The Republic of Colombia
The Magdalena River

Master Plan

中国电建
POWERCHINA
中国水电工程顾问集团公司
HYDROCHINA CORPORATION
CORMAGDALENA

December 2013

Contents

Attached Drawings:

Foreword

As the biggest river in Colombia, the Magdalena River has a 1613km long main stream with a drop of 3685m, flowing through 11 Departments from south to north and converges in the Caribbean Sea while passing Barranquilla City and converges in Cartagena Bay through Dique Canal. The tributaries extend to 8 more Departments and Bogota D.C. The Basin covers an area of 266,500 km^2, 23% of the Colombian territory, and is abundant in water resources with an annual mean runoff of 234.7 billion m^3. The Magdalena River Basin is the core area for politics, economy and culture in Colombia with the population and the GDP respectively accounting for about 77% and 85% of the total of Colombia. governance and exploitation of the Basin is of strategic significance for the economic development, social progress and environmental protection of Colombia.

At present, the water resource in the Magdalena River Basin is not well developed and utilized. There exist some outstanding problems: poor water infrastructures as the waterway, ports, flood control, waterlog control, irrigation and others; low multipurpose utilization rate of water resources, frequent occurrence of flood disasters, relatively serious soil erosion and relatively poor aquatic ecosystem. In addition, the economic and social development level in the area along the river is low, with a high proportion of poor people.

The existing groundwork for the Master Plan of the Magdalena River is limited, while overall and systematic planning has never been done. Relatively more researches have been done in such sectors as navigation and environment, and hydropower resources censor, study on controlling reservoirs, and planning for cascade-based navigation and power generation for some reaches were conducted in the period from 1970 to the early 1980s. Other sectors are less studied. The *Handling Plan for the Magdalena-Cauca River Basin* (PMC- el Plan de Manejo de la Cuenca) was formulated in 2007 and established a set of 12-year (up to 2019) objectives mainly covering three major fields, i.e. reforestation, water pollution control and artificial restrictions of volumes. Therefore, the previous plannings and researches cannot meet the economic and social development requirements for governance, exploitation and protection of the Basin (River) and it is urgent to carry out a comprehensive planning.

The Magdalena River Regional Autonomous Corporation ("CORMAGDALENA"), HydroChina Corporation ("Hydrochina"), and China Development Bank Corporation signed a memorandum of understanding in Bogota on February 16, 2009, in order to launch the comprehensive exploitation of the Magdalena River. In the first stage, the three parties would jointly promote international financial and technical cooperation for the project of formulation of the Master Plan of the Magdalena River. On May 10, 2011, Hydrochina, CORMAGDALENA, and the Presidential Agency for the Social Action and the International Cooperation signed *the Interinstitutional Agreement of the Project of "Formulation of the Master Plan of Exploitation of the Magdalena River" Assitance Non-Fundable of the Chinese Government to the Colombian Government* in Bogota. On November 8, 2011, Hydrochina, CORMAGDALENA, the Presidential Agency for the Social Action and the International Cooperation, as well as relevant departments and agencies of China and Colombia held the first meeting of the Management Committee and the Technical Committee in Bogota, marking that the project officially entered the implementation stage.

According to the Agreement, the scope for the Master Plan is the jurisdiction of CORMAGDALENA, including 128 municipalities along the main stream of the Magdalena River (1,613 km), the Canal del Dique (114 km) and lower reaches of the Cauca River (187 km), involving 13 departments, including Cauca, Huila, Tolima, Cundinamarca, Caldas, Boyacá, Antioquia, Santander, Cesar, Bolívar, Sucre, Magdalena, and Atlántico. The planning area is 69,400 km^2, accounting for 26% of the Basin, with a population of 6,075,000 in 2010, about 17% of the Basin. The Master Plan takes navigation, hydropower generation and environmental protection as the key themes, concurrently with other general themes as land improvement (flood control, waterlog control and irrigation), riparian zone use, river course regulation, fishery resources utilization, and recreation.

The contents and obligations of Chinese and Colombian parties for the project implementation are as follows: The Chinese Party is responsible for dispatching experts to Colombia to conduct comprehensive study and some field reconnaissance on the Magdalena River, and to study and formulate the Master Plan and submit relevant reports. The Colombian Party is responsible for providing documentation required for the project study and assisting with project implementation.

The basic task of the Master Plan is to provide the strategic, global and forward-looking general arrangement for rational exploitation of water resources, flood and waterlog control, and protection of ecology and environment in accordance with the requirements of sustainable economic and social development and maintenance of healthy function of the River and against the main problems existed in planned area based on adequate investigation and analysis on natural characteristics, resources and environmental features of the Magdalena River, identifying of objectives and tasks for governance, exploitation and protection, determining the general layout scheme, preparing sectoral plans and putting forward plan implementation opinions, so as to provide a basis for scientifically direct and standardize the activities in the governance, exploitation and protection of the River.

The principles of formulation of the Master Plan are as follows: a) The main contents of the Master Plan should be as per the Project Agreement. The working depth should be determined with reference to the applicable standards of China for comprehensive plan of river basin, with consideration of the specific conditions in Colombia, and adapted to the available data actually collected. b) Colombia's laws, regulations and related policies should be followed. Except where the technical standards are clearly required in Colombia, China's standards should apply. c) The the Master Plan should be based on relevant sectoral plan and special planning. For the three major sectors with some work basis including navigation, hydropower generation, and environmental protection, detailed sectoral plan should be proposed. For other sectors in lack of basic data and with weak planning basis, conceptual plans should be formulated with directional planning advice proposed. d) The outcomes of the existing planning and studies are fully utilized after necessary analysis and review are conducted. PMC should serve as a guidance for the Master Plan; projects which have been listed in the program by CORMAGDALENA, if consistent with the the Master Plan, can be considered as short-term projects. e) The main experience of formulation and implementation of comprehensive planning of river basins in China should be learned, and opinions and advice should be extensively sought from relevant Colombian government authorities and agencies, and Colombian Party's recognition (problem diagnosis) of the status of and the vision of governance, exploitation and protection of the Magdalena River should be understood.

The implementation of the Project generally includes six stages, i.e., preliminary preparation (commercial negotiation and technical data collection), comprehensive field investigation, compilation of the outline of the Master Plan, field reconnaissance, study of planned programs, and preparation of the Master Plan report. Accordingly, Hydrochina dispatched 6 groups of experts to Colombia for comprehensive investigation, collection of basic data and communication and technical exchange. The main work completed includes the following.

Basic data, as necessary for formulation of the Master Plan, of hydrology, topography, geology, resources, environment, economy and society as well as the existing planning studies and the current situation of the governance, exploitation and protection have been collected. Comprehensive field study and field reconnaissance such as survey, , geological and hydrological works and corresponding office documentation analysis have been carried out. The basic condition of the river has been investigated and studied.

The main problems in governance, exploitation and protection of the River and the demands of the social and economic development on the River have been analyzed. An overall planning system has been established. Sectoral plans with multiple use of water resources, flood control, and environmental protection as the main frame and the environmental impact assessment have been formulated. The recommendations for integrated river basin management have been put forward. The opinions on implementation of the Master Plan have been put forward. The effect of the implementation of the Master Plan has been analyzed.

In the general planning system, it has been defined that the main tasks of the governance, exploitation and protection should be multipurpose utilization of water resources, flood control and disaster mitigation and environmental protection. In the principles of comprehensive governance and multipurpose utilization, with the tenet of promoting harmony between human being and nature and full play of the multiple service function of the river, the objective of the general planning has been put forward as achieving coordinated development of resources, economy, society, and environment. The control indicators for the ecological base flow, the water quality objective and the flood control of the controlling profile have been put forward. The general planning layout has been finalized through research.

1 Nature Overview of Basin

The Magdalena River Basin lies between N 1°33'-11°07' and W 72°17'-76°38', with an area of 266,500 km^2, accounting for 23% of Colombia's territory area. It borders the Caqueta River, one tributary of the Amazon River, to the south, the Caribbean Sea on the north, the Orinoco River Basin to the east, and small river basins in the east bank of the Pacific Ocean to the west.

The Magdalena River originates from a Lagoon on the las Papas Plateau of the Andes, runs from south to north through 11 departments including Huila, Tolima, Cundinamarca, Caldas, Boyacá, Antioquia, Santander, Bolívar, Cesar, Magdalena, and Atlántico, and finally joins the Caribbean Sea. The mainstream of the River is 1,613 km long with a total drop of 3,685 m. Its tributaries extend to Bogota D.C. and 8 departments, i.e. Cauca, Valle del Cauca, Quindio, Risaralda, Cordoba, Norte de Santander, Sucre, and La Guajira.

1.1 Physical Geography

1.1.1 Topography

The Basin of the Magdalena River (including the Cauca River) is about 420 km wide in east-west and about 1055km long in north-south. The basin runs through multiple geomorphic units, including high and medium tectonic denuded mountains, low hills, valley basins in the upper basin and low hills, denuded peneplains, alluvial plains, lake plains and marshland in the middle and lower basin.

The basin lies in the central and western Colombia, which mostly belongs to the Andes Mountain. The land relief is high in the south and low in the north. The river head in the south has an elevation of 3,685 m a.s.l., and Caribbean alluvial plain lies in the north, with an elevation of generally less than 100 m a.s.l. The Andes have three ranges in Colombia, i.e. the western range(Cordillera Occidental), the central range (Cordillera Central) and the eastern range (Cordillera Oriental). The central range is the watershed between the Magdalena River and its largest tributary, the Cauca River. Most ridges have elevation higher than 3,000 m a.s.l., among which the volcano Nevado del Huila has an elevation of 5,365 m a.s.l. The main stream of Magdalena River runs between the eastern range and the central range. The Cauca River Basin lies between the central range and the western range. See Fig. 1.1-1 for the topographical features of the basin.

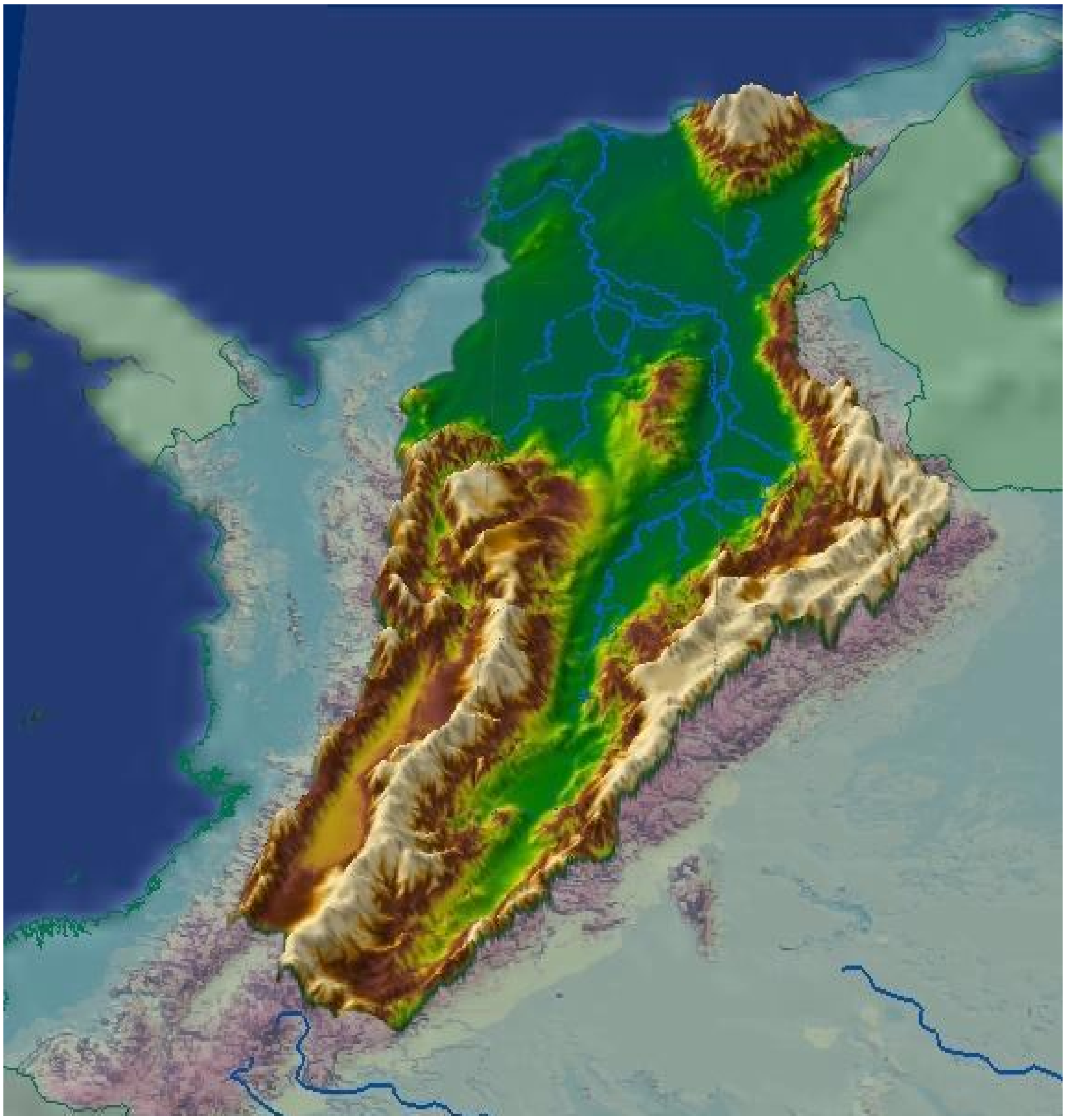


Fig.1.1-1 Topography of the Magdalena River

1.1.2 Overview of River System and River Reaches

The basin has well developed river system and numerous tributaries. There are 66 tributaries with a catchment area of more than 1,000 km^2, of which 9 primary tributaries have catchment area of more than 5,000 km^2, and 4 primary tributaries, i.e.

Sogamoso, Cesar, Cauca, and San Jorge, have catchment area of more than 10,000 km^2. The latter four rivers have a total catchment area accounting for 45.6% of the basin, joining the Magdalena River in the middle and lower reaches. The river system of the Magdalena River Basin is shown in attached Map 1, and the primary tributaries with catchment area more than 500 km^2 are shown in Table 1.1-1.

Table 1.1-1 Statistics on Areas and Lengths of Primary Tributaries

Location	Name of Tributary	Area (km²)	Length (km)	Location	Name of Tributary	Area (km²)	Length (km)
Upper basin	GUARAPAS	861	56	Middle basin	GUARINO	783	92
	SUAZA	1565	89		LA MIEL	2200	104
	PAEZ	4450	127		NEGRO	4610	214
	YAGUARA	1510	59		COCORNA	845	86
	NEIVA	1199	71		ERMITAÑO	501	78
	BACHE	1501	105		NARE	5756	187
	VILLAVIEJA	573	50		SANBARTOLOME	2645	115
	AIPE	958	81		CARARE	7263	274
	PATA	592	57		OPON	3470	179
	CABRERA	2500	115		SOGAMOSO	23450	348
	PRADO	1519	74		CIMITARRA	4039	179
	SALDAÑA	9240	199		SIMITI	3034	125
	LUISA	752	98		LEBRIJA	8790	258
	SUMAPAZ	3142	137		MORALE	1428	80
	BOGOTA	5987	305		RIO SIMANA	900	85
	COELLO	1767	108	Lower basin	CESAR	21590	379
	SECO	546	52		CÑO CULEBRA	657	21
	TOTARE	1524	76		CÑO CHIMICUICA	3687	127
	RECIO	656	76		CUENCA AFERENTE A LA CGA GRANDE	6858	130
	LAGUNILLA	868	88		CAUCA	59840	1183
	GUALI	815	96		SAN JORGE	16700	395

The main stream of the Magdalena River upstream of Honda is the upper Magdalena River, with a length of 663 km, a drop of about 3,495 m, and a basin area of 55,441 km², accounting for 20.8% of the entire basin. The main tributaries joining the upper

Magdalena River include the Saldana River and the Bogota River. The reaches upstream of Betania Reservoir are mostly of canyon, with a length of 251 km and a drop of 3,200 m, accounting for about 87% of the total drop of the main stream, and the reaches about 112km long downstream of the river head have a drop of 2,790 m. The reaches from Betania Reservoir to Honda have a length of about 412 km, and a drop of about 295m. The valley in most reaches is wide except the about 40 km long river section downstream of Girardot and the about 8 km long section upstream of Honda. The area near the river bank is of hill or low hill topography with floodplain and terrace distributed, and is the main area of agriculture and animal husbandry.

The river section from Honda to El Banco (upstream of the Cesar estuary) are the middle Magdalena River, with a length of 556 km, a drop of about 164 m, and a basin area of 84,261 km2, accounting for 31.6% of the entire basin. The river section downstream of Salgar have gradually widening riverway, small slope, and flood protection wall and dike along the river. The main tributaries joining the river in the reaches include Nare River and Carare River. The reaches downstream of Barrancabermeja have even and wide land on both banks with the joining tributaries of Sogamoso River and Lebrija River, where many lakes and marshland exist, prone to flood disaster.

The reaches downstream of El Banco (upstream side of Cesar estuary) are the lower Magdalena River, with a length of 394 km (to Barranquilla Port), a drop of about 26 m, and a basin area of 126,839 km^2, accounting for 47.6% of the entire basin. The lower basin is the Caribbean alluvial plain with low relief and have large seasonal floodplain with tidal flat, waterway and lake/marsh wetland system due to 3 main joining tributaries including the Cauca River, the Cesar River, and the San Jorge River. The Ciénaga Grande de Santa Marta lies on the right bank of the estuary.

The tributary Cauca River originates from the Sotará plateau wilderness, about 50km northeast of the head of the Magdalena River. The Cauca River is 1,180 km long in main stream and joins the Magdalena River near Pinillos, Bolívar Department. Its basin area is 59,840 km^2, accounting for 22.45% of the total Magdalena-Cauca basin. The Cauca River flows almost in parallel with the main stream of the Magdalena River and the annual water volume accounts for 32.3% of the total water volume of the entire Basin. The Magdalena River Basin is also customarily referred to as

Magdalena-Cauca River Basin.

1.1.3 Climatic Characteristics

The Magdalena River Basin is located in a tropical region near the equator. Its climate change during a year is small. The climate characteristic difference of the basin is mainly affected by topography. Most areas in the basin has clear rainy season and dry season in a year, the former covering April, May, October, and November, while the latter covering December ~ next February and July and August.

The temperature change during a year is small. Affected by the topography, different elevations have many climate characteristics from tropical to frigid climate. San Agustin in the upper basin is located at an elevation of about 1,600 m, with an annual average temperature of only 17.8□. The area downstream of Neiva is a valley and hilly area, with high temperatures and average temperature of 27□ - 29□. Barranquilla at the estuary has an average temperature of 27.8□. There are several mountains with an elevation exceeding 5,000m in the basin and the top of the mountains is covered by snow all the year round.

