALI (2007), in the year 2005 the complete storm water drainage system in Cali presented a total of 98 sites filled with garbage and 65 sites filled with debris for a total of 162 illegal solid waste disposal sites, known as chronic dumpsites. The drainage system affected the most was the East System with an incidence of 69%. It is important to notice that these chronic dumpsites have a variable location depending on the maintenance and cleaning provided by EMCALI and the new locations that citizens will select to dispose their solid waste (see Table 5.3).

Table 5.3 Number of illegal disposal sites found in the main channels of the three drainage systems in Cali in 2005.

System	Type of waste	
	Number of solid waste disposal sites	Number of debris disposal sites
South Drainage System	25	21
East Drainage System	71	42
North-west Drainage System	2	2
Total	98	65

Source: Adapted from EMCALI, 2007a

In addition, Table 5.4 shows the total volumes of solid waste extracted from the channels and from other sewage structures in the three different drainage systems (years 2006 and 2007). It is important to notice that the illegal and uncontrolled disposition of solid waste in the channels is a critical problem since it is the main cause of flood problems in the city.

5.5.4 Presence of solids and sediments in the channels

The presence of solids and sediments in the channels and in the drainage structures is mainly caused by:

- Deforestation and erosion in the hills and tributary rivers that contribute with a high load of sediments to the drainage systems.
- The impact from slums and the inadequate use of the soil which are deteriorating the river basins causing high dragging of solids to the channels.
- Low slope in channels e.g. South Channel, whose low slope contributes to the settlement and accumulation of solids
- Lack of knowledge and education from the community regarding the proper use of channels and drainage structures

Table 5.4 Volume of solid waste extracted from the sewage system in Cali in year 2006 and until July, 2007

Month	Solid waste extracted in the cleaning of channels (m^3)		Solid waste extracted in the cleaning of sewage system structures (m^3)	
	2006	2007	2006	2007
January	12480	13758	0	20
February	10650	15256	130	1600
March	14355	15671	500	0
April	9570	14031	1995	0
May	13418	17809	5070	40
June	10240	17204	5060	0
July	10305	13842	525	480
August	10885	-	570	-
September	9570	-	0	-
October	13750	-	320	-
November	14170	-	420	-
December	11474	-	130	-
TOTAL	140867	107571	14720	2140

Source: EMCALI, 2007b
(-) Without date

Accumulation of sediments in the channels decrease their hydraulic capacity and generate bad odors due to decomposition of organic matter. Also, high accumulation produces clogging of the system likely causing flood events. Moreover, the sediments are dragged during rainy events which increase the dragged volume and causes high discharge loads to the Cauca river, causing as well depletion in the dissolved oxygen levels in the river to the extent of non treatment. Figure 5.20 is a typical example of the amount of sediments deposited on the channels.

Figure 5.20 Presence of sediments in the channels

According to the department for the environmental recovery of the channels of EMCALI, the volume of sediments extracted from the channels in 2005 was 137935 m^3 (South Drainage System), 172360 m^3 (East Drainage System) and 8683 m^3 (North-west System), being the east and South systems the most critical ones.

5.5.5 Bad state of Combined Sewage Overflows (CSOs)

The bad state of the CSOs in the drainage structures is mainly caused by:

- Lack of monitoring and maintenance that allows wastewater to infiltrate in the storm water channels and rivers , see Figure 5.21
- Dragging of sediments and rubbish which deteriorate and clog the CSO structures

Figure 5.21 Combined sewage overflows in bad conditions.

The sewage system in Cali is composed of 635 CSOs whose main function is to deviate the excess of combined water mainly during the winter season. 58% of the CSOs are located in the East Drainage System, 20% in the South System and 22% in the North-west System. In the North-west System the CSOs located at the left margin of Cali River and right margin of the Aguacatal River present the bigger problems due to lack of maintenance. However, the North-West System is the one with fewer problems in comparison to the other two drainage systems. In 2005 according to EMCALI (2007) out of the 635 CSOs, 29% presented an inadequate maintenance, 32% required reparation and only 21% had an optimal operation.

5.5.6 Landscape deterioration

Landscape deterioration is mainly caused by:

- Inadequate use of channels, specially around their protection area
- Lack of surveillance
- Lack of awareness campaigns to teach community the correct use and maintenance of channels and sewerage infrastructure.

5.5.7 Presence of slums

The slums in Cali better known as “subnormal settlements” are defined as illegal communities which lack the basic public services of water and sanitation. Due to the formation of slums, the city has been growing in an unorganized way, without any planning and worsening the capacity of delivery of water and sanitation services. According to the municipal planning department in 2004, the slums in the city are mainly distributed near the mountainside (in the districts or “*comunas*” 1,2,20 and 18), along the dike on the Cauca river and in the district of Aguablanca (See Figure 5.22).

Figure 5.22 Slums located on the Cauca river bank

Table 5.5 shows that *comuna* 1 concentrates 28% of the total slum dwellings in the city, followed by *comuna* 18 with 25% and on the third place *comuna* 20 with 17% dwellings presence. These three *comunas* located in the North-west and South Drainage System gather in total 70% of the slums in the city of Cali.

Table 5.5 Distribution of the slums on the different districts (*comunas*) of the city.

Zone	Location	Number of Dwellings
Mountain hill	Comuna 1 (North-west)	6503
	Comuna 2 (North-west)	985
	Comuna 18 (South Drainage)	5820
	Comuna 19 (South Drainage)	212
	Comuna 20 (South Drainage)	3853
	SUBTOTAL:	17373
Cauca River Dike (Jarillon)	Comuna 6 (East Drainage)	754
	Comuna 7 (East Drainage)	810
	SUBTOTAL:	1564
District of Aguablanca	Comuna 13 (East Drainage)	978
	Comuna 14 (East Drainage)	1566
	Comuna 15 (East Drainage)	1623
	Comuna 21 (East Drainage)	135
	SUBTOTAL:	4302
TOTAL		23239

Source: DAP, 2004

Regarding the presence of the slums only in the channels of the drainage systems, Table 5.6 shows the number of slums located in the channels of the three drainage systems. The North-West System presents the biggest number of slum dwellings.

Table 5.6 Distribution of slums in the channels of the three drainage systems.

Drainage System	Number of slums in the channels	Number of dwellings per slum
East	3	65
South	2	31
North-west	5	96

Source: EMCALI, 2006

According to the DAPM (Municipal Administrative Planning Department) to the date of August 1999 the Secretary of Social House and Urban Renovation had carried out the program of regulation of the dwellings of which 7 slums (51 dwellings or the 6,3%) had been totally relocated and 24 slums out of 110 (21,82%) had been partially relocated. From this, it can be deduced that in 1999 the final number of dwellings not regulated in the slums was of 16558. Nevertheless, in spite of the plans of regulation, public recognition and relocation mentioned in the POT, in the year 2004 the number of slums' dwellings had increased to 23239 (see Table 5.5) which means that the causes that originate the presence of slums are still present.

Problems caused by slums presence

The subnormal establishments or slums are illegally integrated to the current urban structure as they uncontrollably connect to the network of delivery of public services so that they can satisfy their basic needs of electricity, drinking water and sanitation. This situation has produced a big impact in the environment and in the delivery of public services such (drinking water and sanitation) like the increase in the unaccounted for water and the costs that these represent for the municipality.

EMCALI (2007) carried out measurements in 21 sectors of the city which allowed extrapolating a total consumption expressed in unaccounted for water of 1290000 m^3/month which with respect to the total supply of drinking water to the city represents a monthly loss of 7,2% of water produced. This consumption approximately represents a value of $16500 million pesos lost per year. Likewise, the waste water generated in the slums is discharged directly to the water sources without any type of treatment. The estimated slums' wastewater discharged load to the different drainage systems in the city was approximately 6891 BOD kg/day and 4373 TSS kg/day.

Another environmental impact generated specially by the slums located in the Jarillón of the Cauca river (dike) is the continuous erosion of the dike debilitating its structure which is in charge of protecting the city from the floods produced by the overflow of Cauca river. In the hypothetical situation that the dike will collapse, the east area of the city of Cali would be flooded, which would represent a serious risk for the life of 60% of the population of the municipality, as well as the affectation of the infrastructure of water supply and sewage system, in addition to the damage that can occur to the drinking water treatment plant Puerto Mallarino, that supplies 76% of the urban population of Cali.

Location of the slums is another critical problem. While in flat areas the establishments have been located mainly at the 1) borders of the Cali and Cauca rivers and 2) in low zones prone to floods by storm water, in slopes they have been located in areas with high geologic instability, sometimes on lands that at previous times served as mining operation areas which are likely prone to collapses. There is also likelihood of raise in water levels of the superficial water sources and landslide risks (Restrepo et al., 1998).

5.5.8 South Drainage System

The South Drainage System is the one that presents the most critical conditions regarding environmental impacts. Following, a detailed description of the main issues is presented.

Presence of wastewater in the storm water channels

The presence of wastewater in the channels is mainly due to the illegal sanitary connections, failures in the operation of the CSOs which cause that the wastewater enters the channels or drain directly to the rivers or open water bodies.

The South Drainage System contributes with an average flow of 1,71 m^3/s to the Cauca river out of which 70% comes from the channels Ferrocaril and Cañaveralejo and 30% comes from Melendez, and Líli rivers during summer season (EMCALI, 2007a). A study carried out by the consultancy firm MANOV, (2006) reported that one of the main causes for the presence of wastewater is the illegal connections. In this regard the Cañaveralejo Channel shows approximately 41% of wastewater presence, followed by the subsystem Melendez-Líli Rivers with 34% and finally the Ferrocaril System with 25%. Since the final South Drainage discharge point to Cauca River is approximately located five kilometers upstream the intake point of the drinking water plant Puerto Mallarino water quality can be affected by the South Channel discharges and can be a potential danger to human health.

The South Drainage System apart form collecting and discharging wastewater generated from the city, transports also leachate generated in the disposal site of Navarro through the South Channel (see Figure 5.23). Since the level of saturation of the disposal site of Navarro is above the levels of the South Channel, the South Channel acts like an underground drainage for the dumpsite and the nearby agricultural lands (Restrepo *et al*. 1998).

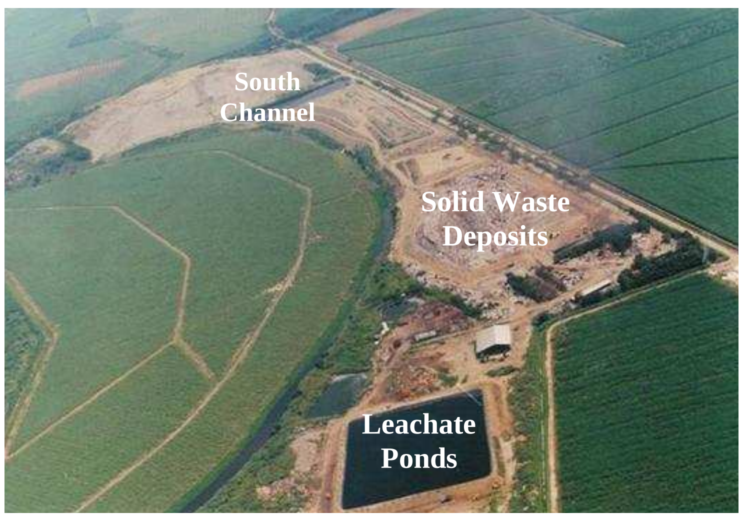

Figure 5.23 Tranports leachate generated in the disposal site of Navarro through the South Channel.

Regarding ground water, the leachate contamination mark reaches about two kilometers along the “Madrevieja” with a depth of 10 m according to CVC (2004). Madrevieja is an abandoned natural water channel (or stream) that is located along the solid waste disposal site of Navarro. This natural channel is the main system of runoff drainage of the Navarro solid waste site (including leachate) since it crosses the waste deposit from the east to the west. According with INGESAM (2005) and Restrepo *et al.* (1998), the CVC in 2004 confirmed the direct hydraulic connection between Madrevieja and the aquifer, in precise sites considered as high risk zones: the leachate circulates through Madrevieja until about 2 km downstream the disposal site of Navarro, where in winter it is pumped to the old stream of the Líli river to drain the zone and in summer, it is used for the irrigation of the sugar cane crops located in the area.

Pollution in the channels due to solid waste and debris disposal

According to EMCALI (2007), in the year 2005 there were 25 illegal solid waste disposals and 21 illegal debris disposal in the channels of the South Drainage System. At the time, the Ferrocaril

Channel was found in the most critical conditions presenting in average 24 illegal disposal sites between solid waste and debris.

Presence of sediments in the channels

The department for the environmental recovery of the channels of EMCALI reported in 2005 that the total volume of sediments settled in the South Drainage System was 1378914 m^3 being the South Channel the one with the most critical conditions with a total deposited volume of 123680 m^3.

The deterioration of the river basins produced by human intervention and excess in agricultural activities causes landslides whose materials finally remain and accumulate in the drainage system of the city. For the South Channel in special, the deforestation and erosion in the Meléndez and Cañaveralejo river basins have contributed with a high load of sediments dragged to the drainage system.

Additionally, the sediments are dragged during rainy events which increase the dragged volume and causes high discharge loads to Cauca river, causing as well depletion in the dissolved oxygen levels in the river to the extent of non treatment.

Presence of hazardous substances

Surface water

It is proved that there are hazardous substances present in the waste waters coming from the South Drainage Systems such as: phenols, chromium, mercury, led that come from the industrial discharges to the sewage system and from leachate. The recorded values for these substances do not comply with the Colombian legislation (EMCALI, 2007a) as it will be explained below.

Figure 5.24 shows the results from the most recent sampling campaigns carried out in the main discharges points to the South Channel (summer and winter 2006) regarding the values of these components in the South Drainage System. Likewise, Table 5.7 shows the recorded values in comparison to the national limits for the discharge of wastewater to open water bodies (Article 72, decree 1594/84) and for the admissible limits of water quality for human consumption looking at it from the point of view of the Cauca river as the receiver of such substances (Article 38, decree 1594/84). This situation is dramatic since the contamination of the main water source for the City of Cali is developing into a chronic contamination event.

Figure 5.24 shows that sampling points Cañaveralejo River and Cañaveralejo Channel are inside the limit established by the Colombian legislation (Art 74) for the admissible values of total phenols, lead, chromium and mercury. However, the recorded values are outside the established limits in Articles 38 and 39 for discharges to water bodies that are intended for human consumption (prior treatment).

Sampling point Ferrocaril Channel is inside the limit established by the Colombian legislation for the admissible values of total phenols, lead, chromium and mercury. However, the recorded values are outside the established limits by the Colombian legislation for water bodies that are intended for human consumption (prior treatment). The concentration of phenols and chromium were homogeneous in all the data recorded in the monitoring campaign which means that The Ferrocaril Channel is the highest and most frequent contributor of phenol substance to the South Channel.

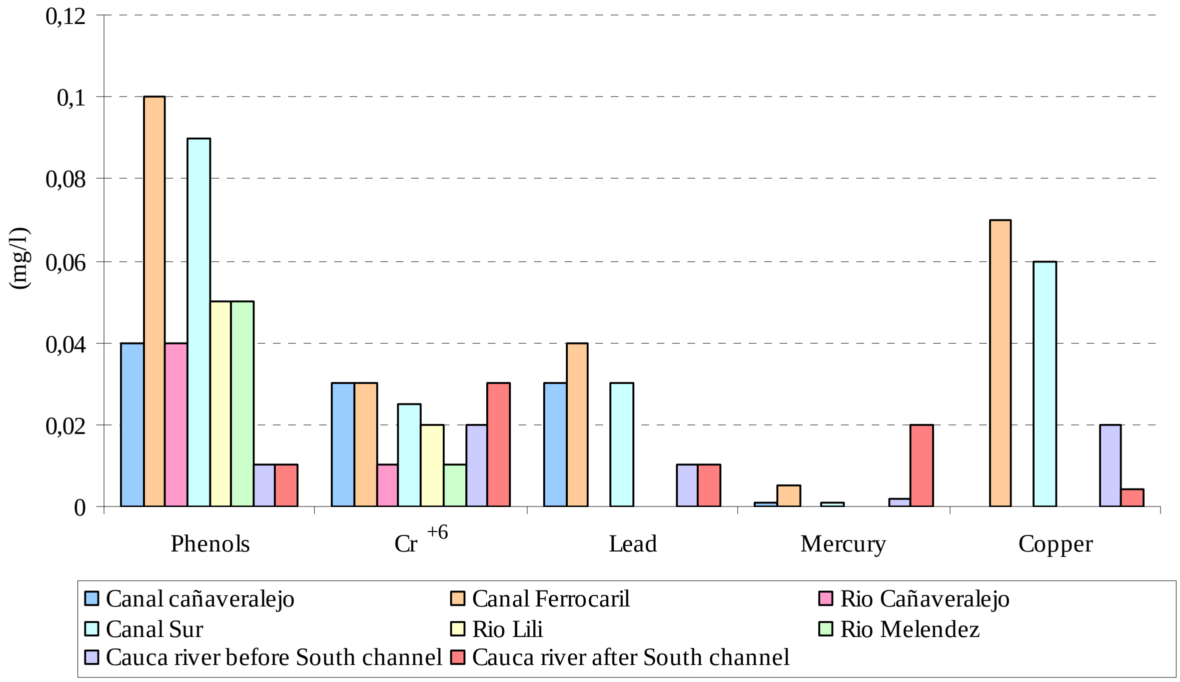

Figure 5.24 Values of hazardous substances (mg/l) present in the subsystems of the South Drainage System.
Source: Adapted from: EMCALI, 2007a

Table 5.7 Comparison of recorded hazardous substance's values (2006), in the South Drainage System, with the Colombian regulation.

Sampling point	Phenols (mg/l)	Cr^{+6} (mg/l)	Lead (mg/l)	Mercury (mg/l)	Copper (mg/l)
Cañaveralejo Channel	0,04	0,03	0,03	0,001	
Ferrocaril Channel	0,1	0,03	0,04	0,005	0,07
Cañaveralejo river	0,04	0,01			
South Channel	0,09	0,025	0,03	0,001	0,06
Líli river	0,05	0,02			
Melendez river	0,05	0,01			
Cauca river (before South Channel)	0,01	0,02	0,01	0,002	0,02
Cauca river (after South Channel)	0,01	0,03	0,01	0,02	0,004
Decree 1594 de 1984 art 74	0,2	0,5	0,5	0,02	3
Decree 1594 de 1984 art 38	0,002	0,05	0,005	0,002	1

Source: Adapted from: EMCALI, 2007a

Sampling points Melendez and Cali rivers are inside the limit established by the Colombian legislation (art 74) for the admissible values of total phenols. However, the recorded values are outside the established limits in articles 38 and 39 for water bodies that are intended for human consumption (prior treatment)

Sampling point South Channel is inside the limit established by the Colombian legislation (art 74) for the admissible values of total phenols, lead, chromium and mercury. However, the recorded

values are outside the established limits in articles 38 and 39 for the parameters Phenols, chromium and mercury.

Sampling points Cauca river (before and after the South Channel discharge are outside the established limits in articles 38 and 39 for water bodies that are intended for human consumption (prior treatment)The highest contributors regarding hazardous substances are Cañaveralejo and Ferrocaril Channel. Most of the industries that produce medical and dental equipment, rubber, plastic, press materials and metals are located along these channels and are the main sources of the substances described above (EMCALI, 2007a).

Ground water

Regarding ground water, according to the study of INGESAM (2005), which considered data reported in the different advanced environmental monitoring carried out in the area of Navarro by CVC, EMSIRVA, and SERVIAMBIENTALES, significant hazardous substances have been identified in the most important water areas that are exposed to the dumpsite's effects: Madrevieja and the aquifer. These pollutants have been classified as critical due to their high possibility of producing chronically toxicity events in the neighboring districts (See Figure 5.25). These polluting agents are: arsenic, cadmium, cyanide, copper, phenolic compounds, chromium, mercury, silver, lead and selenium. Table 5.8 shows the registered maximum values found in the water sources of the zone of Navarro (results of the diverse monitoring campaigns) in comparison with the environmental norm in Colombia for the quality of the water for human consumption (decree 1594).

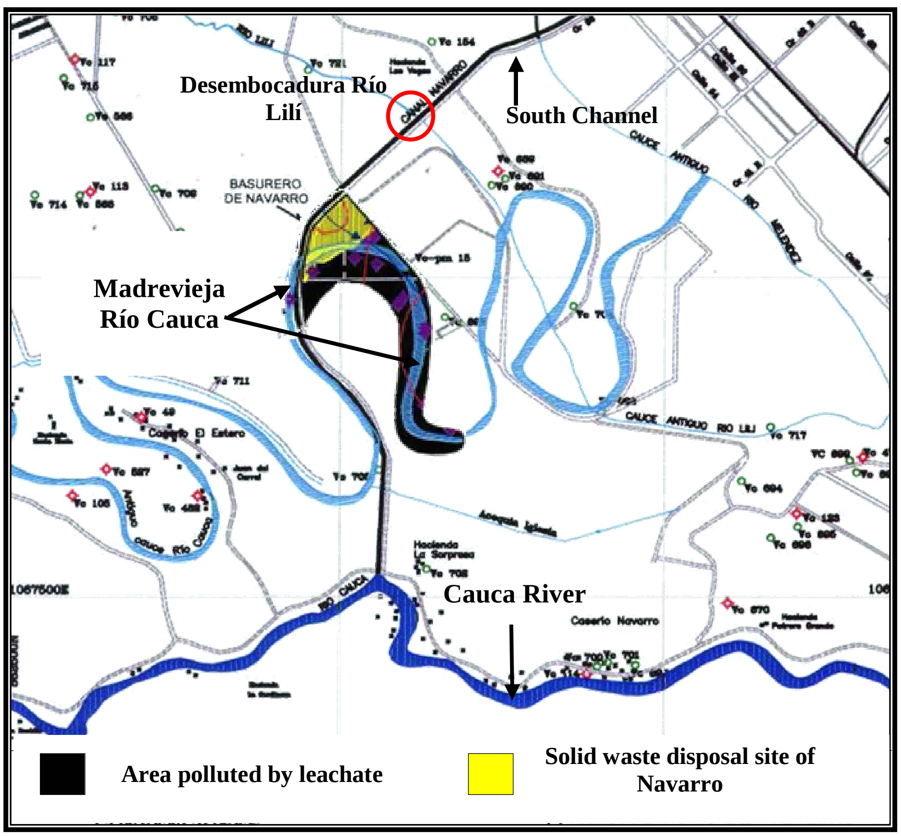

Figure 5.25 Area affected by leachate pollution from the Navarro solid waste disposal site.
Source: CVC,2004 cited by Agudelo et al, 2005.

Table 5.8 Comparison between the concentrations of hazardous substance found in surface and ground water resources located in the Navarro area with the environmental Colombian standards.

Substance	Maximum registered concentration (mg/l)	Location	Decree 1594 of 1984 (mg/l)
Mercury	0,0240	Ground water	0,002
Phenols and phenol compounds	0,135	Ground water	0,002
Chromium	0,36	Surface water	0,05
Cadmium	0,04	Ground water	0,01
Cyanide	1,80	Ground water	0,20

Adapted from: INGESAM, 2005

The outcomes from Table 5.8 are critical since the hazardous substances apart from exceeding the Colombian standards are present in ground water sources considered as potential water resources for the city (CVC, 2004 cited by Agudelo *et al*, 2005). In addition, potential risks associated to these pollutants can cause chronic toxicity events in adjacent areas (INGESAM, 2005).

5.6 WASTEWATER DISCHARGES FROM THE CITY OF CALI

5.6.1 Identification of non-domestic wastewater discharges in the city

According to CVC (2006) cited by EMCALI (2007), in year 2005 the BOD discharge load from the city of Cali to Cauca River was estimated around 38% from the total wastewater discharge load in the Valle del Cauca department (see Figure 5.26).

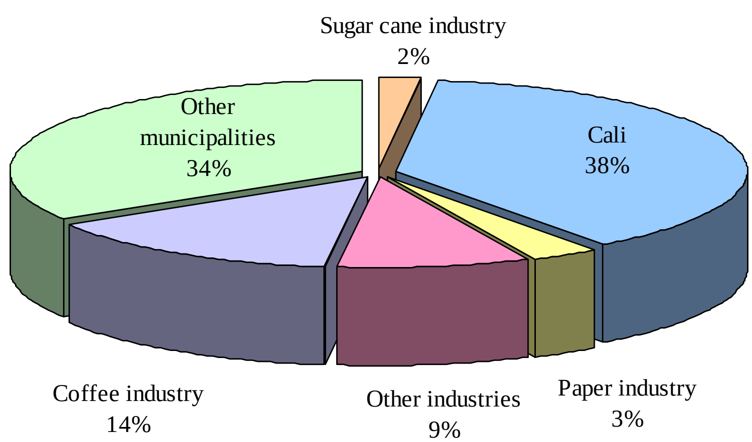

Figure 5.26 BOD discharge load to Cauca river in year 2005.
Source, CVC 2006 cited by EMCALI , 2007

According to information reported by DAGMA in 1998-1999 regarding non domestic sector discharges to the sewage system in the city (commercial and industrial sectors), the total BOD and TSS load discharged was approximately 24% and 26% from the total wastewater load generated in the city respectively. However, this is the only existing reference since after 1999 there has not been complete and reliable information regarding the number of commercial and industrial establishments and their average discharges (EMCALI, 2007a).

From the reports given by DAGMA in year 1999, the most representative sectors in wastewater discharge loads (spilling more than 1000 kg/day) were: food sector, beverages sector, hospitals and clinics, commercial establishments and chemical products industry (Figure 5.27). In addition, the

most representative industrial production inside the food and drinks sectors are observed in Figure 5.28 and Figure 5.29, respectively. The type if food industry that contributed the most BOD loads was the corn industry (2928 kg/day), followed by chew gum industry (2465 kg/day) and oil industry (2099kg/day). Regarding the production of drinks, the highest contributors in BOD loads were Bavaria (which produces beer) with 2400 kg/day and Coca-cola with 1900 kg/day.

5.6.2 Final wastewater discharge points from the city of Cali to Cauca river

Flows and BOD loads

Currently, the city of Cali directly drains its wastewaters on the left margin of the Cauca river in the following discharge points: 1) South Channel, 2) Pumping station Puerto Mallarino, 3) Sludge from drinking water Plant Puerto Mallarino. 4) Effluent of the WWTP-C and 5) Pumping station Paso del Comercio.

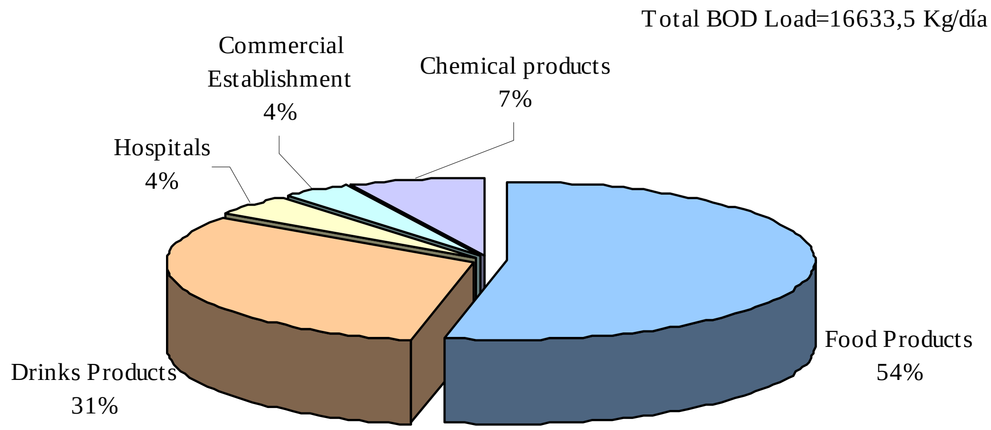

Figure 5.27 Industrial sectors that most contributed with BOD load discharges (more than 1000 BOD kg/day) in Cali, year 1999.
Source: DAGMA, 1999

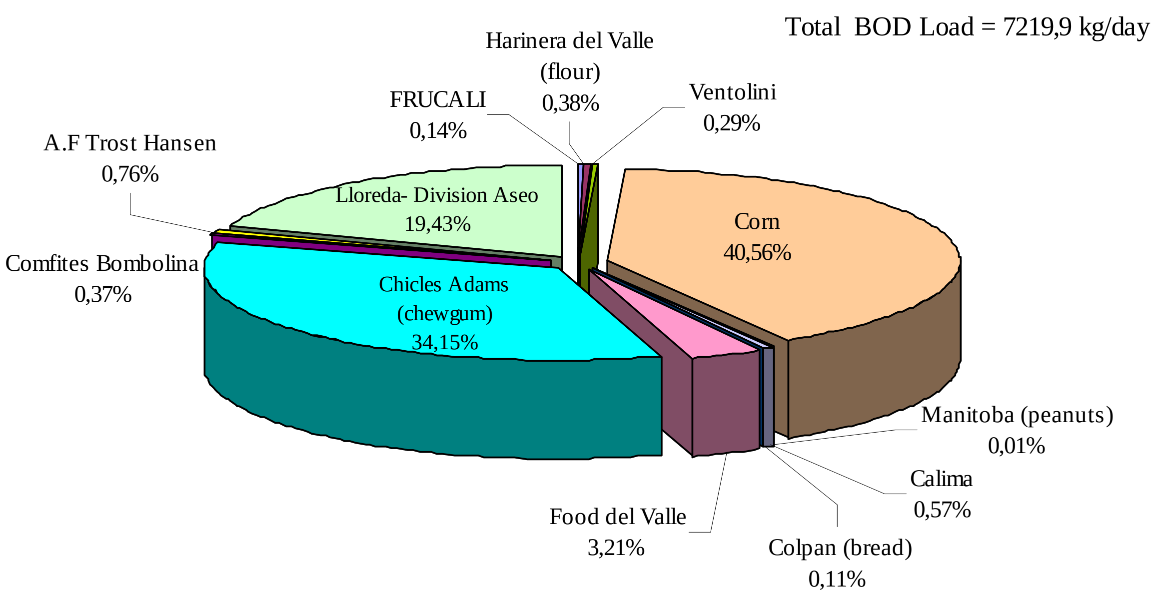

Figure 5.28 BOD load from the food industries in Cali, year 1999.
Source: DAGMA, 1999

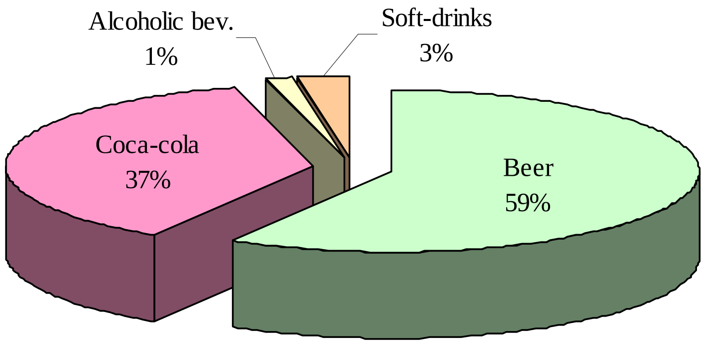

Figure 5.29 BOD load from the beverages industries in Cali, year 1999.
Source: DAGMA, 1999

The different discharge points, their location and their respective flow and BOD load contribution are shown in Table 5.9. The values from Table 5.9 came as a result of the studies and monitorings carried out in the discharge points in the city.