The Magdalena River Basin has abundant rainfall, but there is large difference between areas. The middle basin has the highest rainfall, especially the central range area downstream of Honda between the left bank and the Cauca River, where the rainfall is very abundant, even more than 5,000 mm in some locations. The precipitation is retively low in the upper basin and the Caribbean plains, especially in the area from Neiva to the head of the Betania Reservoir and the west side of the area from Bogota to Tunja along the eastern mountain range, where it features with low precipitation value, with an average annual precipitation of less than 1500 mm. Many areas in the basin have two rainy seasons and the bimodal distribution of two rainy seasons in the middle basin is obvious. Rainstorms in the middles basin are remarkable. The maximum 24h rainstorm precipitation is 690mm at Salada La station. Berrio and Barrancabermeja on the main stream have an average annual maximum 24h rainfall of 114.3 mm and 115.2 mm respectively, and an measured maximum 24h rainfall of 182.0 mm (in 1983) and 188.4 mm (in 1979) respectively.

The basin has an average annual evaporation of 1500 mm ~ 2100 mm, an average annual wind speed of 1.3 m/s ~ 2.6 m/s, an average annual relative humidity of about 70% in the middle basin and about 80% in the upper and lower basin, an annual solar radiation duration of about 1,500 h in the area upstream of Betania Reservoir and more than 2000 h in the area downstream of Neiva.

1.2 Runoff

The Magdalena River Basin is rich in water resource, with an average annual runoff of about 912 mm (about 1000 mm in the Amazon Basin). Similar to the rainfall distribution in a year, the runoff in most areas in a year is in a bimodal distribution. The monthly runoff measured at the hydrological gauging stations on the main stream accounts for 4.76% ~ 11.88% of the annual runoff and the interannual change is small.

The upper basin has an average annual flow of 1,294 m^3/s, and annual runoff of 40.8×10^9 m^3, accounting for 17.4% of the Calamar hydrological gauging station on the lower reaches. The ratio of the maximum average annual flow to the minimum one is 2.0. The mean monthly runoff accounts for 5.98 % ~ 11.29% of the annual runoff. The runoff is relatively high from April to June and from November to December, and relatively low from January to February and from August to September.

The middle basin has an average annual flow of 4,054 m^3/s (at Penoncito station), and an annual runoff of 127.8×10^9 m^3, accounting for 54.5% of the hydrological gauging station on the lower reaches. The figure is 37.1% higher than that of the upper reaches. The runoff increment in the middle reaches is high. The ratio of the maximum average annual flow to the minimum one in the middle river is 2.0. The average monthly runoff over years accounts for 5.18% ~ 11.88% of the annual runoff. The monthly runoff is relatively high from April to June and from October to November, and relatively low from January to February and from August to September.

The Cauca River has an average annual flow of 2,408 m3/s (at Las Varas Station), and an annual runoff of 75.9×10^9 m^3, accounting for 32.3% of the hydrological gauging station on the lower reaches. The interannual runoff change is small. The average monthly runoff over years accounts for 5.01% ~ 11.19% of the annual runoff. The runoff is relatively high from October to November, and relatively low from February to March.

Calamar Hydrological Gauging Station on the lower river covers a catchment area of 257,438 km^2, accounting for 96.6% of entire basin area, with an average annual flow of 7,443 m^3/s, and an annual runoff of 234.7×10^9 m^3. The interannual runoff change is small. The maximum and minimum annual flows are 139% and 62.3% of the mean annual flow respectively, with a ratio of 2.2. The runoff in a year is evenly distributed, with a maximum mean monthly flow of 10,399 m^3/s and minimum of 4,245 m^3/s. The mean monthly runoff over years accounts for 4.76% ~ 11.67% of the annual runoff. The runoff is relatively high from October to December, and relatively low from February to April.

The hydrological gauging stations on the main stream of the Magdalena River (see Fig. 1) and the interval runoff characteristics (see Table 1.2-1) basically reflect the situation of the regional runoff, and the average annual flow and control catchment area are well correlated.

Table 1.2-1 Hydrological Gauging Stations on the Main Stream and Corresponding Interval Runoff Characteristics

Area	Code of Hydrological Gauging Station	Catchment Area	Average Annual Flow	Average Annual Runoff Depth
		km^2	m^3/s	mm
Upstream of Pericongo	2102701	3650	158	1365
Pericongo -Neiva	2102701, 2109707	12055	330	863
Upstream of Neiva	2109707	15705	488	980
Neiva~ Purificación	2109707, 2113701	10410	275	833
Purificación ~ Nariño	2113701, 2123701	21795	395	572
Nariño -Arrancaplumas	2123701, 2123702	6449	111	543
Upstream of Arrancaplumas station	2123702	54359	1269	736
Basin upstream of Honda in the upper reaches	2123702	55441	1294	736
Honda-Salgar	2123702, 2303701	2591	157	1911
Salgar-Berrio	2303701, 2309703	17642	948	1695
Berrio-Sitio Nuevo	2309703, 2318728	43259	1300	948
Sitio Nuevo-Penoncit	2318728, 2502733	21806	365	528
Basin upstream of Penoncit in the middle reaches	2502733	139657	4054	915
Cesar River Basin	2502733, 2502702	21635	132	192
Cauca River Basin	2502720	59013	2408	1287
El Banco-Calamar (excluding Cauca River)	2502720, 2502702, 2903702	37133	776	659
Basin upstream of Calamar in the lower reaches	2903702	257438	7443	912
Dique Canal division	2903736	Average annual divisional flow is 462 m^3/s, accounting for 6.3%.		

1.3 Flood

Floods in the Magdalena River Basin are caused by rainstorm. The average annual peak discharge and periodic flood volume increase gradually with the catchment area, especially in the middle basin, where the increase is relatively large. As there are two rainy seasons during a year, there are correspondingly two flood periods (April ~ June and October ~ December), which features that the upper and middle reaches have larger flood in the first flood period, and the lower reaches have larger flood in the second flood period. The area upstream of Betania Reservoir in the upper basin has small average annual maximum peak discharge and periodic flood volume but large modulus. The reaches near Honda and from Ladorada to Berrio of the middle reaches have large peak discharge and periodic flood volume increment, and long flood duration. The flood in the lower reaches lasts very long.

The upper basin has an average annual maximum peak discharge and maximum monthly flood volume of 3579 m^3/s and 4.45×10^9 m^3 respectively (correspondingly, 4.11×10^9 m^3 for November of downstream), which are about 30.4% and 16.5% (15.2%) of those measured by Calamar station in the lower reaches. A flood in the reaches lasts for 3 days to 10 days in general. The measured maximum peak discharge is 5090 m^3/s, and measured maximum monthly flood volume is 8.36×10^9 m^3.

The middle basin has an average annual maximum peak discharge and maximum monthly flood volume of 6340 m^3/s and 14.95×10^9 m^3 respectively (on November), which are about 53.8% and 55.4% of those measured by Calamar hydrological gauging station, and 77% and 236% higher than those of the upper reaches. The middle reaches are important area where floods form in the basin. The flooding time in the reaches lasts for more than 45 days in general, with peak duration of about 3 days. The measured maximum peak discharge is 11200 m^3/s, and measured maximum monthly flood volume is 28.1×10^9 m^3.

The Cauca River has an average annual maximum peak discharge and maximum monthly flood volume of 4076 m^3/s and 8.49×10^9 m^3 respectively, accounting for 34.6% and 31.4% of those measured by Calamar hydrological gauging station respectively. The annual maximum flood process is generally more than 40 days. The measured maximum peak discharge is 4800 m^3/s, and the measured maximum monthly flood volume is 11.4×10^9 m^3.

Calamar hydrological gauging station in the lower basin has an average annual maximum peak discharge of 11780 m^3/s, and average monthly maximum flood volume over years of 27×10^9 m^3. The measured maximum peak discharge is 16900 m^3/s, and the measured monthly maximum flood volume is 42.4×10^9 m^3.

The area on the left bank in the middle basin and The Cauca River basin area important sources of floods in the lower reaches. The 22.9% catchment area at the control station of the Cauca River Basin brings about 31.4% monthly flood volume. The 33.1% catchment area of the interval between the two control stations on the middle Magdalena collects about 38.9% flood volume whereas the 22.8% catchment area of the interval between the two control stations of the lower Magdalena (excluding the Cauca River Basin) forms only 13.6% flood volume. The wetlands, swamps in the middle and lower basin, especially wetlands, marshes and other depressions downstream of El Banco, have important influence to flood regulation, resulting that the peak discharge magnitude of floods in the lower reaches is not large (the measured maximum peak discharge is 16900 m^3/s) but the flood lasts very long (usually more than 60 days).

1.4 Sediment

The Magdalena River has relatively large sediment load. As an important hydrological gauging station in the lower basin, Calamar hydrological gauging station has a catchment area accounting for 96.6% of the basin, and its sediment characteristic value basically reflects the suspended sediment in the basin.

Calamar hydrological gauging station has an average annual suspended sediment load of 149.65×10^6 t, a mean annual sediment concentration of 0.637 kg/m^3, an average annual suspended sediment load modulus of 581 t/km^2, and maximum average monthly sediment load of 48.48×10^6 t. The ratio of the maximum annual sediment load to the minimum one is 4.7, indicating that the interannual change is relatively large. The maximum annual sediment load is 323.5 million ton. The mean monthly sediment load of each month accounts for 3.29%~13.96% of the annual sediment load, where the sediment load from October ~ December accounts for 38.89% of that of the whole year and the sediment load from February ~ April accounts for 10.85% of that of the whole year, showing a non-obvious bimodal distribution within a year. The mean annual sediment load of the station is 164.16 million ton after the establishment of the Betania Reservoir.

The upper Magdalena upstream of Betania Reservoir (with a catchment area of 13572 km^2) has an average annual suspended sediment load of 2.02×10^6 ton ~ 6.75×10^6 ton, and relatively large sediment load modulus. The Magdalena River downstream of Betania Reservoir are obviously affected by Betania Reservoir. The Neiva River has an average annual sediment load of only 4.85×10^6 after completion of the reservoir, down by 73.6% compared with that before completion of the reservoir. After the reservoir is completed Honda and Berrio Reaches have average annual sediment load down by more than 50% compared with that before the reservoir is completed. The mean average suspended sediment load of the control station of the upper Magdalena River is 18.3 million ton after completion of Betania Reservoir, which is 11.1% of that of the control station of lower reaches in the same period. The sediment load from October ~ December accounts for 33.07% of that of the whole year.

The middle Magdalena River from Berrio to El Banco has an average annual suspended sediment load of 62.49×10^6 ton, accounting for 41.8% of that in the lower reaches; the middle Magdalena River has large sediment yield, with an average annual sediment load modulus of 960 t/km^2. The river reaches of Honda ~ Ladorada and San Pablo ~ Peñoncito have average annual sediment load modulus of more than 1300 t/km^2; these reaches have the highest sediment load modulus in the main stream of the Magdalena River. Rainstorm, soil erosion and riverbank erosion are important causes of increased sediment in the middle reaches. The mean annual sediment load of the control station at middle reaches has been 95.2 million ton since the establishment of Betania Reservoir, which accounts for 58.0% of that of the control station on the lower Magdalena in the same period. The sediment load from October ~ December accounts for 32.11% of that of the whole year.

The Cauca River has an average annual suspended sediment load of 54.75×10^6 ton, accounting for 36.6% of that of the control station at lower reaches, and sediment load modulus of 928 t/km^2, indicating that the area has relatively large sediment load modulus and sediment yield. The mean annual sediment load of the same period of main stream is 54.81 million ton, which accounts for 33.4% of that of the control station on the lower Magdalena River of the same period. The sediment load from October ~ December accounts for 33.36% of that of the whole year.

1.5 Regional Geology

The Magdalena River Basin is mostly of the three mountain ranges of the Andes, including the western mountain range (Cordilleras Occidental), the central mountain range (Cordillera Central), and the eastern mountain range (Cordillera Oriental). It is caused by the interactions of tectonic plates to the west of Nazca or the Pacific Ocean and north of Caribbean Sea. The central mountain range is the highest. The part from Ecuador to Antioquia has elevations of more than 3000 m a.s.l., which is caused by Antioquia magma intrusion. As the magma intrusion weakens, the mountain range height decreases rapidly from south to north, and is divided into several small branches, ending at the Caribbean plains. The western mountain range is the extension of the western range of Ecuador Andes; it is the western boundary of the basin and western slope of Valle del Cauca, and extends northward into the Caribbean plains. The eastern mountain range is the youngest of all the ranges; it branches from the central mountain range, extending northward until the Norte de Santander plain.

The Magdalena River Basin has outcrop of strata from Precambrian to Cenozoic Quaternary. Three types of rocks, i.e. magmatic, sedimentary and metamorphic rocks, are distributed in the basin. The Precambrian strata are distributed in the core area of the central mountain range, the Sierra Nevada de Santa Marta (snow mountain ranges), and Santander Mountain (Macizo de Santander), in the form of an independent mountain and generally narrow shape; it is mainly comprised of metamorphic rocks. The Paleozoic strata include Permian, Carboniferous, Devonian, Silurian, Ordovician and Cambrian rocks, with outcrop area accounting for 9% of the basin; it is mainly distributed in the central mountain range (Cordillera Central), with a small part in the western slope of the eastern mountain range (Cordillera Oriental) and a small independent mountain on the Sierra Nevada (snow mountain ranges); its rocks include magmatic metamorphic and sedimentary rocks. The Mesozoic Jurassic and Triassic strata are distributed in the Sierra Nevada de Santa Marta (snow mountain ranges), the western slope of the eastern mountain range, Ibague laccolith of the central mountain range, and Perijá mountainous area; the main rock type is igneous rock. The Mesozoic Cretaceous stratum is mainly distributed in the western slope of the eastern mountain range, Baudo of the central mountain range, Sierra Nevada and serranía del Perijá, with outcrop area accounting for 18% of the basin. The main rock types include intrusive rock, Baudo volcanic rock, and sedimentary rock. The Cenozoic Tertiary strata are distributed in the bottom of the Magdalena valley and the northeastern part of the basin. It is the main stratum of the basin, covering 26 % of the area. Its maim rock types include intrusive rock and pyroclastic sedimentary rock. The Cenozoic Quaternary stratum is composed of loose sediments, widely distributed on the riverbed and alluvial plains in the middle and lower reaches.

The mountain ranges are mostly anticline tectonics with granite, gneiss and other rocks exposed at the axial part, and residues of sandstone and limestone of Cretaceous and Tertiary on both wings. The Andes are young fold mountain system formed by plate movement in the early geologically active Cenozoic Era (66.40 million years ago to present). With several folding, uplifting and fracturing, magma intrusion and volcanic activity, crustal activities remain. The region has large-scale fracture structure developed. The Magdalena River Basin is located in the volcanic and seismic zone of Pacific Rim. A series of active volcanoes are distributed in the central mountain range on the west of the Magdalena River about 60km ~ 70km from main stream in straight-line distance. Volcanic materials are distributed in most reaches of the basin, and regional faults developed along the river also exist in the basin. According to Colombia's historical earthquake distribution, earthquakes with magnitude above M5.5 occurred mainly in the upper Magdalena River Basin, as shown in Fig. 1.5-1 Colombia's Historical Earthquake Epicenters Map (M5.5+). As per Colombia's seismic peak ground acceleration zoning map, the main stream of the Magdalena River has seismic peak ground acceleration with 50-year exceedance probability of 10% decreasing gradually from 0.35g in the upper reaches to 0.10g in the lower reaches, and the corresponding basic earthquake intensity is VIII~VII, as shown in Fig. 1.5-2 Seismic Peak Ground Acceleration Zoning Map of the agdalena River.

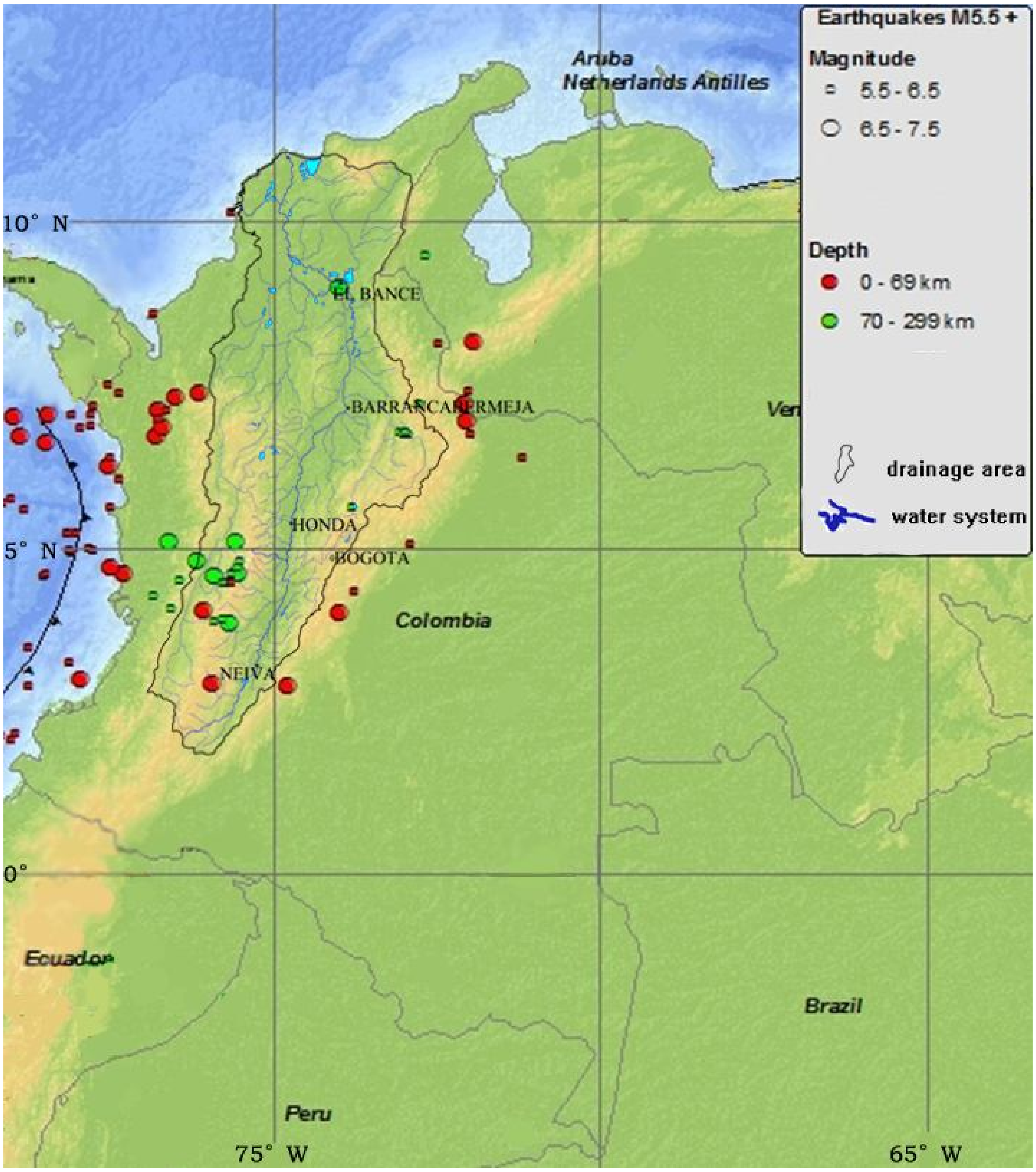


Fig. 1.5-1 Colombia's Historical Earthquake Epicenters Map (M5.5+)
(Source: USGS)

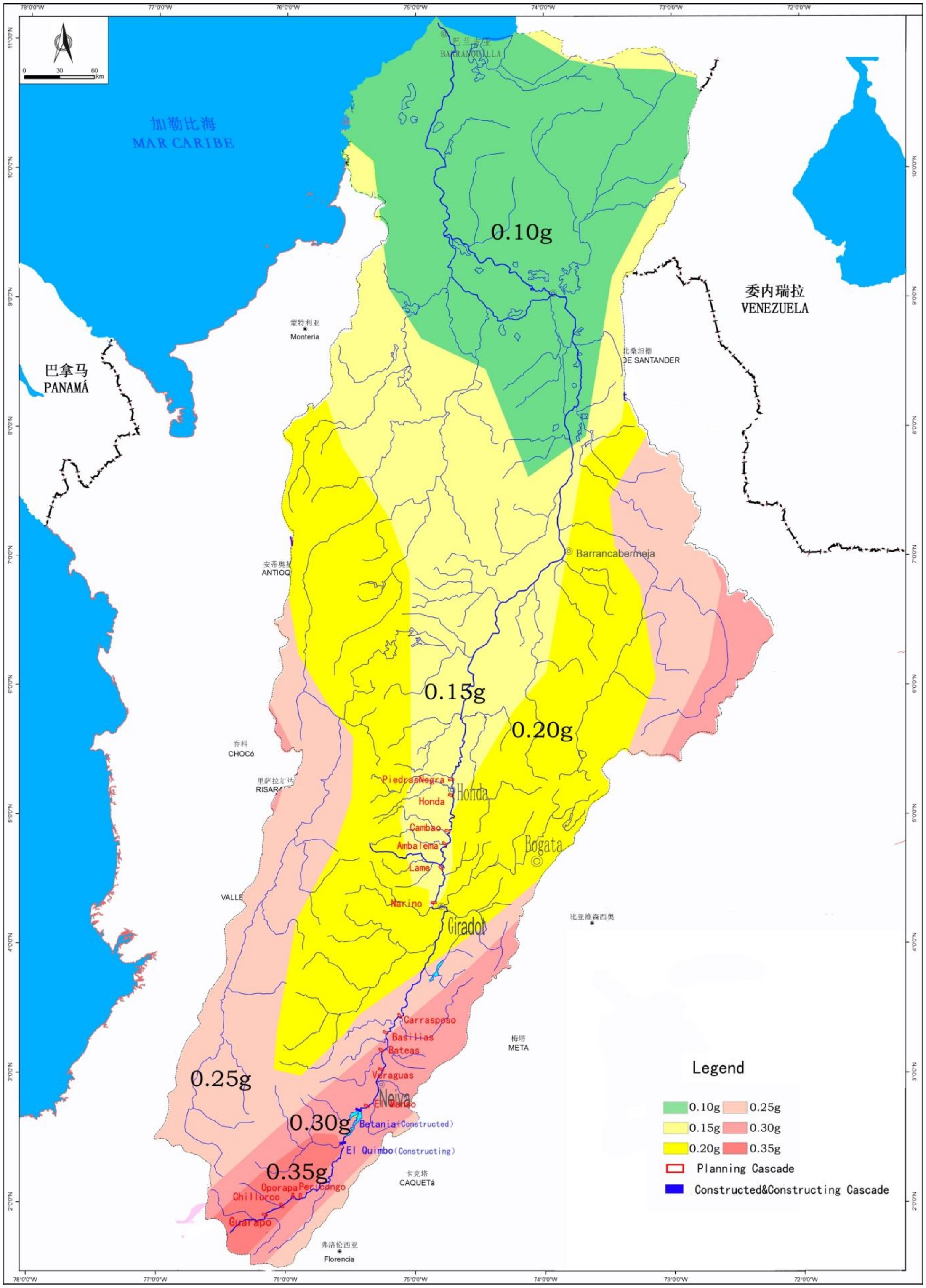


Fig. 1.5-2 Seismic Peak Ground Acceleration Zoning Map of Magdalena River

1.6 Natural Resources

The Magdalena River Basin is rich in water, land, hydropower, water transport and mineral resources.

The basin has an average annual runoff of 234.7×10^9 m^3, about 6700 m^3 per capita.

The basin has a per capita land area of 0.76 ha. It has relatively developed agriculture and animal husbandry, with existing arable land of 2.98×10^6 ha, accounting for about 65% of the country.

The developable installed capacity of the water power resource in the basin is 35,440 MW (as per the census in 1978, with single-station installed capacity of more than 100MW), accounting for 38.6% of the country, while the developable installed capacity on the main stream of the Magdalena River is 6,821 MW, accounting for 19.2% of basin.

The basin has rich mineral resource. Colombia has the largest coal reserves in Latin America, with geological reserves of about 24×10^9 tons, mainly distributed in the Magdalena River Basin. Oil and gas resources in the basin are mainly distributed in the upper and middle Magdalena River basin. Phosphate, gypsum, iron-limestone, limestone, emerald, precious metals, copper, nickel, marble and granite are distributed in the basin.

The Magdalena River is a navigation artery connecting Colombia's main inland production and consumption centers with the coastal area. The navigable length of its main stream and tributaries is 2,770 km in total.

1.7 Ecological Environment

The basin has a complex and diverse ecosystem. Its main vegetation is natural secondary forest vegetation, which is followed by commercial forest, hygrophilous vegetation, mangroves at estuaries, with forest coverage of 26.36%. Its wetland ecosystem has an area accounting for 2.56% of the basin. In the basin, there are 21 natural ecological reserves and 2 important animal and plant protection bases, taking the natural ecology as the object to be protected; in the planned area, there are 14 national forest reserves, 1 wetland reserve proposed by an international convention, and 21 plants to which conservation priority is given.

The basin is rich in species of animals and plants. There are about 230 timber species, mainly including pine, eucalyptus, cedar, nagkassar, olive, etc. There are 2735 animal species, including 1721 bird species (20% of the bird species in the world), 54 amphibian species (ranking the 2^{nd} in amphibian species number in the world), 506 reptile species and 454 mammal species (the two ranking the 6^{th} in their species number in the world). In the basin there are also a large number of Colombia-specific species and 66 vertebrate species to which conservation priority should be given.

The basin has 112 waterfowl species in 10 orders and 23 families, 202 fish species in 11 orders, 39 families and 102 genus, 43 large benthonic animal species, 81 large invertebrate species, 321 phytoplankton species, 49 zooplankton species and 79 Epiphytic organisms species, including 51 special fish species, 23 important endangered fish species, 35 migratory fish species, 42 fish species distributed in wetland and marsh and 26 fish species having large commercial values.

1.8 Natural Disasters

a) Floods and Waterlog

Colombia suffers relativley serious floods and waterlog. According to IDEAM's statistics, 28% of the population and 12% of land in Colombia are vulnerable to the threat of floods. According to the Document Country - DP 2010, the number of floods in the period from 1989 to 2009 accounts for 48% of the total number of disaster events in Colombia. According to DesInventar database, since 1970, the number of houses damaged and people dead due to floods account for 43% and 10% of the respective total number of those of all disasters. The Magdalena River Basin has abundant rainfall, with widely distributed areas that are liable to floods and waterlog, which are mainly concentrated in the plains in the middle and lower basin. Since there are two rainy seasons, flood disaster may occur twice in a year. secondary disasters such as landslides and debris flows caused by floods and mountain torrents in local area frequently occur in mountainous and hilly areas in the main stream and tributaries in the upper basin. In recent years, the Magdalena River basin frequently suffers flood disasters, and the most serious conditions occurred in 2010 and 2011. According to statistics, due to the floods in these two years, about three million people became homeless, 570,000 houses were damaged, 813 schools and 15 health service centers were affected. For humanitarian assistance and rehabilitation of damaged public facilities, the budget for the investment to the projects to be constructed from

2011 to 2014 is estimated to be 3% of Colombia's national GDP in 2011.

b) Draughts

The basin has abundant rainfall in general, but some areas remain affected by droughts in some periods. As per the drought indicator classification specified in *Atlas Cuenca del Rio Grande de la Magdalena*, the Bogota area in the basin is quite short of water; the upper and lower basin area is at the brink of water shortage, while the other areas has rainwater sufficient to meet local demand.

c) Seismic and volcanic disasters

The Magdalena River Basin is located in the circum-Pacific volcanic and seismic zone, where earthquake often occurs. An earthquake measuring 5.5 magnitude on the Richter scale hit Popayan, Cauca Department on March 31, 1983, with epicenter about 5 km northwest to Popayan, killing 250 persons. Another earthquake measuring 6.6 magnitude on the Richter scale hit Silvia, Cauca Department on June 6, 1994, causing a series of secondary disasters such as landslides and mountain torrents, killing more than 200 persons, more than 100 persons missing, and damaging 620 houses in vairous degrees. An earthquake measuring 6.2 magnitude on the Richter scale hit Armenia, El Quindio Department on January 25, 1999, killing 1,230 persons and damaging more than 5,600 buildings.

As per the *Atlas of Volcano Disasters in Colombia*, a series of active volcanoes are distributed in the Central Cordillera in the Magdalena River Basin, on the west of the Magdalena River 60 km - 70 km in aerial distance from the main stream. The main types of volcanic disasters include volcanic earthquakes, volcanic gases, volcanic airborne substance, pyroclastic flow, lava flow, lahar, volcanic shock wave, etc. Secondary disasters such as debris flows triggered by volcanic eruptions and landslides caused by earthquake are serious. Ruiz Volcano erupted for the second time in 1985, which caused debris flow damaging Armero Town about 10 km from the Magdalena River and killing 25,000 persons.

2 Current situation of Governance, Development, and Protection of the Basin and Existing Problems

Certain achievements have been obtained in restoration of navigation, hydroelectric development, construction of infrastructures for flood control, irrigation, and protection of aquatic ecosystem and environment in the Magdalena River Basin, which have promoted economic development and social progress of the basin. However, there still exist several problems, such as low multiple utilization level of water resources, frequent floods and waterlog, relatively serious soil erosion, bad water quality and water ecology, backward construction of navigable channels and ports, and incomplete basin integrated management.

2.1 Current situation

2.1.1 Current situation of Multipurpose Utilization of Water Resources

a) Navigation. After improvement and dredging of the navigable channels and gradually restoration and upgradation of ports for some years, the navigation conditions of the Magdalena River have been greatly improved. The current waterway transport network mainly consists of 887 km of the main stream downstream of Salgar, 114 km of the Canal del Dique, and 187 km of the lower tributary Cauca River. Among those navigable channels, 631 km downstream Barrancabermeja and the Canal del Dique are for one thousand tons. A navigation network connecting the inland with the Caribbean coastal urban ports has been preliminarily formed. In 2011, freight volume in Magdalena River is 2,240,000 t (including oil product of 2,060,000 t), and passenger volume is 2,110,000 persons. The riverway plays a very important role in the development of petroleum industry and regional economy.

b) Hydropower. Electric system in Colombia is dominated by hydropower. In 2009, the hydropower installed capacity was 9,001 MW, taking up 66% of total installed capacity and with hydropower stations mainly distributed in the Magdalena River basin. The hydropower resources in the basin and the hydropower stations constructed or under construction are mostly distributed in the tributaries. Among those tributaries, the hydropower resources of the Bogota River and the Nare River are highly developed. The total installed capacity on the main stream is 960 MW, taking up 10%

of theoretical reserved hydropower resources of the main river, including one hydropower station with an installed capacity of 540 MW already constructed and one hydropower station with an installed capacity of 420 MW under construction. In the tributaries, large-scale hydropower stations under construction include: SOGAMOSO (820MW), ITUANGO (2400MW, 1200MW in Phase I), etc.

c) Irrigation. In the planned area, irrigation areas are mainly distributed in the river valley from Honda to the Betania Reservoir in the upper basin and the surrounding plains of the Dique Canal in the lower basin. The area of constructed irrigation areas is 153,896 ha, in which there are 12 large and medium irrigation areas with an area of 145,893 ha, and 75 small irrigation areas with an area of 8,003 ha. Seventy-two percent of the large irrigation areas are applied with pumping irrigation method. Two irrigation areas are under construction, with a total design area of 24,225 ha.

d) Utilization of fishery resources. Capture fishery is the main source for food and income of the 46,000 riverside fishermen. According to 2002 fishery production in Colombia provided by INCODER (Instituto Colombiano de Desarrollo Rural), freshwater fish production and total catch (including marine fishery) in the basin respectively took up 62% and 18% of the total production and catch in Colombia. In order to protect and reasonably utilize the fishery resources in the basin, cage cultures in reservoir is developed with 107 aquaculture farms and 1770 aquaculture cages with a total area of 105.0 ha. There are 6,663 pond culture farms, including 17,836 aquaculture ponds with an area of 1,983.4 ha. Meanwhile, Colombia government issued relevant regulations on fishery resource management and capture management, and associations of fisheries are established. The river reaches of La Dorada-Honda, Puerto Boyacá, Puerto Berrío, Puerto Wilches-Barrancabermeja, Gamarra, El Banco, Magangué, Plato, San Cristobal- Canal and Barranquilla are the major areas.of fishery resource utilization

2.1.2 Current situation of Flood Control and Disaster Mitigation

The middle and lower Magdalena River have often suffered flood. Cities, towns and agricultural zones seriously threatened by floods have gradually been provided with partial flood control works such as embankment and flood protection walls. According to relevant data, 125 flood control works have been built till 2004, relieving the flood threat for more than 900,000 riverside residents. Villages seriously affected by disasters have been treated with measures e.g. overall elevating. In recent years, CORMAGDALENA has increased investment in flood control. Quality objects for flood reduction have been put forward in PMC implemented since 2007. The flood control measures of the plan mainly consist of mapping flood impact degree of various regions, establishing and maintaining warning system, consolidating riverside buildings possibly affected by flood, etc.

2.1.3 Current situation of Environmental Protection

For basin environmental protection, relevant laws and policies have been formulated, several studies have been developed, and plans as POMIN and PMC are put forward. Since 2000, bank protection, improvement of slope surface, forestation, sewage treatment, wetland protection and other works have been implemented.

a) Water environmental protection. Investigation and studies on status of the water resources of the basin and water environmental monitoring have been developed and relevant control and treatment plan on water pollution has been formulated. Domestic wastewater treatment rate for the cities within the basin is less than 10%, and household garbage treatment rate is about 23%. Water quality in the basin gets better but still poor in general.

b) Prevention and control of soil erosion. Relevant researches on soil erosion within the basin have been conducted. The area with above low degree of erosion takes up 81% of the total plan area. Prevention and control of scattered and small-scope soil erosion have been held. Slope remediation, ecology restoration as well as afforestation of small-scale basin, commercial plantation and river bank protection have been implemented. Area of commercial plantation is 19528 ha (84.5% in lower reaches and 15.2% in middle reaches). Certain achievements have been obtained in prevention and control of soil erosion, but the erosion is still serious.

c) Water ecological protection. Researches on basin aquatic biological resources, fish resources and wetland protection have been developed; 2 closed fishing seasons have been defined, and 3 fish proliferation and releasing stations have been built to restore fish resources; several actions dredging the connectivity among lakes, marshes and wetlands have been taken in downstream flooded areas, but aquatic ecological environment has not been improved radically.

2.1.4 Current situation of Integrated Management of the River Basin

Currently, CORMAGDALENA is mainly responsible for restoration of ports and channels under its administration, rational utilization and maintenance of lands, electricity generation and distribution, utilization and protection of environment, fishery resources and other renewable resources as well as coordination and management of the basin. Members of the board of directors consist of representatives from Ministry of Environment, Housing and Territorial Development, Ministry of Transport, Ministry of Trade, Industry and Turism, Ministry of Agriculture and Rural Development, Ministry of Mines and Energy, Ecopetrol and provincial and municipal governments along riverside. It is managed parallelly by water administrative affairs management and environment authorities as well as public utility companies for water supply and power supply within the plan area. The river management status is the coexistence of basin management, sectoral management and administrative regional management.

2.2 Major Existing Problems

2.2.1 Multiple Utilization of Water Resources to Be Further Promoted

a) Navigation. Since its foundation, CORMAGDALENA has done much work in waterway regulation and port construction of the Magdalena River, but at present, the waterway dependability is relatively low and the construction of port infrastructures is backward due to conditions of the waterway and defects in the support system. Navigation fails to give its full play of being the large channel for water transport in the comprehensive transport system and it is the bottleneck for outward transport of inland resources such as coal and petroleum. Therefore, it fails in optimizing industrial distribution and promoting regional economic development.

b) Hydropower. 1) The existing cascade development plan for the main steam of the Magdalena River has been 30 ~ 40 years up to now. The work to do includes the coordination of the relation between hydropower development and ecological environmental protection and reservoir inundation and the optimization and adjustment of the cascade development plan according to the current engineering technical-economic and social-economic conditions and the requirements of the environmental protection concept. 2) The exploitable hydropower resources of the

Magdalena River Basin accounts for 38.6% of that of the whole country, mainly distributed in the tributaries. At present, only 2 hydropower plants with good construction conditions have been developed on the main stream of the Magdalena River. Thus, the degree of development and utilization of hydropower resources is low. 3) The hydropower projects completed and under construction in the basin have been developed based on the results of the general hydropower resource investigation in 1978. These hydropower projects only have single function. Due to the lack of large control reservoirs in the basin, the requirements on multiple utilization including flood control, navigation and irrigation can not be satisfied at the present stage. 4) With insufficient combination between hydropower development and the promotion of local economic development, the contradictions with ecological environmental protection and resident relocation are prominent.

c) Irrigation. This basin is the area with the largest agricultural production potential and the major grain producing area in Colombia. Because of private ownership and high centralization of land, there is no systematic irrigation plan in Colombia. In addition, the government has not made enough investment in irrigation infrastructures and the investment mainly comes from the water users, so the development of irrigation is restricted. Due to serious aging problem and being out of repair for long years of the irrigation facilities in the existing irrigated area in the plan area and the lowutilization rate of irrigation water, supporting facilities and rehabilitation are needed. Currently, the irrigation area in the plan area only accounts for 22.7% of the farmland area, indicating a potential for enlarging of the irrigation area. Besides, the land resources are not in rational utilization, the suitable farmlands are occupied as grassland and urban land and careless agricultural cultivation method is applied.

d) Utilization of fishery resources. 1) The fish production decreases remarkably along with the decline of the fishery germplasm resources. The fishing production dropped from 80,000 t in 1960 to less than 20,000 t in 2010. 2) There are few species in fish culture. In the first half of 2012, the species of aquaculture were less than 10, mainly including *Tilapia mossambica* and the native species like *Prochilodus magdalenae, Petenia kraussii*, *Brycon moorei and Colossoma bidens*. 3) The potential of fishery production has not been exerted effectively. The number of idle ponds and the idle water surface account for 29.7% and 18.4% of the corresponding total number in the current situation respectively. The unit fish production is at a low level and the aquaculture method is careless. 4) The support system of fishery production is defective. The aquaculture enterprises are in small scale and disperse. Nearby sale mode is mostly adopted by the capture fishery. The associations of fisheries are in small scale and lack of effective communication mechanism. In addition, the high-efficient operation mode integrating the production, fishery supplies, processing and marketing has not been established.