Table 5.9 Flow and BOD load discharges from the final wastewater discharge points in the three drainage systems in Cali. Year 2005

Drainage System	Discharge point	flow (l/s)	% flow from the total WW	BOD (mg/l)	Load (kgBOD/day)	Source
South	South Channel	2417	30,1	68,5	14211,7	MANOV 2006
North-west	Collector Margen Izquierda	808	10,2	157,3	10981,3	EMCALI 2005
	Floralia pumping station	150	1,9	342	4432,3	EMCALI 2005
East	Paso del Comercio pumping station	791	10	85	5809,1	EMCALI 2005
	Puerto Mallarino pumping station	29	0,4	72,9	182,7	EMCALI 2005
	Sludge from Puerto Mallarino treatment plant	247	3,14	330,8	7059,5	EMCALI-Universidad del Valle 2006
	WWTP-C effluent with TPA (BOD removal 40%)	3417	44	142,1	41920,8	EMCALI, 2006*
	WWTP-C effluent without TPA (BOD removal 30%)			165,8	48907,6	EMCALI, 2006*

Source: EMCALI-Universidad del Valle , 2006a
(*) Result from statistic analysis WWTP effluent mid 2005-mid 2006

The highest wastewater load and flow is coming from the treated effluent from the WWTP-C which paradoxically is treating the 40% of the total wastewater produced in the city. In addition, the use of primary advanced treatment (TPA) in the plant (addition of ferric chloride) represents only an increment of 15% total BOD removed which in terms on the total polluting load discharged to the river still represents the highest discharge point. The other discharge points do not receive any type of treatment but only transport the wastewater from the city to Cauca river.

Hazardous substances

In terms of presence of hazardous substance in the wastewater discharges, the South Drainage System channel is the one that is more documented. The east and North-west Drainage System does not count with information regarding monitoring of these substances until now.

As it was explained in section 5.5.8 , the South Channel has been found to have presence of phenols, lead, mercury and copper that were thought to come exclusively from Navarro disposal but have been found to come also from the industrial sector (INGESAM, 2005). This situation is dramatic since the contamination of the main water source for the City of Cali may be developing into a chronic pollution event. Additionally, most of the industries that produce medical and dental equipment, rubber, plastic, press materials and metals are located along the channels in the South Drainage System and are the main sources of the hazardous substances mentioned.

5.7 SOME DRAINAGE SYSTEMS PERSPECTIVES

The plan for the management of wastewater discharges and sanitation (Plan de Saneamiento y Manejo de Vertimientos –PSMV) for the city of Cali, which has been formulated by EMCALI, foresees a strategic action plan to improve the water quality of the main human water resource in Cali: the Cauca river. The plan has a work horizon from years 2007 to 2016 and has proposed different strategies to tackle the main environmental issues present in the drainage systems and hence in Cauca river. Following a short description of the main issues to be solved by the plan are mentioned. All plans have been based on the current scenario which was taken as year 2005.

As it was mentioned before, the PSMV formulated different plan and strategies to improve quality of Cauca river. The main decontamination strategies are summarized below:

Regarding drainage systems

- Building of Infrastructure works to eliminate wastewater from the channels. In this regard, the amount of wastewater arriving to the different drainage systems is thought to be reduced.

- Operation and maintenance plans to improve current situation of deteriorated sewerage infrastructures to prevent for instance dragging of solids, floods, etc.

- Control of wastewater discharges to the different drainage systems

- Recovery of landscape and green areas e.g. channels protection areas and Pondaje lagoons.

- Education and awareness campaigns focused on the proper use of the drainage structures and their importance for the community. Currently, the environmental educational campaign “recuperemos a canalito” or “lets recover the channels” is taking place.

- Establishment of control mechanisms to avoid presence of slums in the channels and in their protection areas.

- As part of the plan, currently, there are infrastructures being built with the aim to contribute to improve Cauca river’s water quality. Such infrastructure works are: middle section of Cañaveralejo collector, replacement of Oriental interceptor and the “trasvase” works.

  The middle section works in the Cañaveralejo collector will regulate the illegal connections to the system and will prevent the wastewater discharge of approx. 400 l/s to Cañaveralejo and Cauca river.

  The replacement works in the Oriental Interceptor will improve its hydraulic capacity and will avoid that the current excess wastewater is transported to the channels and finally to Cauca river

via South channel. The new oriental interceptor will transport around 480 l/s extra wastewater to the WWTP-C during peak periods.

The "trasvase" works are new infrastructure works that will collect and transport wastewater produced in the North-west part of the city to the WWTP-C. Hence, the influent to the WWTP-C will be increased in 850 l/s added to the present flow in 2005 (3,8 m^3/s). Trasvase works also include the excavation of a 4,2 km conduction line that will communicate Floralia pumping station and WWTP.

The PSMV formulated individual plans for each drainage system, estimating the future wastewater flows in the systems after the decontamination strategies. Table 5.10 shows the decontamination goals expressed as load and flow decrease in each drainage system. Such decrease in load was obtained as a result of considering decontamination works, landscape improvement works and maintenance and optimization in the sewerage structures as well.

Table 5.10 Estimated reduction in flows and BOD in each drainage system 2007-2016

Drainage Systems	Flow (l/s)	Estimated load to be reduced in each drainage system					
		Subtotal to year 2011 (kg/day)		Subtotal to year 2016 (kg/day)		Total 2007-2016 (kg/day)	
		BOD	TSS	BOD	TSS	BOD	TSS
South	1440	5702	6995	3629	4451	9331	11446
East	430	2758	2976	66	71	2824	3046
North-west	915	12005	8640	407	293	12412	8933
Future urban area *	374	2586	1862	2485	1789	5072	3651
All systems	3159	23062	20473	6687	6804	29839	27077

Source :EMCALI, 2007a
(*) Includes growth inside the present city

Regarding Cauca river

Directly or indirectly, the measures described above will contribute to the improvement of the quality of Cauca river by e.g. reducing the amount of wastewater and solid waste arriving to it. In addition, with regards to the direct discharge of wastewater to the river, the PSMV plan proposes the following:

- Increasing of the wastewater flow that arrives to WWTP-C so that more wastewater is treated. EMCALI has proposed to increase the influent flow to 6,18 m^3/s for year 2011 and 6,9 m^3/s for year 2016 which is equivalent to 89% and 97% of the expected total wastewater production from the city during those years. With the increasing of the treated flow, the BOD load in the effluent of WWTP-C will 61712 kg/day for year 2011 and 64632 kg/day for year 2016.

- Improving of the WWTP-C operation to achieve secondary treatment, which includes studies to select the most sustainable technology. The alternative that has been studied at small scale is activated sludge stabilization contact. EMCALI expects that in the coming five years the a appropriate technology will be selected.

Moreover, Table 5.11 shows the estimated waste water flows and BOD loads (by drainage system) that will be conveyed to WWTP-C during years 2007, 2011 and 2016 in addition to the current flow (3,8 m^3/s).

Table 5.11 Estimated extra flows and BOD loads that will arrive to WWTP-C after decontamination works, period 2007-2017

Drainage System	2007			2011			2016		
	Flow (l/s)	BOD (kg/day)	TSS (kg/day)	Flow (l/s)	BOD (kg/day)	TSS (kg/day)	Flow l/s	BOD (kg/day)	TSS (kg/day)
South	880	5702	6995	0	-	-	0	-	-
East	60	394	425	40	263	283	0	-	-
North-west	850	11530	8299	0	-	-	30	407	293
Future urban areas	42	565	407	27	365	263	22	295	212
Total	1832	18192	16126	67	628	546	52	702	505

Source: Adapted from EMCALI, 2007a
(-) Without Date

However, although the PSMV plan considers infrastructure works to improve the current state of channels and main components of the sewage system, its main objective is to convey more wastewater from the present and future Cali's urban areas to wastewater treatment plants, basically an end-of-pipe approach. In this regard, the PSMV-plan comprises the construction of the WWTP-South in addition to WWTP-C that will treat wastewater produced in the future urbanization areas. The WWTP-South will start operation only starting form year 2016 with a wastewater influent of 19 l/s. However, the plan does not mention the treatment technology that will be selected for this WTTP-Sur.

The optimization of the service of sewerage: Register and hydraulic modeling

EMCALI hired to Hiperaguas for make the design by sectors of the drinking water distribution system and the optimization of the sewerage through the implementation of the hydraulic model simulation.

Regarding the optimization of the service of sewerage, the objectives of this project are the following:

- Update of the technical register of the sewerage system of EMCALI through GIS (geographic information system).
- Hydraulic modeling of existing sanitary sewerage networks, without hydraulic calibration.
- Hydraulic modeling of drainage networks (channels and collectors) existing, without hydraulic calibration.
- Analysis of futures sceneries of modeling for the sewerage system: zones of future expansion and developments of new systems.

At present is being constructed the hydraulic model of the system of sewerage of Cali, in the software INFOSEWER. Initially the construction of the model is focused to obtaining the real conditions of connections, the direction of flows and the construction and affiliation with the database.

Between the perspectives of EMCALI with the results of this project, there is the formation of a group of modeling of systems, which would to guarantee the continuity in the use of these tools of modeling.

Early Warning Project

The main objective of the proposal of the early warning is to mitigate the vulnerability of the water intake of the river Cauca for distribution in Cali.

This project is aimed to design the operational components of a station of early warning that will be integrated to the monitoring network of the Cauca river and design the computer platform associated with the station of early warning that will support the take decisions process for EMCALI and others institutions involucrated with the integrated management of the water of Cauca river

Furthermore, through of this strategy will be possible identify the factors of risk in the water quality of the Cauca river upstream from the water intake up to the dam of Salvajina; identify the vulnerability of the drinking water plants that are supplied by the Cauca river and propose the preventive, corrective and mitigation plans in the drinking water plants to reduce the risks (critical and chronic).

Programs of Sanitation and Management of Waste-Discharges plan

EMCALI has formulated the Program Control of Wastewater in Rains Channels - CARCALL - and the Sanitation Program, in order to achieve the targets proposed in the PSMV. Following the general subject and the principal aspects of each program are shown.

Program of Control of wastewater in Rain Channels – CARCALL

The Program of Control of wastewaters in the rain channels - CARCALL, was created for resolve the problem of the presence of wastewaters in the rain system, which is caused by the wrong connections, situation aggravated by the presence of solid residues that come to the sewerage and the sediments that comes from the deforestation in the hillside.

The subject of this program is to contribute with the improvement of the water quality of the rivers of the city, by means of the reduction and control of the wastewaters in the runoff systems of Cali.

The specific subjects of the program are the following:

- Planning and built sanitary infrastructure to avoid the arrival of wastewaters to the runoff system, whose are discharge to the rivers without treatment.
- Prepare the necessary designs to eliminate the problem of wrong connections.
- Create a strategy of education to the community in general on the use and handling of the system of sewerage of the city.
- Reduce the payment of taxes.

In the CARCALL program there are registers all the works of construction that will transport the wastewaters to the WWTP-C. Also the update construction works and the maintenance of structures and the others components of the sewerage system.

Sanitation Program

The main purpose of this program is optimize the sewerage system through the works of construction, replacement and repairs; activities aimed to improve the service and provide welfare state to community. The activities to carry out in the Sanitation Program are the following:

- Replacement of the networks in bad state.
- Construction and optimization of the channels and collectors.
- Construction of structures of retention of solids for avoid the clogging of the networks.
- Optimize the combined sewerage overflow systems existent and locate and design new ones.
- Optimize de pumping stations; improve the efficiency and the service; increase the capacity and set up instrumentation equipments for reduce the consumption of energy.
- Construction of works for avoid flooding.
- Optimize the wastewater treatment plant - Cañaveralejo (WWTP – C).
- Works of construction of the massive transport system of Cali (MIO).
- Works of construction of sewerage system in expansion areas.
- Optimize the maintenance and use of the sewerage system.
- Develop a integral system of register of the information of the Sewerage of Cali.
- Make an inventory and diagnosis of the combined sewerage overflow system (location, hydraulic operation, physical conditions of maintenance and use).

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Diagnosis report

Study Case: Cali, Colombia

6. Control of Wastewater Pollution in the City of Cali

February, 2008

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6 CONTROL OF WASTEWATER POLLUTION IN THE CITY OF CALI

6.1 WASTEWATER PRODUCTION IN THE CITY OF CALI

As it was mentioned in Section 5.6, Cali's current situation, based on year 2005, shows a BOD discharge load from the city to Cauca River estimated around 38% from the total discharge load in the Valle del Cauca department (CVC, 2006 cited by EMCALI , 2007a). Table 6.1 show the flows and BOD load discharges measured in the six different wastewater discharge points from the city. Refer also to Table 5.8, Section 5.6 to appreciate more in detail BOD concentrations.

Table 6.1 Flows and BOD load discharges measured in the final wastewater discharge points. Year 2005.

Final wastewater discharge points	Flow (l/s)	BOD (kg/day)
South Channel	2417	14212
Collector Margen Izquierdo	808	10981
Floralia Pumping Station	150	4432
Paso del Comercio Pumping Station	791	5809
Puerto Mallarino Pumping Station	29	183
Sludge from Puerto Mallarino	247	7060
WWTP-C effluent with TPA	3417	41921

Source: Adapted from EMCALI-Universidad del Valle, 2006a

Table 6.1 shows that the greatest wastewater flows from the city of Cali come from South channel and effluent from the wastewater treatment plant Cañaveralejo (WWTP-C). On the other hand, the effluent from the WWTP-C represents the biggest BOD load discharged to the river whether using addition of ferric chloride or not (TPA). The WWTP-C receives and treats around 56 % of the total wastewater flow produced in the city (EMCALI, 2007a). However, its discharge impact to Cauca river is the highest since the dilution capacity of the river in that point is affected by this critical single load.

In addition, as it was mentioned in Section 5.6, there is also presence of hazardous substances in the wastewater discharges specially from the South channel. Such substances are phenol compounds, lead and mercury. Presence of these substances is critical since they all finally arrive to Cauca river which is also the water source for drinking water for the city of Cali.

6.2 INDUSTRIAL WASTEWATER IN THE WASTEWATER OF THE CITY

The industries in the urban area of Cali discharge directly their wastewater in the sewage system of the city. According to DAGMA in the period from 1998 to 1999 the total BOD and TSS load discharged by the industrial and commercial sectors in the city was approximately 24% to 26% from the total wastewater load generated in the city. The main impact to the domestic wastewater is the contribution of hazardous substances present in the wastes from the industries such as the metal, dental, and mechanic industry (refer to Section 5.6 for detail information).

6.3 WASTEWATER TREATMENT PLANT -CAÑAVERALEJO DESCRIPTION

6.3.1 General overview

From the decade of the 80's, EMCALI formulated the plan for wastewater decontamination, based on the studies of feasibility for the treatment of wastewaters of Cali. It was defined that the service of sewage system would be complemented with three wastewater treatment plants: the WWTP-Cañaveralejo, that would convey the main collectors and interceptors, with a coverage of approximately 85% of waste waters of the city, the WWTP - Rio Cali, that would receive the wastewater generated in the north-western zone of the city transported by the marginal collectors to the Cali river, with a coverage of approximately 15% and the WWTP - South (WWTP-S) that would receive the waste water generated by future zones of urban expansion of Cali. At the moment, WWTP-Canaveralejo (WWTP-C) is the only one constructed and in operation.

The WWTP-C is located in a lot of 22 Hectares; it is located between communes 6 and 7 of the city of Cali (Llanos, 2000). The wastewater influent to the plant comes from: the General collector (by gravity) and the pumping stations of Cañaveralejo, Navarro and Aguablanca. Figure 6.2 shows the location of the WWTP-C.

The only way of control of wastewater pollution in the city of Cali is made through the use of the wastewater treatment plant of Cañaveralejo (WWTP-C) which treats around 56% of the total wastewater flow produced in the city (EMCALI, 2007a). Following a description of the plant, its operation and treatment efficiencies is made.

6.3.2 WWTP-C components

The plant began operating in December of year 2001 (EMCALI, 2007a). It can operate in two ways: through conventional primary treatment or through advanced primary treatment (TPA). The conventional treatment consists on a simple sedimentation whereas the TPA consists on the addition of ferric chloride ($FeCl_3$) as coagulant and organic polymer to enhance flocculation and improve the removal of solids. The general scheme of the plant is shown in Figure 6.1. Following, the main treatment units are described. In addition Annex 6.1 shows the pictures of the main components of the plant.

Figure 6.1 General scheme wastewater treatment plant Cañaveralejo (WWTP-C)

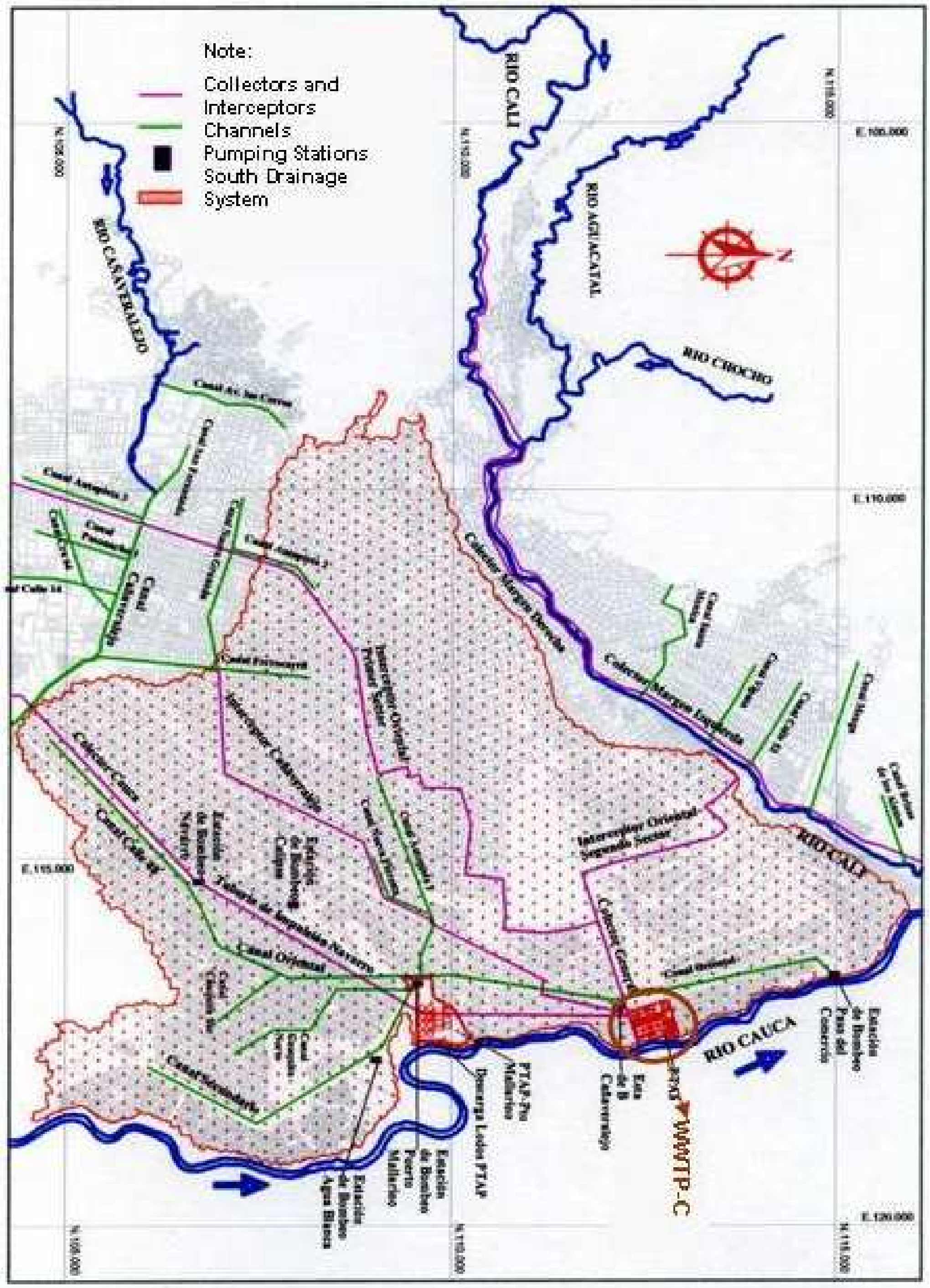

Figure 6.2 Location WWTP-C with its influents from Cañaveralejo, Navarro and Aguablanca pumping stations and General collector (East drainage system)

- ***Waterline:***

The water line scheme and its main components is shown in Figure 6.3. Afterwards a description of the components is made.

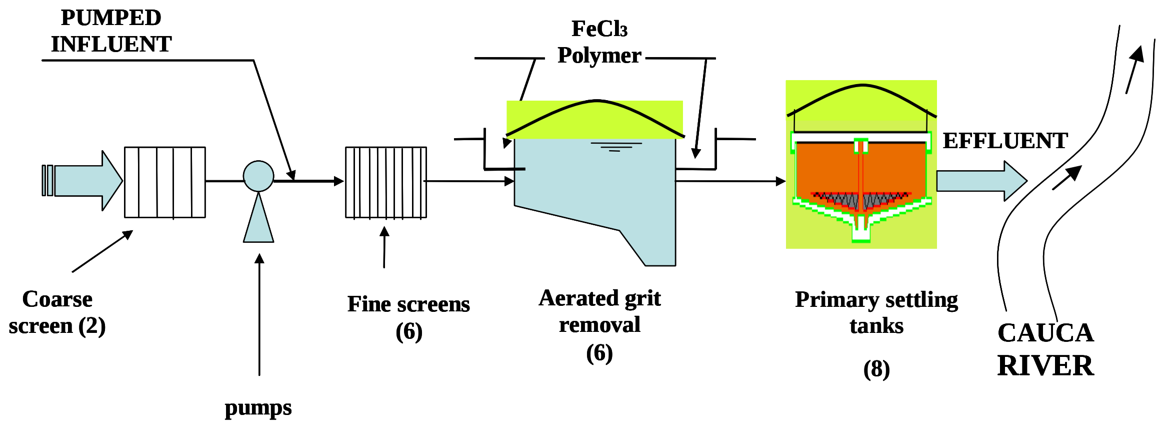

Figure 6.3 Water line scheme
Note: (#) Quantity of units

Coarse screens: There are 2 course screens than function mechanically to remove garbage. Their height is 2 m by 2,6 meters wide. Separation between bars is 10 cm.

Pumping station: It is composed by four screw pumps, with 2 m of diameter and a nominal capacity of 2 m^3/s each. The total number of fine screens is six, with height 2,5 m by 1,8 m wide.

Flow mixing chamber: It is a chamber that mix all wastewater flows coming to the WWTP-C, from pumping stations Aguablanca – Navarro and Cañaveralejo with wastewater coming from General collector. Mixed water is then raised by means of the screw pumps. There is also a continuous pH measuring system. Before the fine screens there are a bypass systems composed by 2 bypass chambers to deviate excess waste water to Cauca river, generally under big storm water events.

Fine screens and aerated grit removal: The fine screens retain solids bigger than 2,5 cm. The aerated grit removal consists of 6 aerated chambers in line with the fine screens. The process of settling and separation of sand on the bottom of the chambers is done through the addition of air by means of diffusers. The retention time of the aerated chambers is 3 minutes. The sand removal is done by means of ejection pumps that conduct the settled material to storage containers. Then the material is finally disposed in a place outside the plant premises. The volume of the each chambers is 394 m^3 . Advanced primary treatment (TPA) is used to improve the removal efficiency of non-soluble BOD and TSS by the addition of ferric chloride coagulant before wastewater enters the aerated grit removal system. Similarly, an organic polymer is added to enhance flocculation in the exit channels from the grit chambers. There are 2 tanks for the storage of ferric chloride (50 m^3).

Primary sedimentation tanks: After the aerated grit removal process, wastewater is conduced to the primary sedimentation tanks. There is also a bypass connection (before primary sedimentation) to discharge excess of wastewater to Cauca river in case it is needed. There are in total 8 sedimentation tanks, distributed in two groups of four. The tanks are circular, with diameters of 47,5 meters and height of 4,20 meters (volume of 8690 m^3). Wastewater is fed from the bottom of each tank and exists already treated from above. Treated effluent is conveyed to chambers which transport it to the final discharge point: Cauca river (see Figure 6.4). The sludge that remains on the bottom is removed from the bottom and is pumped to the thickener, prior to digestion. The floating sludge that remains on the supernatant is taken away by a mechanical sweep system and it is

transported to 2 storage containers and finally to a grease trap where the wastewater is re-circulated by gravity to the beginning of the treatment process. The grease is gathered and taken away from the plant.

Figure 6.4 WWTP-C Discharge.

- ***Sludge Line:***

The sludge line scheme and its main components is shown in Figure 6.5. Afterwards a description of the components is made.

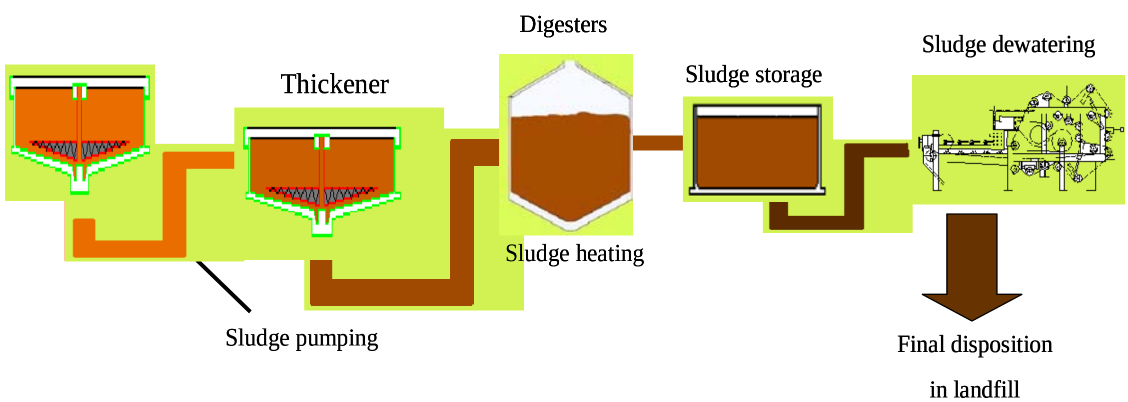

Figure 6.5 Sludge line scheme

Thickener: The sludge produced in the primary sedimentation is pumped with a DS concentration of 2% until 4 to 6% to the thickener. There is one thickener with a volume of 3322 m^3.

Anaerobic digesters: There are four digesters which receive the sludge from the thickener. The digesters function in the mesophilic range at controlled temperature of 35° C. The volume of each digester is 6200 m^3.

Sludge dewatering. It is composed by seven dewatering units (filter press) with a daily capacity of 997 m^3/d. Lime powder is also added to the bio-sludge to avoid odors and presence of vectors.

Finally, the dry sludge is disposed in a mono-fill which is located outside the plant in an area nearby drinking plant Puerto Mallarino. Figure 6.6 shows the location of the dry sludge mono-fill.

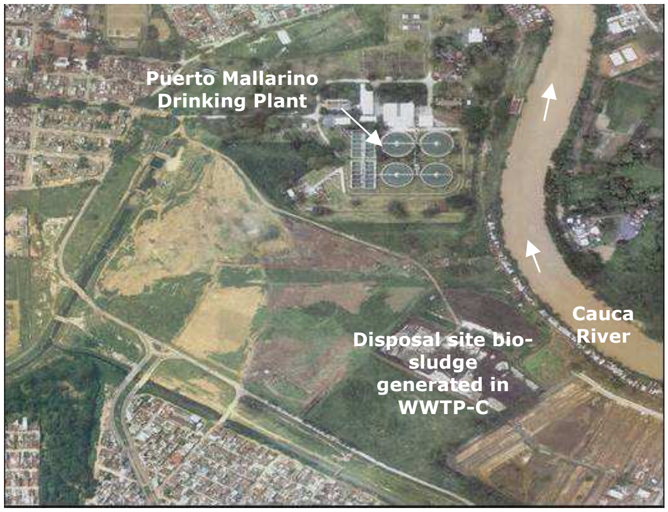

Figure 6.6 Location final disposal site for the bio-sludge coming from WWTP-C

Energy generation: Before generation of energy, the gas that is produced in the digesters is circulated in two gas purifiers to remove H_2S. The gas coming from the digesters is stored in two storage tanks with capacity of 1000 m^3 each. There are two generators of electric energy from the burning of biogas. Each generator has a capacity of 1000 Kw that would be used to generate energy for the internal consume of the plant. At present, the generators do not being used, but the biogas produced has two functions: mix and produces heat into the digestors, the excess of gas is burned using two burning units with capacity 1000 m^3 each as well.

Odor control: The WWTP-C counts with an odor control system called soil beds. The treatment consists on the filtration of air through biologic filters which by means of biological reactions occurring in their interior, transform the gases that cause bad odor (sulfuric gas and others). The filters are made by organic material (humus), volcanic ashes and organic layers.

Comparison between original and current operation

Table 6.2 shows the original design criteria for the WWTP-C. The plant design was originally developed in year 1999.

Table 6.2 Design parameters WWTP-C

Parameters	Value
Projected year	2015
Area of influence (ha)	9800
Population served (inhabitants)	2060000
Average flow rate (m^3/s)	7,6
Maximum flow rate (m^3/s)	12,24
Influent BOD (mg/l)	211
Influent TSS (mg/l)	180

Source: Llanos, 2000

Table 6.3 shows the comparison between the original design components and the components that are currently in operation. In this regard it is important to notice that not all the components operate

at the same time due to current lower treatment capacity in comparison with original design: Current (2007) average influent around 3,8 m^3/s vs. original average influent flow of 7,6 m^3/s. In practice, all units are used by periods switching them off and on so that their regular operation is not affected by lack of use.