2.2.2 Safety Guarantee System for Flood Control and Disaster Mitigation to Be Established

Flood and waterlog disasters frequently occur in the Magdalena River Basin. The construction of flood control structures falls behind and effective flood control and disaster mitigation system has not been formed. There is no flood control reservoir project on the main stream and the tributaries of the river, all reservoirs completed do not undertake the flood control task, and no flood retarding area has been planned along the river banks. The flood is mainly subject to natural regulation and storage by the natural lakes, marshes and wetlands along both banks of the middle and lower river. Due to the lack of regulation and control means, the flood control capacity is poor. At present, the major flood control measures along the Magdalena River are embankments and anti-flood walls, most of which are simple in construction without supporting facilities and fail to form a closed protective circle. The anti-flood capacity of the existing flood control works is rather limited. The PMC of CORMAGDALENA has planned some flood control and early warning measures like risk map, but in general, the construction of flood control projects in the Magdalena River Basin is still in the initial stage. In case of severe flood, no reliable countermeasures can be applied. Furthermore, the lack of scientific plan and managemen and negligence of flood control safety in the economic and social development of the flood plains also indirectly causes the increase in flood loss.

2.2.3 Environmental Protection to Be Intensified Urgently

The water environment quality is poor. To be specific, 80% of industrial manufacturers in Colombia are centralized in the basin and the major pollutant discharging and emitting enterprises are concentrated on petroleum, mineral, dairy product processing, etc. The basin is featured by structural pollution. There are a few industrial waste water treatment facilities which are proven with not good effect. In addition, 70% of agricultural production in Colombia is centralized in the basin, where it is developed with planting industry and breeding industry. Due to the lack of effective control measures, non-point source pollution shows an increasing tendency. The domestic waste water in the basin mainly comes from densely populated cities. The sewage treatment facilities and their processing capacity are in serious shortage. For these reasons, the level of waste water treatment needs further improvement. The overall water quality is poor in the basin. Particularly, obvious polluted belts along river banks are found at the urban river reaches.

Soil erosion is relatively serious. In the basin, the vulnerable natural environment, widely-distributed loose deposits and irrational overdevelopment and deforestation lead to the decrease of the forest area. This finally results in large soil erosion areas and relatively serious degree of soil erosion. The control of soil erosion is still at the beginning stage.

The aquatic habitat shrinks. Serious silting in the basin, with the addition of invasion and occupation of the lakes, marshes and wetlands by the development of agriculture and animal husbandry, lead to the shrinkage of the aquatic habitat in some water areas, the decreasing connectivity between rivers and lakes and the change of habitat conditions, all of which finally result in the decrease of the aquatic biodiversity and the amount deduction of fish resources.

Environmental monitoring system is in shortage. The environmental monitoring system is incomplete in the basin, so the information about current environmental status is deficient. Further normalization and institutionalization should be implemented for the environmental monitoring system of the basin.

2.2.4 Integrated Basin Management to be Further Strengthened

Though some progresses have been made in integrated management of the Magdalena River, the following problems still exist. First, the unified management of the river should be urgently strengthened, the practicle and high-efficient trans-department and trans-regional coordination mechanism needs urgent improvement, and the function division and joint-cooperation of the river management and administrative management needs further clarification and implementation. Second, the system of laws and regulations is unsound and it can not meet the requirements for integrated management of the basin. Third, the ability in integrated management of the basin still has a way to go in improvement. Fourth, the river plan system should be improved and the role of guidance and restraint of the river plan on governance, development and protection of the Magdalena River should be enhanced in the future.

2.3 Recognitions on Governance, Development and Protection of the Magdalena River

2.3.1 Complexity and Chronicity in Governance of the Magdalena River Basin

The major problems existing in the governance and protection of the Magdalena River are that: 1) utilization of water resources needs to be further strengthed; 2) the the safeguard system for flood control and disaster mitigation needs to be established; 3) environmental protection needs to be intensified urgently; and 4) the integrated management of the basin needs to be further improved. The channel evolution and environment governance of the river are quite complicated. Governance and development of the river should conuct scientific flood management, rational allocation, development, utilization and protection of water resources, effective prevention and control of soil erosion, improvement of the ecological environment and maintenance of the river health. As the basic characteristics of the River will hardly change in a relatively long time, the fundamental problems still exist. Therefore, the chronicity and complexity of the governance and development of the river should be fully expected and it is unrealistic to solve the problems about the river in a short time.

2.3.2 Overall Consideration of Requirements for Economic-social Development and Ecological Environment Governance

The Magdalena River Basin has an important strategic position in the economic and social development of Colombia, with the development, utilization and protection of the water resources of the river related to energy supply, food supply and regionally economic and social sustainable development in the country, the flood control of the river related to regional economic development and social security, and the ecological environmental protection related to the ecological security of the Magdalena River

Basin and relevant regions. Therefore, overall plan and all-round consideration, the combination of promoting the beneficial and abolishing the harmful, and attaching equal importance to development and protection should be applied in the governance, development and protection of the Magdalena River.

2.3.3 Consideration of Keeping River Healthy during Governance, Development and Protection

The Magdalena River has many natural and social functions such as navigation, power generation, irrigation, flood discharge, riverbed shaping, self-purification of water, ecology maintenance, recreation and tourism. It has been proved by historical experience that irrational development and utilization of water resources, large-scale discharge of pollutants and soil erosion lead to river channel sedimentation of the main stream and tributaries of the Magdalena River, serious water pollution and shrinkage of the aquatic ecological environment, all of which threat the health of the river and further affect the functions of the river. For this reason, keeping the river healthy is premise for the governance, development and protection of the Magdalena River. Strict water resources management system should be applied for unified management and regulation of water resources of the river. In addition, full consideration should be given to the water resources and the bearing capacity of the water resources and the economic growth mode should be changed to build a resource-saving and environment-friendly society.

2.3.4 Natural and Economic Laws to be Followed

Regarding to the governance, development and protection of the Magdalena River, the knowledge about natural laws should be acquired continuously in practice and emphasis should be laid on harmonious coexistence between human beings and the river. The economic laws should be followed, full consideration should be given to the factors such as supply-demand relationship, economic policy and social environment, and the coordination development among population, nature, resource, economy and environment should be well handled.

2.3.5 Integrated Management of the Basin to be Strengthened

The works in the governance, development and protection of the Magdalena River constitute a trans-regional & trans-department multiple and systematic project which involves the division of water right and authorization of all parties concerned and the adjustment and coordination of interest relationship. Therefore, perfect laws and regulations should be applied for overall management, adjustment, specification and guidance. Relevant laws, regulations and policies, which are adaptable to the characteristics of the river and can reflect the demand for basin management, should be formulated and issued and the authoritative, high-efficient and unified management and operation systems should be established and refined to provide legal environment and support for the health of the Magdalena River.

High technologies like IT technology should be fully applied to perfect the flow and sediment monitoring and forecasting system of the Magdalena River, so as to establish a technically-advanced scientific decision-making and support system and improve the modernization level in governance, development and protection of the basin. For key problems with significant impact, multiple departments and disciplines should be organized for tacking the problems and providing powerful science and technology support for the governance, development and protection of the Magdalena River.

3 Requirements of Economic and Social Development for Governance, Development and Protection of the Basin

Located in the central and western Colombia, the Magdalena River Basin is rich in land, minerals, water and other resources, with relatively high level of economic and social development. The economy of the basin has an extremely important position in Colombia' national economy. Growing population and sustained economic and social development poses higher requirements for governance, development and protection of the Magdalena River.

3.1 Current Economic and Social Status

3.1.1 Population and Distribution

Colombia has a land area of 1,142,000 km^2, including 32 departments and a capital district (Bogota), 1122 municipalities. It is the second most populous country in South America, with a total population of 45,510,000 in 2010 and an average population density of about 40 people/km^2. Its average annual growth rate of population was 1.22% from 2001 to 2010.

The Magdalena Rive Basin covers 19 departments and the capital district of Bogota, with 728 municipalities. The basin has population accounting for about 77% of the total population in Colombia, with an average population density of about 130 people/km^2 and urbanization rate of about 77%. Bogota, Medellin, Cali, Barranquilla and Cartagena are five major populated cities in the basin, with a total population accounting for 32% of that in Colombia. Except Barranquilla and Cartagena located on the bank of Atlantic coast, the other major cities are located in the mountainous areas in the middle and lower basin.

The region under the Master Plan covers 128 municipalities (47 in the upper basin, 24 in the middle basin and 57 in the lower basin) in 13 departments, with a population of 6,075,000 in 2010, accounting for 17.3% of the total population of the basin, with an average population density of about 87 people/km^2, and urbanization rate of 79.5%. Population is mainly concentrated in large- and medium-size cities such as Barranquilla, Cartagena, Soledad, Malambo, Magangué, Barrancabermeja, Girardot, and Neiva.

3.1.2 Current situation of Economic Development

Since 2001, Colombia's economy has maintained an overall steady growth. Its gross domestic product (GDP) growth rate from 2001 to 2010 was 1.7% - 6.9% (see Table 3.1.2-1), with an average annual growth rate of 4.1%. Its GDP reached USD 302.4 billion in 2010 (then current price) up by 4.0% from a year ago, with per capita GDP of about USD 6,650, with primary industry, secondary industry, and tertiary industry structure of 7.1: 35.0: 57.9. Its industry-based GDPs are listed in Table 3.1.2-2.

Colombia's regional economic development is very unbalanced, with economic focus mainly concentrated in large cities in mountainous area with high elevations or on coast; small and medium cities and towns and rural areas lag behind in economic and social development, with a high proportion of poor people.

Colombia's agriculture mainly includes crop farming, animal husbandry, forestry and fishery, which are distributed throughout the country. Coffee and fresh flowers are the most important agricultural exports and mainly distributed in the upper and middle Magdalena Rive Basin.

Colombia's industries mainly include mining and manufacturing industries. Coal and petroleum are its most important exports. The total coal production in 2001 was 75 million ton, with production areas mainly concentrated in the Departments of La Guajira (55%), Cesar (19%), Cundinamarca (9%), Boyaca (9%), and Cordoba (8%). The daily petroleum output in 2010 was 785000 barrels and the main production areas are concentrated in the eastern plains and the upper and middle Magdalena Valley. The manufacturing industry mainly includes food and beverage, sugar, textile, rubber, metallurgy, automobile and parts, cement, and petrochemical industries, etc., and the production areas are mainly concentrated in Bogota, Cali and Medellin with a small proportion in Barranquilla, Cartagena, Bucaramanga and Manizales..

Colombia's tertiary industry is well developed, and mainly concentrated in large cities such as Bogota and Medellin.

3.2 Layout of Economic and Social Development and Forecast of Indicators

3.2.1 Strategic Layout

As per Colombia's national development plan, the government intends to maintain sustainable steady growth of the overall economy in medium and long term and promote employment of the whole society by stimulating, encouraging and promoting the development of key industries to achieve the policy objective of improving the people's livelihood. In short term, the government will focus on promoting the development of five industries, including mining, housing, infrastructure construction, agriculture, and technology innovation, and exert its guidance function to fuel Colombia's overall economic development.

In recent years, the mining industry of Colombia develops relatively fast and gradually becomes the main driving force for the overall development of economy. The basin is rich in such natural resources as hydropower and mineral reserves. About 70% of Colombia's hydropower output, 40% of Colombia's coal industry, 16% of Colombia's petroleum industry, and all Colombia's petroleum refining industry are concentrated in this basin. The basin is dominated by light industries and six industrial corridors have been formed in the basin, as shown in Fig. 3.2-1. In addition to that the industrial corridor along the coast of Caribbean Sea covers Barranquilla and Cartagena cities in the estuary area of Magdalena River, there are three industrial corridors extending to the main stream of Magdalena River. Nevertheless, only the layout of local area of La Dorada/Salgar on the middle Magdalena River is arranged along the River. The gradual improvement and modernization of the navigation system of the Magdalena River will play an important role in the gradual formation and development of the industrial belt along the River.

Table 3.1.2-1 Colombia's GDP Statistics from 2000 to 2010

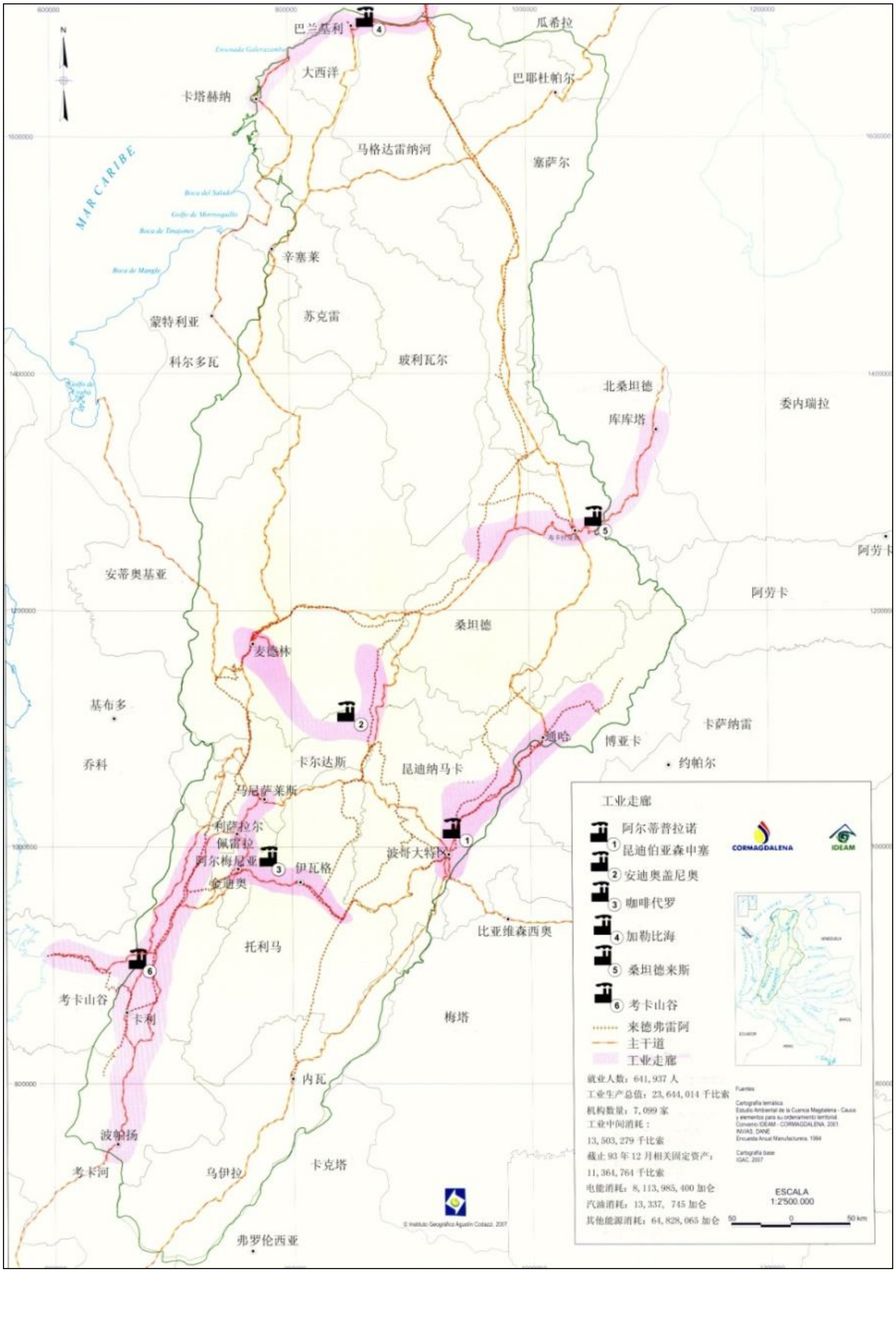
Year	GDP				Total Population	Per Capita GDP	
	Current Price Level		Based on Constant Price in 2005			Current Price Level	
	1×10^9 Pesos	Annual Growth Rate (%)	1×10^9 Pesos	Annual Growth Rate (%)		Pesos	Annual Growth Rate (%)
2000	208,531	-	284,761	-	40,295,563	5,175,036	-
2001	225,851	8.3	289,539	1.7	40,813,541	5,533,727	6.9
2002	245,323	8.6	296,789	2.5	41,328,824	5,935,881	7.3
2003	272,345	11.0	308,418	3.9	41,848,959	6,507,808	9.6
2004	307,762	13.0	324,866	5.3	42,368,489	7,263,936	11.6
2005	340,156	10.5	340,156	4.7	42,888,592	7,931,153	9.2
2006	383,898	12.9	362,938	6.7	43,405,956	8,844,362	11.5
2007	431,072	12.3	387,983	6.9	43,926,929	9,813,388	11.0
2008	480,087	11.4	401,744	3.5	44,451,147	10,800,329	10.1
2009	504,647	5.1	408,379	1.7	44,978,832	11,219,656	3.9
2010	544,924	8.0	424,599	4.0	45,509,584	11,973,830	6.7