Table 6.3 Comparison of design and current operation parameters in the WWTP-C.

Characteristic	Design*	Current**
Average influent flow (m^3/s)	7,6	3,82
BOD removal with TPA (%)	42 ± 5	40
BOD removal without TPA (%)	≥ 25	32
TSS removal with TPA (%)	63 ± 5	68
TSS removal without TPA (%)	≥ 50	62
Grit removal chambers	6	4
Sedimentation	8	4
Digesters	4	3
Energy generators	2	Not functioning
H_2S purifier	2	1
Sludge dewatering units (filter press)	7	4

Source: EMCALI, 2001.
Source: EMCALI, 2006. Note: Average data recorded in the plant in year 2006.

6.3.3 Wastewater characterization

The design capacity of the WWTP-C was established as 7,6 m^3/s for the year 2015. During the year 2006, the average influent flow rate ranged between 3,16 m^3/s and 4,49 m^3/s, with an annually average of 3,82m^3/s. Figure 6.7 shows the average of flows during year 2003 to 2007, it shows the increase of influent flow.

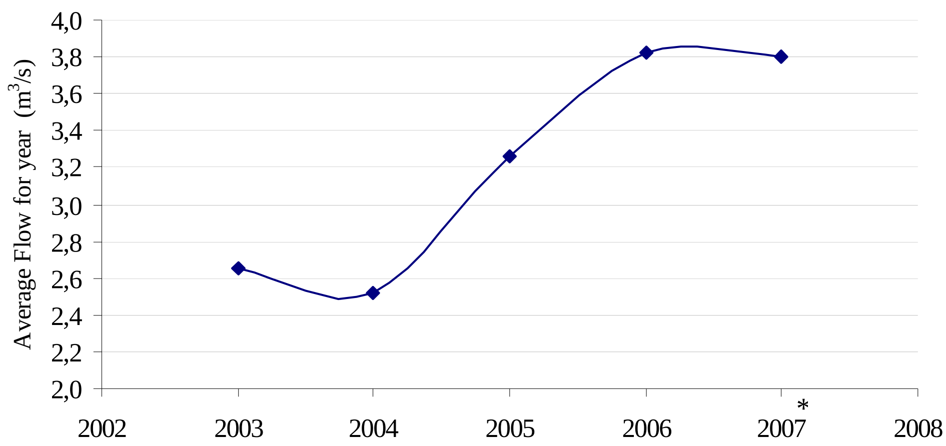

Figure 6.7 Average influent flow WWTP-C during year 2003 to 2007
Note: *Average January – September
Source: EMCALI, 2007b

In the plant, composite samples are taken during the day so that wastewater characterization is carried out daily. Table 6.4 shows the average monthly values registered for the influent and effluent in year 2006.

Table 6.4 WWTP-C influent and effluent characterization, year 2006

Month	Flow (m^3/s)	Influent				Effluent			
		TSS (mg/l)	BOD (mg/l)	COD (mg/l)	Total P (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	Total P (mg/l)
January	3,78	172	208	456	4,73	78	156	322	2,8
February	3,66	175	219	474	3,81	66	136	300	2,1
March	4,08	164	198	378	-	57	125	239	-
April	3,80	167	230	415	-	59	134	240	-
May	3,64	192	226	483	6,0	55	127	281	4,0
June	3,81	174	217	438	7,2	56	136	290	5,8
July	3,16	218	271	587	8,4	65	178	364	6.4
August	3,53	189	275	566	5,7	60	177	348	4,4
September	3,72	211	235	508	6,0	62	154	328	4,9
October	3,91	238	254	548	6,9	68	156	341	4,7
November	4,49	247	191	461	4,6	90	122	301	4,1
December	4,21	202	211	472	4,7	70	132	286	4,0

Source: EMCALI, 2006.

Removal efficiencies

Table 6.5 shows the monthly removal efficiencies measured in 2006 for the parameters of BOD and TSS. According to the design criteria (refer to Table 6.2) in average the plant complies with the removal efficiencies in terms of BOD and TSS with or without TPA. Additionally, it can be seen that BOD and TSS removals are slightly higher when TPA is used.

Table 6.5 WWTP-C comparison removal efficiencies with and without TPA, year 2006

Month	% removal with TPA		% removal without TPA	
	BOD	TSS	BOD	TSS
January	30	63	22	49
February	40	64	29	52
March	39	66	39	59
April	42	63	33	57
May	44	71	-	-
June	40	69	25	59
July	37	70	33	68
August	40	72	31	65
September	37	69	31	71
October	46	77	38	70
November	-	-	37	63
December	-	-	39	64

Source: EMCALI, 2006.

However, using TPA requires higher operation costs due to the use of chemical, to year 2006, the montly average costs was approximately $96.459.522, because of the $FeCl_3$ and organic polymer consumption (see section 6.3.6), to achieve only around 15% extra removal. The use of ferric chloride in the plant is not frequent since is influenced by different factors.

For instance during the first half of 2006 the plant operated with TPA in a continue way, stopping the treatment every 5 days in average (due to problems with valves in the plant and maintenance

activities). During the second half of the year the plant operated without TPA in November and December due to failures on the monitoring system. Additionally, Table 6.6 shows the total BOD production in Cali and the respective BOD removal efficiency of the WWTP-C, in year 2005. The WWTP-C received around 56 % of the total BOD wastewater load produced in the city of Cali. However, after treatment only 18,6% to 24,8% BOD removal (from the total BOD produced in the city) was achieved. In addition, the influence of primary advanced treatment in the whole treatment represents an additional 15% BOD removed which compared to the total load discharge to Cauca river still represents the highest contribution in terms of BOD load to Cauca river.

Table 6.6 Total BOD load production in Cali and BOD removal efficiency of the WWTP-C, in year 2005

Parameter	Value
Total BOD load produced in Cali (ton/day)	113
BOD load discharged to Cauca river without treatment*	
BOD load arriving to WWTP-C (ton/day)	70
BOD load effluent from WWTP-C with TPA (ton/day)	42
BOD load effluent from WWTP-C without TPA (ton/day)	49
BOD load removal WWTP-C with TPA (ton/day)	28
BOD load removal WWTP-C without TPA (ton/day)	21
BOD removal from the total BOD produced in the city (%)	24,8
BOD removal from the total BOD produced in the city (%)	18,6

Source: adapted from EMCALI, 2007a

***** From the other sewage discharge points to Cauca river: South channel, Margen izquierdo collector, pumping stations of Floralia, Puerto Mallarino and Paso del Comercio, and sludge from Puerto Mallarino.

6.3.4 Sludge characterization

The efficiency of the digestion process is defined after the removal of volatile total solids (SV) and the quantity of methane that is generated. Each digester counts with a measuring device that registers the volume of generated biogas. The production of bio-gas during year 2006 was approximately of 3039327 $m^{3.}$ Table 6.7 shows the average removal monthly efficiency of SV for the four digesters in the plant (year 2006).

Table 6.7 % SV removal efficiencies during year 2006

Month	Digester A*****	Digester B	Digester C	Digester E
January	-	50	49	48
February	-	44	45	44
March	-	41	43	42
April	-	48	47	47
May	-	47	46	46
June	-	51	49	50
July	-	50	48	49
August	-	47	46	46
September	-	44	42	44
October	-	42	42	42
November	-	41	41	41
December	46	58	-	56

Source: EMCALI, 2006.

***** digester A starting working on November 2006

6.3.5 Bio-solid production

Bio-solid is the digested sludge that has been also dried and that is ready for final disposal. Based on the production reports carried out in the plant during January to May 2007, the average production of bio-solid was 75 ton/d. This production depends also from the way of operation (TPA or not). During year 2006, around 38673 tons of bio-solid were finally disposed on the lot "Puertas del sol" which is equivalent to 34220 m^3. In addition Figure 6.8 shows the historical production of sludge from 2003. The sludge production has increased since 2004 with a total production of 34220 m^3 in 2006. Such trend is due to the increase in wastewater treated since 2004 (see Figure 6.8). The total production of sludge until May, 2007 was 9774 m^3 .

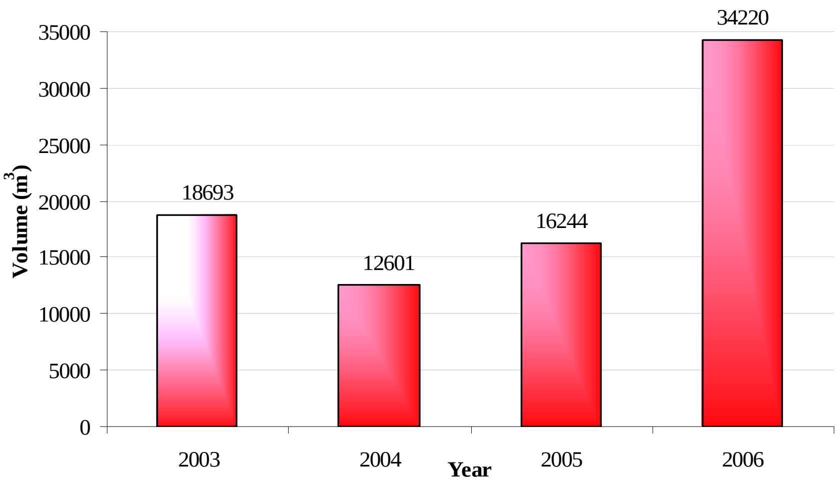

Figure 6.8 Historic production of bio-solids during the treatment of wastewater.
Source: EMCALI, 2007b

Physical and chemical characterization of the bio-solid

After the treatment of the sludge, a bio-solid with a concentration of total solids around 32% and a density of 1,13 ton/m^3 is obtained. Table 6.8 shows the physical and chemical characterization of the bio-solids produced in 2006.

Table 6.8 Physical and chemical characterization of the bio-solid, year 2006.

Month	T(°C)		pH (Un.)		ρ (ton/m^3)	Humidity (%)	Total Solids (%)	Volatile Solids (%)
	Min.	Max.	Min.	Max.				
January	25	33	7.89	8.46	1.11	69	31	12
February	27	33	7.79	8.22	1.12	69	31	13
March	25	32	7.72	8.23	1.13	69	31	13
April	-	-	7.39	8.10	1.13	68	32	12
May	-	-	7.35	8.28	1.10	68	32	13
June	-	-	7.71	8.30	1.12	67	33	13
July	-	-	7.55	8.30	1.13	69	31	13
August	-	-	7.48	8.35	1.12	69	31	13
September	-	-	7.20	8.27	1.14	70	30	12
October	-	-	7.59	8.16	1.14	68	32	12
November	-	-	7.55	8.41	1.17	66	34	11
December	-	-	7.70	8.35	1.13	66	34	12

Source: EMCALI, 2006
(-) Without date

6.3.6 Chemical consumption

Table 6.9 shows the consumption of chemicals used in the plant during 2006. Ferric chloride and organic polymer are used during the TPA process in the grit removal chambers. Lime powder is used in the thickener to control pH and during the process of final disposition of bio-solids to cover then to avoid odors and presence of vectors.

Table 6.9 WWTP-C consumption of chemicals in year 2006

Month	Consumption of chemicals during the TPA process		Costs TPA ($)	Consumption of chemicals in the sludge line	
	Ferric Chloride (kg/month)	Polymer (kg/month)		Polymer (kg/month)	Lime powder (kg/month)
January	74271	1600	88.429.772	2400	46375
February	80278	2275	100.352.368	2600	44475
March	109808	2150	128.857.174	3525	38325
April	112388	2500	134.503.373	2875	9300
May	14867	2050	32.826.126	3750	15800
June	128394	1850	144.861.550	3500	27925
July	71672	1150	81.889.884	-	61500
August	1702	575	6.733.668	-	52175
September	87162	1000	96.103.991	-	11500
October	21308	175	22.886.569	-	70751
November	*	*	*	3625	107346
December	*	*	*	4050	6169
TOTAL	701849	15325	$ 837.444.476	26325	491641

Source: EMCALI, 2006
Note: Unit cost chemicals used with TPA process: Ferric Chloride 1.002 $/kg, Polymer 8.744 $/kg.
Unit cost chemical used in the sludge line: Polymer 12.133 $/kg, Lime powder 325 $/kg.
(*) WWTP-C without TPA
(-) Without date

6.3.7 Energy consumption

According with the information given by EMCALI, currently in the plant it is registered a usage of electric energy between 750 and 800 kw/hour. This amount of energy is provided by the energy public service (EMCALI). However, it is expected in the plant that in a near future the two generators of energy from biogas (that are in the plant) will be used. The capacity of energy generation of each generator is 1000 kw. According to Llanos (2000) the plant requires a feed of 1600 kw/hour (for its designed demand). Currently, the biogas produced is only used for the mixing of sludge and for the heating of water used in the heat exchangers (to ensure a temperature of 38^{o}C in the digesters). The biogas that remains is burned daily.

6.4 PERSPECTIVE

6.4.1 Wastewater treatment plants

As it was mentioned in Section 5.7, the Plan for sanitation and management of wastewater discharges, PSMV (EMCALI, 2007a), proposed for the coming period 2007-2016 a gradual increment in the wastewater flow entering the WWTP-C so that its complete capacity will be fully achieved. In this regard, Figure 6.9 shows the estimated BOD and TSS loads that will annually enter the WWTP-C in addition to the current flow (based on year 2005). Such flow estimations come as a result of the general decontamination plan followed in the drainage systems in the city during the next ten years that were described in Section 5.7. Moreover, the plan estimates that in year 2016, the WWTP-C would reach an influent flow of 6,9 m^3/s which corresponds to the 89,3% of its design flow (7,6 m^3/s).

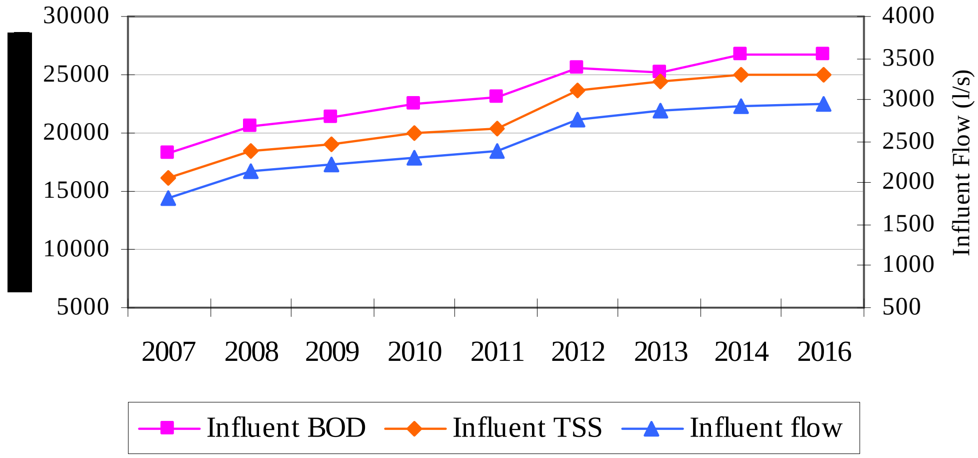

Figure 6.9 Additional estimated wastewater influents to arrive gradually to the WWTP-C from year 2007 to 2015and their characterization
Source: EMCALI, 2007a

Likewise, Table 6.10 presents the total flow and BOD load that will be transported to the WWTP-C. Such flows and loads include the different wastewater contributions from the drainage areas and from the future urban areas in the city of Cali. In addition, the table shows the total flow and removal treatment efficiencies that would be treated in the WWTP-S, in the case that it is constructed and operated from year 2016.

6.4.2 Implementation of secondary treatment in WWTP-C

EMCALI started in year 2005 the study of feasible alternatives for the upgrade of the WWTP-C to secondary treatment. In this regard, EMCALI and Universidad del Valle tested different aerobic alternatives at lab scale during year 2006. After lab scale studies one activated sludge system was selected to be implemented at pilot scale since it provided the best results during the lab experiments.

Lab scale studies: At lab scale, five aerobic systems were tested. Table 6.11 shows the characteristics of the systems:

Table 6.10 Perspectives for total influent and effluent's flows, and discharge loads from WWTP-C and WWTP-S as a result of the decontamination plan formulated in the PSMV.

Parameters	2006	2007	2010	2013	2016
WWTP-CAÑAVERALEJO, removal BOD 33% and TSS 56%					
Influent loads					
BOD(kg/day)	69055	81544	92448	96389	98436
TSS (kg/day)	52904	62035	74049	78059	79795
Flow(l/s)	3810	4762	6269	6757	6950
Effluent loads					
BOD (kg/day)		54634	61875	64581	65952
TSS (kg/day)		27296	32463	34346	35110
WWTP-South, removal BOD 80% and TSS 85%					
Influent loads					
BOD(kg/day)		0	0	0	258
TSS (kg/day)		0	0	0	186
Flow(l/s)		0	0	0	19
Effluent loads					
BOD (kg/day)					52
TSS (kg/day)					28
Total removed by two treatment plants					
BOD(kg/day)		26910	30508	31808	32690
TSS (kg/day)		34739	41467	43713	44843
Flow (l/s)	3810	4762	6269	6757	6969

Source: EMCALI, 2007a

Table 6.11 Summary of physical characteristics in the studied alternatives at lab scale for secondary treatment in WWTP-C

Characteristics	Suspended growth				Attached growth
	Extended aeration	Contact stabilization	Adsorption/ Bio-oxidation A/B	Conventional	Rotating biological contactor
Volume (l)	10	10 CR*: 3,5 SR**: 6,9	14,5 AR+: 2,5 BR++: 12	10	10 Phase 1: 5 l Phase 2: 5 l
HRT (hours)	30 -8	Total: 13,1-2,5 CR: 3,3-0,5 SR: 9,8-2	Total : 34-5,8 AR: 4-1 BR: 27,3-4,8	8-2	22-0,8

Source: EMCALI-Universidad del Valle, 2007
*CR: contact reactor, **SR: Stabilization reactor, + AR: Adsorption reactor, ++ BR: Bio-oxidation reactor

The substrate influent wastewater to the systems mentioned in Table 6.11 was the influent to the grit removal chambers without any addition of chemicals followed by a simulated conventional settling in a 1 m^3 tank with HRT of 2 hours (like in the full scale settling tanks).In the inoculated sludge for the activated sludge system a concentration of MLSS of 3100 mg/l was guaranteed.

Table 6.12 shows the physicochemical characteristics of the wastewater influent to the WWTP-C and the influent used in the lab scale experiments.

Table 6.12 Physic-chemical characteristics of the WWTP-C influent and the lab experiment influent

Variable	Units	Full scale WWTP-C influent		Lab scale influent	
		Average	Number data	Average	Number data
pH	units	6-10	181	6,5-7,5	118
Total BOD	mg/l	238	236	164	22
Filtrated BOD	mg/l			85	11
Total COD	mg/l	490	243	286	68
Filtrated COD	mg/l			183	41
BOD/COD		0,5	236	0,6	20
TSS	mg/l	194	245	81	60
VSS	mg/l	131		74	49
TKN	mg/l			32	23
NH_3	mg/l			20	23
NO_2	mg/l			0,188	11
BOD/N/P				100:20:8	

Source: Adapted from EMCALI-Universidad del Valle, 2007 and Universidad del Valle, 2006.

Furthermore, Table 6.13 shows the summary of the removal efficiencies from each studied alternative, showing that all systems reached BOD and TSS efficiencies higher than 80% in the settled wastewater and in this way the systems were complying with the national standards stated in Decree 1594-1984.

Table 6.13 Summary results of each alternative in terms of effluent quality and removal efficiencies

System	HRT	Effluent (mg/l)			Removal efficiency (%)		
		BOD	COD	TSS	BOD	COD	TSS
Extended aeration (1)	12-16	<3	<29	<4	98-99	88-94	96-99
Contact stabilization (2)	3,5-5	<16	<42	<15	90-92	77-90	86-90
A/B system (3)	5,8-8,7	<11	<50	<3	92-97	80-95	95-99
Conventional (4)	4-6	<21	<38	<3	88-96	89-98	96-99
Rotating biological contactor (5)	2-4	<12	<51	<16	95-96	80-88	87-96

Source: EMCALI-Universidad del Valle, 2007

According to Universidad del Valle (2006a), Technology 1 was more robust to sudden increments of organic load but used long HRTs. Technology 2 used low HRTs and required the least space among all technologies. However due to the high production of sludge a more robust sludge system should be considered in the plant. Technology 3 presented similar behavior to technology (2) with additional enhancement of nitrification processes in the BR reactor. However it would need extra settling line between both reactors and higher space requirements. Technology 4 presented similar trend to technology 1 but al lower HRT. Technology 5 is vulnerable to external factors like lack of energy to rotate discs or high grease loads that could break down the bio-film. Hence, the technologies of contact stabilization and conventional activated sludge were the ones chosen to be implemented at pilot scale. Both technologies operated at low HRT and presented less complexity in operation.

Pilot scale studies: The study of the two selected technologies mentioned previously is currently taken place in the WWTP-C and has not be finished yet. Until today, the system of contact stabilization is the one that has been tested using and adapting a activated sludge pilot plant created in 1985 which has an average capacity of 0,66 l/s.

The sludge for the pilot plant was taken and inoculated from sludge from the secondary settling tanks from the WWTP-Aguas del sur, located in the Caney neighborhood in Cali which uses activated sludge system.

The pilot plant has been ran in phases varying the influent flow until it reaches the design flow of 0,66 l/s and varying the re-circulated sludge. Table 6.14 shows a summary of the results from the operation phases of the pilot plant.

Table 6.14 Effluent quality and removal efficiencies in the pilot scale plant contact stabilization

Phase	Influent (l/s)	Recycled Sludge (%)	HRT	Removal efficiencies (%)			Effluent quality (mg/l)		
				BO D	COD	TSS	BO D	COD	TSS
Beginning	0,18 25%Q_{design}	100	3,1	-	-	-	-	-	-
		130		-	-	-	-	-	-
1	0,33 50%Q_{design}	100	1,7	84	91	96	28	29	8
		85		89	93	97	17	24	1
		70		82	91	99	29	31	1
2	0,50 75%Q_{design}	85	1,1	87	90	84	26	31	10
		70		85	92	92	33	30	5
		55		83	90	86	31	32	10
3	0,66 100%Q_{design}	40	0,8	83	87	94	52	35	5
		55		81	77	80	46	78	17
4	0,56	55	1	83	91	87	41	29	12

Source: -EMCALI-Universidad del Valle, 2007

According to EMCALI-Universidad del Valle (2007) the most stable operation condition was in phase 2 with a recycle flow of 55%. Moreover, in general it has been seen that the contact stabilization system can achieve BOD, COD and TSS removal efficiencies higher than 80%.

Regarding removal of nutrients, nitrogen and phosphorous has been measured once per week in the influent and effluent in the pilot plant so that the trend of such components could be appreciated. Table 6.15 shows the summary of the measurements of nutrients during two phases of the study.

Table 6.15 Nutrients' characterization in influent and effluent from pilot plant

Phase	θc (cell retention time)	Parameter	Influent (mg/l)	Effluent (mg/l)
1 HRT: CR: 3h SR: 5,9 h	15 days	TKN	40,6	16,4
		NH_3	36,9	5,7
		NO_2	0,1	1,3
		NO_3	3	16
		Phosphate	20	14,5
2 HRT: CR: 1,7 h SR: 3,3 h	7 days	TKN	40,5	13,3
		NH_3	33,6	12,6
		NO_2	-	-
		NO_3	-	-
		Phosphate	13,4	5,8

Source: EMCALI-Universidad del Valle, 2007

It can be seen that the pilot contact stabilization plant is able to achieve around 60-70 % total nitrogen removal and 30% to 60% phosphate removal.

6.4.3 Impact of the future waste treatment perspective on the quality of Cauca river

PSMV made use of modeling simulations to evaluate the impacts of the future wastewater treatment to Cauca river in the period 2005-2016. The modeling strategy considered only the Section Hormiguero-Mediacanoa which covers the stations upstream and downstream the city of Cali Many scenarios were formulated in order to evaluate the different future scenarios and impacts on Cauca river.

In this regard scenario 1 and 2 (S-1, S-2) considered the base condition (year 2005) and where the base scenarios for the future simulated scenarios (S-3, S-4, S-5 and S-6). For the future scenarios, it was considered the implementation of the infrastructure works for the decontamination of the sewerage system of the city proposed in the PSMV (refer to Section 5.7, chapter 5 for more details). In addition, for the future scenarios S-3 and S-4 the different BOD removal treatment efficiencies of the WWTP-C with or without TPA were considered as well. For scenarios S-5 and S-6 the treatment of the wastewater generated in the future urban areas in the city of Cali was considered by means of the proposed WWTP-S. Table 6.16 shows a summary of the results of the different modeling simulations.

Table 6.16 Description of scenarios to evaluate the future impact of the wastewater strategies in the quality of Cauca river.

scenario	year	Scenario description	Level of treatment in WWTP-C	Influent WWTP-C			Effluent WWTP-C			Discharge to Cauca river		
				flow (l/s)	BOD (mg/l)	BOD load (kg/day)	flow (l/s)	BOD (mg/l)	BOD load (kg/day)	flow (l/s)	BOD (mg/l)	BOD load (kg/day)
S-1	2005	Base scenario	Primary no TPA (30%BOD removal)	3414	237	69868	3414	165,8	48907,6	7856,1	134,9	91584,2
S-2		Base scenario	Primary with TPA (40% BOD removal)	3414	237	69868	3414	142,1	41920,8	7821,1	124,6	84597,4
S-3	2011	Proposed infrastructure in PSMV + WWTP-C primary [1]	Primary no TPA (30% BOD removal)	5829,7	195	98111,4	5829,7	136,4	6867,8	8086,3	123,4	86239,8
S-4			Primary with TPA (40% BOD removal)	5829,7	195	98111,4	5829,7	116,9	58866,9	8086,3	109,4	76428,6
S-5	2016	Proposed infrastructure in PSMV + WWTP-C primary +WWTP-S with secondary treatment [2]	Primary no TPA (30% BOD removal)	6483,1	186	10408,2	6483,1	130,1	72861	8239	120,6	85853,7
S-6			Primary with TPA (40% BOD removal)	6483,1	186	10408,2	6483,1	111,5	62452,3	8239	106	75445

Source: Adapted from EMCALI-Universidad del Valle 2006b

[1] Domestic wastewater discharge from future urban area to WWTP-C

[2] Domestic wastewater discharge from future urban area to WWTP-C and WWTP-S. Effluent discharge from WWTP-S before water intake of Puerto Mallarino drinking water plant

Modeling results suggested that to prevent DO depletion in Cauca river as result of wastewater discharges it is needed more than the implementation of secondary wastewater treatment together with an increment in the removal efficiencies in the treatment plants. Figure 6.10 shows the DO variation along Cauca river in Section Hormiguero-Mediacanoa as result of the simulation scenarios described during years 2011 and 2016.

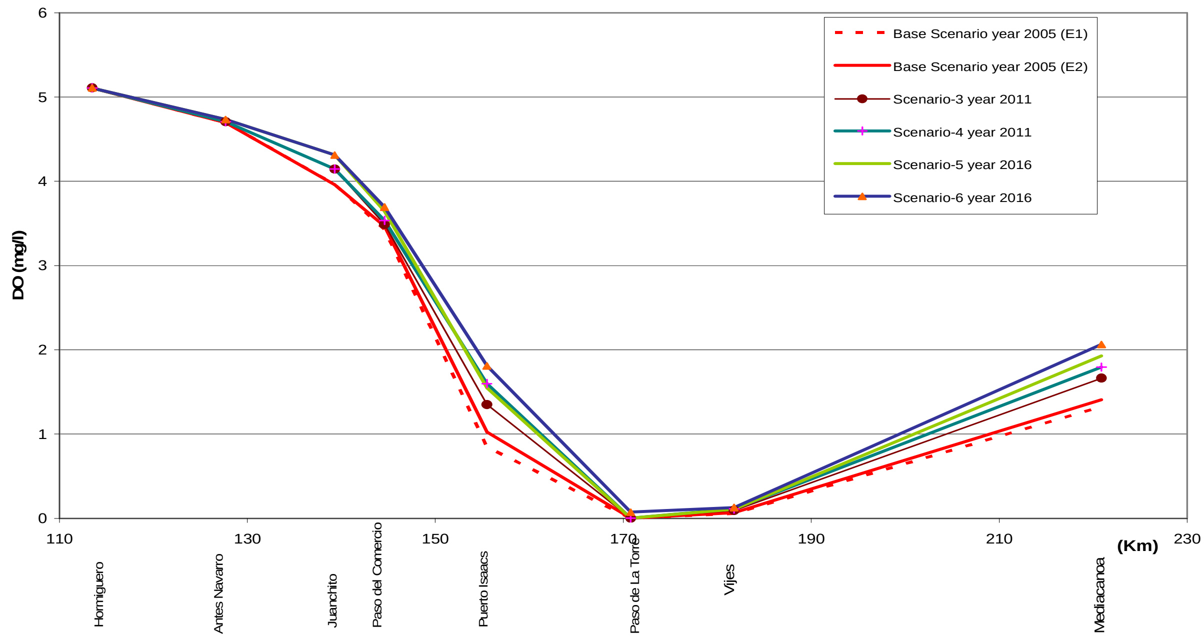

Figure 6.10 DO variation along Cauca river as result of the simulation scenarios described during years 2011 and 2016. Section Hormiguero-Mediacanoa

Source: Adapted from EMCALI-Universidad del Valle 2006b

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Sustainable Water Improves Tomorrow's Cities' Health
SWITCH Project

Study Case: Cali, Colombia
Water Resources

ANNEX 6.1
WWTP-C Pictures

February, 2008

WWTP-C PICTURES


Figure A6.1.1. Bypass chamber


Figure A6.1.2 Flow mixing chamber


Figure A6.1.3 Fine screens


Figure A6.1.4 Solid transport band for the solids caught by fine screens


Figure A6.1.5 Grit removal chamber


Figure A6.1.6 Ferric chloride storage tanks

Figure A6.1.7 Polymer dosage

Figure A6.1.8 Settling tank

Figure A6.1.9 Thickener

Figure A6.1.10 Digesters

Figure A6.1.11 Lime addition before filter press

Figure A6.1.12 Filter press

Figure A6.1.13 Bio-solid transport

Figure A6.1.14 Odor control

Figure A6.1.15 Biogas storage

Figure A6.1.16 Gas burners

Sustainable Water Improves Tomorrow's Cities' Health SWITCH Project

Urban Water Management for the City of Cali
Diagnosis report

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7. Solid Waste Management

February, 2008

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7 SOLID WASTE MANAGEMENT

7.1 GENERAL OVERVIEW

EMSIRVA has been the company in charge of the collection, transport and final disposition of the solid waste produced by the city of Cali since 1966. The coverage of the service is 100% in the urban area and around 90% in the rural area of Cali according to and interview with the Eng. Carlos Espinoza from the EMSIRVA planning department (EMSIRVA, 2007). After the collection of the solid waste in the city, the waste is transported to the final disposal site known as Navarro site. Following the different aspects of the solid waste management in the city will be discussed.