Source: *Colombia's Annual National Economy Accounting* from DANE

Table 3.1.2-2 GDPs of All Industries in 2010

Type of Industry	Concepto	GDP (1×10^9 Pesos)	Proportion	
Primary industry	Agricultura, ganadería, caza, silvicultura y pesca	35,431	7.10%	7.10%
Secondary industry	Explotación de minas y canteras	45,960	9.21%	34.96%
	Industrias manufactureras	69,527	13.93%	
	Suministro de electricidad, gas y agua	19,658	3.94%	
	Construcción	39,340	7.88%	
Tertiary industry	Comercio, reparación, restaurantes y hoteles	63,210	12.66%	57.94%
	Transporte, almacenamiento y comunicaciones	34,681	6.95%	
	Establecimientos financieros, seguros, actividades inmobiliarias y servicios a las empresas	105,048	21.05%	
	Actividades de servicios sociales, comunales y personales	86,280	17.29%	
Total		499,135	100.0%	100.00%
Impuestos menos subvenciones sobre los productos		45,789		
PIB		544,924		

Source: *Colombia's Annual National Economy Accounting* from DANE


巴兰基利
瓜希拉
大西洋
卡塔赫纳
巴耶杜帕尔
马格达雷纳河
塞萨尔
MAR CARIBE
辛塞莱
蒙特利亚
苏克雷
科尔多瓦
玻利瓦尔
北桑坦德
库库塔
委内瑞拉
阿劳卡
安蒂奥基亚
阿劳卡
桑坦德
麦德林
基布多
通哈
卡萨纳雷
博亚卡
乔科
卡尔达斯
昆迪纳马卡
约帕尔
马尼萨莱斯
利萨拉尔
佩雷拉
阿尔梅尼亚
伊瓦格
波哥大特区
金迪奥
比亚维森西奥
托利马
考卡山谷
卡利
梅塔
内瓦
波帕扬
考卡河
乌伊拉
卡克塔
弗罗伦西亚
工业走廊
1 阿尔蒂普拉诺 昆迪伯亚森中塞
2 安迪奥盖尼奥
3 咖啡代罗
4 加勒比海
5 桑坦德来斯
6 考卡山谷
来德弗雷阿
主干道
工业走廊
就业人数：641,937 人
工业生产总值：23,644,014 千比索
机构数量：7,099 家
工业中间消耗：
13,503,279 千比索
截止 93 年 12 月相关固定资产：
11,364,764 千比索
电能消耗：8,113,985,400 加仑
汽油消耗：13,337，745 加仑
其他能源消耗：64,828,065 加仑
ESCALA
1:2'500.000
50 0 50 km

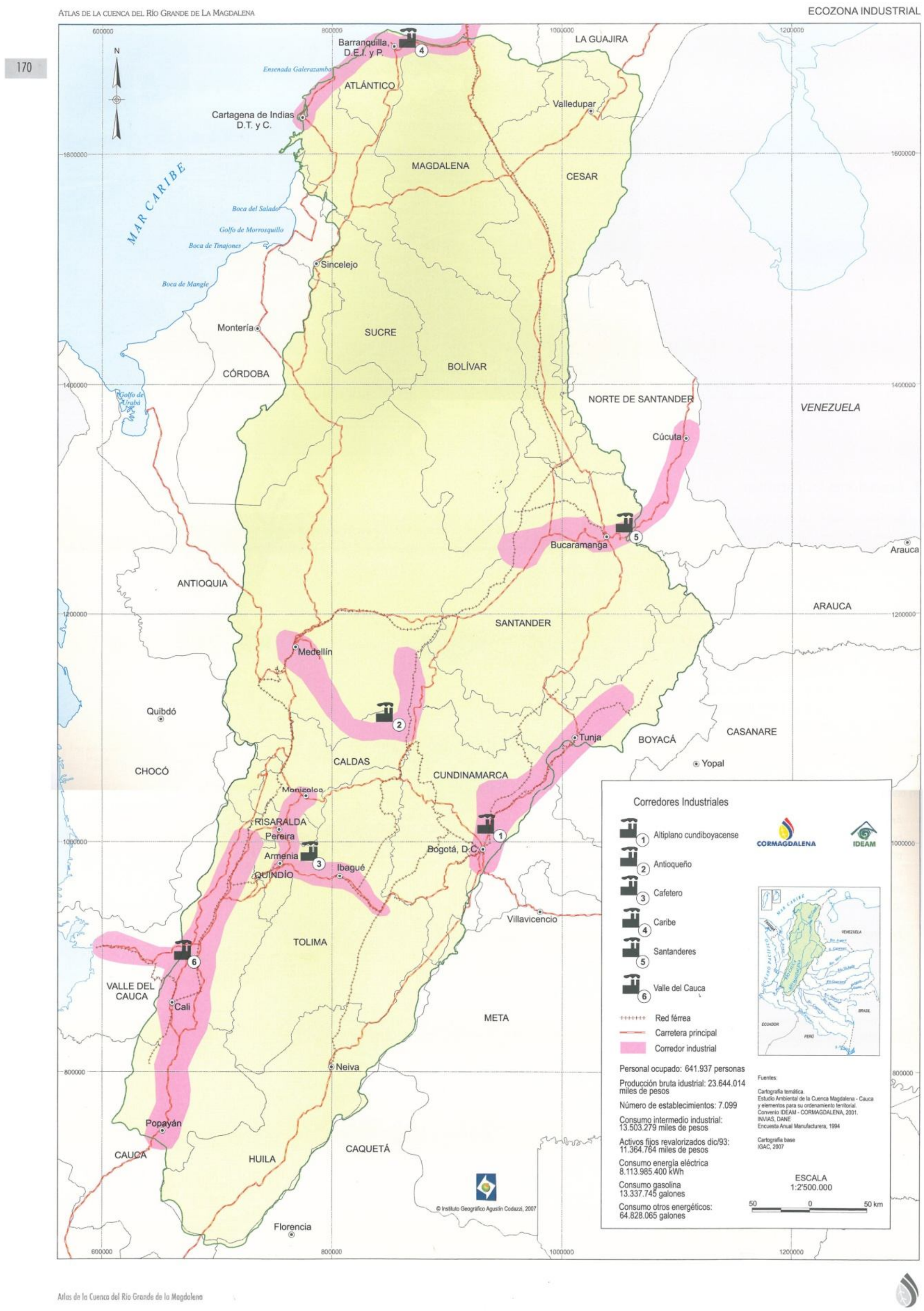


Fig. 3.2-1 Geographic Location of 6 Industrial Corridors in the Magdalena River Basin (Source: Atlas Cuenca del Rio Grande de la Magdalena)

Based on the resource characteristics and economic and social development status of the Magdalena River Basin and with the implementation of Colombia's regional economic development strategy and increase of its national investment, the economic and social development layout in the Magdalena River Basin in the future will have the following advantages and characteristics:

The upper basin involves Huila Department, Tolima Department, Cundinamarca Department, Bogota D.C. and large cities along river including Neiva (capital city of Huila) and Girardot. The main industries in the area mainly include agriculture, tourism, and the secondary industry. This area features high degree of agricultural mechanization, with main products of coffee, rice, cotton, bananas, sugar cane, corn, wheat, and fruits. Animal husbandry in this area is also well developed, with main bred animals of cows and sheep. It is rich in coal reserves, accounting for one third of the total coal reserves in Colombia; iron, salt, marble and other minerals are also produced here. A quarter of Colombia's processing industries are concentrated in the area, including textile, food, glass, cement, chemical industry, tobacco and such other industries.

The middle basin mainly involves Departments of Cundinamarca, Caldas, Boyaca, Santander, Antioquía, Bolívar and Cesar etc. This area has main agricultural products of bananas, corn, and sugar cane, very developed animal husbandry, and main minerals of petroleum, coal, and gold. It is also the leading cement producing area in Colombia. Barrancabermeja is the most important city on the middle Magdalena River, an important petroleum producing area of Colombia, and has the largest petroleum refinery in Colombia.

The lower basin and the Dique Canal mainly involves Departments of Bolívar, Cesar, Magdalena, and Atlántico etc.. Barranquilla and Cartagena in this area are two important port cities along the Atlantic coast and located at the estuary of Magdalena River and the estuary of Dick Canal respectively. The two cities are densely populated with high levels of industrialization. They are two most important commercial centers, main foreign trade ports, and important industrial bases of Colombia. The agricultural products in this area include corn, cassava, rice, etc. The animal husbandry is relatively developed.

3.2.2 Forecast of Main Indicators of Economic and Social Development

According to requirements of national macro economic development, the socio-economic indicators of Colombia are forecasted by tendency method. By estimate, the growth rate of population is about 1%. Refer to Fig.3.2-2 for the forecast of GDP growth rate. It is estimated by 2015, the GDP growth rate will be steady at 5%; the GDP growth rate will drop gradually from 2021, and will be steady at 4% after 2025. By taking 2010 as the reference year, the main socio-economic indicators in the target year for the Master Plan are forecasted as follows:

By 2020, the population will be about 50.91 million, with GDP of about USD 476.9 billion and per-capita GPD of about USD 9,367.

By 2030, the population will be about 56.30 million, with GDP of about USD 723.0 billion and per-capita GPD of about USD 12,841.

3.3 Requirements on Governance, Development and Protection of the Basin

The infrastructures of water resources are the basis of the economic and social development of the Magdalena River Basin and related areas. They are the important conditions for the modern agricultural development and important supports for the construction of ecological civilization, the improvement and the guaranteeing of the people's livelihood. At present, the lagging construction of water conservancy infrastructures in the basin and weak integrated management of the basin do not match the strategic position and the economic and social development demand of the basin. Meanwhile, the basin is also faced with such problems as climatic change, increased pressure in ecological and environmental protection, etc. In order to adapt to the sustainable and economic and social development of Colombia in the future, to guarantee the energy supply, food supply and ecological safety in the country, to effectively control and prevent flood and waterlog disasters and improve the people's livelihood, and to realize the sustainable utilization of water resources, the governance, development and protection of the Magdalena River Basin should be strengthened.

a) Acceleration of navigation construction, and optimization of the comprehensive transport system

Extending from north to south, the Magdalena River lies on the central axis of Colombia's economic and social development, which enjoys superior natural waterway conditions, connects the inland with the cities along the Caribbean coast, and has been preliminarily become an important link for transport of the international logistics in inland areas by many years' construction. At present, the transport means in Colombia consists of highway, railway, waterway, airline and pipeline. The turnover volume of freight transport by highway and railway in 2009 respective accounted for 73.3% and 24.6%, that by waterway accounting for 1.9%. The transport by highway in the middle and lower Magdalena River Basin is heavy, while the volume of transport by waterway is small. The inland waterway transport is featured with such enormous advantages as large volume of transport, low energy consumption, low investment, less land, light pollution and cheap cost. The governments in countries around the world have attached great importance to the development of the inland river navigation. Developed inland waterway system can even give rise to international economic and industrial belts, improving competitiveness of export products, and is an important support for development of export-oriented economy. However, due to backward development in construction of waterway and ports on the Magdalena River and other infrastructures and as well as lack of support from large cities and important industries support along the River, the navigation has not yet played a role in promoting the inland economic development and the advantages and potential of navigation need to be further exerted. To optimize the comprehensive transport system and improve the comprehensive transportation capacity, the construction of navigation system needs to be further strengthened, the investment should be increased and go in appropriate advance, so as to promote the economic and social development of the basin.

b) Rational exploitation and utilization ofthe hydropower resources, and increase of the energy supply

The energy resources in Colombia consist of 42.88% of hydropower, 35.26% of coal, 10.29% of petroleum, 5.97% of natural gas and 5.6% of the miscellaneous, of which the hydropower ranks first. The power structure is also dominated by hydropower (accounting for about 2/3). The total installed capacity of completed hydropower stations in Colombia in 2009 was 9001 MW, lower than 10% of the technically developable potential of the hydropower resources. The main stream of the Magdalena River has great potential for exploitation, with only one completed hydropower station and one under construction at present. The average annual growth rate of power consumption in Colombia during 2004~2009 was 3.01%, the per capita installed capacity in 2009 was 300 W, and the per capita power consumption was 1216 kWh, only being about 35% of the average power consumption level in the world and at lower level. Although the power supply is surplus in short term, along with the economic and social development, there would be a sustainable growth in energy and power demand. To ensure the energy supply and respond to the requirements of the international society for reduction of carbon emission, the power development in Colombia in the future will still take the renewable clean hydropower resources as the main new power sources. The hydropower resources should be rationally and orderly exploited on the basis of protection of the ecology and environment and minimization of the reservoir inundation,for the purposes of meeting the demand for the growth of power market in the country and actively promote the power market in the surrounding countries.

Along with the global warming in recent years, drought frequencies increase. Although the power is surplus in general at present, Colombia also still suffers power shortage in some periods. Therefore, in Colombia, priority for hydropower exploitation should be given to the construction of hydropower stations with good regulation performance, so as to improve the power supply reliability and enhance the capacity of the power system against the extreme climate.

c) Promotion of multiple utilization of the water resources and integrated management of the basin

At present, the hydropower stations completed and under construction in the basin are mainly exploited for singular function as to generate power, without multiple consideration of hydropower generation, navigation, flood control, irrigation and other multiple utilization purposes. To realize multi-purpose exploitation and rational utilization of the water resources, a complete basin plan system should be established, so as to guide and regulate the river governance and development. Meanwhile, due to weak integrated management of the basin, the construction in the aspects of basin management system and mechanism, laws and regulations, management capacity, etc., should be urgently strengthened.

d) Establishment and refinement of flood control and disaster mitigation system and Assurance of the flood control safety

Due to frequent flood disasters, both banks along the river and the plains downstream of Barrancabermeja on the middle Magdalena River are the key areas for flood control, but no flood control and disaster mitigation system has been formed yet. At present, most of the area belongs to flood plain without any flood control facilities. Although embankment and flood walls are constructed in towns and agricultural areas seriously threatened by the flood for local protection, the works are simple, and in some areas there are no enclosed protection circles formed, the supporting waterlog control facilities are incomplete and the flood control and disaster mitigation capacity is limited. Along with the improvement of economic and social development level, increase in population and accumulation in wealth, higher requirements are put forward for the flood control and disaster mitigation. Meanwhile, affected by the global climate change, the extreme weather in the basin occurs more frequently, the flood may be more likely to happen. The flood loss will be greater in case of extraordinary flood. Therefore, flood control and disaster mitigation system should be established and improved, with proper measures taken. To ensure the flood control safety is an important task for the governance and exploitation of the Magdalena River.

e) Strengthening the environmental protection, and maintaining the river health

The water quality in some reaches and tributaries of the basin are heavily polluted. Some reaches and areas suffer from shrinkage of aquatic habitat, decline of biological resources and prominent problem in aquatic ecosystem. Meanwhile, the soil erosion is large in area and high in intensity. To improve the ecological environment and maintain the river health, and to advance the sustainable economic and social development, the following measures should be taken: to strengthen the protection of aquatic environment, to strictly control the discharge capacity into the river, to strength the aquatic ecological protection, to restore the aquatic ecosystem heavily damaged, to advance the control of soil erosion and to reduce the sediment into the river.

f) Rationally utilization of land, fishery and recreation resources, and promotion of local economic development

In recent years, the agricultural development is emerging advantages in Colombia and gradually becomes important for promoting the economic growth. The government has proposed to strive to develop the agriculture for people's livelihood and economy. Enjoying abundant resources of water, earth, light and heat, as well as superior agricultural production conditions, the Magdalena River Basin is the major grain producing area in Colombia. The land utilization and agricultural cultivation method in the plan area are careless, the irrigation rate of arable lands is low and the land resources are not rationally utilized. To ensure the food supply and to adapt to the increasing demand for international grain market, the following measures should be taken: to optimize and adjust the land use structure, to improve the arable land, to advance the irrigation development, to improve the production capacity of the arable land, and to increase the yield of grain.

The Magdalena River Basin is always the most important major freshwater fish producing area in Colombia, with a yield accounting for more than 60% of the whole country. Capture fishery is the main source for food and income for the fishermen along the banks, while the fishery aquaculture also supplies the international market. The plan area is rich in water area resources, but low in utilization rate. Meanwhile, due to irrational exploitation and catch, the fish resources greatly decline. To meet the demands of domestic and international markets, measures should be taken to gradually recover the fish resources, rational fishing should be realized and the development of aquaculture should be promoted, so as to gradually form a relatively complete fishery industrial chain, improve the added value of fish products and boost the fishery economy.

The basin is rich in recreation resources, but few have been exploited. Along with the economic and social development and the improvement of the livilihood, the demands for recreation are much higher. The recreation facilities should be planned and constructed, so as to meet the demands of the local residents in the plan area and the people in the surrounding areas.

For various reasons, the economic development along the Magdalena River is low, most residents along the banks live in the bottom of the society. Therefore, the advantages of the river should be fully exerted; if it is allowable by the the ecological and environmental conditions, land, fishery and recreation resources should be rationally exploited, turning the resource advantages into economic advantages, so as to promote the local economic development and improve the livelihood of the people.

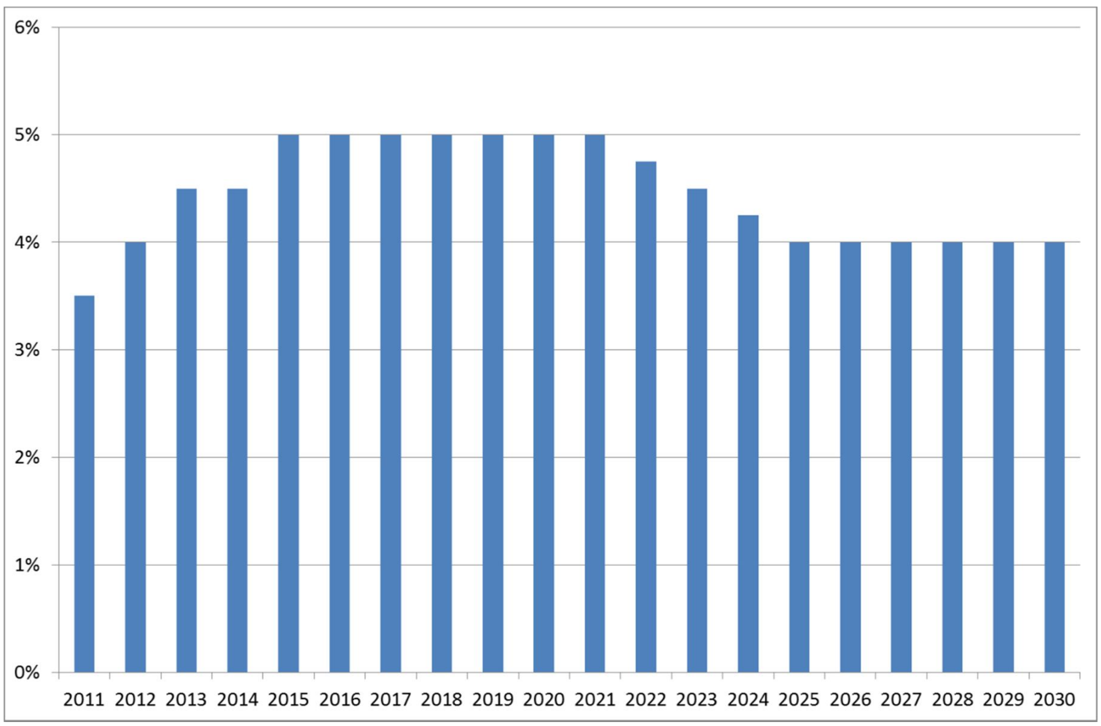


Fig. 3.2-2 Forecast of GDP Growth Rate of Colombia

(Source: Plan de Expansión de Referencia Generación – Transmisión 2010-2024)

4 General Planning

For overall plan of the Magdalena River, under the premise that the natural characteristics, current situations of the governance, development and protection and major existing problems of the basin have been investigated and analyzed, the general arrangement are proposed after the plan guidelines and principles have been defined and the tasks, plan objectives and main control indicators for the governance, development and protection have been determined on the basis of summarizing the experience in river governance and forming main awareness and in accordance with the requirements of economic and social development on the governance, development and environmental protection of the river.