7.2 SOLID WASTE GENERATION

Table 7.1 shows the historical average annual solid waste produced by the city of Cali. Since the year 1970 until the month of April 2007, an amount of 13’874.000 tons of solid waste have been produced by the city of Cali. The monthly average solid waste produced in the city during the last six years (2000-2006) was 47891 ton/month.

Table 7.1 Historical amount of solid waste produced by the city of Cali

Year	Solid waste (ton)	Year	Solid waste (ton)
1970	143280	1989	329400
1971	150480	1990	402800
1972	158040	1991	412920
1973	168480	1992	421200
1974	176400	1993	428400
1975	184680	1994	438480
1976	192960	1995	478450
1977	201240	1996	568800
1978	209880	1997	523440
1979	218160	1998	663840
1980	268130	1999	568800
1981	277200	2000	576720
1982	282240	2001	568510
1983	286200	2002	609108
1984	289440	2003	669812
1985	292320	2004	531470
1986	302040	2005	517140
1987	310680	2006	550091
1988	320040	2007 (data to April)	183032
Total			**13’874.303**

Source: adapted from: INGESAM, 2005a and solid waste production Report years 2002-2007 by EMSIRVA

Similarly, according to information provided by EMSIRVA, in the month of April 2005 approximately 75% of the collected solid waste was of domestic origin, followed by a 10% of waste

generated in the cleaning of the streets and around 8,5% industrial waste, the remaining was debris with 2,6% and hospital origin 0,4%.

As stated by Municipio de Cali (2006), the composition of the domestic waste is mainly organic origin (59%), followed by waste with sanitation origin (7,7%) and plastics (6,9%), the remaining is constituted by paper, rubber, textiles, wood and glass matter as it can be seen in Figure 7.1.

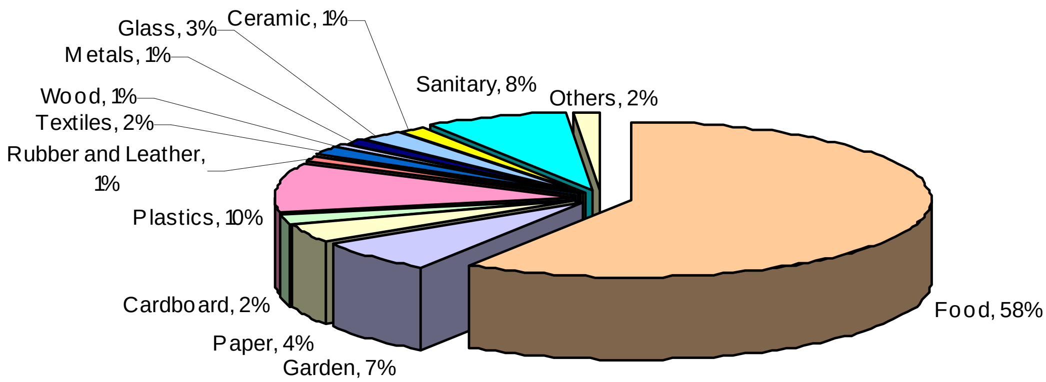

Figure 7.1 Composition of domestic waste generated in the city of Cali in 2006
Source: Municipio de Cali, 2006

7.3 SOLID WASTE SEPARATION

As stated in an interview on November 28, 2007 to Psychologist Nestor Martinez (EMSIRVA-education department employee), in the city of Cali there are no regulated recycling practices. However, EMSIRVA carries out recycling awareness campaigns to educate people in these practices. The Education department of EMSIRVA has four recycling and separation at source education practices targeted to all sectors of the community. The four programs are:

- Educando recuperando: Targeted to primary schools, including teachers and students' families.
- Social Service: Targeted to secondary students specially those that are about to graduate.
- Prácticas educativas empresariales: Targeted to the industrial and commercial sectors which are EMSIRVA costumers via capacity building strategies.
- Domestic and community capacity building: Targeted to the house holds and communities in a door-to-door basis.

Moreover, according to Municipio de Cali (2006), in a survey carried out in 2006 to 2196 people in the city of Cali, 92,6% of them had knowledge regarding solid waste separation at source. However only 31,5% of them had incorporated the practice of solid waste separation at their homes. Likewise, people belonging to higher estratos e.g. estrato 6 are among the ones that carry out separation practices more often.

7.4 SOLID WASTE COLLECTION AND TRANSPORT

The information provided in this item comes as a result of an interview with the Eng. Carlos Espinoza from EMSIRVA planning department on November 29, 2007. EMSIRVA manages the

collection and transport of solid waste based on the origin of the waste. For instance in the city, the collection and transport practices are divided based on three types of waste origin: domestic, industrial-commercial and hospitals origin.

7.4.1 Domestic origin

EMSIRVA counts with 103 solid waste collection equipment for the city of Cali and there are not solid waste transfer sites in the city. Before the month of April, 2007 the collection and transport practices were done door-to-door, two times per week. After April, 2007 the collection of solid waste is carried out door-to-door three times per week. EMSIRVA counts with a collection schedule grouped by days and neighborhoods for the solid waste collection, the neighborhoods groups are called “comunas”:

-1. For “comunas” 1, 2, 3, 4, 14, 16, 22 the service is provided Monday, Wednesday and Friday.

-2. For “comunas” 5, 6, 7, 10, 11, 15 the service is provided Tuesday, Thursday and Saturday.

-3. For “comunas” 8, 9, 12, 13, 17, 18, 19, 20, 21 the service is split by neighborhood and collected either as in option 1 or 2.

When the neighborhoods do not have road access and the service can not be done door-to-door, there are the so called “Centros de Acopio” or solid waste deposit sites in the neighborhood where people go to deposit solid waste and the trucks come to pick it up. This service is also carried out three times per week.

7.4.2 Industrial-commercial origin

For the industrial and commercial waste collection the service covers the industries and commercial establishments that have previously registered with EMSIRVA as costumers. Not all industries and commercial establishments are registered with EMSIRVA since there are small private companies that also provide this service not carried out door-to-door.

The service is not provided in a door-to-door basis. Rather there are established “industrial-commercial routes” where the trucks collect the solid waste. The frequency of collection depend on the industry needs and solid waste production. This service is directly paid by the industry to EMSIRVA depending on the previously agreed frequency of collection and amount of waste produced in the industry.

7.4.3 Hospitals origin

As in the industrial-commercial routes, EMSIRVA has pre-established hospital routes to collect hospital waste. These routes reach all levels of hospital-related offices from the emergency centers, autopsy centers, small medical practices to private and public hospitals.

At the hospitals, the wastes are collected and disposed in special bins according to the type of waste: biodegradable, inert, toxic-bio sanitary, chemical, heavy metals and radioactive. EMSIRVA collects and treats the waste according to its origin and afterwards the treated waste is disposed off in the disposal site of Navarro burying it and covering it.

The common hospital waste treatment practices carried out by EMSIRVA are: neutralization at temperatures around 2000^{o}C and incineration. This practices are made at a sterilization plant own by EMSIRVA which is located in the urban periphery located in the west part of Cali.

The EMSIRVA hospital rout has been recognized worldwide by the European Economic Assocciation (E.E.A.) and the Pan-American Health Organization (PAHO) because has followed the environmental regulations regarding collection, transport, treatment and final disposal. Regarding the collection of debris the environmental authority in charge of it is DAGMA.

7.5 SOLID WASTE RECOVERY

In Cali, some of the materials that are recycled are paper, cardboard, glass, metals, iron and aluminum. Common practice is that in the city there are informal “recycling groups” constituted by people that separate and recycle valuable waste. These recycling practices are done at three levels:

- Separation of the waste at house level and then giving the recycled waste to the recycler person
- Separation of the waste at street level prior it is picked up by the solid waste truck.
- Separation of the waste at Navarro site. In this regard there is a formal recognized group of recycling people (scavengers) by EMSIRVA constituted approximately by 609 people. The scavenger association is called UFPRAME. However, there is more than 2000 scavengers informally recycling valuable waste at Navarro site. One of the advantages of belonging to the UFPRAME group is that EMSIRVA is currently promoting capacity building strategies in the field of recycling to approx 150 scavengers so that in a future the recycling activities can be done in a more technical and organized way and transferred to the other UFPRAME members.

As stated by Municipio de Cali (2006) around 20% of the domestic solid waste produced in the city is composed by material that can be recycled such as paper, cardboard, plastic, glass, and metals which could represent an amount of 159 ton/day of valuable solid waste.

7.6 SOLID WASTE FINAL DISPOSAL

7.6.1 General description of Navarro disposal site

The site where the solid waste produced in Cali is disposed off is denominated deposit of Navarro. Officially its operation began in 1984, although from year 1968, the company of solid waste management in Cali: EMSIRVA began depositing the waste in the zone where today deposit of Navarro is located. During years 1970 to 1990 Navarro operated as an open dumpsite, without any control or technical operation of garbage. During this period there was a lot of controversy with respect to its operation, so in 1999 the CVC imposed a waste management plan for the recovery and environmental restoration of the Navarro area and also for the closure of the Navarro dumpsite. CVC established the construction of a “transitory landfill” in order to give a transitory solution of the disposal of waste while a better disposal alternative was found (Subdirección gestión ambiental, 1999). Consequently, in the period from 1998 to 2001 the closing and sealing of the “open dumpsite” was carried out and the operation of the “transitory landfill” was initiated. According to an interview with the Eng. Carlos Espinoza from EMSIRVA planning department on November 29, 2007, EMSIRVA has January 31, 2008 as the deadline to finally shut down the disposal site of Navarro.

The solid waste deposit Navarro is located in the district of Navarro, in the south of Cali to the left margin of Cauca river and nearby of the south channel (see Figure 7.2). The area is characterized by a flat topography, with low slopes to the natural drainage of Cauca river. The area is also

characterized by a high degree of flooding. Moreover, there are important body waters located nearby this area such as: a) Canal Sur, b) Líli river, c) Meléndez river, and d) Cauca river. The area is characterized by the presence of phreatic levels at a depth of 4,5 meters respect to the ground level.

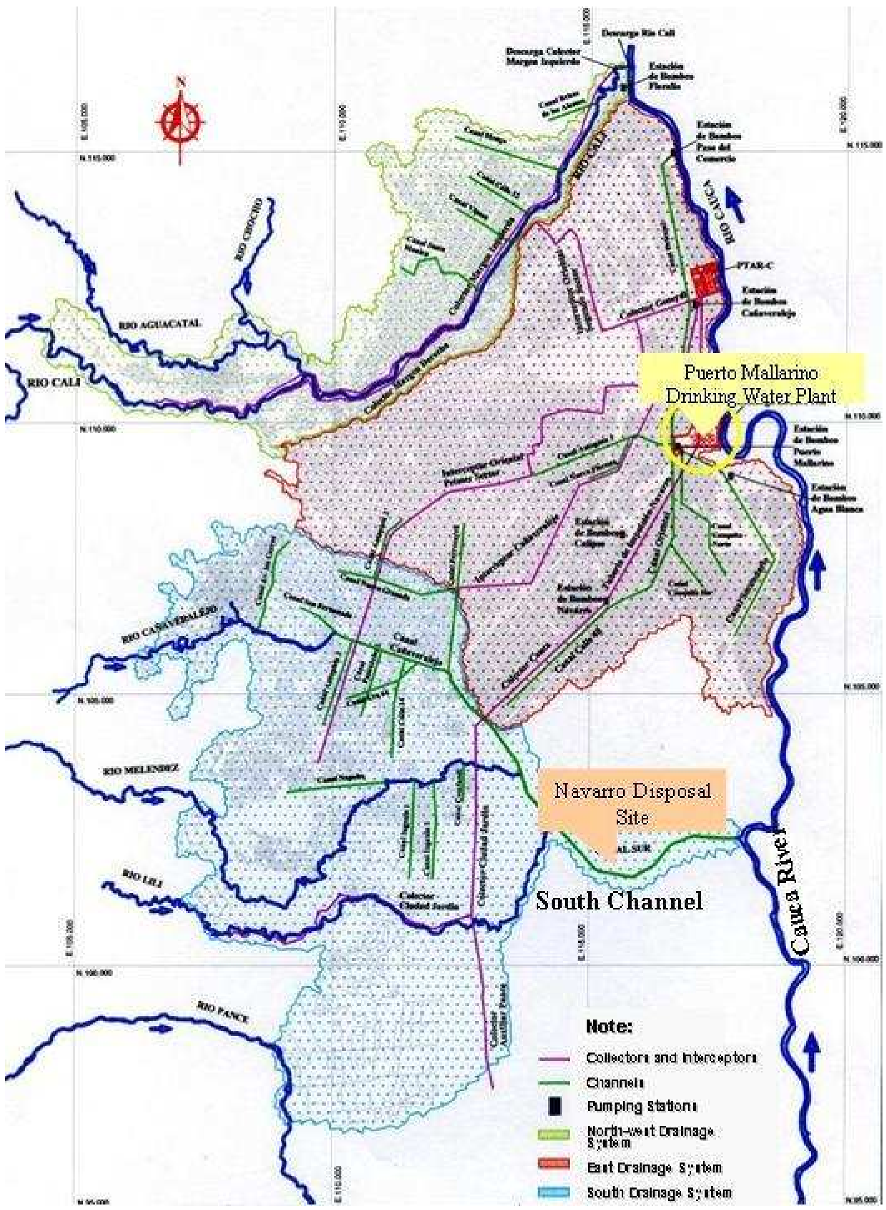

Figure 7.2 Location Solid waste deposit of Navarro.

The total area of the site is approximately 41 ha. From this area, 22,6 ha where used as open dumpsite from years 1970 to 1990 and are currently out of service. In this open dumpsite, two garbage hills where created through the years as result of the disposal of domestic, industrial and hospital waste. The two garbage hills are known as Old hill and Hospital hill. On the entrance of Navarro site, Old hill is located. Old hill looks like the trunk of a cone, with a height of 45 m and occupies an area of 12 ha. This cone was made from the accumulation of domestic and industrial

solid waste generated in Cali between 1970 and 2002, equivalent to 12’000.000 ton of garbage (INGESAM, 2005). At the southeast of the site, Hospital hill is located which, likewise, Old hill was created between 1970 and 2002 and was mainly made from the accumulation of waste from hospitals. Its height is 18 m with an area of 1,7 ha. These two garbage hills are currently closed and out of operation.

To the northeast of Old hill it is located the first and second phase of the transitory landfill, which each one consists of three garbage deposits called “vasos 1,2 and 3” and “vasos 4, 5 and 6” respectively. The area occupied by “phase 1” is 2,2 ha with a height of 10 meters. Likewise, the area occupied by “phase 2” is 5,5 ha with a height of 20 m. On the available space between “vasos 1, 2, 3” and Old hill a new solid waste deposit called “vaso D” was constructed and is currently in operation.. Figure 7.3 shows the distribution of solid waste deposits in Navarro.

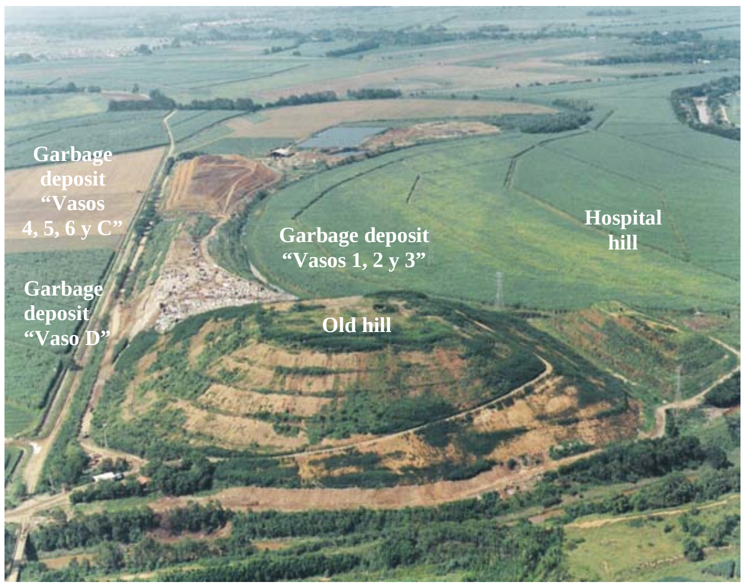

Figure 7.3 Location of solid waste deposits in Navarro.
Source: INGESAM , 2005

Once Old hill was closed, on October 2001 the construction of the transitory landfill began, which is located in the same area where the old dumpsite is. The idea of the transitory landfill was to give a temporary solution to the problem of solid waste disposal of Cali and other towns while a new and temporary strategy of disposal was created. Furthermore, it was sought that the landfill was built following technical specifications to cause less impact on the environment. From 2002, the operation and maintenance of the transitory landfill is managed by EMSIRVA.

The operation’s characteristics of the current “Navarro transitory landfill” are showed below.

7.6.2 Design of the system

The transitory landfill is an area type landfill which means that the landfill is built on flat terrains. The base of the landfill is the terrain after it has been excavated. Solid waste is deposited in the excavated holes until it reaches a certain height. The final result is a geometric figure similar to the trunk of a pyramid. In the case of Navarro, each of these “half-pyramids” are called disposal deposit or “vaso”.

The Navarro transitory landfill consists of solid waste deposits or “vasos” namely: 1, 2, 3, 4, 5, 6, C and D. “vasos 1, 2 and 3” were in operation until 2002. “vasos 4, 5 , 6 and C” operated until 2006. Currently, only “vaso D” is in operation Each of these “vasos” was built as follows:

i. Terrain excavation

ii. Leveling of the base of the “vasos”, keeping a slope of 1% to the middle part of the terrain so that leachate could drain more easily to the leachate drain system

iii. Construction of the perimeter dikes to guarantee stability of the solid waste mass. The dimensions of the dikes are: base width (7,0 m), crown width (3,0 m) and height (2,0 meters).

iv. Installation of Impervious layer (see Figure 7.4). It consists of: a) clay layer of 50 cm (to prevent leachate leaking to aquifers) , b) rock layer , diameters between 15 – 30 cm (to enhance leachate flow to final drains), c) installation of a polythene geo-membrane of 1,5 mm of high density.

v. Installation of leachate central collector system and chimneys to evacuate gases (see Figure 7.5).

Figure 7.4 Installation of the impervious layer and leachate central collector in “vaso D” in 2004.
Source: INGESAM, 2005

Figure 7.5 Chimney for the evacuation of gas for “vasos 4, 5, 6 and C”.
Source: INGESAM, 2005

Additionally, the transitory landfill counts with a storm water drainage system which is independent from the leachate drainage system. Storm water deposited directly on the surface of the “vasos” is evacuated through a network of secondary channels built on the slope of the terrace. These channels are connected to rectangular channels called “torrenteras” which go from the highest part of the landfill to the lowest part. These channels are made from rocks with diameters of 30 cm that dissipate energy. These rectangular channels are connected as well to a big perimeter channel that rounds the garbage deposits base and connects with “Madrevieja”, that is an abandoned natural water stream that is located along the solid waste disposal site of Navarro (INGESAM, 2005).

For the leachate production, currently, the volume of leachate that is generated is stored in two ponds which are located in the east part of Navarro. These two ponds are known as Big pond 1 and Big pond 2 (Gran Laguna Nº 1 y Gran Laguna Nº 2). In 2005, a third pond was built since the other two were almost full. The volume of the first two ponds is 74580 m^3 and the third one is 80000 m^3. There are also small auxiliary ponds (total volume of 3156 m^3) which are located beside the slope of

the “vasos”. Their function is to temporally store leachate that is produced in the “vasos” prior it is pumped to the Big pond N 2 (see Figure 7.6).

Figure 7.6 Location of main and auxiliary leachate ponds in Navarro
Source: INGESAM, 2005

7.6.3 Operation of the system

The disposal of solid waste in the transitory landfill is carried out as follows:

i. The operation of the system begins with the control and weight of the trucks that collect solid waste in the city. In the entrance, there is a system of scales to registered the gross amount of solid waste that arrives to Navarro. The scale system works 24 hours.

ii. Once the weight is registered, the trucks move to the respective unloading zone (respective “vaso”) using roads that were constructed in the place. In the solid waste deposit or “vaso”, trucks unload garbage (the unloading zone is called operational front site). The operational front site is aprox. 5 m of height x 15 m in length and 25 m in width. In this area scavengers pick, separate and recycle garbage that can be re-used.

iii. Once the recycling activities are over, the solid waste is extended and compacted on layers of 50 cm. The group of compacted layers of solid waste in a day is called “cell”. A cell can reach a height of 2 m x 23 m width in a day. These cells are covered with a soil layer (10 cm width) until it reaches a height of 5 meters. Between cells, a road of width 2-3 m is built to allow the circulation of heavy machinery for the maintenance of the slopes of the landfill.

iv. The so called “vasos” are made by building up cells on top of each other. At the end, the “vaso” looks like the trunk of a pyramid of around 5 m high. The base of each trunk is moved between 2- 3 m respect to the previous trunk so that at the end the “vaso” looks like a terrace structure with heights between 17 m and 20 m.

v. Produced leachate is only stored in the ponds as explained in the previous section.

7.6.4 Amount of disposed solid waste

Apart from the solid waste produced by Cali that amounts in average to 47891 ton/month (see Table 7.1), Navarro receives the solid waste from the towns of Yumbo and Jamundí. In the information of garbage production given by EMSIRVA, it can be seen that since 2005 other towns are depositing garbage there as well .These towns are: Candelaria, Palmira, Villarica. Figure 7.7 shows the solid waste contribution by the city of Cali in 2006. The city of Cali contributes with 87% of the solid waste to Navarro, followed by the contribution of the industries in the same city.

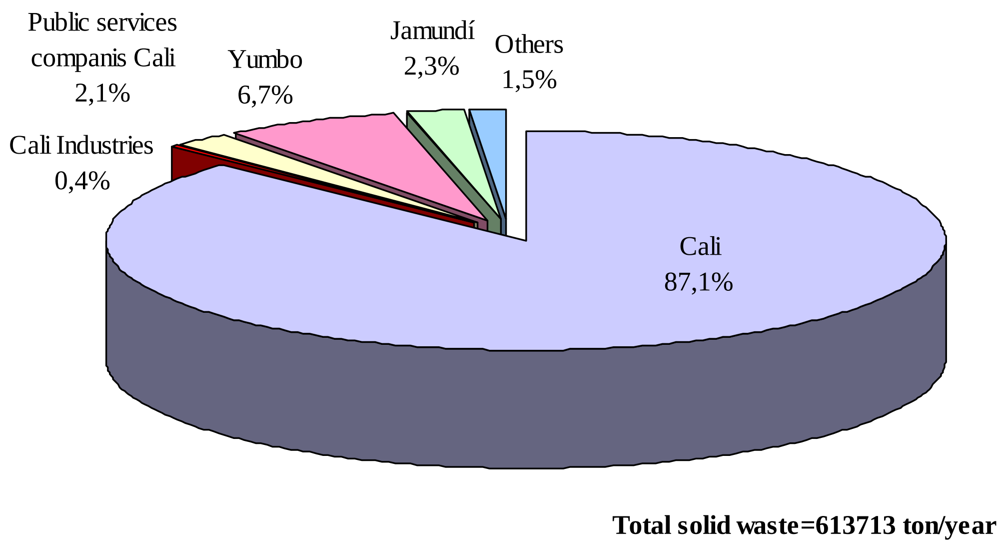

Figure 7.7 Distribution of solid wastes received at Navarro, year 2006.
Source: EMSIRVA, 2006. Production reports

7.6.5 Leachate production and disposal

There is not still an homogeneity among the estimated production of leachate in Navarro site. For instance, according to INGESAM (2005), EMSIRVA in 2005 measured in a monitoring campaign an average leachate flow of 5,94 l/s. In year 2004, Collazos (2004), cited by INGESAM, (2005), estimated a leachate production of 3,58 l/s through a model called *corenostos*, which is a model available in Navarro site to predict amount of leachate. Similarly, according to CVC (2004), a leachate flow of 7,6 l/s was estimated for a total production of 240000 m^3 in year 2004 From this 7,6 l/s, its was stated that 5 l/s are collected and stored in the leachate ponds and the remaining 2,7 l/s are discharged to “Madrevieja” which conveys them to the old stream of Líli river and to one of the collectors in Aguablanca district. From this 2,7 l/s, approximately 0,9 infiltrate to the surface aquifer in the area (Agudelo *et al.*, 2005).

In Navarro, there have been detected two types of leachate according to their stabilization degree: new leachate and old leachate. New leachate can be found in the ponds beside “Vasos 1, 2, 3 and C” whereas old leachate can be found in the big ponds or in the cleaning ponds. Although it is considered that the old leachate presents less polluting load than the new one, both are characterized by high COD loads, polluting ions such as metals, organic material and minerals and present strong odors and dark colors (CVC, 2004, cited by Agudelo *et al*. 2005). In addition, the Table 7.2. presents a characterization of leachate.

Table 7.2 Characterization of New and Old leachate in Navarro.

Parameter	Unit	Leachate type	
		New [a]	Old [b]
pH	Un.	6,64	8,5
Total Solids	mg/l	48020	13506
Total Suspended Solids	mg/l	1410	198
Total Dissolved Solids	mg/l	46610	13309
COD	mg O_2/l	62700	6269
Total Alkalinity	mg $CaCO_3$/l	-	665
Total hardness	mg $CaCO_3$/l	-	1700
Calcium hardness	mg $CaCO_3$/l	-	600
Magnesium hardness	mg $CaCO_3$/l	-	1100
Chloride	mg Cl^-/l	-	2147
Total Nitrogen	mg/l	1900,7	736
Ammoniac nitrogen	mg/l	955	578
Phenols	µg Phenol/l	-	321
Cyanide	µg CN^-/l	-	7,84
Mercury	µg/l	-	3,21
Cadmium	mg/l	-	< 0,04

Source: [a]Garzón & Vélez, 2005; [b]CVC, 2002, cited by Agudelo et al., 2005

During 1998 to 2002, under the management of the solid waste agency SERVIAMBIENTALES, a pilot leachate treatment plant was built. The plant included physical and biological treatment. However, nowadays the plant is out of operation due to lack of use and maintenance. Figure 7.8 shows the treatment units:

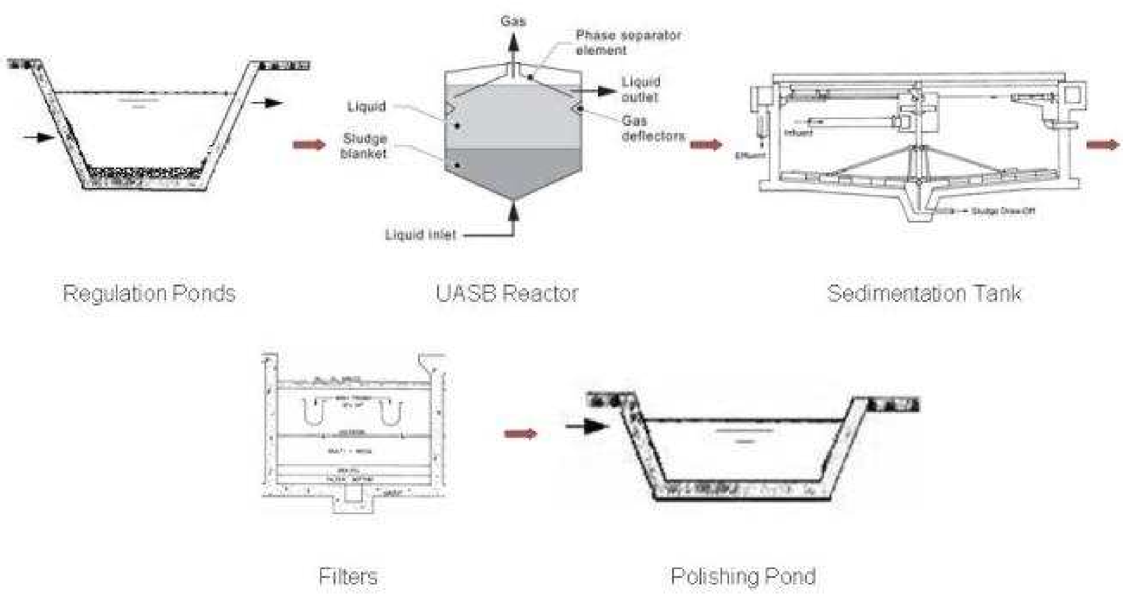

Figure 7.8 Pilot leachate treatment plant

Note: Sludge treatment consists of units for the drying of sludge.

In addition, during years 2001 and 2003 another treatment plant for the management of leachate was built. The plant operated through force evaporation with a flow of 3 l/s. However, due to high operation costs, the plant was stopped and currently is abandoned and out of operation. Nowadays,

there is no leachate treatment taking place in Navarro. CVC (2004) cited by INGESAM (2005) defined a trend in the leachate flow, which is summarized as follows:

- The underground flow was defined. Since the groundwater flow is slow with an average velocity of 1 to 4 cm/day, leachate contamination has not increased vertically but rather horizontally.
- Phreatic level depth in winter is 1 to 3 m.
- Phreatic level depth in summer is 2 to 4 m.
- Not saturated underground area is shallow and made of gravel, with exception of "Madrevieja" area which is made of sand and limes that enhances leachate infiltration.

7.6.6 Production and treatment of gases

INGESAM (2005) estimated the production of gas in Navarro during 2004. The model predicted a gas production of 180456 m^3/d, out of which 53% corresponded to CH_4 and the remaining 47% to CO_2. For the management of gases, there are chimneys installed in Navarro. These chimneys are cylinders of 1 meter diameter, built with metallic nets and filled with rocks. The number of chimneys is 6 per hectare. The installation of them starts on the bottom of the landfill and it is extended as long as the solid waste column increases. In this way, a constant gas evacuation is guaranteed before its combustion.

7.7 ENVIRONMENTAL IMPACTS

7.7.1 Regarding solid waste collection and transport

As it was mentioned in Chapter 5, Section 5.5, regarding solid waste collection and transport, the biggest problem in Cali is the inadequate disposal of solid waste all around the city. The inadequate disposal in channels, drains and structures of the sewerage system cause problems of floods, presence of vectors in the city and bad sanitation and hygiene environment.

The presence of solid waste and debris in the storm water channels and in the drainage structures is mainly caused by:

- Presence of slums which directly deposit their waste into the channels and the drainage systems.
- Unavailability of official debris disposal sites and solid waste transfer stations
- Lack of "city culture" and community spirit to care for their city
- Lack of knowledge and education from the community regarding the proper use of channels and drainage structures

As mentioned in Section 5.5.3 in year 2005 the complete storm water drainage system in Cali presented a total of 98 garbage sites and 65 debris sites for a total of 162 illegal solid waste disposal sites, known as chronic dumpsites. Moreover, the total amount of solid waste extracted from the channels and sewage structures in year 2006 reached approximately 155587 m^3, being the channels the most affected structures.

7.7.2 Regarding the final solid waste disposal site of Navarro

The main environment impact caused by the disposal site of Navarro is the leachate contamination in surface and underground waters. As it was mentioned in Chapter 5, Section 5.5.8, CVC (2004)

has recognized the ground water contamination by leachate, which reaches about two kilometers along the "Madrevieja" with a depth of 10 meters. Leachate contamination is also reflected in the presence of hazardous substances such as arsenic, cadmium, cyanide, copper, phenol compounds, chromium, mercury, silver, lead and selenium. As it was mentioned in Chapter 5, Section 5.5.8, a monitoring campaign carried out by INGESAM (2005) in ground and surface water, within the perimeter of Navarro disposal site, registered presence of these substances at which in comparison to decree 1594 (environmental norm in Colombia for the quality of the water for human consumption) were outside the permissible established values. For more detailed information refer to Section 5.5.8.

Furthermore, regarding surface water around Navarro site which is mainly composed by Cauca river, "Madrevieja" and South channel, such systems are in imminent danger of contamination through percolation of leachate or clandestine direct discharge to them. For instance, Newspaper El País in 2005, declared that leachate was being directly discharged to South channel trough a hose pump (see Figure 7.9). Moreover , according to El Pais in 2006, incidents such as the recent birth of six babies suffering from genetic mutations known as one-eye babies and mermaid babies has aroused more doubts about the effects of leachate contamination in surface waters. The latter due to the fact that the mothers of the babies were living in the influence zone of Navarro disposal site (Agudelo *et al.*, 2005).

Figure 7.9 Leachate discharge to south channel through a hose pump
Source: El Pais, 2005, cited by Agudelo *et al.*, 2005

7.8 PERSPECTIVES IN THE MANAGEMENT OF SOLID WASTE

- **Integrated Solid waste management plan PGIRS**

The city of Cali formulated in 2004 an Integrated Solid waste Management Plan (PGIRS) that looks to improve the current solid waste management towards and integrated management in the future. Its time spam is contemplated from 2004 to 2019. The plan was established by the Municipality of Cali with the support of the involved stakeholders (NGOs, EMSIRVA, DAGMA, CVC among others). Its main goals are: to minimize at source the generation of solid waste, to adequately treat and dispose the non-recovered waste and to maximize the reuse of waste when possible. In order to accomplish these goals, the plan proposes five lines of action:

i. City culture

ii. Cleaner production
iii. Valuation of organic and inorganic solid waste
iv. Good solid waste service quality
v. Appropriate final solid waste disposal.

Action line 1- City Culture

The main objective is to achieve a "sustainable solid waste culture" in the community. Such culture should emphasize reduction in the generation of solid waste, solid waste source separation, solid waste reuse at source and adequate disposal. The programs to achieve this objective consist in awareness raising campaigns targeted to all levels in the community and to strengthen the communal organizations that work towards conservation of the environment.

Table 7.3 shows the goals and indicators that will measure the achievements in action line1.

Table 7.3 Goals and indicators that will measure the effectiveness of Action line 1

Base Line	Targets to December, 2007	Indicator	Source of information
110 chronic dumpsites by December 31, 2003	To reduce the number of chronic dumpsites by 30%	Number of recovered sites	DAGMA EMSIRVA
53160 ton/month solid waste disposed in the final site in December 31, 2003	To reduce the amount of solid waste that arrives to the final disposal site by 30%	Amount of solid waste disposed in the site	EMSIRVA

Source: Municipio Santiago de Cali, 2004

Action line 2-Cleaner production

The main objective is to implement processes that use technologies that reduce environmental pollution and reduce stress on natural resources. The strategies to achieve this objective are: research for technologies to treat hazardous wastes, implementation of a plan for the management of hospital wastes, implementation of incentives towards implementation of cleaner technologies at industrial and commercial level, and implementation of a control plan for the management of debris. Table 7.4 shows the goals and indicators that will measure the achievements in action line 2.

Table 7.4 Goals and indicators that will measure the effectiveness of Action line 2

Base Line	Targets to December, 2007	Indicator	Source of information
There are not transfer sites or final disposal sites for debris, 2004.	Cali will count with transfer sites and legal disposal sites of debris.	Number of sites in place	DAGMA EMSIRVA E.S.P.
There is no waste source separation	10% of the debris will be recycled and reused	Number of implemented program	DAGMA EMSIRVA E.S.P. Municipal planning
To be defined	To increase by 50% the PGIRS practices at industrial and commercial level	Number of companies using PGIRS practices.	DAGMA Secretaría de Salud Pública Gremios

Source: Municipio Santiago de Cali, 2004

Action line 3- Valuation of organic and inorganic solid waste

The main objective is to incorporate the productive cycle of solid waste in Cali with participation of all involved parties: scavengers association, academic sector, public service companies. There will be recovery programs, source separation programs, transfer stations, promoting campaigns for

classification and characterization of waste and formal participation of scavengers. Table 7.5 shows the goals and indicators that will measure the achievements in action line 3.

Table 7.5 Goals and indicators that will measure the effectiveness of Action line 3

Base Line	Targets to December, 2007	Indicator	Source of information
No source separation	20% of the reused waste will be recovered	Number of recovered waste in tons.	EMSIRVA
Solid waste characterization year 1996.	Carry out a new characterization of the waste produced in Cali.	New characterization done	Municipal planning

Source: Municipio Santiago de Cali, 2004

Action line 4- Good solid waste service quality

The main objectives are to guarantee the continuity, quality and coverage of the delivery of solid waste service in an effective, economic way. In order to carry out this strategy there will be capacity building and strategy-strengthen programs for the involved institutions (solid waste company). In addition, the same type of programs will be targeted for scavengers groups. Table 7.6 shows the goals and indicators that will measure the achievements in action line 4.

Table 7.6 Goals and indicators that will measure the effectiveness of Action line 4

Base Line	Targets to December, 2007	Indicator	Source of information
40% of the roads in the city are cleaned, swept December 2003	Increase in 20% the service of road and public spaces clearing.	Kilometers of cleaned streets	EMSIRVA ESP
238 scavengers without formal status, July 2004.	40% of scavengers are formally organized	Number of scavengers formally recognized	Fomento Económico. Bienestar Social Feresurco
1960 official complains due to bad quality service, December 31, 2003	Reduce by 50% the number of complains.	Number of complains per year	EMSIRVA

Source: Municipio Santiago de Cali, 2004

Action line 5- Appropriate final solid waste disposal

The main objective of this line is to have an adequate solid waste final disposal site for the city of Cali. The line involves the research and studies on the most appropriate technologies for the final disposal.

The line includes also as target the closure of the site of Navarro and programs for the re-adaptation and re-location of the formal recycling groups working currently at Navarro. Table 7.7 shows the goals and indicators that will measure the achievements in action line 5.

Table 7.7 Goals and indicators that will measure the effectiveness of Action line 5

Base Line	Targets to December, 2007	Indicator	Source of information
Navarro site is under discussion to be closed	Navarro site has been officially closed.	System of monitoring and control post-closure	Emsirva CVC
Cali does not count with a defined final solid waste disposal site.	Cali count with an appropriate, official technical apt disposal site	Final disposal site working properly	Alcaldía Municipal

Source: Municipio Santiago de Cali, 2004

- **Accomplishment of the Action lines stated in the PGIRS**

To the date of November, 2007 and according to information provided by the Planning department of EMSIRVA and Education department of EMSIRVA (Personal Interview on November 28, 2007) the following targets are currently being achieved:

Action line 1- City Culture

EMSIRVA is carrying out awareness and education campaign as it was explained in Section 7.3.

Action line 2-Cleaner production

Hospital routes for the collection of hospital wastes are implemented following the appropriate technical standards as it was mentioned in Section 7.4.3.

Action line 3- Valuation of organic and inorganic solid waste

- PGIRS awareness campaigns to promote source separation and recycling are being implemented. The camping name is. *"Yo separo mis residuos, y tu?* Mainly promoted by the municipality with cooperation of other involved stakeholders.

- A new characterization of the domestic waste in the city of Cali was made in the year 2006 updating the characterization of year 1996.

Action line 4- Good solid waste service quality

- Coverage of the solid waste collection is 100% in the city of Cali.

- 85% of the roads in the city are swept and cleaned.

- There are 609 scavengers that are formally recognized and that belong to a formal cooperative group working in the disposal site of Navarro.

Action line 5- Appropriate final solid waste disposal

- By January 31, 2008 the disposal site of Navarro must be officially closed.

- Currently, the most likely place to establish the technical landfill for the city of Cali is the Municipality of Yotoco (see Figure 7.10). However, the final decision regarding the type of disposal site and location is currently being made.

Figure 7.10 Location of the new disposal site or the city of Cali.

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Sustainable Water Improves Tomorrow's Cities' Health SWITCH Project

Urban Water Management for the City of Cali
Diagnosis report

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8. Future Urban Expansion Areas in Cali

February, 2008

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8 FUTURE URBAN EXPANSION AREAS IN CALI

8.1 GENERAL OVERVIEW

The future urban expansion area in Cali would be located to the south of the city and it is composed by the sectors named: Corredor Cali – Jamundí and Navarro (see Figure 8.1). According to the Municipal planning department, currently, there is only a established road network already approved by the Municipality for the Cali-Jamundí –Sector (Refer to Figure A8.1-1 in Annex for the detailed map). Regarding the type of urban developments in this area, there is not a general urbanization proposal for either sector. However, in the sector of Cali-Jamundí, individual urbanization proposals are being studied by the Planning Department. These individual proposals are mainly requested by construction companies which have already bought land in the sector and that are looking to develop their own areas.

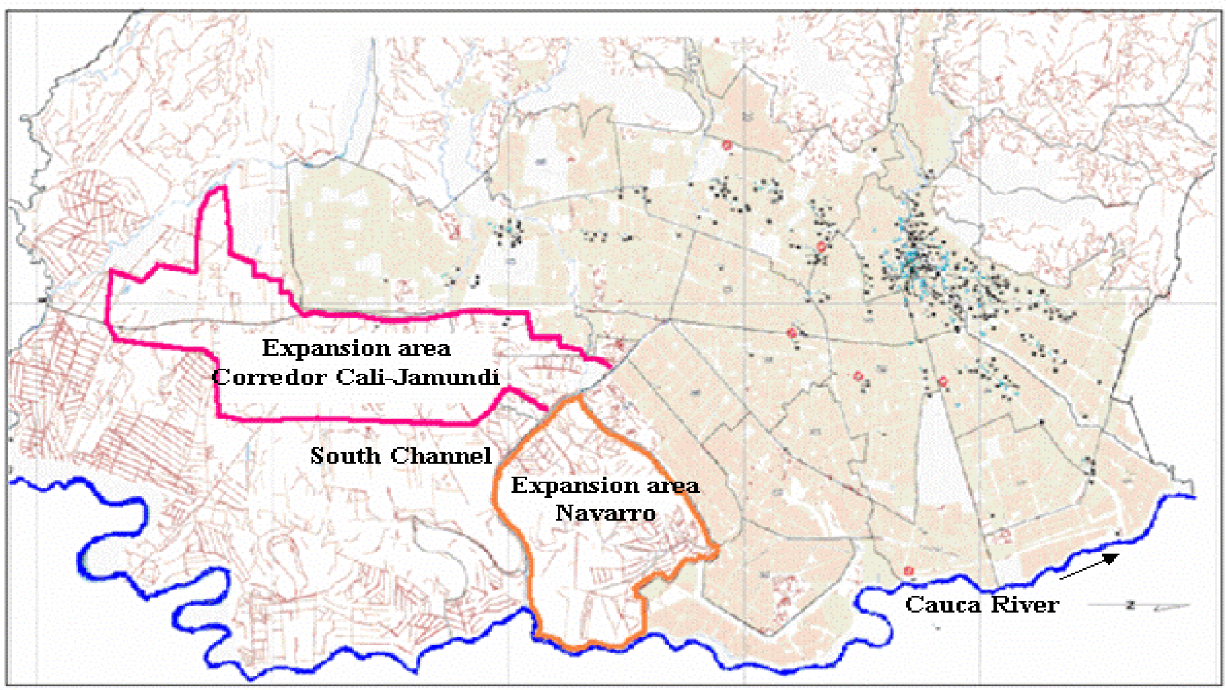

Figure 8.1 Current and future area distribution in the city of Cali
Source: Municipio de Cali, 1998.

Moreover, both sectors: Cali-Jamundí and Navarro would be developed and classified according to the economical status of their inhabitants using the figure of “estratos”. 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. In this regard, Navarro sector is meant to be for estratos 1 and 2 and Cali-Jamundí for estratos 3, 4, 5 and 6.

Following, a description of each expansion sector is made with their respective proposed strategies regarding water supply, sewerage systems and wastewater treatment based on studies carried out by EMCALI and private consultancy firms.

8.2 CALI-JAMUNDÍ SECTOR

8.2.1 General Characteristics

The future urban expansion area defined in the POT (Land ordering plan) as Cali-Jamundí is located to the south of the city and it is formed by 1652,85 hectares. Its topography is uniform with a slight descent slope to Cauca river (see Figure 8.1). Currently, this area is mostly used for agriculture purposes.

According to the Municipal Planning Department, currently, there are two approved urbanization developments (partial urbanization plans) in the sector Cali-Jamundí called *Plan parcial Melendez and Plan parcial Las vegas-Comfandi* (Refer to location map in Figure A8.1-2, Annex). As it can be seen in the map, there are other proposed urbanization developments which have not been yet approved by the municipality and are still under review and consideration.

Moreover, the only available information until now regarding delivery of drinking water and sanitation services in this expansion sector is the feasibility studies undertaken by EMCALI. EMCALI in 2005 hired the consultancy firm Hidrooccidente to make the feasibility studies for the delivery of such services. Therefore, all the information described in the section Cali-Jamundí corresponds to the study carried out by EMCALI-Hidrooccidente (2006).

8.2.2 Drinking water supply

8.2.2.1 Population density and drinking water supply

There are not norms or legislation that regulate the sector of Cali-Jamundí sector regarding the type of infrastructure, dwellings and urbanization layouts. The gross area of this area is of 1654 ha. Table 8.1 shows the net area of the Cali-Jamundí sector which would receive drinking water and sanitation services and which is divided according to estratos as mentioned before. The distribution of population density proposed in this study (which also follows POT guide lines) are shown in Table 8.2. In this study, year 2030 was taken as the projected year.

Table 8.1 Expansion area “Corredor Cali-Jamundí” Estimated drinking water demand in year 2030

Estrato	Area (ha)	Demand (l/per/ha)
3	305	275
4	528	417
5	490	354
6	35	21
Total	1358*	1067

Source: EMCALI-Hidroocidente, 2005
*Note: The total area calculated in the Table does not include 122 ha from estrato 6 which has been already considered in the Project drinking water supply, Upgrade of the pumping system of High Pance, carried out by Unión Temporal Cali (2004).

Table 8.2 Proposed drinking water demand and population density in the area Cali-Jamundí

Year	Gross demand (per/ha)				Gross demand (l/per/ha)			
	Estrato 3	Estrato 4	Estrato 5	Estrato 6	Estrato 3	Estrato 4	Estrato 5	Estrato 6
2010	87	69	56	33	218	240	273	371
2015	134	107	86	52	209	230	261	356
2020	216	172	139	83	206	226	257	350
2025	303	241	194	117	203	224	254	346
2030	390	310	250	150	200	220	250	340

Source EMCALI-Hidrooccidente, 2006

8.2.2.2 Proposed alternative

Based on Table 8.1, when the expansion sector Cali-Jamundí would be totally developed, its full water demand would be 1067 l/s. From a previous study called "*Prolongación de la Tubería de Transmisión Oriental-TTO*" or "prolongation of the Oriental transmission pipe TTO" by INGESAM, it was already defined that the TTO would supply the Cali Jamundí sector with a flow of 510 l/s.

Based on these previous conditions, Hidrooccidente proposed the following as the drinking water supply strategy in the sector; also Figure 8.2 shows the layout of the proposed strategy:

- The main objective was to supply the expansion area through pumping from Puerto Mallarino and Rio Cauca drinking water plants, so in place technology was used.
- Prolongation of the TTS line trough Calle 25 until Carrera 115
- Prolongation of TTO through Calle 53 until Carrera 122
- Construction of a linking structure between TTO and TTS in Carrera 109
- Supply of water by gravity the south area in the Cali-Jamundí sector which is equivalent to an average flow of 538,95 l/s.
- Supply of water by pumping the tanks in the south area (Cra 127 and Cra 118) which is equivalent to 528,07 l/s

Table 8.3 shows a summary of the proposed water supply strategy in the Sector Cali-Jamundí.

Table 8.3 Proposed drinking water supply area distribution in expansion sector Cali-Jamundí

Area (ha)	Estrato	Supply (l/inhab.d)	Density (inhab/ha)	Demand (l/s)	Zone
77,08	5	250	250	55,76	Direct pumping from Puerto. Mallarino & Río Cauca plants
94,46	4	220	310	74,56	
82,77	4	220	310	65,33	
50,76	4	220	310	40,07	
166,81	5	250	250	120,67	Pumping Carrera. 118
245,27	4 and 3	220 and 200	310 and 390	186,40	
317,56	4 and 3	220 and 200	310 and 390	303,21	Direct pumping from Puerto. Mallarino & Río Cauca plants
33,81	6	340	150	19,96	Pumping Carrera. 127
289,48	5, 4 and 3	250, 220 and 200	250, 310 and 390	201,06	

Source: EMCALI-Hidrooccidente, 2006

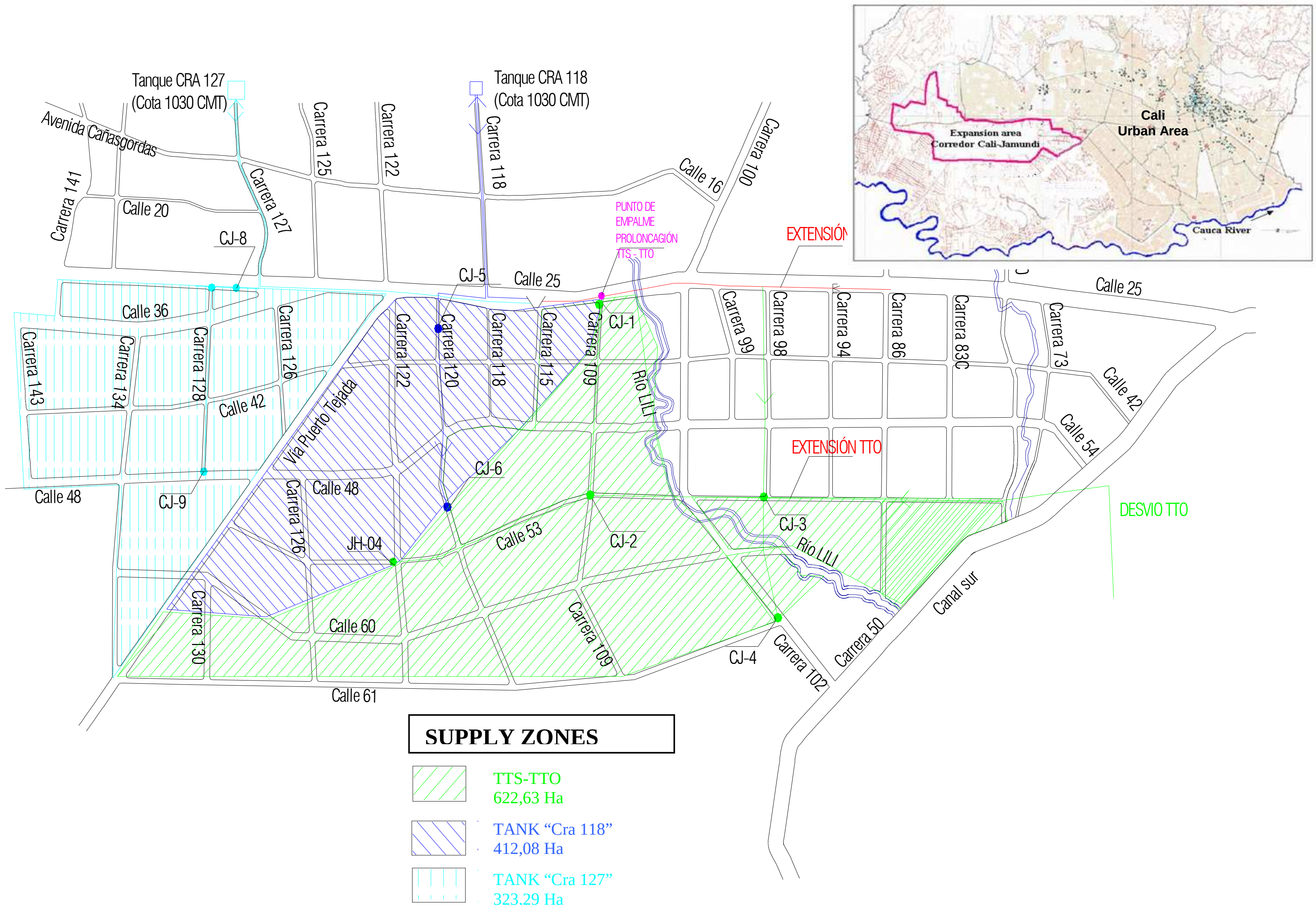

Figure 8.2 Proposed drinking water layout and supply zones in the sector Cali- EMCALI-Hidrooccidente
Source: EMCALI-Hidrooccidente, 2006

8.2.3 Sewerage system

8.2.3.1 Wastewater characteristics

The production of wastewater per person was estimated using a return coefficient of 0,80 applied to the drinking water demand. Table 8.4 shows the estimated wastewater production during the period 2010-2030.

Table 8.4 Wastewater production period 2010- 2030

Year	Wastewater production (l/per/day)			
	Estrato 3	Estrato 4	Estrato 5	Estrato 6
2010	174	192	218	297
2015	167	184	209	285
2020	165	181	206	280
2025	162	179	203	277
2030	160	176	200	272

Source. EMCALI-Hidrooccidente, 2006.

Likewise, the BOD and SST concentrations of the wastewater in this area were estimated as 157 mg/l and 113 mg/l respectively. These concentrations represent the typical domestic wastewater concentrations in Cali based on measurements registered in the Collector Margen Izquierda (EMCALI, 2007).

Design Flows

Apart from the wastewater flows estimated in Table 8.4, the following flows were also taken into account in the design of the sewerage system:

- For options that considered separate sewerage systems, an additional wastewater flow of 0,1 l/s.ha that considers illegal storm water connections was included.
- Superficial Infiltration flow in the collectors joins of 0,115 l/s.ha was also considered.

8.2.3.2 Proposed alternatives

- The draining of the wastewater produced in the area of Cali-Jamundí, whether combined or separate system, would be done using secondary collectors which would be placed in the future roads located in East-West direction. The principal collectors would be placed in the roads located in South-North direction which would convey wastewater to the proposed WWTP-Sur which could be located in front of the current solid waste disposal site of Navarro along the left side of South channel.
- Cali-Jamundí area was divided in four drainage sectors according to the sewerage system. Such sectors were named Sector 1, 1A, 2 and 3 (See Figure 8.3).

The different sewerage alternatives proposed by Hidrooccidente are summarized in Table 8.5.

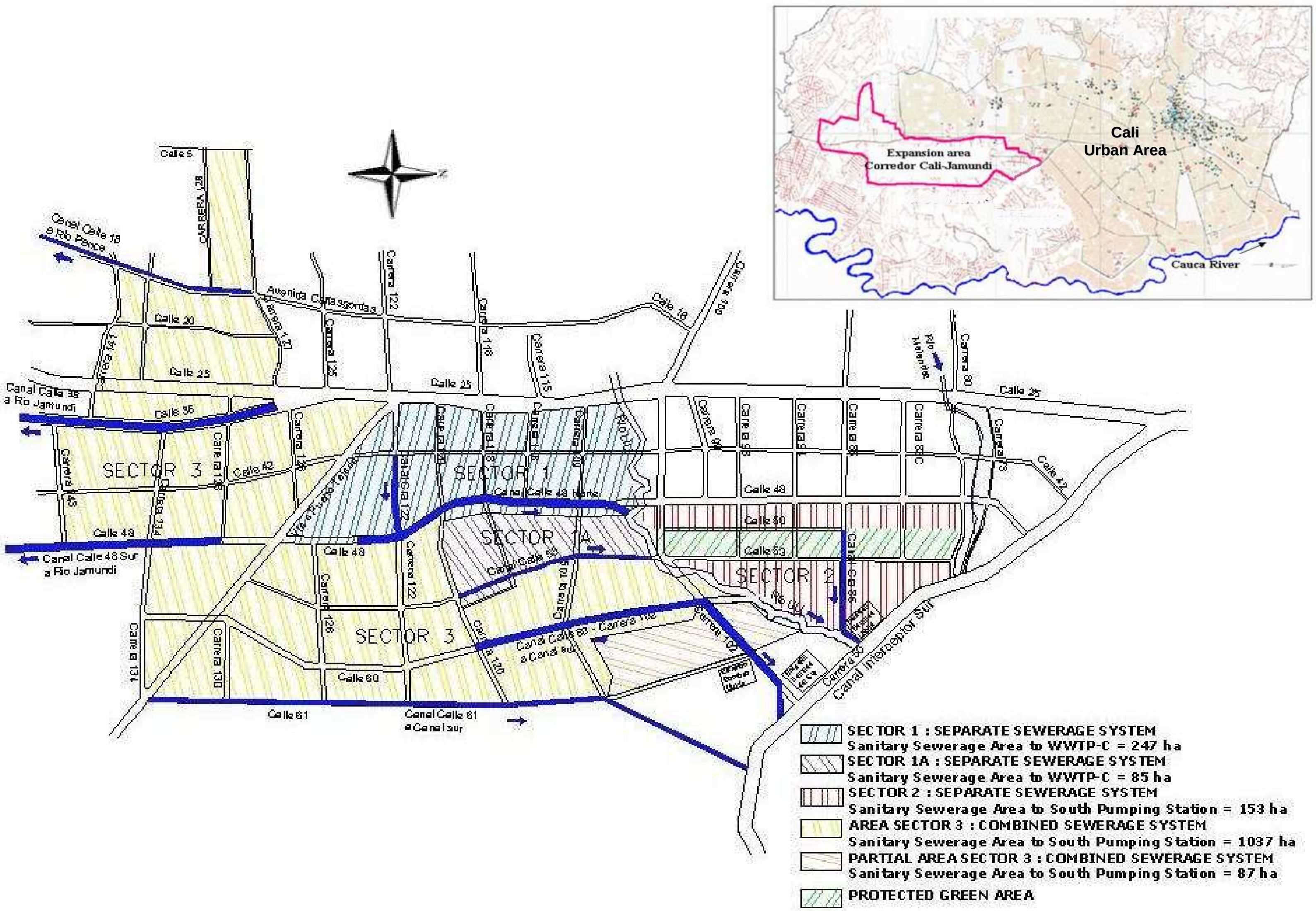

Figure 8.3 Proposed drainage Sectors in the are Cali-Jamundí.
Source: EMCALI-Hidrooccidente, 2006

Table 8.5 Summary of proposed sewerage system alternatives. Expansion Area: Cali, Jamundí

Alternative 1 Separate system	Alternative 2 Combined system	Alternative 3 Separate and combined system	Alternative 4 Separate and combined system
Waste water – Sectors 1, 1A (332 ha) drain by gravity a flow of Q=427 l/s to WWTP-C via Pance collector. – Sectors 2 and 3 drain by gravity to the future Sur pumping station (Q=1034 m^3/s). See Map in Annex , Figure A8.2-1	– Sectors 1, 1A (332 ha) drain by gravity a flow of Q=427 l/s to WWTP-C via Pance collector. – Construction of pumping station in calle 48 with carrera 102 to drain wastewater coming from zone 1 to WWTP-C. – Sectors 2 and 3 drain by gravity to the future Sur pumping station (Q=1034 m^3/s). See Map in Annex , Figure A8.2-2	*Separate system Wastewater:* – Sectors 1, 1A (332 ha) drain by gravity a flow of Q=427 l/s to WWTP-C via Pance collector. – Sector 2 drains by gravity to the future Sur pumping station (Q=1034 m^3/s). *Separate system Storm water:* – Sectors 2 must be pumped to South channel (Q=5,7 m^3/s), as well as part of sector 3 which would be pumped to the channel located in Calle 60-Carrera 102 (Q=5.1 m^3/s). See Map in Annex , Figure A8.2-3	*Separate system Wastewater:* – Sectors 2 and 3 are under flood risk so they have separate system, draining wastewater to future Sur pumping station *Separate system Storm water:* – Sector 2 drains stormwater by gravity to Líli, Pance and Jamundí rivers. The remaining part of zone 2 drains to South channel – Sector 3 drains store water by gravity to the channel located in Calle 60-Carrera 86. – See Map in Annex , Figure A8.2-4
Storm water – Sectors 1, 1A, 3 and part of 2 drain by gravity to Líli, Pance and Jamundí rivers. The remaining part of zone 2 drains to South channel – Construction of pumping station with capacity 5.7 m^3/s to drain 90 ha from zone 2. – Modeling simulations shown that Líli river has to undergo a hydraulic improvement to be able to transport storm water	*Storm water* – Sector 2 is pumped to South channel (Q=8 m^3/s), as well as 87 ha from zone 3 which would be pumped to the channel located in Calle 60-Carrera 102 (Q=5.1 m^3/s). . – Sectors 1, 1A and a big part of zone 3 drain to Líli, Pance Jamundí rivers and South channel.	*Combined sewerage* – Sector 3 is design solely as combined system which drains to the collector which arrives to future Sur pumping station	*Combined sewerage* – Sector 1 drains the combined wastewater to Pance collector until WWTP-C.