4.1 Guidelines and Principles

4.1.1 Guidelines

The relations between demand and possibility, between part and whole, between exploitation and protection, between short term and long term, and between different interest groups should be coordinated with the principles of "overall plan & coordination and comprehensive governance & utilization", and the concept of "promoting the harmony between human and nature", according to the natural characteristics, resources and environment of the Magdalena River, as well as the demands for regional, basin and national economic and social development, and aiming at solving the major problems such as weak water conservancy infrastructures in the plan area, low multiple utilization rate of water resources, frequent flood disaster, relatively serious soil erosion and poor aquatic ecological environment. . Thus, the rational determination of the tasks, objectives, main control indicators and layout schemes of the Master Plan, the gradual establishment and improvement of multiple water resource utilization system, flood control and disaster mitigation system and environmental protection system and the rational exploitation and multiple utilization of water resources should be executed to convert the resource advantages into economic advantages, effectively reduce the effect of flood disaster and guarantee flood control safety. In this way, it is able to protect the water environment and water ecology, maintain the heath and functions of the river and support the economic and social sustainable development of the basin.

4.1.2 Principles

a) The principle of "protection first and proper exploration" should be followed. In the plan scheme, it is proposed to avoid important sensitive ecology and environment factors to reduce adverse impact to the greatest extent, maintain the health of river life, promote the harmony between human and water, and avoid and reduce the impact on the concentrated settlement and the centralized distribution area of agriculture and animal husbandry land as far as possible.

b) The principle of "overall coordination, comprehensive governance and multiple utilization" should be stick to. The things to be considered not only include the requirement of economic and social development on the governance, development and protection of the Magdalena River, but also the restraint of the river health on economic and social development. Attention should be paid on the discipline plan in compliance with the overall plan and the connection between short-term plan and long-term plan. Comprehensive river plan is connected to the national economic development plan, the overall plan for land utilization and the development & protection plan of relevant departments concerning agriculture, forestry, energy, transport, environment, etc. Besides, the economic and social development layout should adapt to the bearing capacity of the water environment and the water ecology.

   The demands of navigation, hydropower generation, flood control and disaster mitigation, irrigation, fishery, recreation and other respects should be analyzed in a comprehensive way. Full consideration should be given to the rational connection and coordination among the plan of multiple utilization of water resources, flood control and disaster mitigation and environmental protection and among the plan of other disciplines. The public interests in flood control safety, water environment and water ecology security should be guaranteed in priority and the water resources should be developed in a multiple way and utilized in high efficiency in consideration of the needs of each region and industry.

c) The principle of "taking measures adaptable to local conditions and making the focal points stand out" should be stick to. Countermeasures should be taken according to the different natural conditions, the economic and social development levels and the current situation of the governance, development and protection of the basin. The prominent problems of the Magdalena River should be focused for key plan. The plan objectives, arrangement and key measures for the short term and long term should be rationally determined based on the order of importance and emergency. The short-term plan objectives should be coordinated with PMC.

d) The principle of "paying equal attention to engineering and non-structural measures and strengthening integrated management of the basin" should be stick to. Not only the arrangement of major important measures for governance and exploitation of the basin should be planned, but also the functions in social management and public service of the basin should be strengthened, the system of mechanisms, policies, laws and regulations for basin management and improve the management ability.

4.1.3 Scope and Target Year

The plan scope is the jurisdiction of CORMAGDALENA, including 128 city/town areas along the main stream of the Magdalena River (1,613 km), the Dique Canal (114 km) and the lower Cauca River (187 km). In accordance with the demands for the studies of specific issues, the analysis scope is expanded to the main tributaries and the river basin. The key plan themes are navigation, hydropower generation, and environmental protection. General plan themes are land improvement (flood control, waterlog drainage and irrigation), riparian zone utilization, river channel regulation, fishery resource utilization and recreation.

The present datum year for the plan is 2010. However, due to the difficulty in data collection and updating, the latest data should be used as far as possible. The short-term plan target year is 2020 and the long-term plan target year is 2030.

4.2 Tasks in Governance, Development and Protection

According to the physical geography characteristics, the resource and environment features, the strategic position and the requirement on national & regional social-economic development of the Magdalena River Basin, the main tasks for the governance, development and protection of the Magdalena River are determined as navigation, hydropower generation, environmental protection, flood control and drainage of stagnant water, irrigation, fishery, recreation, etc.

The tasks for the governance, development and protection of all river reaches have special focuses due to the great differences among the physical geography characteristics, resource conditions and flood disaster features, as well as different economic and social conditions and the ecological environment characteristics, of the upper, middle and lower Magdalena River. Such tasks are determined as follows based on comprehensive consideration of the resource and environment features, the requirement on social-economic development and the overall arrangement for governance, development and protection of the entire Magdalena River.

a) The main tasks for the governance, development and protection of the upper reaches are hydropower generation, environmental protection, irrigation, navigation and recreation, fishery, resource utilization and recreation, as well as reducing the flood control task of the middle and lower reaches. To be specific, the main tasks for the river reaches from river head to Isnos are ecological protection zone of the river head and recreation, and the task of navigation is not considered for the river reaches upstream of Neiva.

b) The main tasks for the governance, development and protection of the middle reaches are navigation, flood control and drainage of stagnant water, environmental protection, fishery, recreation and hydropower generation.

c) The main tasks for the governance, development and protection of the middle reaches are navigation, flood control and drainage of stagnant water, environmental protection, irrigation, fishery and recreation.

4.3 Planning Objectives

Overall objectives: to promote the harmony between people and nature, fully give play to the multiple service functions of the river, establish perfect systems concerning multiple utilization of water resources, flood control and disaster mitigation, environmental protection and integrated management of the basin, so as to maximize the comprehensive benefits in economy, society and environment and support the economic and social sustainable development with sustainable utilization of water resources.

a) Objectives in 2020

Consolidate and improve the high-grade waterways in the main stream of the Magdalena River downstream of Barrancabermeja and in the Dique Canal, as well as the main ports in the region, in order to improve the navigation capacity of the waterway from Salgar to Barrancabermeja and the adaptability of the important ports in the region. Strive to develop the land-and-water transport and river-sea transport services of petroleum, coal, container, etc. for the initial shaping of a modernized navigation system.

Steadily promote the construction of 3 ~ 4 hydropower plants with the total installed capacity of 500MW ~ 700MW on the upper Magdalena River.

Build a frame for the flood control and disaster mitigation system and improve corresponding capacity to reduce personal casualty and property loss, prevent the economic activities and social life in the cities and towns from suffering great loss and prevent the progress of sustainable development from significant disturbance in case of heavy flood.

Tap the potential of existing irrigation area and complete the construction of irrigation areas which are under construction to increase the grain yield.

Make the water environment and ecological environment improved significantly. Control the domestic pollution sources, industrial pollution sources and agricultural non-point source pollution in an effectively way. Make the municipal wastewater treatment rate reach 80% and above, make the treatment rate of household garbage reach 70% and fulfill 40% of the tasks in the control of soil erosion. Engage in forestation actively. Improve the aquatic eco-environment, keep the connectivity between aquatic organisms and fish passageway and gradually recover the fish recourses. Establish the environment monitoring system step by step.

b) Objectives in 2030

Fully build up the water transport network with its framework being the modernized high-grade waterway in the main stream of the Magdalena River downstream of Salgar and in the Dique Canal and form a land-and-water transport and river-sea transport port systems with rational layout, perfect functions, specialization and high efficiency to undertake the foreign trade transport services of most of the petroleum, coal, container, etc. in the river basin, which can drive the export-oriented industrial development along the river. Gradually extend the navigation network to the places upstream of Salgar in combination with the development of hydropower cascades.

Initially realize rational development and utilization of water resources. Intensify the development of water resources in the main stream of the Magdalena River to make the development and utilization rate of water resources increase to 20%

approximately.

Make the flood control and disaster mitigation system adaptable to the economic and social development level of the basin taken initial shape, further improve the capability of flood control and disaster mitigation and take countermeasures for floods and secondary disasters caused by mountain torrents to avoid personal casualty and reduce property loss as much as possible.

Finish the continued construction of the supporting facilities and transformation of the canal system for the large-sized and key medium-sized irrigation areas in the plan area and construct a batch of new irrigations areas and water source projects.

Realize healthy development of water environment and water ecology in an elementary degree to make the river ecosystem in benign development. Make the municipal wastewater treatment rate reach 85%, make the treatment rate of household garbage reach 80% and fulfill 75% of the tasks in the control of soil erosion. Establish a comprehensive monitoring system for the monitoring of water quality, water ecology and soil erosion in an elementary degree.

4.4 Controlling Indicators

The "red line" for economic and social development activities and the "base line" for guaranteeing ecological security should be marked to specify the development and utilization activities and the control development intensity for different river reaches in the basin and provide basis for the integrated management of the whole basin. According to the tasks for the governance, development and protection of different river reaches and the region of the Magdalena River and in consideration of the requirements for keeping the Magdalena River healthy, the control indicators should be selected based on ecological flow, water quality, flood control, etc.

On the basis of the data obtained currently, the ecological base flow and water quality of the control section and the flood control water level have been proposed in this planning. The control indicators such as total in-river pollutants of the control section and the rational development and utilization rate of water resources may be studied and set out when it is available.

a) Ecological flow of the control section

Ecological flow of river channel refers to the flow demanded for maintaining the basic shape of the riverbed, guaranteeing the water conveyance capacity of the river channel, keeping certain self cleaning capacity of the water and realizing the health of the river ecosystem. It is planned to set 13 ecological flow control sections at the boundaries of the upper, middle and lower main stream, at the confluences between the important tributaries and the main stream, and on the river reaches near the boundary of major departments. The ecological flow of each control section is controlled based on the two methods for calculation of ecological flow in Colombia provided by Cormagdalena, i. e. based on 75% of the minimum year-to-year monthly mean flow (minimum monthly mean flow among the mean flow of 12 months) or based on controlled daily mean flow of the control section corresponding to 97.5% of guarantee rate according to the curve for daily mean flow frequency for more than 5 consecutive years. See Table 4.4-1 for the control values

b) Water quality objectives of the control sections

COD, BOD and NH3-N are selected as the controlling indicators for the water quality of control section with reference to International and Chinese practices and in consideration of relevant water quality protection objectives and grading standards of PMC as well as the current water quality indicative data. It is planned to set 13 water quality control sections, and the COD, BOD and NH3-N controlling indicators of each section are shown in Table 4.4-1.

Table 4.4-1 Objective Values for Ecological Flows of Control Sections and Surface Water Quality Control in the Plan Area

S/N	Name of Cross Section	Controlled Ecological Flow (m^3/s)	Controlled Water Quality (mg/L)		
			COD	BOD5	NH4-N
1	Backwater zone of Guarapo Reservoir	61	≤20	≤3	≤0.1
2	Downstream face of the dam of Pericongo Reservoir	73	≤20	≤3	≤0.1
3	Cabrera Rio Desembocadura	342	≤20	≤3	≤0.1
4	Saldana Rio Desembocadura	396	≤30	≤10	≤1
5	Guali Rio Desembocadura	685	≤60	≤20	≤5
6	La Miel Rio Desembocadura	1020	≤30	≤10	≤1
7	Barrancabermeja Estacion	1286	≤30	≤10	≤1
8	Crimitarra Rio Desembocadura	1480	≤60	≤20	≤5

Table 4.4-1 (Continued)

S/N	Name of Cross Section	Controlled Ecological Flow (m^3/s)	Controlled Water Quality (mg/L)		
			COD	BOD5	NH4-N
9	El Banco Estacion	1596	≤25	≤5	≤0.5
10	San Jorge Rio Desembocadura	2300	≤30	≤10	≤1
11	Tacamocho Estacion IDEAM	2889	≤30	≤10	≤1
12	Calamar Estacion IDEAM	2594	≤25	≤5	≤1
13	Dique Estacion	147	≤25	≤5	≤0.5

c) Flood control water levels for key cities

The key cities with flood control consideration along the Magdalena River should be the 13 cities in the middle and lower reaches which are highly threatened by flood or have much population. Refer to Table 4.4-2 for the flood control water levels of these cities.

Table 4.4-2 Flood Control Water Levels for Key Cities Unit: m

City	Flood Frequency				
	P=2%	P=5%	P=10%	P=20%	P=50%
La Dorada	172.63	172.38	172.17	171.93	171.51
Barrancabermeja	76.01	75.82	75.65	75.46	75.12
Puerto Wilches	66.17	65.92	65.70	65.46	65.03
La Gloria	36.85	36.42	36.05	35.62	34.85
Tamalameque	33.17	32.82	32.47	32.07	31.34
El Banco	29.53	29.21	28.93	28.59	27.98
Pinillos	22.19	21.92	21.65	21.33	20.74
Magangué	19.64	19.15	18.75	18.27	17.41
Plato	15.25	14.45	13.85	13.05	11.65
Calamar	9.48	9.04	8.66	8.21	7.4
Ponedera	5.92	5.62	5.36	5.06	4.53
Soledad	3.39	3.18	3	2.82	2.48
Barranquilla	2.95	2.76	2.6	2.43	2.13

Note: The flood control water level means the design water level.

4.5 General Arrangement

The overall arrangement scheme should establish relatively perfect systems concerning multiple utilization of water resources, flood control and disaster mitigation and environmental protection by centering on the overall objectives to realize the governance, development and protection of the Magdalena River. The planning systems are both correlated and mutually restricted. The overall planningn and arrangement needs to be proposed with full consideration of rational connection and coordination and on the basis of overall planning for the economic and social development and the environmental protection requirements.

4.5.1 Multi-Purpose Utilization System of Water Resources

The tasks for the multi-purpose utilization system of water resources include navigation, hydropower generation, irrigation, fishery, recreation, riparian zone utilization, river channel regulation, etc.

a) Acceleration of construction of modernized navigation and improvement of the comprehensive transportation capacity of the region. As an important part of the comprehensive transport system, navigation should go in appropriate advance of economic development. Through waterway regulation works, dredging, maintenance, as well as the comprehensive measures like curve cutoff, bank protection and soil erosion control, it is planned to gradually build the high-grade modernization waterways in the main stream of the Magdalena River downstream of Salgar and in the Dique Canal and improve the two river-sea hub ports, i.e.Catagena and Barranquilla to realize seamless connection between inland water navigation and sea transport, as well as gradually transform and construct the four land-and-water transport modernization inland center ports, i.e. Gamarra, Barrancabermeja, Berrio and Salgar, and other ports to realize seamless connection among inland water navigation, inland highway and railway. In addition, the construction of a perfect water transport support system and the research on vessel standardization are also considered in the plan. In this way, a modernized water transport system, which takes the main stream of the Magdalena River and the Dique Canal as the framework and centers on the main ports and is featured by river-sea transport, land-and-water transport, smoothness, high efficiency and safety, will take shape step by step and this system will promote the export-oriented economic development of the river basin. In respect to the long-term plan, the channelized works and waterway regulation works will be implemented step by step based on the navigation demand and the development of hydropower cascades to extend the navigation network to Neiva.

b) Active promotion of the rational and orderly development of water resources. According to the natural conditions like the topography, geology and hydrology of the main stream of the Magdalena River and with full consideration of the control factors such as reservoir inundation, ecological environment and major engineering geological problems, the work to do includes coordinating the requirements for the functions like hydropower generation, navigation, irrigation, flood control and recreation, studying the engineering layout and development mode of the cascades in the river reaches upstream of Salgar, emphasizing the adjustment to reservoir layout and putting forward rational cascade development proposals for the purpose of promoting hydropower development in an orderly way and realizing multiple utilization of water resources.

c) Intensification in the construction of irrigation infrastructures. The measures, such as continuous construction of supporting facilities of existing irrigation projects, repair and transformation of irrigation and drainage channels, change of the extensive land farming mode, prioritizing of irrigation system should be taken to improve the effective irrigation area and the irrigation efficiency, reduce the flood disaster and improve the land productivity. Besides, research on potential irrigation areas and water source projects should be executed based on the conditions of water and soil resources and in consideration of the cascade hydroelectric development.

d) Rational utilization of fishery resources. Through active development of aquaculture and improvement of the production and scale, the fishing activities should be standardized to protect and recover the natural fish resources. By utilizing the rivers, lakes, wetlands, ponds and reservoir resources, the fishing bases dominated by the breeding of local commercial fishes should be constructed to control the introduction and domestication of foreign cultured fishes and increase the fish production. Support systems, such as the fishery material supplies including fry production and fish feed and the processing and marketing of aquatic products should be improved to promote the development of aquaculture with high quality and high efficiency.

e) Promotion of recreation development. Systematic plan and orderly construction of recreation faculties should be conducted based on rational utilization of the unique landscape resources such as mountain, water, riparian zone, river, lake, wetland, reservoir and animal in the plan area and in consideration of the rational connection with tourism resources, so as to expand functions and increase products.

4.5.2 Flood Control and Disaster Mitigation System

The flood control and disaster mitigation system covers flood control and waterlog control.

According to the nature and characteristics of flood disaster and economic and social situations, follow the practice of combining the principle of "flood storage and discharge in combination but flood discharge as the priority" and "avoiding flood", and the flood control thought of properly assuming the flood control risks for flood control and disaster mitigation in general. Besides, integrate and coordinate the relationship among upper, middle and lower reaches, and between the left and right banks, the generation of benefits and elimination of harms, and human versus nature. With emphasis placed on the middle and lower reaches, gradually establish a complete flood control and disaster mitigation system with engineering and non-structural measures in combination and non-structural measures prevailing.

Economical and rational engineering and non-structural measures should be taken according to local conditions in the upper main stream and mountainous and hilly areas of tributaries. The flood-regulating potential of reservoirs which are already constructed, still being constructed and yet to be constructed should be tapped as much as possible. The construction of reservoirs with flood control function should be included in proper plan to assume the task of flood control of the area and that of middle and lower reaches.