Source: Adapted from EMCALI-Hidrooccidente, 2006

8.2.3.3 Selected alternative

In its final recommendations, the firm Hidrooccidente stated the following:

- The most appropriate option should include separate sewerage system in sectors 1 and 1A which would drain by gravity their wastewater to the WWTP-C to take advantage of its total capacity.
- Sector 2 presents risk of flooding. If the system is separate there is the need of pumping 47% of the rainwater that falls in the drainage area and if the system is combined 100% of the rain water needs to be pumped. Therefore it is suggested the implementation of a separate system in that sector.
- Sector 3 presents 87 ha which are under flood risk as well (nearby Sur wastewater pumping station). Hence a separate system must be implemented in this sector as well.

8.2.4 Wastewater Treatment

8.2.4.1 Proposed alternatives

The selected alternatives proposed by EMCALI-Hidrooccidente (2006) for the treatment of the wastewater generated in the area Corredor Cali- Jamundí were:

Alternative 1: Pumping to WWTP-C

Alternative 2: Conventional activated sludge system

Alternative 3: UASB system plus low rate activated sludge system

Alternative 4: UASB system plus aerated lagoons

The alternatives 2, 3 and 4 refer to the proposed wastewater treatment plant in the sector Cali-Jamundí called WWTP-Sur.

The influent wastewater to the WWTP-C in year 2030 was estimated to be 7,28 m^3/s which made feasible to consider alternative 1.

According to the terms of reference of this project, for the treated effluent form WWTP-Sur there are the following available options to take into account. The location of the WWTP-Sur is shown in Figure 8.4.

1. Pumping to the channel located in street 48 during summer season and to South channel in winter
2. Total or partial discharge to
3. Use as waster source for irrigation in summer season and discharge to south channel in winter.
4. Tertiary treatment and disinfection before discharging it to South channel
5. Combination of the latter
6. Other options

Furthermore, the level of treatment of the alternatives 2, 3 and 4 was considered the same since the same BOD and TSS removal efficiencies were expected. In addition, the denitrification of the effluent via addition of ferric chloride and disinfection with UV light before discharge to South channel was also contemplated. Table 8.6 shows the summary of the proposed wastewater alternatives.

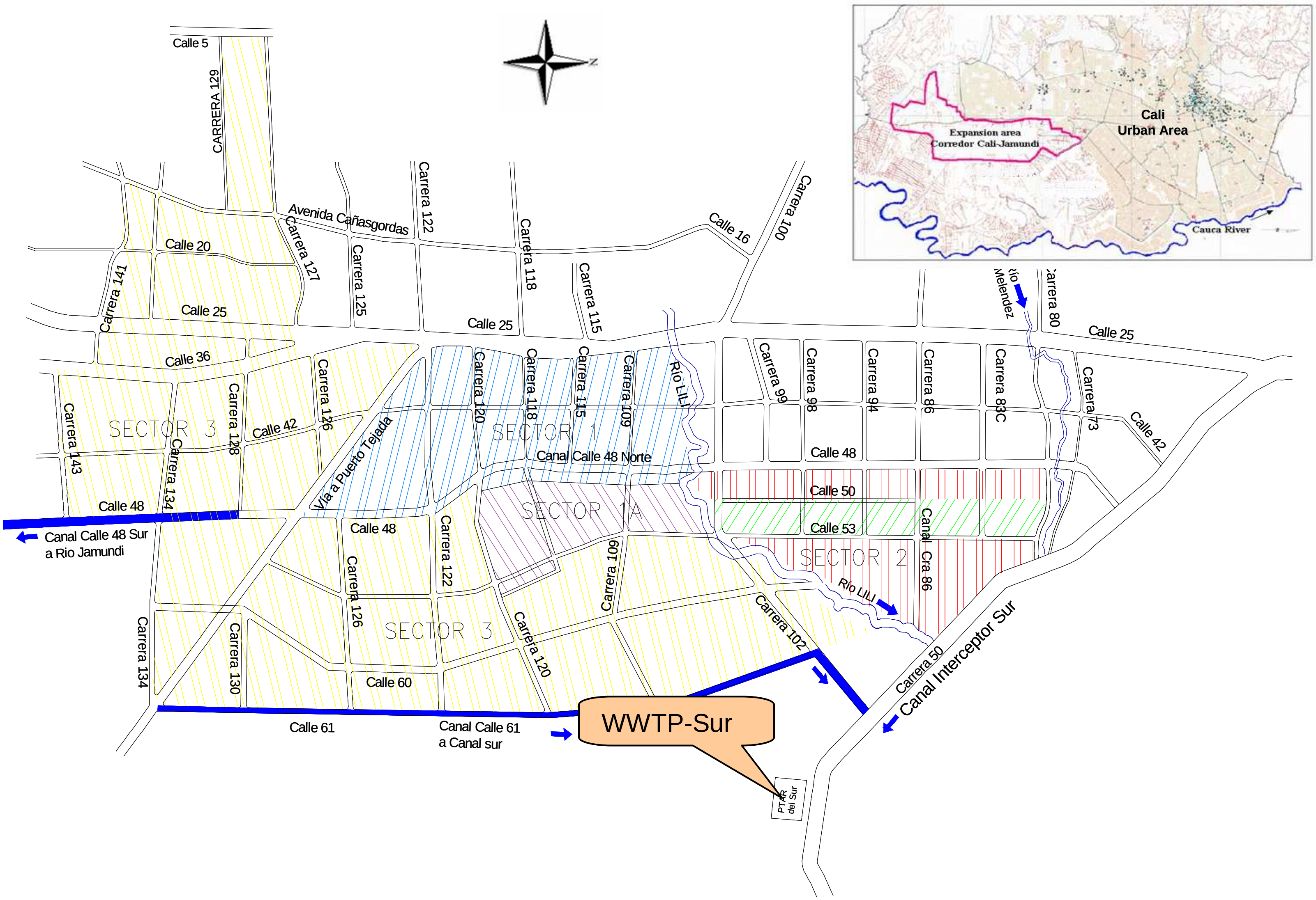

Figure 8.4 Location of WWTP-Sur.
Source: EMCALI-Hidrooccidente 2006

Table 8.6 Proposed wastewater treatment alternatives in Cali-Jamundí area

Alternative	Alternative No 1. Pumping to WWTP-C	Alternative No 2. Activated sludge*	Alternative No 3 UASB + show rate activated sludge*	Alternative No 4 UASB + aerated ponds*
General description	– Construction of pumping station in front of Navarro disposal site to transport wastewater (WW) generated in Cali-Jamundí sector to existing Navarro pumping station – From Navarro station WW is pumped to WWTP. – An independent boost pipe is projected to convey the WW generated in the city to WWTP-C – WWTP-C in year 2030 is able to treat 7,28 m^3/s	– WW generated in Cali-Jamundí are conveyed to WWTP-Sur, in front of current Navarro disposal site – Due to the elevation levels of the sanitary collectors , a screw-type pumping station needs to be built (1470 l/s)	– Same as alternative 2	– Same as alternative 2
Components	N/A	– 1 Screw-type pumping station – 3 fine screen channels – 3 aerated grit chambers – 2 primary settling tanks – 4 aeration tanks – (Q=1061 m^3/s) – 2 Secondary settling tanks – Denitrification with ferric chloride – 2 sludge digesters – 2 sludge storage tanks – 2 Filters press	– 1 Screw-type pumping station – 3 fine screen channels – 3 aerated grit chambers – 6 UASB – 8 aeration tanks – 8 Secondary settling tanks – Denitrification with ferric chloride – 6 anaerobic sludge storage tanks – 5 Filters press	– 1 Screw-type pumping station – 3 fine screen channels – 3 aerated grit chambers – 6 UASB – 3 aerated ponds and 1 anoxic pond (Phase I) – 3 Settling ponds – 3 aerated ponds and 1 anoxic pond (Phase II) – 3 Settling ponds – 2 anaerobic sludge storage tanks – 2 Filters press

Source Adapted from EMCALI-Hidrooccidente, 2006
*Design flow of the systems (Q) =1,061 m^3/s.

Table 8.7 shows the design characteristics of the different components of the proposed wastewater treatment systems

Table 8.7 Characteristics of the main components of the treatment units

Component	Characteristics
Fine screens channel	System of transport strips
	Waste chute (spacing 0,6 inches)
	Number of units: 3
Aerated grit chambers	Air diffusers, ejection pump, screw sand collector, (Length 11,8, width 3,6m)
	Retention time: 3 minutes
	Total area: 178 m^2
	Number of units: 3
UASB	Retention time: 6,5 hours
	Useful Height: 4,5 m; total: height 7,0 m
	Length: 38 m
	Width per unity: 25 m
	Area: 6840 m^2
	Number of units: 6
Sludge tank	Retention time: 5 days
	Useful Height: 4,5m
	Diameter 7 m
	Area: 16,8 m^2
	Number of units: 2
Filter press	Capacity: 6,8 m^3/h
	Operation time: 8 Hours
	Number of units: 2
Aerated and anoxic pond	Useful depth: 3,5m
	Width: 59 m
	Length: 177 m
	Volume: 109068 m^3
	Number of units: 3
Settling pond	Useful depth: 3,5m
	Width: 59 m
	Length: 74 m
	Volume: 45.827 m^3
	Number of units: 3

Source Adapted from EMCALI-Hidrooccidente, 2006

8.2.4.2 Technology Selection

The process of selection of the most appropriate technology was based on a technical, economical, and environmental assessment.

Technical assessment

Table 8.8 describes the parameters considered in the technical evaluation of the proposed wastewater treatment technologies.

Table 8.8 Technical evaluation of technologies.in Cali-Jamundí area

Infrastructure	Advantages	Observations
Screw-type pumping station	Required in alternatives 2, 3 and 4. It keeps the same design characteristics in all alternatives	
Pumping station to Navarro pumping station	It is required in alternative 1. The pump type would be centrifuge.	
Navarro pumping station	Current infrastructure is used	
WWTP-Sur	– It allows the exclusive treatment of wastewater produced Cali-Jamundí sector – The different alternatives foreseen three type of technologies: o Alternative 2 Conventional activated sludge system o Alternative 3 UASB system plus low rate activated sludge system o Alternative 4 UASB system plus aerated lagoons	– High phreatic levels in the sector made compulsory the use of piles as foundation structures and to raise the land level for the implementation of the slopes of the ponds – The final effluent disposal alternatives fore sought are in summary: discharge to wetlands and discharge to south channel. Such alternatives are not favorable since either way suggest the wastewater discharge upstream the water intake of Puerto Mallarino.
WWTP-C	Current infrastructure is used. In addition, only an investment in the upgrade of the plant to secondary treatment is estimated	

Source Adapted from EMCALI-Hidrooccidente, 2006

Economical assessment

The economical assessment was based on the investments costs, operational and maintenance costs of the components of the different proposed alternatives. Table 8.9 shows the description of the components based on the economical assessment. For the purposes of this report, it was not considered the need to include money value of each component, but rather the final considerations of the report. Therefore, after economically analyzing each alternative, Hidrooccidente suggested that the least costly alternative was alternative 1, followed by alternative 4. Alternatives 2 and 3 were the most expensive ones.

Environmental assessment

The critical points to analyze each alternative from the environmental point of view were (EMCALI-Hidrooccidente, 2006):

- To avoid increasing the pollution to South channel known also as Navarro channel
- The WWTP-Sur may strengthen the current characteristic of the sector as a sanitary polygon based on the presence of south channel and Navarro solid waste disposal site
- The WWTP-Sur causes devaluation of the surrounding terrains
- Using WWTP-C ensures the use of infrastructure already in place which currently is being underused

Table 8.9 Economic assessment of the wastewater treatment alternatives in the sector Cali-Jamundí

Costs	Alternative No 1. Pumping to WWTP-C	Alternative No 2. Activated sludge	Alternative No 3 UASB + show rate activated sludge	Alternative No 4 UASB + aerated ponds
Investment costs	– Pumping station (PS)to puma water to Navarro pumping station (PS1) – Replacement of pumping equipment in PS1 – Boost pipe line from PS1 to WWTP-C – Secondary treatment in WWTP-C (flow from expansion area). – Replacement equipment in WWTP-C – Secondary thickener WWTP-C (flow from expansion area).	– WWTP-Sur construction – Construction pumping station entrance to WWTP-Sur – Replacement of pumping equipment in WWTP-Sur – Replacement equipment in WWTP-Sur	– WWTP-Sur construction – Construction pumping station entrance to WWTP-Sur – Replacement of pumping equipment in WWTP-Sur – Replacement equipment in WWTP-Sur	– WWTP-Sur construction – Construction pumping station entrance to WWTP-Sur – Replacement of pumping equipment in WWTP-Sur – Replacement equipment in WWTP-Sur
Operation and maintenance costs	– Energy PS – Energy PS1 – Operation and maintenance WWTP-C – Maintenance boost pipe line from PS1 to WWTP-C	– Operation and maintenance WWTP-Sur – Energy pumping station entrance to WWTP-Sur	– Operation and maintenance WWTP-Sur – Energy pumping station entrance to WWTP-Sur	– Operation and maintenance WWTP-Sur – Energy pumping station entrance to WWTP-Sur

Source Adapted from EMCALI-Hidrooccidente, 2006

- Using WWTP-C is more advantageous since the technology is already known
- UASB technology is a non proved technology since its real efficiencies are still under discussion. Additionally, there are no UASB technologies with similar size as the WWTP-Sur would be so there is no option for comparison.
- It is not advisable that EMCALI uses its resources in the implementation of not proved technologies, even more, when there are conventional technologies which have been tested and proved worldwide. Furthermore, EMCALI has experience in the design and operations of conventional plants as WWTP-C.
- UASB alternative is an uncertain investment for EMCALI, which is not compatible with the type of urban development wanted for the area which in addition causes high environmental impacts.

8.2.4.3 Selected technology

Based on the assessment described above, Hidrooccidente recommended the alternative 1 as the most appropriate technology in the expansion area Cali- Jamundí.

8.3 NAVARRO SECTOR

8.3.1 General characteristics

According to the POT, the area defined as “regimen diferido Navarro” is not directly included within the established areas for future urban development. However, the POT states that the area may be used in a future as an urban development sector provided that urbanization and environmental studies say so. Currently, the municipality of Cali has selected this area as urban development for the “estratos” 1 and 2 (Gandini & Orozco, 2006). This zone is located to the south of the city in the area called Navarro (see Figure 8.1). It boundaries to the north is the urban perimeter, to the south is the South channel, to the east is the protected green belt and to the west is the polygon that defines the environmental protected area around Cauca river. The soils in the sector area characterized by low hardness with a high level of liquefaction and high degree of enlargement of the seismic waves. Navarro sector is established to be under risk of floods by storm water or overflow of south channel and Cauca river. In this area, the solid waste disposal site of Navarro is located. The total area of the Navarro sector is 823,74 hectares, from which 615,52 ha are designed to be urbanized and 196,6 ha correspond to the so called “ejidos municipales” which mean areas of communal property. The soils in the sector are adapted for agriculture and cattle breeding, being the main crops the re sugar cane one.

For the implementation of water supply and sewerage systems in this sector, EMCALI hired the consultancy firm Gandini and Orozco to make the feasibility studies for the delivery of such services. Therefore, all the information described in the sector of Navarro corresponds to the study carried out by Gandini and Orozco (2006). It is important to highlight that in the study, Gandini and Orozco point out the lack of a defined urbanization scheme by the Municipal planning department. Consequently, the consultancy firm proposed a road layout to locate the water supply and sewerage pipes.

8.3.2 Drinking water supply

8.3.2.1 Population density and drinking water supply

For the estimation of the population growth, the firm estimated a growth that is defined in Table 8.10. The saturation density of 500 inhab/ha was based on the population growth estimated in the POT in estratos 1 and 2 in the current city (486 to 507 inhab/ha) arriving finally to a saturation population of 307760 inhabitants.

Table 8.10 Estimated population growth in the Sector of Navarro

Year	Population in Navarro (inhab)	
	Increment	Population
	Annual	Total
2010	12000	12000
2020	6000	96000
2025	6000	126000
2030	6000	156000

Source: Gandini & Orozco, 2006

The base average water consumption was 140 l/inhab/day which corresponds to the monthly average consumption in estratos 1 and 2 in the current city of Cali in year 2005. The non-domestic consumption was estimated as 3% of the total consumption. The water losses were estimated as 25% of the total. The projected water demands are shown in Table 8.11.

Table 8.11 Drinking water demand in the Sector of Navarro.

Year	Total population	Total demand	
		l/s	m^3/year
2010	12000	25,0	779
2020	96000	200,46	6235
2030	156000	325,74	10131

Source: Adapted from: Gandini & Orozco, 2006

For the study of the drinking water and sewerage systems alternatives, the sector of Navarro was divided in North sector (389,7 ha) and south sector (423,5 ha). For purposes of the study it was assumed that the total estimated population in year 2030 would be located in the north sector.

8.3.2.2 Proposed alternative

Table 8.12 shows the design criteria used in the proposal of the drinking water supply alternatives. Furthermore, Table 8.13 shows a summary of the proposed drinking water supply alternatives in the Navarro expansion sector. Annex A8.3 shows the respective layouts schemes for each alternative.

Table 8.12 Design criteria for the proposed in drinking water supply alternatives

Supply with losses of 25%	187 l/inhab.d
Maximum daily consumption factor	1,20
Maximum hourly consumption factor	1,50
Hourly maximum flow	1200 l/s
Average flow	666 l/s
Daily maximum flow	800l/s

Source: Adapted from: Gandini & Orozco, 2006

Table 8.13 Summary of proposed drinking water alternatives

<table>
<tr><th>Alternative</th><th>Description</th></tr>
<tr><td rowspan="2">1. TTNV (Navarro transmission pipe) with direct supply from Puerto Mallarino plant.
Refer to Figure A8.3-1 in Annex</td><td>Parallel to TTO line. It is feed by Puerto Mallarino plant</td></tr>
<tr><td>This alternative causes high energy costs due to pumping through long distances from Puerto Mallarino until Navarro sector</td></tr>
<tr><td rowspan="3">2. Autonomous system
Refer to Figure A8.3-2 in Annex</td><td>New drinking water plant located in Navarro sector using Cauca river as water source upstream South channel.</td></tr>
<tr><td>The drinking plant would be composed by , grit removal chambers, settling tanks, rapid filters and chlorination.</td></tr>
<tr><td>The sector of Navarro would be supplied through pumping.</td></tr>
<tr><td rowspan="2">3. Construction of 4 wells located along drinking water network. Wells' depths would be more than 400 meters.
Refer to Figure A8.3-3 in Annex</td><td>Each well would have its own water treatment system and pumping system.
The hydraulic capacity of each well would be 200 l/s</td></tr>
<tr><td>The water treatment would consist of: biological reactor, aeration, rapid filters and chlorination</td></tr>
</table>

Source: Adapted from: Gandini & Orozco, 2006

8.3.3 Sewerage system

8.3.3.1 Wastewater characteristics

The return flow was established as 0,85 from the drinking water consumption. The design flow for the pre-design of the sewerage network was assumed at 1,5 l/s. The storm water flows were estimated using the model EPA-SWMM-V-5.0. The following were the considered parameters for the proposed design of the sewerage systems:

- Average WW Q = 423,52 l/s
- Infiltration Q = 110-7 l/s
- Illegal connections Q = 61,50 l/s
- Maximum hourly WW Q = 669,48 l/s
- Rain Q = 46288,65 l/s

8.3.3.2 Proposed alternatives

The proposed alternatives for the sewerage networks were classified as separate and combined sewerage systems varying the materials of the transport pipes from PVC to concrete. In overall the alternatives were classified according to Table 8.14.

Table 8.14 Alternative proposed scenarios for the sewerage systems in the Navarro sector

Alternative	Scenarios
Alternative 1: Separate sewer system	*Sanitary sewers* 1A. PVC network pipes, pumping to Aguablanca Pumping Station (ABPS),WWTP-C and discharge to Cauca river. 1C. PVC network pipes, pumping to proposed WWTP-Navarro and pumping to Cauca river. 1B. Concrete network pipes, pumping to ABPS, transport to WWTP-C and discharge to Cauca river. 1D. Concrete network pipes, pumping to proposed WWTP-Navarro and pumping to Cauca river. *Storm water* In all scenarios storm water will be convey to Cauca river.
Alternative 2: Combined sewer system	2A. Combined network pipes, pumping to ABPS, WWTP-C and discharge to Cauca river. 2B. Combined network pipes, pumping to proposed WWTP-Navarro and pumping to Cauca river. For both alternatives the use of CSOs in contemplated with transport of excess rain water via open channels and their direct discharge to Cauca river. 3A. Combined network pipes, pumping to ABPS, WWTP-C and discharge to Cauca river. 3B. Combined network pipes, pumping to proposed WWTP-Navarro and pumping to Cauca river. For both alternatives the use of CSOs in contemplated with transport of excess rain water via closed pipes and their direct discharge to Cauca river.

Source: Adapted from: Gandini & Orozco, 2006

8.3.3.3 Selected alternative

The consultancy firm left the decision of the preferred alternative to EMCALI.

8.3.4 Wastewater treatment

8.3.4.1 Proposed alternatives

There where different proposed systems for the treatment of wastewater in the sector of Navarro. The design criteria were determined using year 2030 as the projected year. The design parameters are the following:

- COD=380 mg/l
- BOD=200 mg/l
- TSS=200 mg/l
- Inhabitants=156000
- Return coefficient 0,85
- Drinking water supply = 140 l/inhab/day
- Maximum Flow = 540 l/s
- Average Flow = 300 l/s

The following was proposed for the wastewater treatment in the Navarro area:

- A new WWTP in the area of Navarro
- Transport of the Navarro wastewater to Aguablanca pumping station and afterwards to WWTP-C

The selected alternatives proposed by Gandini & Orozco, (2006) for the treatment of the wastewater generated in the Navarro area were:

Alternative 1 UASB + aerated ponds + high rate settling (WWTP-Navarro)

Alternative 2 UASB + percolation filter + secondary settling tank (WWTP-Navarro)

Alternative 3 Conveying and pumping to WWTP-C

Figure 8.5 shows the suggested location of the proposed WWTP-Navarro. In addition, the estimated design parameters and components of the systems are defined in Table 8.15. The pretreatment for alternatives 1 and 2 was defined the same.

8.3.4.2 Selected alternatives

The study made use of an economical assessment in order to classify the technologies according to their investment, operation and maintenance costs. From such classification, the least costly option was alternative 3, followed by Alternative 1 and afterwards Alternative 2. Moreover, between alternative 1 and 2, the less expensive alternative was number 1: UASB + aerated pond + high rate settling The effluent final discharge from the WWTP-Navarro would be Cauca river in case its construction is finally decided. Disinfection would be applied to the effluent before it is discharged to Cauca river.

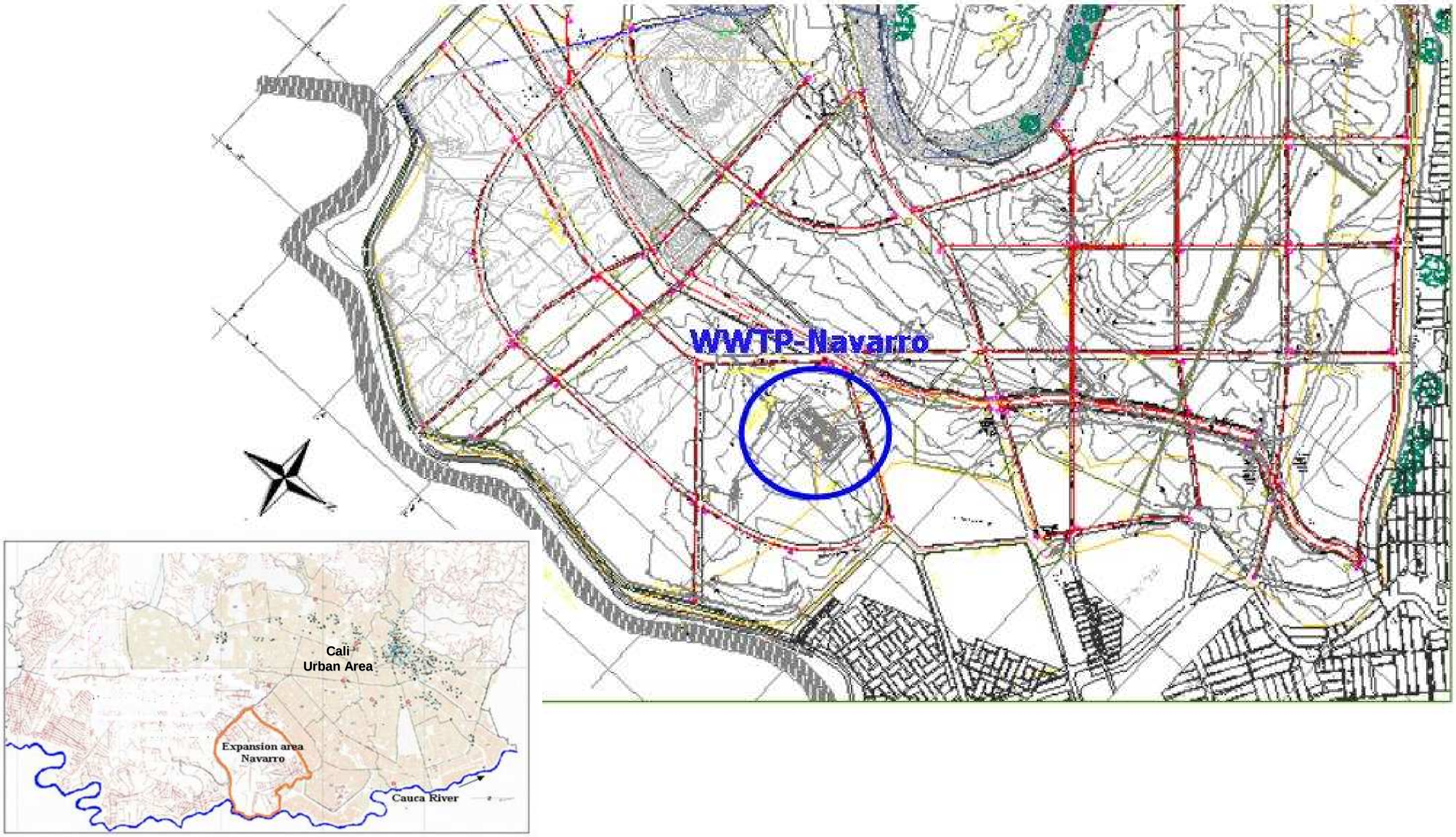

Figure 8.5 Suggested location of proposed WWTP-Navarro.
Source: Gandini & Orozco , 2006

Table 8.15 Components of proposed wastewater treatment alternative systems in the Navarro sector

Pre-treatment	Alternative 1 UASB + aerated ponds+ high rate settling	Alternative 2 UASB + percolation filter+ secondary settling tank	Alternative 3 Conveying and pumping to WWTP-C
– Gross screens – Solid waste storage tank (0.08 m^3) – 3 horizontal flow grit removal chambers (150 l/s) – Sand storage tank	Total area =2.6 ha *UASB* – 4 reactors :75 l/s each – HRT:6 hours – Depth: 4m – Width 25 m – Length:16 m – BOD removal efficiency 60% – Sludge production 1l/m^3 – 3 sludge dry blankets per reactor *Pond* – 1pond – BOD removal efficiency: 70% – Water volume 536 m^3	Total area = 2.2 ha *UASB* Same as alterative 1. *Aerobic percolating filter* – 4 filters – BOD removal efficiency: 70% – Volume: 1016 m^3 – Area 508 m^2 *High rate secondary settling tank* – HRT: 3 h – 4 modules :75 l/s	– Navarro's wastewater pumped to Aguablanca pumping station and afterwards to WWTP-C – WWTP-C design flow of 7.6 m^3/s would be reached in 2030 according to Gandini & Orozco. Other EMCALI studies suggest that the design flow would be reached in year 2017. – Possibility of implementation of aerobic ponds as secondary treatment in WWTP-C to reach BOD removal of 80%. *Proposed Options within alternative:* o WWTP-C +ponds + parallel plates until 2017. o WWTP-C until 2030 o WWTP-C until 2017

Source: Gandini & Orozco , 2006.