The natural flood storage and detention abilities of lakes, marshes and wetlands are restored and maintained in middle and lower reaches with key protection by embankment/flood wall and management of flooded areas as the basis, structural measures such as control of river course and non-structural measures such as flood forecast and early warning, and flood insurance are taken to form the comprehensive flood control and disaster mitigation system.

4.5.3 Environmental Protection System

The tasks for the environmental protection system include the protection of water environment and water ecology, soil erosion control, forestation, environment monitoring, etc.

In order to maintain a good ecological environment, the overall plan and coordination of the relation among governance, development and protection, the intensified treatment of domestic and industrial pollution sources, the control of agricultural pollution sources, the emphasis on the protection and restoration of the aquatic ecosystem, the promotion of soil erosion control and forestation and the establishment of environment monitoring system should be executed based on the problems in water quality, water ecology and soil erosion in the basin and following the concept of "ecology first and sustainable utilization", the principles of the combination among prevention, treatment and management and connection between short-term and long-term objectives, as well as the guidelines of "overall plan, point source treatment, non-point source control and making the focal points stand out".

a) Intensification of water environmental protection. With the control objective of the water quality in the river channel, the control of pollutant discharge in river, the acceleration in the abatement of point sources like domestic and industrial pollution resources of the cities and the surroundings and the intensification of the regional non-point source pollution abatement should be done to make the water environment gradually tend to benign development. With the control objective of the ecological water in the river channel, the rational control of the development and utilization degree of water resources and the intensification of the scheduling, operation and management of hydropower projects should be executed to make the ecological flow and water quality of the control section meet the ecological environment requirements.

b) Strengthening the protection and restoration of aquatic ecosystem. Based on the functional demands of aquatic ecosystem, the rational plan of waterway management and hydropower development scheme for the basin, the intensification in the protection and restoration of habitat, wetland and connectivity between river and lake and the construction of conservation areas should be done to guarantee the integrity of the aquatic ecosystem and the biodiversity of aquatic organisms and gradually realize the restoration of fish resources.

c) Promotion of soil erosion control and forestation. Emphasis should be laid on prevention and protection to maintain good ecology. Supervision and management should be strengthened to restrain man-made soil erosion in an effectively way. Comprehensive control of soil erosion should be provided to accelerate the pace of ecological construction and forestation.

d) The environmental monitoring system should be gradually established. Basic information about the environment of the basin should be collected to establish the environment monitoring system.

4.5.4 Analysis on Layout of Key Multipurpose Projects

The key multipurpose projects in the plan area include the navigation and electricity junction project and reservoir project.

4.5.4.1 Layout Analysis of Comprehensively-developed Navigation and Electricity Project

The long-term objective for the navigation of the Magdalena River should realize navigation through the whole river reaches downstream of Neiva, while the short-term objective should realize navigation in the river reaches downstream of Salgar.

Salgar ~ Wilches Reach: The navigation ability of this reach can be improved by two means, i. e. through improvement of waterway or cascaded and canalized waterway for power generation and navigation. According to the results of water resources investigation in 1978, 7 cascade hydropower plants were arranged in the reaches, with the preliminarily proposed total installed capacity of 2,447 MW and the utilized water drop about 85 m. According to the *Overall Policies on Utilization of the Middle Magdalena River* in 1983, 4 comprehensively-developed navigation and electricity cascade hydropower plants were arranged in the reaches, with the preliminarily proposed total installed capacity of 977 MW and the utilized water drop about 40 m. Due to the relatively poor construction conditions, large one-time investment, long construction period and the involvement of ecological environment issues, the preliminary study of navigation and electricity cascade hydropower plant has not been carried out for a long time, so that the requirement for short-term navigation can not be satisfied. Besides, the waterway regulation project has started for the river reaches from Salgar to Barrancabermeja (256 km), there is slim necessity to construct canalized waterway for the navigation and electricity cascade project within the plan period. Therefore, the cascade arrangement is not considered for the river reaches from Salgar to Wilches in this plan and relevant studies will be carried out if necessary in the future.

Salgar ~ Neiva Reach: The highways are relatively developed along the reaches. At present, , since the navigation is available only in part of the reaches due to insufficient water depth of the natural river channel and the separation by supercritical flow at Honda. Large and medium sized cities like Neiva and Girrardot are distributed along the river from Salgar to Neiva. The navigation through the whole river reaches depends on the requirement of future economic development in the area on navigation. In order to connect with the long-term navigation objective, navigation structures or reserved positions should be provided for the hydropower projects planned and constructed on the river reaches from Salgar to Neiva.

4.5.4.2 Layout Analysis of Key Reservoir Projects of Main Stream

The sources of flood and sediment in the basin mainly come from the middle Magdalena River and its tributary, the Cauca River. The 4 major tributaries, of which the catchment area is greater than 10,000 km^2, flow in the Magdalena River at its middle and lower reaches. Among these tributaries, the Cesar River and the San Jorge River are plain rivers without the conditions for constructing a controlling reservoir, and the Sogamoso hydropower plant under construction on the middle Sogamoso River has a relatively large controlled catchment area, but a relatively small reservoir regulation storage. Based on the factors such as the topographical and geological conditions, reservoir inundation and geographic location, the main stream of the Magdalena River and its major tributaries such as the Cauca River and the Nare River are suitable for the construction of large scale controlling reservoirs. In addition, the reservoirs completed with regulation capacity (with the total reservoir storage about 6×10^9 m^3) are also distributed on these rivers. As shown by relevant data, the middle Cauca River is the section mostly concentrated with hydropower resources in this basin, and the total installed capacity of the 4 hydropower plants under construction and to be constructed is as high as 8,650 MW, with the total reservoir storage about 6×10^9 m^3. Upon completion, these reservoirs will relatively well control the flow and sediment in the Cauca River Basin. The reservoirs constructed in Nare River Basin have relatively good overall regulating capacity. For the reservoirs of other tributaries, both the control catchment area and storage are small

Currently, there are two large regulation reservoirs on the main stream of the Magdalena River, including one completed and one under construction. The two reservoirs are adjacent cascades and both are projects for the single purpose of power generation. The Betania hydropower plant completed has a catchment area of 13,572 km^2 upstream of the dam site, the average annual discharge of 398 m^3/s and the reservoir regulation storage of 0.805×10^9 m^3, while the El Quimbo hydropower plant under construction has a catchment area of 6,832 km^2 upstream of the dam site, the average annual discharge of 235 m^3/s and the reservoir regulation storage of 1.824×10^9 (maximum 2.601×10^9) m^3. Both of the two reservoirs have good self regulation capacity, but with a relatively small catchments area, they only have good regulation and control effect on the runoff and flood of the upper Magdalena River and slightly influence the water regime of the middle Magdalena River.

Analyzed from the topographical and geological conditions, the river reaches at Honda valley, which is on the main stream of the Magdalena River and closely neighboring the outlet section of the upper reaches, are suitable for constructing large scale regulation reservoirs. In additions, the control catchment area of the river reaches accounts for 20% of the whole river basin and the geographical location is ideal. The Honda multi-purpose reservoir proposal was studied in the 1970s and now this proposal is analyzed again for the plan.

a) Previous study results

At the beginning of the 1970s, the Honda multi-purpose reservoir proposal with the normal water level of 280m was studied in the national water resources investigation.

With the normal water level of 280 m, the dam height is 98 m, the reservoir storage is 20.2×10^9 m^3 and the regulation storage is 16.0×10^9 m^3. The reservoir is about 100 km long, with the average width of 5.4 km and the inundated area of 563 km^2. The inundation influences 6 towns and some rural residences, involving the resident population of 13,000 from about 2,000 households. Following the order of importance, the applications of the reservoir include power generation, navigation, recreation, flood control and irrigation. The major benefits are as follows:

1) Power generation: The hydropower plant has an installed capacity of 1,800 MW and its average annual energy output is 8,800 GWh.

2) Navigation: Through reservoir regulation, the minimum flow at the dam site increases

from the measured 540 m^3/s to nearly 1,300 m^3/s. With the increase of waterway depth in the lower reaches, it is able to improve the navigation conditions of the low water reaches downstream of La Dorada and reduce the cost for waterway maintenance. Besides, an important auxiliary benefit on the waterway in the lower reaches brought by the reservoir is the reduction of sediment deposit and the sediment intercepted is about 35×10^6 m^3 per year (conservative estimation).

3) Recreation: Honda reservoir is located at the center of the metropolis like Bogota and Medellin and it can provide conditions for the recreation and fishery activities of these densely-populated cities.

4) Flood control: Though the flood peak of Honda reservoir is not high, it lasts for a long time (usually as long as 45 days) with large flood discharge. Take the maximum flood measured (in 1938) at a hydrometric station near the dam site as an example. In case of reserving the flood storage space about 6 m above the normal water level and discharging the flood as per the discharge of 2,600m^3/s, by which the hydropower station can generate power in full operation, the flood retained and stored could be about 3.1×10^9 m^3. With coordination with other reservoirs on the main stream and tributaries, it is able to reduce the flood inundation on the middle and lower Magdalena River.

5) Irrigation: The animal husbandry lands from Honda to La Dorada are suitable for mechanized farming. Upon completion, Honda reservoir could provide irrigation water source for farming activities on these lands.

As concluded in the study, it is technically and economically feasible to construct a dam on the Honda river reaches, and the dam could have considerable benefits on multiple utilization and profound significance on the economic and social development of Colombia. It is suggested to carry out a techno-economic feasibility study on the project. However, due to the large amount of land under effect of reservoir inundation and population to be resettled, as well as the high construction cost (USD 4,383 / kW, price of that year), Honda reservoir proposal was not adopted in the water resource investigation results.

b) Analysis results in formulation of the Master Plan

In this plan, preliminary field investigation and plan design has been carried out for the Honda reservoir proposal. The dam site is proposed to locate at a distance of about

4 km upstream of Honda, of which the catchment area is 54,211 km^2 and the average annual discharge is 1,240 m^3/s. With the consideration of reservoir backwater not influencing Girardot, it is preliminarily proposed a full supply level of 260 m, reservoir inundation area of 571 km^2, regulation storage about 8.9×10^9 m^3, storage coefficient of 23% and maximum head about 70 m, all of which contribute to a good regulation and control effect on the runoff, flood and sediment.

1) Navigation benefit. With reservoir regulation, the flow in low-water season can increase from 500 m^3/s to 1000 m^3/s to reduce the dredging and maintenance cost for the waterway in the lower reaches and a deep waterway from the Honda dam site to Girardot in the upper reaches.
2) Sediment regulation and control effect. The annual average suspended load discharge at Honda dam site is about 18.10×10^6 t (13.66 million m^3 upon the completion of Betania reservoir), accounting for 18.7% and 12.2% of that of the middle and lower reaches respectively. The dead storage of the reservoir is about 4.1 billion m^3 and the corresponding ratio of reservoir storage capacity and sediment load is up to 300. After the construction of reservoir is completed, all the bed load and relatively coarse granular suspended load sediments above the dam site will be intercepted, which could reduce the sediment accumulation of waterway of lower reaches for a long time.
3) Flood control effect. The catchment area and flood of Honda reservoir during control periods account for 38.8% and 27.5% of that of the control section in the middle reaches. Because the time of flood disaster is as long as 40d ~ 60d in the middle and lower reaches, the flood retaining and storage capacity of Honda reservoir has a certain effect on flood control of the middle reaches and reduce the flood control pressure of the area at lower reaches to some extent.
4) Power generation. With the installed capacity of 1,000 MW for the hydropower plant and the good reservoir regulation performance, it would be able to provide stable and reliable energy output for the power system.
5) Irrigation and recreation. The reservoir could provide sufficient water source for gravity irrigation of the downstream areas and provide abundant recreation and tourism products for the metropolis like Bogota and Medellin and for the local residents.
6) In consideration of the large reservoir inundation area and the large population

affected, the relation between resource unitization and reservoir inundation should be coordinated from an overall prospective. In addition, issues concerning the ecological environment are also involved such as change of fish migrating channel and water regime, and impact of clear water discharge on erosion and siltation evolution of lower river course.

To sum up, Honda reservoir project could bring large multiple utilization benefits, but it is rather difficult to solve the problems related to construction land requisition and resettlement of the affected people and the impact on environment is also considerable. As the Honda reach is the only one whose good topographical and geological conditions and geographical location are suitable for constructing a large scale regulation reservoir on the main stream of the Magdalena River, the investigation on the tangible indices for reservoir inundation and impacts on environment should be carried out, and further demonstration of benefits from multiple utilization and study on the necessity and feasibility of construction of Honda reservoir should be conducted in the next stage.

5 Navigation Plan

The Magdalena River is an important water transport passage connecting the inland of Colombia and the Atlantic Ocean and it plays an important role in the economic and social development of the basin and the development of the cities and towns along the river. Along with the acceleration of international economic globalization process, the Magdalena River navigation, as an important component of the comprehensive utilization system of water resources in the basin, meets the historic opportunity of rapid development, bears higher mission and faces more challenges.

With the objective of establishing a modernized navigation system and serving the regional economic development, the navigation plan is made under the guideline of the overall plan, including summarizing the current development situations and characteristics of the waterway, port, ship type, passenger and freight volumes, and support system of the Magdalena River, evaluating the position and function of the Magdalena River navigation in the regional economic and social development and the comprehensive transport system, analyzing the major existing problems, predicting the passenger and freight volumes for water transport in the Magdalena River, making studies on the ship type suitable for Magdalena River navigation, rational plan the waterway grades, defining the significant ports and the development direction of the support system, and raising suggestions on stage-wise implementation and relevant measures.

5.1 Current situation and Existing Problems

5.1.1 Overview on Transport and Mineral Resources

a) Overview on Transport

The main transport modes in Colombia include road transport, railway transport, water transport, civil aviation, etc. By taking the north-south running No. 25 and No. 45 highways as the axises, the roads pass through the mountains respectively on left and right banks of the Magdalena River, with many east-west running trunk roads connecting the cities on both banks to form a road network. The railways are nearly parallel to the Magdalena River, running north and south. The inland water transport is dominated by the Magdalena River while the marine transport starts at the costal port of the Atlantic Ocean and ends at the places all over the world. Centered at Bogota, Civil aviation connects multiple cities throughout the country.

Road transport is the leading transport mode and its total length is 129,485km, including a total length of 13,386 km for Class I highways, which accounts for 10.3% of the total road length. In 2009, the domestic turnover volume of freight transport by road was 177 million t, accounting for 73.3% of the total domestic turnover volume of freight transport, and 170 million person-times of passengers were transported by road. There is great difficulty in road construction because the population is mainly concentrated in the hilly cities with the elevation higher than 1,000 m.

The development of railway can be traced back to 1880. In the 1970s, the railway length reached the maximum value of more than 3,400 km. Thereafter, some of the railways were dilapidated. At present, the length of railway in operation is about 1,700 km. In 2009, the turnover volume of freight transport by railway was 59 million t, accounting for 24.6% of the total domestic turnover volume of freight transport, and the freight was dominated by coal. Later, the country attached importance to railway construction. At present, the railway connecting the Pacific coast and the inland is under construction for coal export to the Asian-Pacific region.

In 2009, the freight transport volume of Colombia done by inland water transport was 4.495 million t, accounting for 1.9% of the total domestic freight transport volume, including the freight volume transported by the Magdalena River of 3.3 million t, accounting for 73% of the total freight volume by inland water transport. Although some of other rivers are also available for navigation, the freight transport volume of these rivers (such as the Putumayo River on the Amazon Plain) are small for they are not in the major economic activity regions of the country.

In the region from Neiva to Salgar in the Magdalena River Basin, the north-south running No. 45 and No. 43 highways connect Neiva, Girardot, Honda, La Dorada and Salgar while the east-west running No. 40 and No. 50 highways connect Bogota, Ibague and other cities. All freights are transported on these highways. There is a civil airport in Neiva to connect other major cities in the country. Water transport is not an important mode of transport in this region, but the Magdalena River has significant impact on the living of the residents along the river. First, water transport on the Magdalena River is an important means of transport for the residents on both river banks. There are many small passenger ships in the bazaar and people go from one bank to the other by the waterway. Therefore, water transport is one of the major modes for short-distance passenger transport. River-crossing bridges are constructed in larger cities like Neiva, Girardot and Honda and on the trunk roads and the river-crossing mode for other places is ferrying. According to the statistical data provided by the Ministry of Transport, the passenger volume by water transport in Girardot was 510,000 person-times in 2009. Second, the Magdalena River is the important source of income for the fishermen on both banks. Third, the Magdalena River is an important place for tourism and recreation of the residents on both banks. As a social public service agency, CORMAGDALENA has constructed many passenger terminals especially for tourism and recreation purposes. The ships used in this region mainly include small passenger ships (with less than 20 seats), speed boats and small fishing boats, all of which are not restricted by the waterway conditions and can realize navigation all year round. Before 1920s, Honda Port was an important port connecting Bogota and the Atlantic Ocean through the Magdalena River, so it was also called Bogota Port, and the maximum tonnage of the ship which reached Honda port was as high as 400 t. Later, the tonnage ship gradually increased due to the development of road and railway. Restricted by the conditions of natural waterways, few cargo ships could navigate in the river reaches from Berrio to Honda and the ports along the river reaches, including Bogota Port, also gradually disappeared from history.

In the region from Salgar to Barrancabermeja, there are several main highways, i.e. No. 45, No. 62 and No. 60 highways, connecting Bogota, Salgar, Medellin, Berrio, Barrancabermeja and other major cities. Road transport is busy and it is an important mode for logistics transfer in this region. Berrio and Salgar are also connected with Medellin and Bogota through railway which extends to the Atlantic coast, but they have been dilapidated in this region. The waterway in the river reaches are provided with the conditions for navigation and it is able to carry 500 t cargo ships. Except that some of the city and town shorelines are partially provided with slope protection or flood control embankment, nearly no improvement has been carried out for other parts of the river channel of the river reach. There are cargo berths in Salgar and Berrio, but their volumes of freight transport are small, having small impact on the regional logistics transfer.

Wetlands and lakes are densly distributed in the region from Barrancabermeja to the marine outfall; the region is dominated by agriculture in terms of regional economy and sparsely populated, and it has suffered from flood disaster over many years. All highways are far from the river channels and many small towns are distributed at both banks. A water transport network has been formed relying on the wetland and river network. The main transport tools are speed boats with less than 20 seats and small cargo ships (with the tonnage of less than 25 t). The waterway in the river reaches is an important water transport passageway connecting the coastal cities of the Atlantic and the inland cities upstream of Barrancabermeja. It is available for the navigation of fleets with the tonnage of 1,000 t, showing great potential in the development of freight transport.