8.4 BIBLIOGRAPHY

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Sustainable Water Improves Tomorrow's Cities' Health
SWITCH Project

Study Case: Cali, Colombia
Water Resources

ANNEXES
GENERALS MAPS

February, 2008

A8.1. GENERAL MAPS ROADS AND URBANIZATION DISTRIBUTION CALI - JAMUNDI

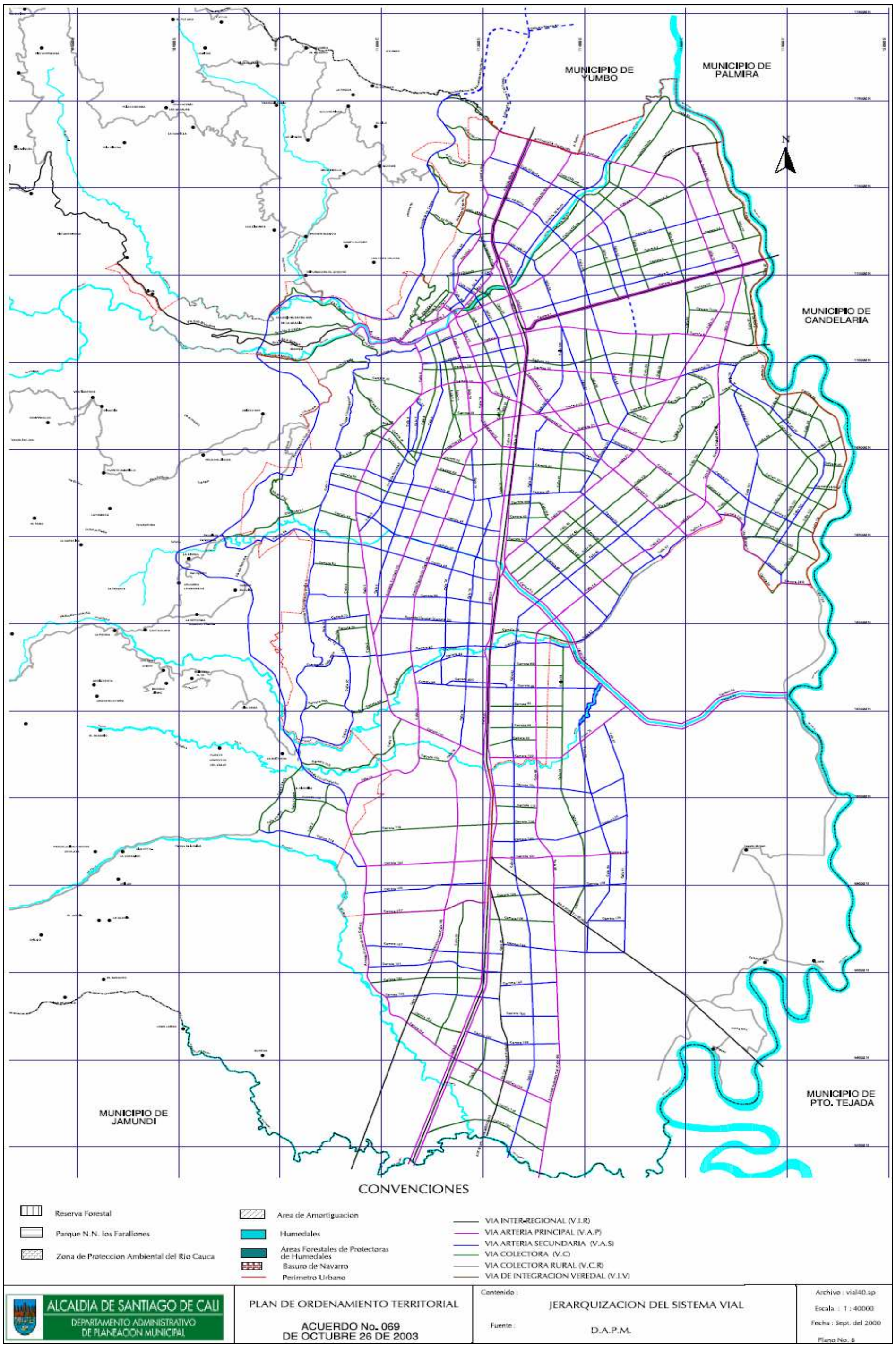

Figure A8.1-1 Road layout scheme in Cali-Jamundí sector
Source: DAP, 2007

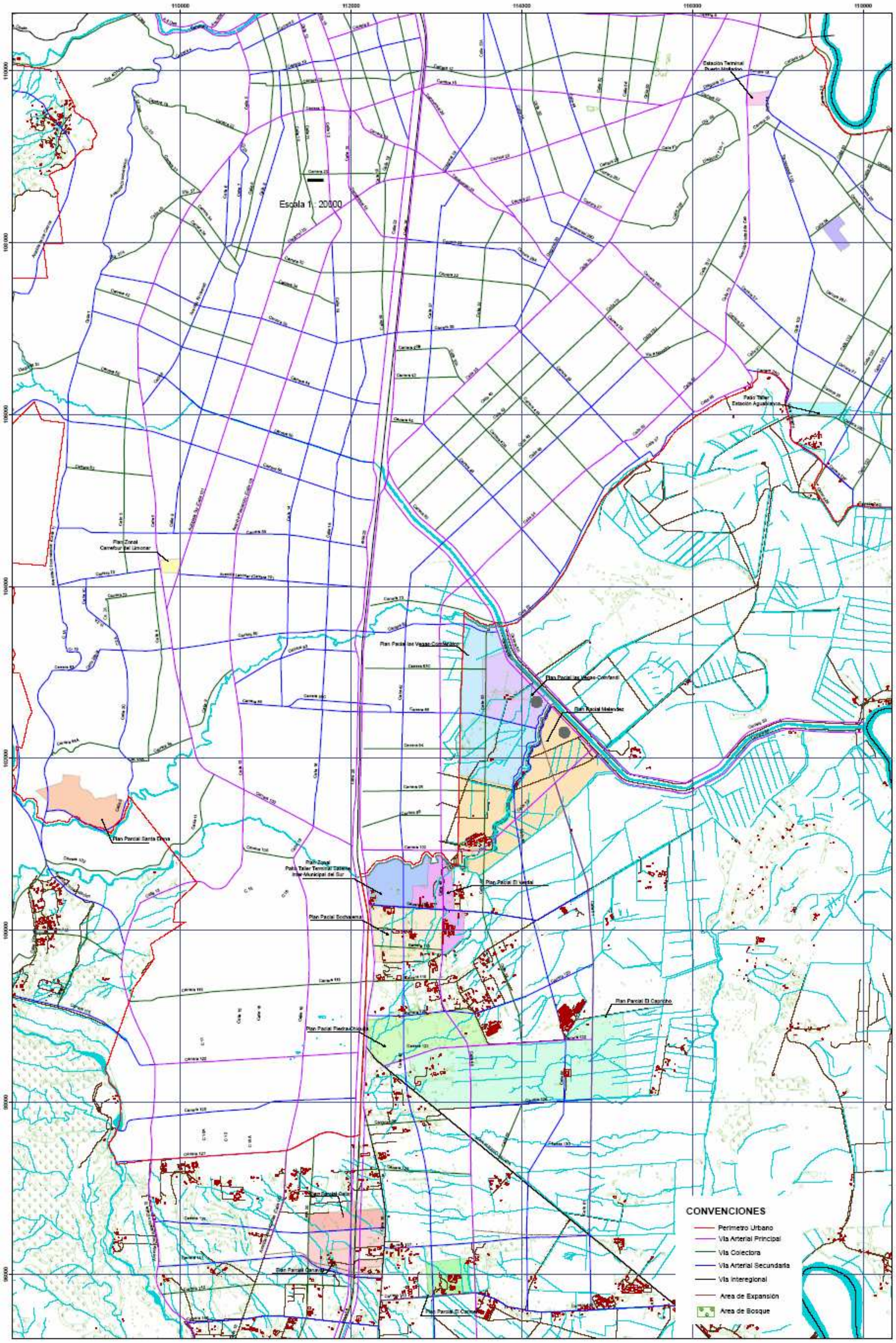

Figure A8.1-2 Partial urbanization developments in Cali-Jamundí sector

Source: DAP, 2007

A8.2 GENERAL SEWERAGE SYSTEMS MAPS CALI-JAMUNDÍ SECTOR

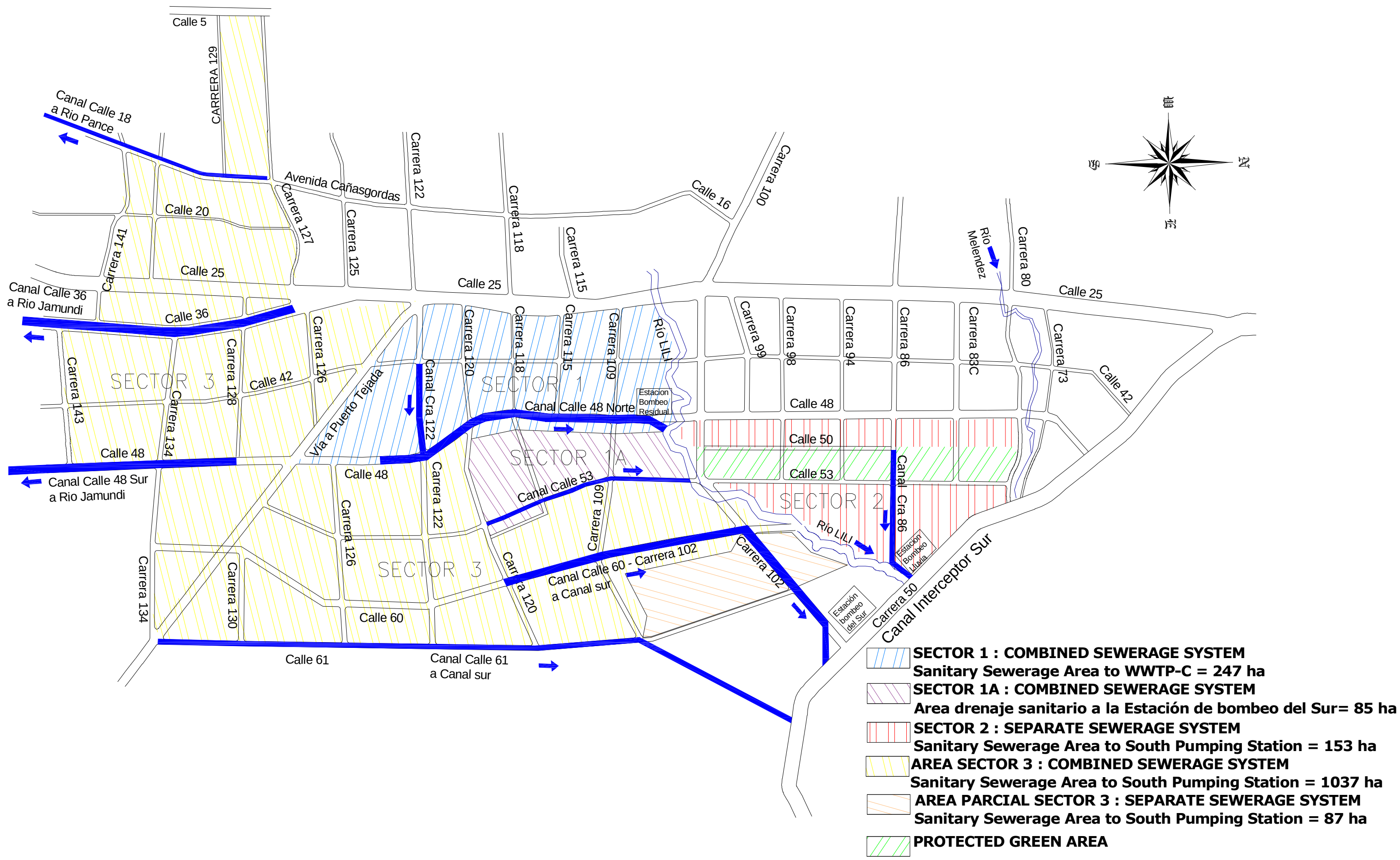

Figure A8.2-1. Alternative 1-Sewerage System in Cali-Jamundí Sector

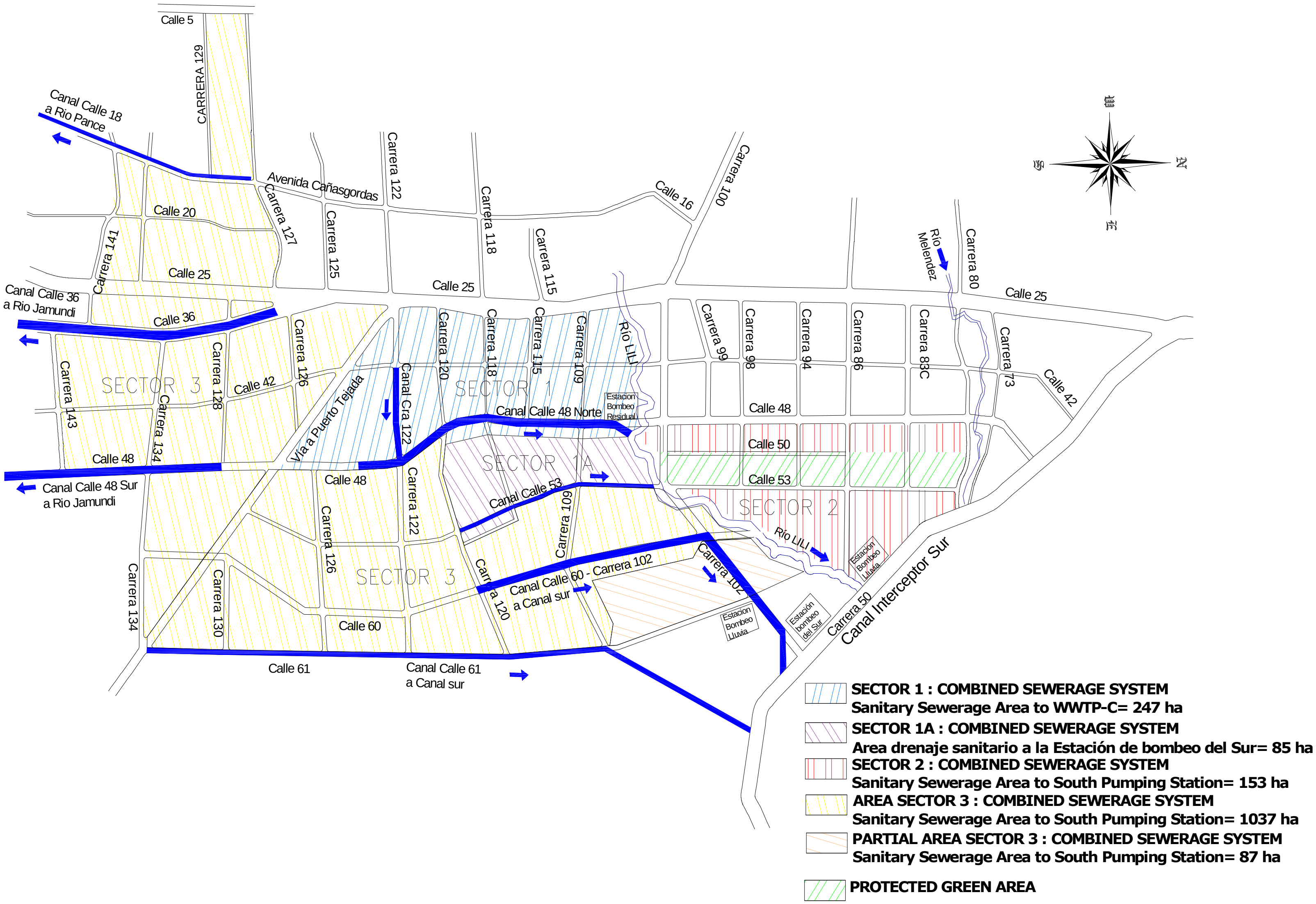

Figure A8.2-2. Alternative 2- Sewerage System in Cali-Jamundí Sector

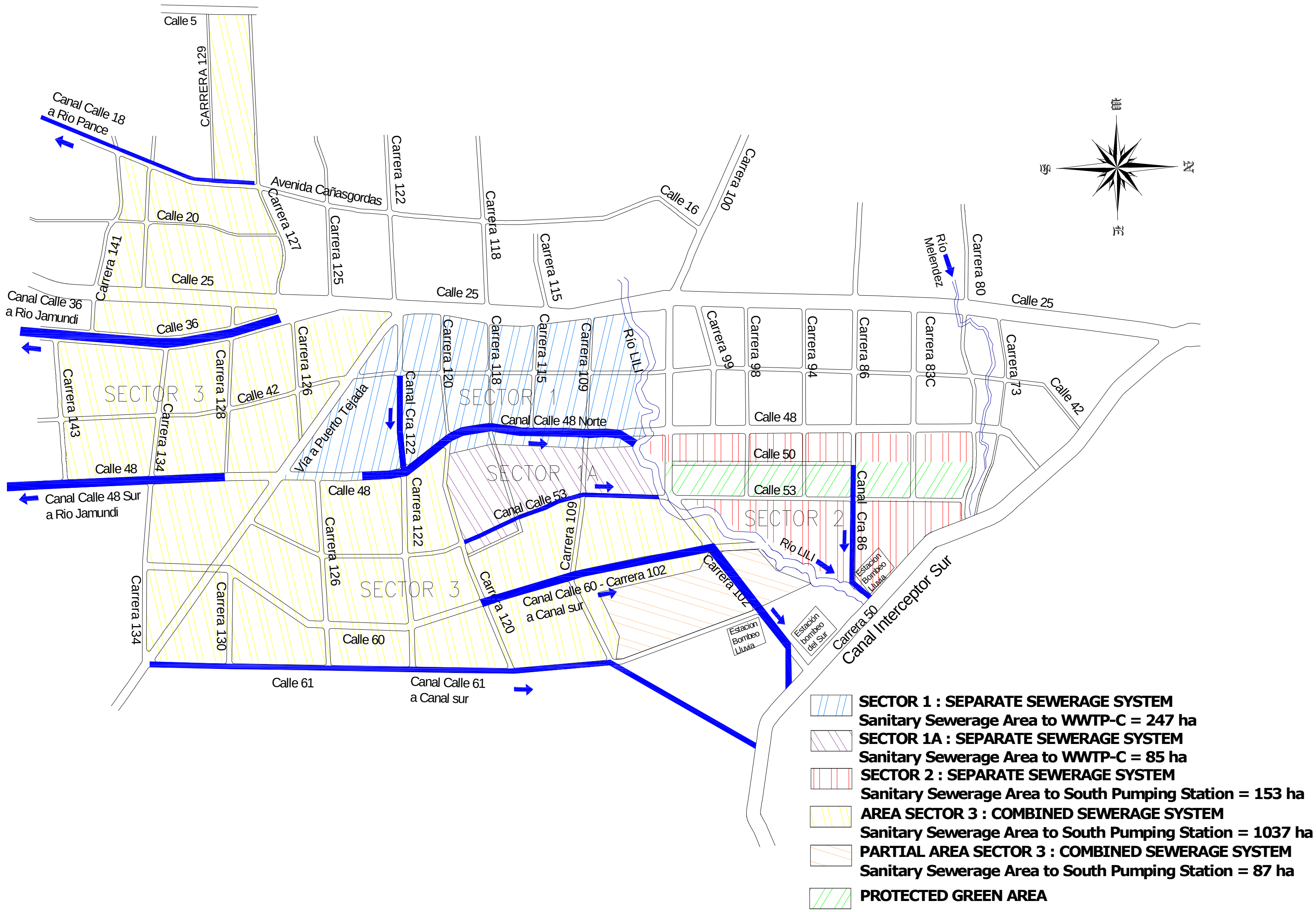

Figure A8.2-3. Alternative 3- Sewerage System in Cali-Jamundí Sector

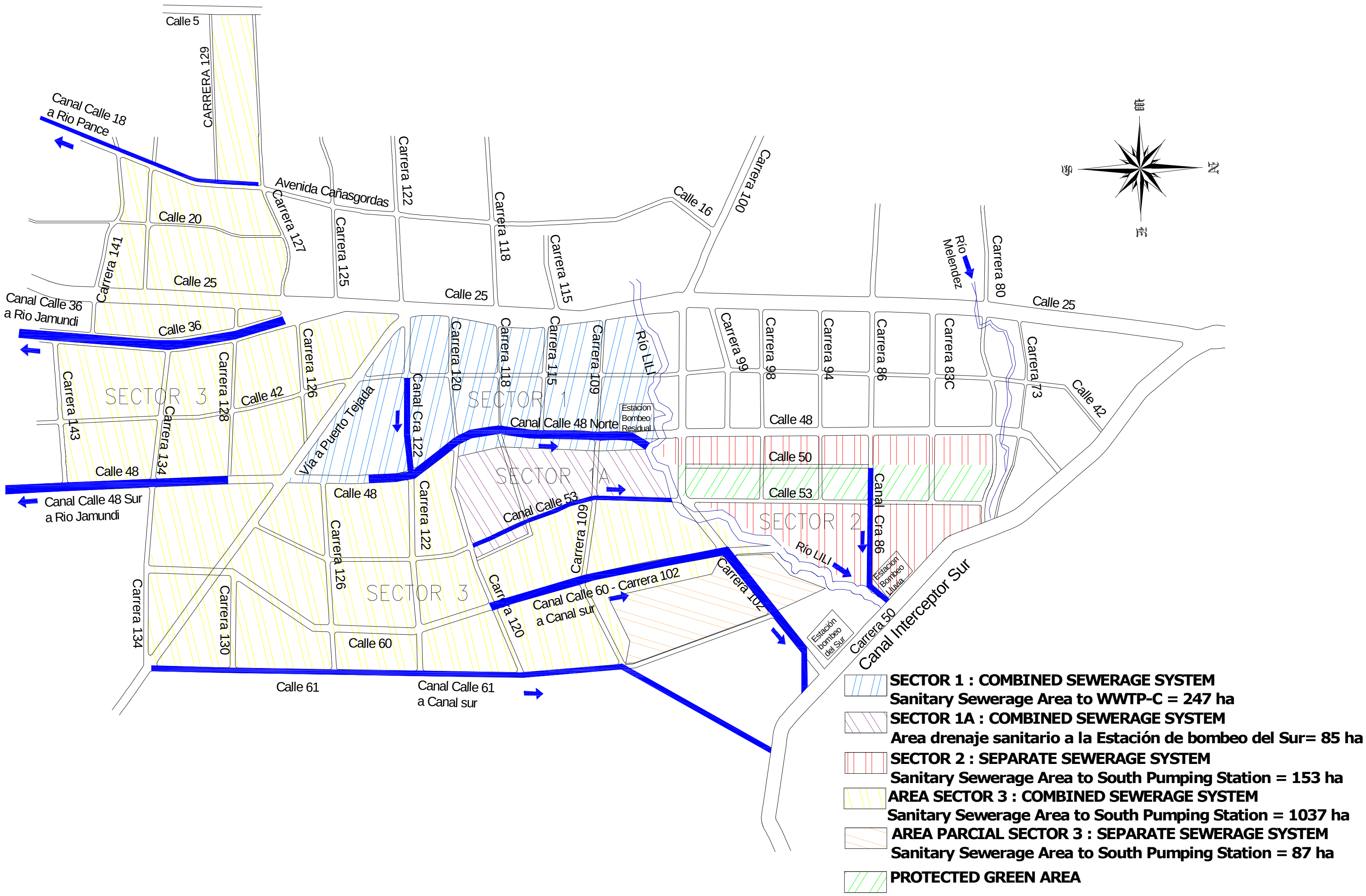

Figure A8.2-4. Alternative 4 Sewerage System in Cali-Jamundí Sector

A8.3 GENERAL MAPS OF PROPOSED DRINKING WATER NETWORKS ALTERNATIVES IN NAVARRO SECTOR

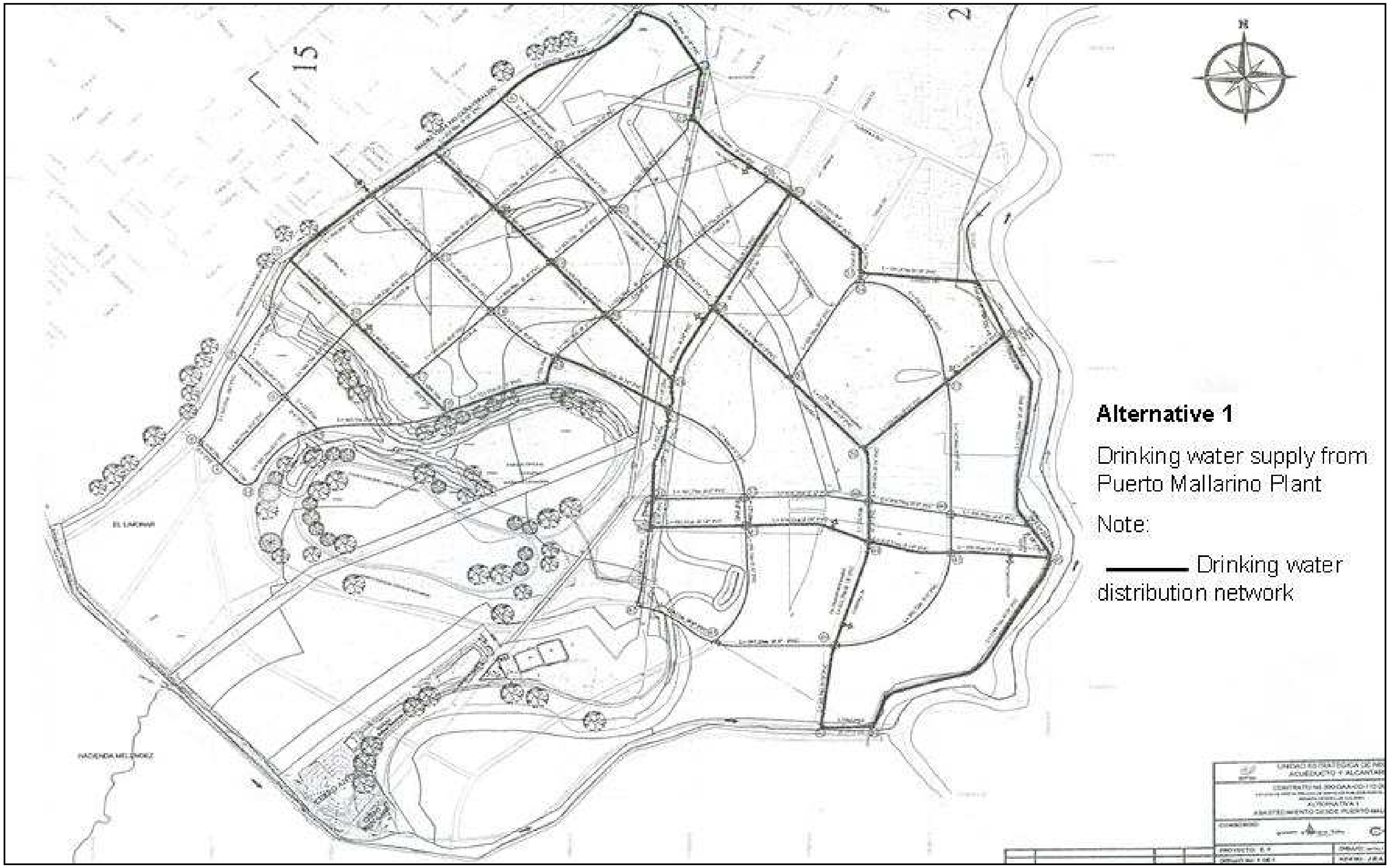

Figure A8.3-1. Alternative 1 – TTNV Navarro transmission pipe with direct supply from Puerto Mallarino Plant.

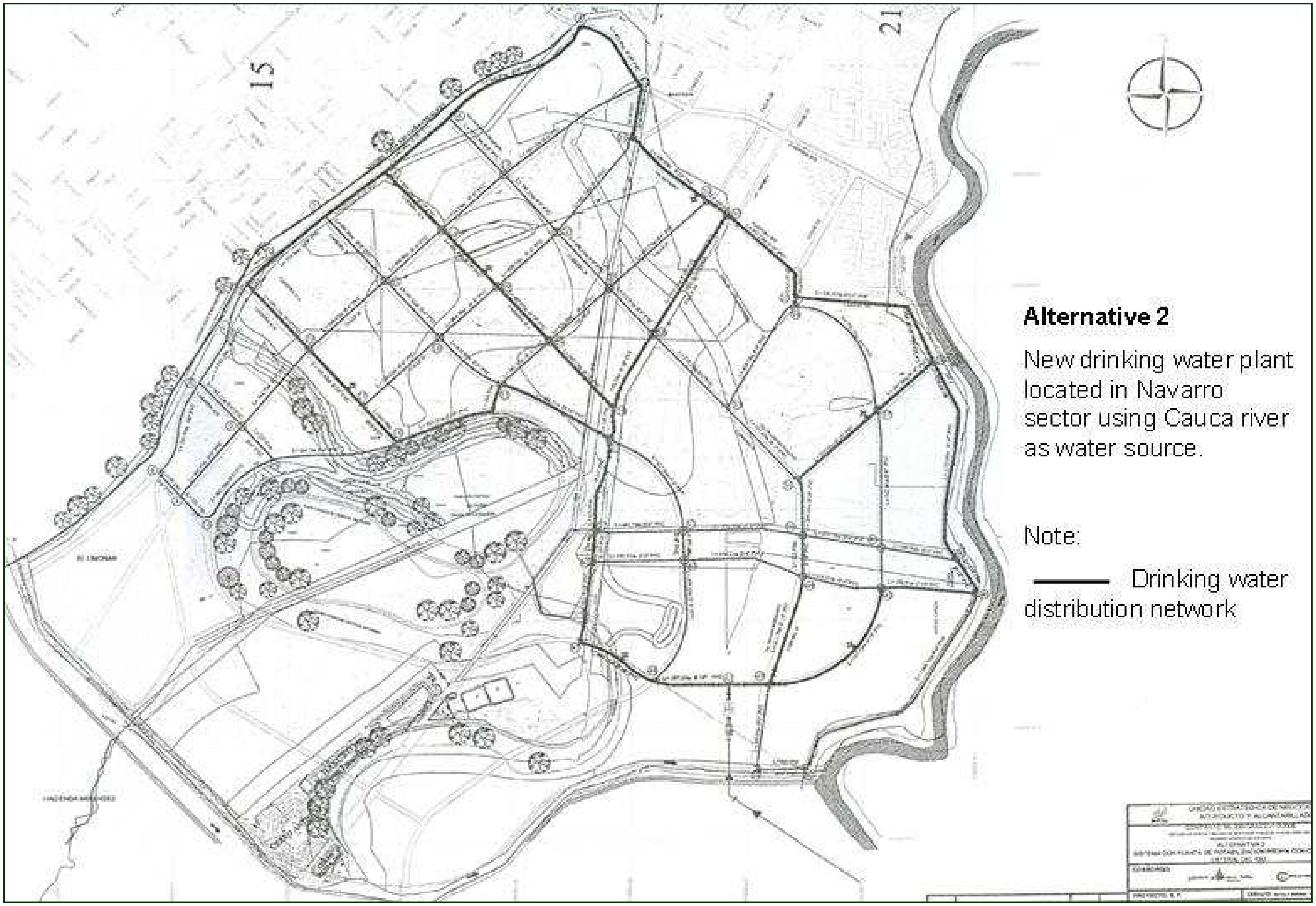

Figure A8.3-2 Alternative 2-Autonomous system in Navarro Sector

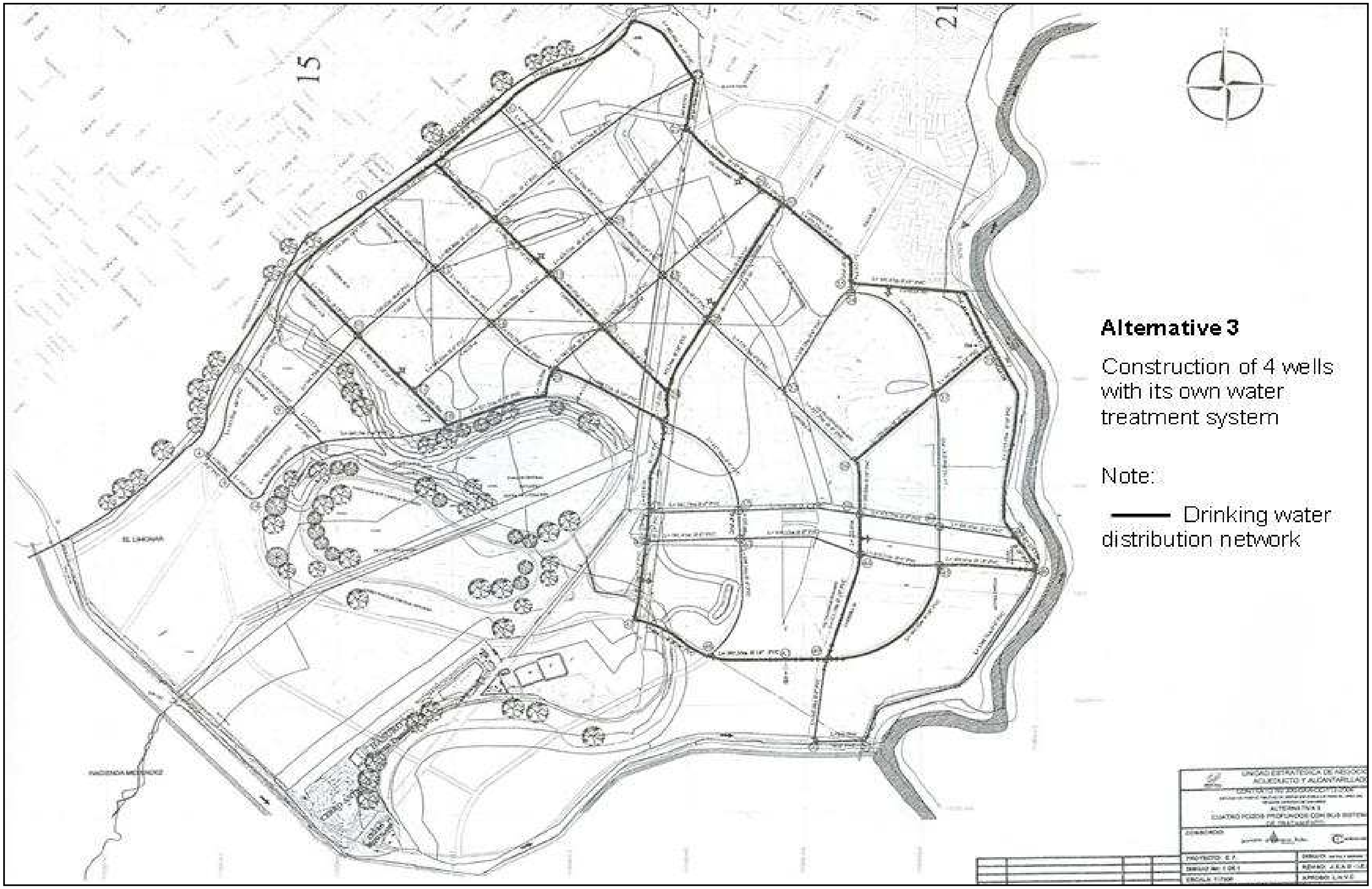

Figure A8.3-3. Alternative 3 - Construction of four wells located along drinking water network in Navarro Sector

Sustainable Water Improves Tomorrow's Cities' Health SWITCH Project

Urban Water Management for the City of Cali
Diagnosis report

Study Case: Cali, Colombia

9. Institutional Framework

February, 2007

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9 INSTITUTIONAL FRAMEWORK

9.1 INSTITUTIONAL STRUCTURE

The institutional role in Colombia is carried out mainly by two institutions: (i) National Government that is in charge of formulating policies, regulating and controlling, and (ii) the municipalities that are in charge of ensuring the appropriate delivery of public services following the national government guidelines. At national level, the associations more related to the management of the water resources are: Ministry for Environment, Housing and Development, Ministry for social affairs, National Planning Department, Ministry for Agriculture and Rural Development and their associated organizations. In addition, the Public Services Commission (Superintendencia de Servicios Públicos Domiciliarios, SSPD) regulates and controls the organizations that deliver public services, and the Water and sanitation regulatory commission (CRA) sets regulations at technical, legal level to control water institutions and guarantee a good service delivery. At regional level the Autonomous regional Corporations (Corporaciones Autónomas Regionales, CARs) and health secretaries are the ones that must ensure the fulfillment of the national policies. Finally, at local level, although the main responsibility is under the health secretaries, the organizations that deliver public services, local environmental authorities and the municipality must manage and control the water resources as well. Figure 9.1 shows the Colombian Institutional structure for the management of the water resources.

9.2 INSTITUTIONS INVOLVED WITH THE MANAGEMENT OF WATER RESOURCES

For the department of Valle del Cauca as well as for the other departments in Colombia there are institutions at national, regional and local level whose mission is to guarantee the environmental sustainability of the water resources in the respective departments. Below, a brief description of the principal institutions is made.

9.2.1 National level

Ministry for the environment, housing and development (Ministerio de Ambiente, Vivienda y Desarrollo Territorial, MAVDT): It defines policies and regulations at technical, economical and planning level for the recovery, conservation, protection, management and favorably use of the environmental resources like water among others.

Water and sanitation regulatory commission (Comisión Reguladora de Agua Potable y Saneamiento, CRA)**:** It set regulations at technical, and legal level to control water institutions and guarantee a good delivery of services.

Public services commission (Superintendencia de Servicios Públicos Domiciliarios, SSPD)**:** It controls, inspects and regulates the public services institutions (ESP) and verify their compliance with national policies, service to users, finances and technical regulations. It also monitors the fate of governmental subsidies within the water framework.

National Planning directive (Dirección Nacional de Planeación, DNP)**:** Designs, guides and evaluates the Colombian public policies, the assigned national given investments and the involvement framework for the private companies.

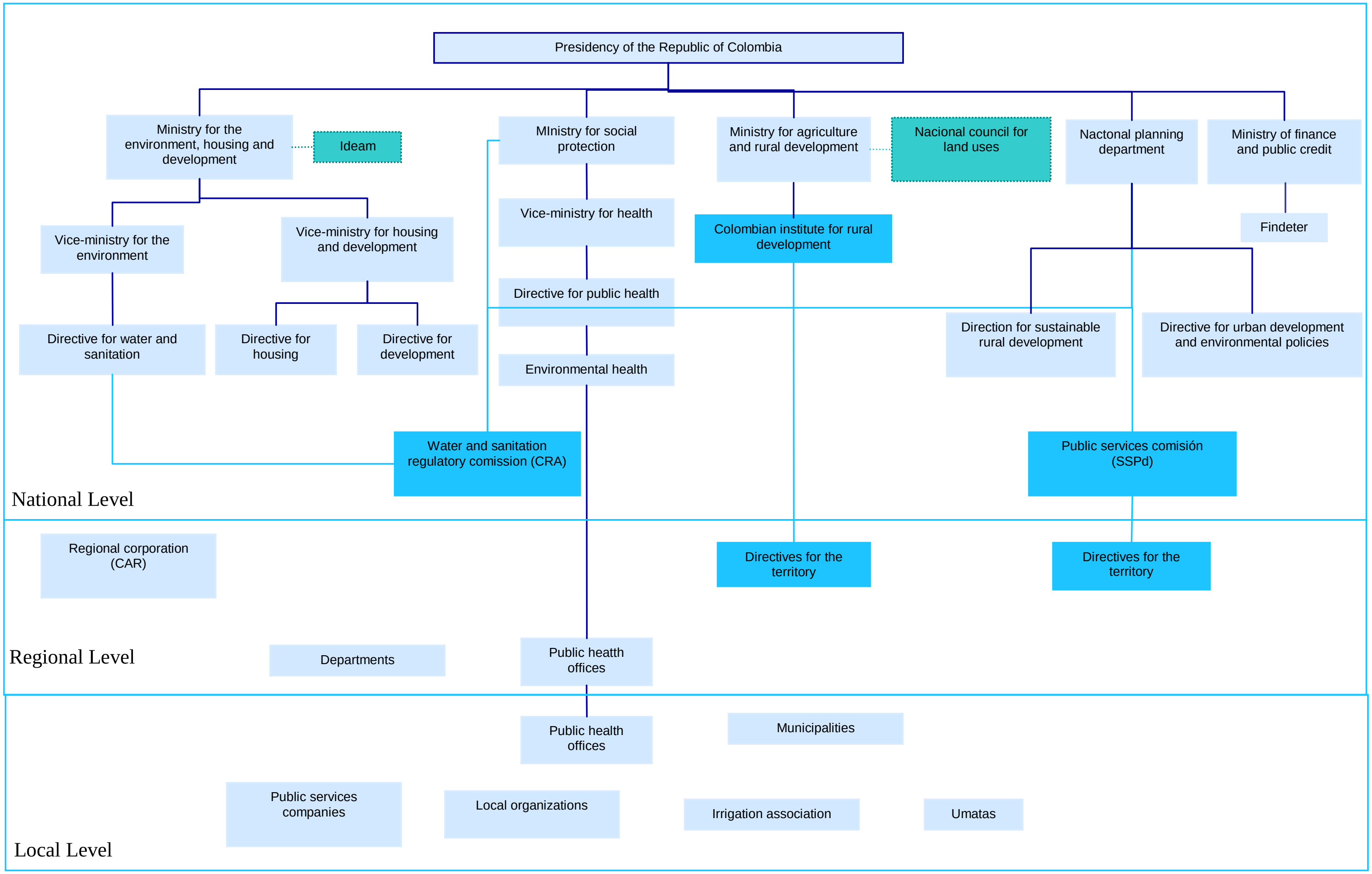

Figure 9.1 Colombian Institutional structure for the management of the water resources
Source: Cinara, 2007

9.2.2 Regional level

Department of Valle del Cauca: It is the local government authority in the region. It establishes and guides development policies and the proper delivery of public services inside the department. It also monitors the economic resources donated by the central government and their appropriate use.

***Regional Corporation of the Valle del Cauca (Corporación Autónoma Regional del Valle del Cauca, CVC)*: **It is the environmental authority for the Valle del Cauca department. It promotes environmental sustainable development among all the involved parts in the region within the national environmental network. It grants environmental permits, imposes environmental punishments (in case of violations of environmental laws and policies) and establish laws and policies for the management of the river basins in the department.

***Public Heath secretary*: **It aims to improve quality of life of the community ensuring an optimal level of health. It guarantees the environmental sustainability in order to reach a good socio-economical level in the community. It also implements prevention policies when the environment and the community are at risk.

9.2.3 Local level

Regulation national institutions:

Municipal administration: The municipalities must promote and carry on the national policies and programs. Law 715-2001 pointed out that they must in a direct or indirect way finance projects related to public service infrastructure, flood prevention, river decontamination; technical assistance to the agriculture sector, protection of the environment, adequate use of water bodies; social participation promotion in the decision making for the delivery of services.

Inside the municipal administration there are sub-dependencies which are directly or indirectly responsible for the management of the water resource. Such dependencies are:

- Municipal council: Its functions are to establish, reform or eliminate taxes, economical contributions and manage the municipal budget according to the Municipal Development Plan.

- Administrative municipal planning department: It is in charge of monitoring and establishing sustainable development of the city according to the land ordering plan (Plan de Ordenamiento Territorial, POT).

- Administrative department for the management of the environment (Departamento Administrativo de Gestión del Medio Ambiente, DAGMA): Its establishment is required when the population in the community is higher than 1’000,000 inhabitants. It’s the local environmental authority whose mission is to strive for the sustainable development of the environment inside the legal framework and policies set by the Ministry for the Environment.

- Health secretaries: . It aims to improve quality of life of the community ensuring an optimal level of health. It guarantees the environmental sustainability in order to reach a good socio-economical level in the community. It also implements prevention policies when the environment and the community are at risk.

Public services delivery companies:

The 1991 political constitution gives power to the Nation to guarantee the delivery of basic services such as drinking water and sanitation to all Colombians. The delivery of services can be carried out by public or private companies. In the city of Cali the public companies that provide these services are EMCALI and EMSIRVA companies.

Cali's Municipal Water Services company, EMCALI: It contributes to the well-being and development of the community guaranteeing economic conditions throughout the delivery of essential public services such drinking water and sewerage services.

Solid waste municipal company, EMSIRVA: Its mission is to guarantee an optimal integrated management of solid waste, ensuring a) social and economic benefits for the community, b) permanent organizational development of the company, c) educational campaigns in favor of the protection of the environment and d) continual improvement in the quality of the service and relations with the users.

Municipal urban renovation company, EMRU: It was created as a industrial and commerce national company to carry out strategies to accomplish what is stipulated in the POT. Its functions are to coordinate and manage urban renovation projects between the municipality and the private sector when it is required.

Trade associations:

Colombian association of Sanitary engineers (ACODAL): Its a national organization whose mission is to promote, develop and strengthen the water, environment and sanitation level.

National association of Colombian entrepreneurs (ANDI): Its function is to promote the progress of the entrepreneurs activities by strengthening competitively.

Non-governmental organizations (NGO):

Colombian network for the natural resource and civil society, RESNATUR: It looks to preserve civil society initiatives through processes of sustainable management of the biologic diversity reservoirs.

Río Cali Foundation: It is interested in topics related to river basin conservation, land ordering and natural resource management.

Río Cauca Foundation: It is interested in Cauca river basin conservation.

Pacífico Verde Foundation: It looks to propend sustainable human development through projects related to participation of civil society in the delivery of basic services, the rational use of the land and environmental resources.

Sustainable development and citizens participation Foundation, FUNDESPAC: It works to guarantee sustainable conditions in indigenous, peasants and ethnic groups. It has carried put projects such as the reforestation of Cali and Meléndez rivers, organic agriculture, septic tanks construction among others.

Academic and research institutions:

Universidad Autonoma de Occidente: It has bachelor programs in administration of the environment and natural resources and post-graduate in environmental management.
Universidad del Valle: It has bachelor programs in water management, sanitary engineering and post-graduate courses in environmental management in Sanitary engineering. Inside the Faculty there are research groups dedicated to the study of the water resources and management:

- Institute for the research in water supply, sanitation and water resources conservation (Instituto de Investigación y Desarrollo en Abastecimiento de Agua, Saneamiento Ambiental y Conservación del Recurso Hídrico, CINARA).
- Engenineering School of the Natural Resources and Environment (Escuela de Ingeniería de los Recursos Naturales y del Medio Ambiente, EIDENAR).

9.3 ENVIRONMENTAL POLICIES AND REGULATIONS

National Level

In Colombia, the legal current framework related to the management of the water resources dates from 1974 when the national code for the natural resources was established. From then, a series of norms have been created in order to regulate the use of water resources. Among the many National water-related regulations the following are the principal ones which directly or indirectly affect the city of Cali.

National Regulations

- Decree 2811, 1976: Policy of control for users of Cauca river. It establishes the prevention and control norms to avoid contamination of the water resource and guarantee quality of water for posterior use.
- Law 9, 1979: Known as the Sanitation national code, it establishes the proceedings and measurements to carry out regulation and control of discharges.
- Decree 1594, 1984: It is the regulation norm from the national code of natural resources. Together with law 9, 1979 regulates the uses of water and wastewater. Regarding wastewater, it defines the discharge limit of hazardous substance to open body waters and sewerage systems, it establishes the permit of wastewater discharges, pollution compensation tax and environmental studies impacts.
- Political constitution 1991. Articles 49, 78, 79, 80 and 366. It establishes that the state has the responsibility of protecting diversity and integrity of environment, promote environmental education and control environmental deterioration by implementation of fees or pertinent punishments.
- Law 99, 1993: It establishes the pollution compensation tax when discharging wastewater to open water bodies. This legal figure was seen as a sanction that could punish polluters and as an instrument that could finance water protection as well.
- Law 142, 1994: Public domiciliary services regime: It establishes the legal competition among municipalities in the delivery of secure water supply and sewerage services.
- Law 373 de 1997: It regulates the efficient use of water so that production of wastewater can be minimized.
- Resolution 273, 1997: the minimum wages for the pollution compensation tax are established regarding BOD and TSS concentrations.
- Decree 475, 1998: technical standards for drinking water

- Resolution 1096, 2000: Drinking water and basic sanitation technical design and quality rules (RAS)
- Decree 1729, 2002: The ordering of river basins is set under the control of the competent environmental authority.
- Law 182, 2003: National development plan 2002-2006 towards a community state. It looks to boost the sustainable economical , environmental growth. It focuses in the program *Integrated Water management.*
- Resolution 104, 2003: It establishes the criteria and parameters for the classification of river basins.
- Decree 155, 2004: Water use fee. The fee was considered only in case of profit. The resources are used for water resource development and river basin protection.
- Resolution 376, 2006: establishes the objectives for water quality for water bodies in the urban area of Cali during the period 2007-2017. It establishes also goals for the reduction of contamination by wastewater discharges.
- Resolution 019 de 2007: proceeding for the establishment of the decontamination global goals in water bodies in the municipality of Cali period 2007-2016.
- National policy of cleaner production, 1997. Adoption of technologies that allow reduction of emissions and waste to receiving waters (cleaner technologies). Implement the optimization of natural resources, increase energy efficiency. Generation of waste should be minimized and prevented in order to stabilize environmental impacts that could adversely affect the society and ecosystems. Waste should be reused when possible. The reuse and recycling of wastewater should be encouraged.

National Policies

- CONPES 3177, 2002: Priority actions and guidelines for the formulation of a National plan for the management of wastewater (PMAR).

- CONPES 3246, 2003: It defines the guidelines for the management of the water supply and sewerage systems. It looks fro strategies to reach economic subsidies for the tariffs, new tariffs based on the efficiency and quality criteria in the delivery of public services.

- CONPES 3343, 2005: Guidelines and strategies for a sustainable development in the water, environmental and land sectors. It looks to strengthen the environmental governance so that it is efficient, effective, transparent and equal.

- CONPES 3383, 2005. Plan for the development of water supply and sewerage systems so that total coverage are met considering good quality and quantity. Year 2019 is taken as the horizon year so that an integrated management is reached as well.

Regional Level

At regional level there are different strategies aimed to plan and guarantee the environmental sustainability of the Valle del Cauca department. However, it is important to highlight that the water management approach followed in Colombia is not at the river basin scale. Instead each one of the provinces works independently depending on its political jurisdiction. Following, the main strategies are summarized:

- *Plan for the environmental management in the region of Valle del Cauca 2002-2012 “Participación con compromiso”*. This strategy orients in a coordinated way the management and administration of the renewable natural resources.

- *Plan for the development of the department of Valle del Cauca 2004-2007 "Vamos juntos por el Valle"*, which establishes the strategies to reach environmental sustainability in the region.

- *Plan triennial, PAT.2007-2009,* which defines the actions to accomplish the targets set in the Millennium developing goals through the established national policies.

- *Pact for the recovery of the Cauca River 2001:* It is a pact signed among the Ministry for the environment, regional corporations-CVC the department of Valle del Cauca and the municipality of Cali. The main goal is to formulate a plan for the integrated management of the Cauca river basin. The formulation of the plan must be t established based on the participatory approach from the municipalities, communities and industrial sectors involved in the uses of the river basin.

- *Plan for the integrated management of the Cauca river basin-2005;* It establishes the strategies and measures, to be followed by all the involved parties, to protect, recover, conserve and manage in a sustainable way the Cauca river.

Local Level

At local level the local policies which sustain the urban water management in Cali are:

- *Plan for the development of Cali area 2004-2007.* Its main goals are: 1) Social equity, 2) economical recovery, development and competitiveness, 3) Urban culture, livelihoods, security and peace, 4) Environmental recovery and development of the territory, 5) Institutional enforcement and defense of the public sector.

- *Master plan for Cali 2000-2020.* It coordinates the use and destination of the public areas to ensure the social-economical development considering the needs and interest of the involved population. Regarding the environment it defines land uses, protected areas, risk areas, urban growth. Likewise it defined the uses of the natural resources in the city.

- *Sanitation and management of waste-discharges plan -PSMV-EMCALI 2007.* It includes programs, projects and measures for the management of wastewater in the city following quality standards and policies defined by the environmental authority in the region (DAGMA). The plan encompasses recollection, transport, treatment and final disposition.

- *Environmental management Plan for the city of Cali. DAGMA 2005-2019.* It includes all the decisions and strategies to de developed by the different stakeholders in the city (at institutional, social and economical level). Such strategies are aimed to improve the quality of life of the community as well as to improve the economical productivity.

- *Plan for the solid waste management in Cali-PGIRS 2002.* This plan was developed to be mainly responsibility of the municipalities. Its mission is to establish an integral management of the solid waste taking into account all aspects from the production of the waste until its final disposition and considering strategic aspects like recycling and reuse.

- *Resolution 376-2006 and 019-2007.* Set by DAGMA, these resolutions define goals for the reduction of emissions and waste discharge to water bodies in Cali. Specifications for the uses of the different rivers in Cali are also set. It also set deadlines (to be accomplished by the public agencies) in reducing the waste discharge to the rivers.

- *Environmental municipal management system (SIGAM):* Implemented by the municipality, it establishes environmental profiles and identifies responsibilities and responsible for control, management and control of the environment in Cali.

- *Environmental agendas.* The latest agenda was established in 1998. The agendas are developed at local level to show the current state of the environmental resources inside the city. They also formulate approaches to follow up the development of environmental strategies.

9.4 NATIONAL WATER STANDARDS

9.4.1 Drinking water

Decree 475, 1998 establishes the technical standards for drinking water. Article 7 states the physical quality standards for drinking water. Table 9.1 shows the quality parameters and their values.

Table 9.1 Physical quality criteria for drinking water

Characteristic	Expressed as	Admissible value (mg/l)
True Color	Platinum cobalt units (PCU)	15≤
Taste ad odor		Acceptable
Turbidity	Nephelometric Turbidity Units (NUT)	5≤
Total Solids	mg/l	500≤
Conductivity	micromhos/cm	50 – 1000
Floating substances		Absent

Source: Decree 475, 1998

Article 8 º establishes the chemical standard criteria for drinking water. Table 9.2 presents the limits for the elements and chemical components besides pesticides that may cause adverse effects in human health when exceeding the established limits.

Table 9.2 Chemical quality criteria for drinking water

Characteristic	Expressed as	Admissible value (mg/l)
Aluminum	Al	0,2
Antimonium	Sb	0,005
Arsenic	As	0,01
Barium	Ba	0,5
Boron	B	0,3
Cadmium	Cd	0,003
Free cyanide	CN^-	0,05
Total cyanide	CN^-	0,1
Chloroform	$CHCl_3$	0,03
Copper	Cu	1,0
Hexavalent Chromium	Cr^{+6}	0,01
Total Phenol	Phenol	0,001
Mercury	Hg	0,001
Molybdenum	Mo	0,07
Nickel	Ni	0,02
Nitrite	NO^2	0,1
Nitrate	NO^3	10
Silver	Ag	0,01
lead	Pb	0,01
Selenium	Se	0,01
active Substance to the blue methyl	ABS	0,5
Fat and oils	-	Absent
Total Trihalometanes	THMs	0,1

Source: Decree 475, 1998

9.4.2 Quality standards for water use and wastewater discharges

Decree 1594, 1984 establishes the quality criteria for the uses of water and for the requirements of wastewater discharges to open water bodies and sewerage systems. Article 38 defines the admissible standards for the destination of the water resource for human consumption and domestic use when only conventional treatment is needed (coagulation, flocculation, sedimentation and disinfection). Table 9.3 shows the standards.

Table 9.3 Water quality parameters for water bodies that are destined for human consumption.

Substance	Unit	Value
Ammoniac	N	1
Arsenic	As	0,05
Barium	Ba	1
Cadmium	Cd	0,01
Cyanide	CN-	0,2
Zinc	Zn	15
Chloride	Cl-	250
Copper	Cu	1
Color	Color real	75, Platinum cobalt
Phenol compounds	Phenol	0,002
Chromium	Cr+6	0,05
Diphenyl Polichlorades	Active agent concentration	No detectable
Mercury	Hg	0,002
Nitrates	N	10
Nitrites	N	10
pH	Units	5,0-9,0
Silver	Ag	0,05
Lead	Pb	0,05
Selenium	Se	0,01
Sulfates	SO=4	400
Tensoactives	Active substances	0,5
Total coliformes NMP	NMP	20000 microorganisms/100ml
Feacal coliformes NMP	NMP	2000 microorganisms/100ml

Source: Decree 1594, 1984

Article 72 defines the direct wastewater discharge limits to water bodies which are presented in Table 9.4

Table 9.4 Wastewater discharge limits to open water bodies

Reference	Existing user	New user
pH	5 a 9 units	5 a 9 units
Temperature	< 40°C	< 40°C
Floating matter	Absent	Absent
Fat and oils	Removal > 80% load	Removal > 80% load
Domestic or industrial suspended solids	Removal > 50% load	Removal > 80% load
BOD	Removal > 30% load	Removal > 80% load

Source: Decree 1594, 1984

Article 72 defines the direct wastewater discharge limits to public sewerage systems which are presented in Table 9.5.

Table 9.5 Wastewater discharge limits to public sewers

Reference	Existing user	New user
pH	5 a 9 units	
Temperature	< 40°C	< 40°C
Acids, bases or acidic solutions	Absent	Absent
Settled solids	10 ml/l	10 ml/l
Soluble substances in hexane	100 mg/l	100 mg/l
Domestic or industrial suspended solids	Removal > 50% load	Removal > 80% load
BOD Domestic waste Industrial waste	Removal > 30% load Removal > 20% load	Removal >80% load Removal >80% load
Maximum flow	1.5 times average hourly flow	1.5 times average hourly flow

Source: Decree 1594, 1984

Finally, Table 9.6 shows the limit concentrations of hazardous substances in the discharges, established in article 74.

Table 9.6 Standard admissible concentration for the control of hazardous substances discharges.

Substance	Unit	Concentration (mg/l)
Arsenic	As	0,5
Barium	Ba	5
Cadmium	Cd	0,1
Copper	Cu	3
Color	Cr+6	0,5
Phenol compounds	Phenol	0,2
Mercury	Hg	0,02
Nickel	Ni	2
Silver	Ag	0,5
Lead	Pb	0,5
Selenium	Se	0,5
Cyanide	CN-	1,0
Diphenyl poli-chloride	Active agent concentration	No detectable
Organic mercury	Hg	No detectable
Trichloride -ethylene	Trichloride -ethylene	1,0
Chloroform	Chloroform carbon extract	Chloroform carbon extract
Carbon Tetrachloride	carbon Tetrachloride	1,0
Dichloride-ethylene	Dichloride-ethylene	1,0
Carbon sulfide	Carbon sulfide	1,0
Other organ-chloride compounds	Other organ-chloride compounds	0,1
Organ-phosphate compounds Carbamate variety	Organ-phosphate compounds Carbamate variety	0.1

Source: Decree 1594, 1984

9.5 BOTTLENECKS IN IMPLEMENTING AN INTEGRATED MANAGEMENT OF THE URBAN WATER RESOURCES

In general, the principles of environmental sustainability and integral management of the water resources are considered within the policies and plans at national, regional and local level in Colombia as it was shown in the previous sections. Yet, several issues prevent their implementation and development as it would be explained as follows:

1. The normative for the control of pollution of the water resources, set decades ago and of which an effective part is currently in use, have been designed based on a "corrective approach" and more precisely "the end-of-pipe approach", rather than a preventive and integral one. The current normatives are directed to mitigate the impact of waste discharges on the receiving water bodies mainly through two complementary policies: a first one of control and a second one based on an economic resource known as the water pollution fee when discharging to water bodies which is not working as it was expected.

2. There are problems implementing tariffs that are affordable, and that include resources for coverage expansion, operation and maintenance of water/wastewater services. In addition, according to CONPES (2003) cited by Guio (2004), there is a lack of financial incentives in areas where the marginal cost is higher than the average one. In addition, since there has been a reduction of subsidies, it has been impossible to charge the water use and water pollution fee in the water bill. Regarding the water pollution fee, its implementation has been slow and started to be charged only to users that had any economic reward such as the industries. On the other hand, the implementation at house level has not been possible as far as today and diffuse pollution is not considered either. Therefore, livestock and agriculture activities have been indirectly favored.

3. Although in the past years, it has been observed the development of new policies and programs that aim at the implementation of measures to improve towards the sustainable development still the "end-of-the-pipe" approach is the most widely used when referring to integral management of water resources.

4. There is a tremendous lack of efficient management systems and presence of insufficient information on water measurements to determine "who" contaminates and to which extent. In general to implement monitoring systems, to measure the contamination of soil and underground waters, to construct models of quality of water and to determine the contributions of polluting agents from the industries is a task that entails a great deal of technical, institutional and economical effort.

5. The institutional framework of water and sanitation sector that regulates the national territory, including the city of Cali, in which each institution has an area and a specific subject of intervention prevents the exchange and flow of information, duplicates efforts and resources and prevents the development of an integral water management. Additionally, the jurisdiction areas have been conceived based on political and administrative limits rather than at river basins level. In some occasions, it is not very clear the jurisdiction and responsibility of the institutions when managing the environmental problems in the city; hence problems of water pollution continue without solution.

6. There is a weak capacity of enforcement and a low level of governance regarding water resources. According to the National Development plan 2002-2006, the lack of control and coordination between institutions have produced incoherent disorganization in the judicial Colombian system. The problem can be defined as the continues uncertainty of citizens towards access, responsiveness, equity, efficiency and effectiveness of justice.

7. According to Guio (2004), there is not a defined water law in Colombia. There are many laws and decrees that focus on different aspects of water management. Yet, these laws and decrees are modified several times and the relevance or priority of them can not be understood. In some cases it is not clear if a determined decree is still valid or not so the level of complexity in

understanding these laws increases. Hence, the water legislation is very complex and causes that any attempt for an integrated management will be very difficult.

8. The regulation for the control of the pollution of the water resources is frequently defined only based on the loads of BOD and SST, being as well present contamination that is caused by other type of substances that also require an effective control.

9. The limitation in the availability of economical resources prevents the implementation of programs and technologies conceived inside the framework of the sustainability principles and integral management.

10. Plans of action to mitigate and prevent contamination of water bodies are not planned on a long term. Rather, such plans are proposed in a "short basis" to remediate the so thought "immediate problems"

11. Illegal practices like corruption at different levels affect also the water management practices. Some of these practices are:

- bribery in water projects licitations
- irregularities in contracts that look to favor specific contractors
- Partially completed or not completed contracts that were already paid
- Nepotism

In Colombia water related institutions have been identified as highly vulnerable to corruption with 82% of the environmental institutions under risk of corruption as stated by Colombia Transparency (2003) cited by (Guio, 2004).

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