The region in the middle and upper reaches of the Magdalena River is the base of the most important industries in Colombia, including coal, petroleum and agriculture, and the most important cities are also distributed in this region. Barranquilla and Cartagena, costal cities of the Atlantic Ocean downstream of the Magdalena River, are the most important ports of Colombia. With the increasing development of globalization and rapid growth in international trade, the relation between the inland regions and the costal port cities will become closer, which makes the requirements on transport higher and higher. Currently, the trunk roads in the region in the middle and lower reaches of the basin are very busy and the railway has been dilapidated for many years, so transport is the bottleneck for the inland region of Colombia to be incorporated in the international economic circle. Compared with road and railway transports, water transport is featured by larger transport volume, less investment, less occupation of land, less pollution and less cost. In addition, both road expansion and railway reconstruction need enormous investment and have limited transport volume. Therefore, it is urgent to develop Magdalena River navigation for the economic and social development of the basin.

b) Overview on Main Mineral Resources

The minerals in the Magdalena River Basin mainly include petroleum, natural gas, coal, etc. Since 1980s, Colombia has seen rapid growth in its petroleum industry and stood among the net export countries of petroleum. Petroleum industry has become one of the pillar industries of the country. To be specific, petroleum export took up 25.8% of the total export in 2003, the export revenue of petroleum and its derivatives reached USD 6.328 billion in 2006 and the daily production of crude oil reached 585,000 barrels in June 2008. The reserves and production of petroleum of Colombia hold the 4th rank in Latin America, just following Venezuela, Ecuador and Mexico. The petroleum production areas are mainly concentrated in the eastern plain areas and the middle and upper reaches of the Magdalena River valley. Among the oil fields under development, the production of oil fields in the river basin accounts for 22% of the total production, with that in the upper, middle and lower reaches accounting for 13.2%, 8.7% and 0.1% respectively.

The reserves of natural gas in Colombia is about 198 billion m^3, accounting for about 2.8% of the total reserves of natural gas in Latin America. Throughout the country, there are 12 major natural gas producing areas which are mainly distributed in the Atlantic Coast, Santander, eastern plains and Huila-Tolima Region. The total output of natural gas in the Magdalena River Basin accounts for 7.6% of the total outputof natural gas in Colombia, with that in the upper, middle and lower reaches accounting for 1.1%, 4.9% and 1.6% respectively.

In 2009, the proved reserves of coal in Colombia was about 7 billion t, accounting for about 30% of the total reserves of coal in Latin America. In 2010, 74 million t coal was mined in Colombia, about 90% of which were exported. With a large amount of exploitable reserves, coal mines are concentrated and mainly distributed in 6 regions on both banks of the Magdalena River Basin. The left bank of the Magdalena River mainly covers the Cali Region, the Southwest Medellin Region and the Southeast Cordoba Region, while the right bank mainly covers the Northeast Cundinamarca Region, the Tunja Region and the South Cesar Region. The departments with the maximum coal exploitation in the river basin are Cesar (33%), Norte de Santander (1.10%) and Cundinamarca (0.72%) in sequence. Coal is mainly sold to Western Europe (73%), North America (13.5%), Non-European countries in the Mediterranean Region (7.10%), Latin America (4%) and Asia (1.60%).

Various types of industrial mineral reserves can also be found in the Magdalena River Basin, including asbestos, sulfur, barium oxide, bentonite, kaolin, diatomite, schist, feldspar, fluorspar, phosphate, graphite, magnesium, pumice, talc, gypsum, etc.

5.1.2 Current Situation of the Waterways

a) Overview on waterways in the basin

According to the 2010 statistical data about transport, i.e. *TRANSPORTE EN CIFRAS VERSION 2010*, provided by the Ministry of Transport, the lengths of the navigable rivers in the Magdalena River Basin are given in Table 5.1-1.

Table 5.1-1 Summary of the Lengths of Navigable Waterways in the Magdalena River Basin

PRINCIPALES RIOS	LONGITUD NAVEGABLE (km)				LONGITUD NO NAVEGABLE (km)	LONGITUD DEL RIOS (km)
	MAYOR		MENOR PERMANENTE	TOTAL		
	PERMANENTE	TRANSITORIO				
Cuenca del Magdalena	1188	277	1305	2770	1488	4258
Magdalena	631	256	205	1092	458	1550
Canal del Dique	114	0	0	114	0	114
Cauca	184	0	450	634	390	1024
Nechí	69	21	45	135	100	235
Cesar	0	0	225	225	187	412
Sinú	80	0	110	190	146	336
San Jorge	110	0	83	193	207	400
Otros	0	0	187	187	0	187

Note: This table is sourced from *TRANSPORTE EN CIFRAS VERSION 2010* (2010 statistical data about transport) provided by the Ministry of Transport, Colombia. "MAYOR" in the table refers to the waterways navigable for ships with the tonnage of about 400 t and above and the total length of such waterways is 1,465 km in the basin. "MENOR" in the table refers to the waterways navigable for small speed boats (passenger ships), force-driven small barges (with the cargo capacity of less than 50 t) and the total length of such waterways is about 1,300 km in the basin.

a) waterway network with the Magdalena River as the main line and other tributaries as the branch lines has been formed in the basin to connect the Atlantic coastal cities and 14 inland departments and 287 cities and towns of different sizes. In terms of current economic conditions, the 2770 km-long waterways in the whole basin have played an important role in the life of the residents on both river banks. Waterway is the foremost mode for city-town transport, also the most important channel for the incoming and outgoing of production and domestic supplies. The Magdalena River, the Dique Canal and the Cauca River are the principal waterways for the import and export of petroleum, petroleum products, coal and grains in the basin. Therefore, they are the most important high-grade inland waterways considered for the national plan.

b) Length and scale of the Magdalena River waterway

The Magdalena River is the main waterway of the waterway system in the basin, so it has significant impact on the import and export trade of the country. The waterway section in the middle and lower reaches enjoys good natural conditions and the country pays attention to the improvement and maintenance of this waterway section all the time. Every year, special funds are set up to regulate some shoals which impede navigation and carry out maintenance dredging of some parts of the waterway. The 631 km-long waterway section from Barrancabermeja to Barranquilla has the highest freight volume, always keeping the waterway depth at 2.1 m (navigation dependability: 90%) and available for perennial navigation of one-pusher /six-1000t-order barges fleet.

The 100 km-long waterway section from Berrio to Barrancabermeja has a water depth of 1.35 m (navigation dependability: 90%) and as high as 1.8 m in wet season, available for seasonal navigation of 1,000 t-order fleet. In recent years, with plentiful rainfall, the lowest water depth has been 1.78m, which can basically meet the requirement for the perennial navigation of 1,000 t-order fleet.

The 156 km-long waterway section from Salgar to Berrio has a water depth of 1.35 m (navigation dependability: 90%), available for seasonal navigation of one-pusher / four-500t-order barges fleet.This section of waterway has extremely unstable river banks and various shoals such as estuary, branch and sandbar. The densely-covered braches and islands lead to the river flow diversion of the wide and shallow river channel, the insufficient water depth of the waterway and many branch shoals.

The 410 km-long waterway section from Neiva to Salgar has a water depth of about 0.9 m, only available for the navigation of small passenger ships and small cargo ships with the carrying capacity of less than 25 t.

With good natural conditions, the waterway section downstream of Salgar is a principal producing area of petroleum and coal and most of freight transport occurs in this area, so the country has made much more input in this waterway section. Therefore, the current water depth is basically maintained for it. However, with more developed road transport network and insufficient natural water depth, the waterway in the area upstream of Salgar receives less input and the waterway regulation measures are still in investigation and demonstration phase. Without unified waterway scale standard for waterway, it is difficult to describe the current situations of the waterway, hard for the waterway management and maintenance departments to know the degree and seize the chance to maintain the waterway, e.g. what time should maintenance of waterway be started, how to know the degree of maintenance, how should the governmental departments and the society judge the work done by the waterway departments, and the lack of executable standard bases and law systems is also a problem.

Refer to Table 5.1-2 for the length and scale of the Magdalena River waterway.

Table 5.1-2 Current Situation of Main Waterways in the Magdalena River Basin

S/N	Name of Waterway	Starting and Ending Points of Waterway Section	Length (km)	Water Depth for Waterway Maintenance (m)	Waterway Scale (m)		
					Waterway Depth	Waterway Width	Curvature Radius
1	Main stream of the Magdalena River	Barranquilla Port ~ estuary	22	11.5	11.5		
		Barrancabermeja ~ Barranquilla Por	631	2.1	2.1	65	900
		Berrio ~ Barrancabermeja	100	1.35	1.35		
		Salgar/La Dorada ~ Berrio	156	N/A	1.35		
		Neiva ~ Salgar	410	N/A	0.6 ~ 0.9		
2	Dique Canal	Cartagena ~ Calamar	114	2.1	2.1	65	
3	Cauca River	Caucasia ~ Pinillos	187	N/A	1.35		

c) Dique Canal

The Dique Canal starts from Calamar on left bank of the Magdalena River to Cartagena Bay to flow into the sea, connecting many freshwater lakes. Its total length is 114 km, with the average annual discharge of 462 m^3/s (equivalent to 6.3% of the average discharge of the Magdalena River). Involving 19 cities in Atlantico, Bolivar and Sucre Departments, the canal serves a population of more than 1.5 million.

In the middle 1980s, the Dique Canal reached the waterway width of 65m and the water depth of 2.1 m (navigation dependability: 90%) by regulation and improvement, available for perennial navigation of one-pusher /six-1000t-order barges fleet. At present, the annual transport volume of the canal is about 2 million t, including 80% of petroleum and petroleum products and 20% of other cargoes. It has already become the main channel for transport of import and export cargoes on the Magdalena River.

The Dique Canal also has the functions like water supply, irrigation, maintenance of wetland ecological environment, aquiculture and prevention of sea water encroachment. Since the Cormagdalena Company was established at the beginning of the 1990s, it has kept studying on the treatment of sediment and environmental impact, etc. of the Dique Canal.

d) Cauca River

The 187 km-long waterway from Caucasia downstream of the Cauca River to Pinillos estuary is managed by CORMAGDALENA. The river channel is almost in natural state and the waterway depth is about 1.35 m, available for navigation of 300 t-order ~ 500 t-order fleet. In recent years, due to the demand for inter-city cargo transport and coal transport, there has been more and more voice of paying attention to waterway regulation of the Cauca River. CORMAGDALENA has started the investigation and study on the waterway of the Cauca River.

e) Previous study and construction of waterway

Many authorities and organizations of Colombia have conducted many studies and plan on navigation of the Magdalena River since 1920s. The major study programs completed after 2000 include the study and plan for navigation restoration demand of the Magdalena River in 2001, the waterway study in 2004, PMC of CORMAGDALENA in 2007 and the dredging design for waterway section from Salgar to Barrancabermeja completed in 2011.

1) Study and plan for navigation restoration demand in 2001

With the assistance of Stell Hydraulic Research Corporation and Davis & Craven Corporation, CORMAGDALENA carried out the study on transport restoration demand and plan of the waterway in the Magdalena River and published the study report in 2002. The study was divided into three stages: In the first stage, a comprehensive investigation and analysis of the transport system of the country were made, including the cargo types and logistic directions of road, railway and water transport modes, and the costs of three transport modes were also compared and studied. In terms of water transport cost, consideration was given to all factors like the waterway investments of different waterway sections, waterway support system, port infrastructures and the services, navigation equipment and ships. In the second stage, the service function orientations of the major ports of the river were determined and a systematic analysis on the alternative proposals of the eight waterway grades plan was carried out based on the design and application of the model for the analysis on transport economy. In the third stage, benefit and income estimations for the prospect of each proposal were made to obtain the economic and financial evaluation indicators of each proposal, including benefit-cost ratio (B/C), net present value (VPN) and internal rate of return (TIR).

2) Waterway study in 2004

In 2004, National University of Colombia and the Northern University authorized by CORMAGDALENA completed the investigation and study on the waterway of the river reaches under its administration and drew the river plans (1:50000) and longitudinal profiles of the river channels from the two marine outfalls to Betania section, the Dique Canal and the Cauca River. At present, the river channel plans are used as the waterway plans for satellite navigation.

In this study, the waterway cross-sections were designed according to the possible ship types and their drafts in different waterway sections, the waterway was deepened and the waterway curve was improved mainly by the method of dredging, and the quantities of dredging works were preliminarily estimated.

3) PMC of CORMAGDALENA

In "PMC of CORMAGDALENA", consideration was mainly given to the attraction for the freight volume of Medellin and Bogota and the proposed waterway depth objectives were 2.4 m for the waterway section from the part downstream of Barrancabermeja to the two marine outfalls, 1.35 m for the waterway section from

Berrio to Barrancabermeja and 1.2 m for the waterway section from Salgar to Berrio.

4) Mineral transport plan by Ministry of Mines and Energy (UPME)

UPME's plan for the mineral transport network relied on the restoration of the waterway of the Magdalena River and the basis for water transport plan of minerals was PMC of CORMAGDALENA, so that CORMAGDALENA's execution schedule for the restoration plan of the waterway was also considered for development of mineral production. It was forecasted in the report that the coal production of Colombia would be 144.7 million t in 2019, 16 million t of which would be transported out by the Magdalena River waterway, including 200,000 t by Salgar Port, 3.8 million t by Galan Port, 9 million t by Santander and Norte de Santander Department, and 3 million t by Tamalameque.

5) Improvement study of the Dique Canal

In March 1997, the Ministry of Environment, Housing and Territorial Development of Colombia charged CORMAGDALENA to prepare an environmental protection and navigation restoration plan for the Dique Canal as soon as possible. CORMAGDALENA successively depended on the domestic and foreign scientific research and consultation & design institutions to carry out the work and put forward many alternatives. Due to the complexity of the issue, CORMAGDALENA preferred the following two proposals (Proposal 1 and Proposal 2), and Proposal 2 was recommended temporarily.

Proposal 1: provide gates (navigation locks) at the inlet and outlet of the Dique Canal and regulate the water flow status of the Dique Canal through these gates, so as to reduce the sediment inflow.

Proposal 2: revise the cross-section of the inlet channel to reduce the discharge of the canal (i.e. for water and sediment reduction); construct a channel with narrowed section in the middle reaches to maintain the water level in the river channel and keep the connectivity between river and lake; construct navigation locks and gates at the outlet of the canal (before entering the Cartagena Bay).

6) Salgar ~ Barrancabermeja waterway regulation project

The river reaches for this waterway regulation project is from Salgar in the middle reaches to Barrancabermeja of the Magdalena River, with the total length of 256 km. The design work of this project was done in two sections. The first section is 100 km long, from Berrio to Barrancabermeja and the second section is 156 km long, from Salgar to Berrio. The detailed design of regulation works of the two sections of river channel had been completed by September 2011 and the bidding procedures were started in 2013. It is planned to be completed wthin three years.

In the past, the construction of the Magdalena River waterway was mainly consisted of the maintenance and improvement of the Dique Canal and the waterway downstream of Salgar. The regulation of the Dique Canal with the largest scale was completed in 1985. This regulation project made the number of canal bends reduced to 50, the waterway depth reach 2.1 m and the waterway width reach 65 m, which greatly improved the transport volume of the Dique Canal and met the transport demand of Cartagena Oil Refinery. The regulation with the second largest scale is the waterway maintenance project from Barrancabermeja to Barranquilla. This project is carried out every year to maintain the smoothness of the waterway, with the annual dredging quantity of about 6 million m^3 and the capital input of about USD 30 million per year. Other regulation projects include the regulation and maintenance of the waterway section from Barranquilla Port to the estuary, the maintenance of the waterway section from Salgar to Barrancabermeja, etc.

5.1.3 Current Situation of Ports

a) Overview on ports

According to the data in the statistical yearbook on inland water transport in 2009 provided by the Ministry of Transport of Colombia, there are 14 ports with statistical data about freight and passenger transport in the Magdalena Basin, including 10 on the Magdalena River, 2 on the Cauca River, 1 on Sinu and 1 on Betania Reservoir.

In 2009, the total cargo handling capacity of all ports in the whole basin was 3.46 million t, with the cargo handling capacity of the ports on the Magdalena River accounting for 97% (including the Cartagena Port). The ports with the annual cargo handling capacity reaching one million tons were Cartagena Port and Barrancabermeja Port, being 1.45 million t and 1.40 million t respectively, totally accounting for 82% of the total cargo handling capacity of all ports in the whole basin.

In 2009, the total passenger flow was 2.55 million person-times, excluding a large number of small passenger terminals and ferry terminals like Boyaca Port. Refer to Table 5.1-3 for some parameters of the main ports.

Table 5.1-3 Parameters of Main Ports of the Magdalena River in 2009

Port Name	Passenger Flow in 2009 (Person-time)	Cargo Handling Capacity in 2009 (Ton)	Number of Berths for over 1,000 t-Order Ships
BARRANQUILLA	-	247037	10
CARTAGENA	-	1502572	14
CALAMAR	207304	5340	None
MAGANGUE	643800	19885	None
EL BANCO	243732	4620	None
GAMARRA	85896	114418	4
B/BERMEJA	190492	1429774	5
PTO. BERRIO	315122	33054	4
PTO. SALGAR	347202	171	3
GIRARDOT	513522	0	None
TOTAL	2547070	3356871	

Note: The data about passenger flow and cargo handling capacity in 2009 come from *Estadisticas Transporte Fluvial 2009* (statistical yearbook on inland water transport in 2009). The number of standard berths is the preliminary statistical data for the plan and the freight and passenger volume does not include that of other ports.

Fig 5.1-1 Current Situations of Salgar, Berrio, Barrancabermeja and Capulco Ports

b) Characteristics and problems of port development

Port is the most important component of the whole navigation development system and the port conditions directly affect the business expansion of the navigation and transport enterprises. Most of the ports with normal berths on the Magdalena River were constructed in the 1940s. After several decades of downturn, some of these ports, such as Capulco Port, Galan Port and Salgar Port, have been repaired and utilized in recent years, indicating the recovery of port development. There are many passenger terminals along the waterway and a large number of special passenger terminals have been constructed successively for the convenient traveling of the residents on both banks. The characteristics and problems of the development of ports on the Magdalena River are as follows:

1) Numerous passenger terminals vs. a few cargo terminals

Passenger terminals are important components in the transport of 128 cities and towns along the Magdalena River. Most of the cities and towns are provided with special berths and some are constructed with special passenger stations, so the waterway passenger transport system is almost complete.

Among numerous ports, only a few are provided with normal berths for cargo terminals, including ports of Cartagena, Barranquilla, Gamarra, Barrancabermeja, Berrio and Salgar. For the cargo terminals at other ports, due to the natural bank slope, no stable approach channel and no berthing operation conditions, the loading and unloading of cargoes are basically done by manual method.

2) Cargo owners' wharfs in stable operation vs. public wharfs with poor conditions

Due to their stable bulk cargo supplies, the cargo owners' wharfs always have normal berths, with wharf facilities well maintained and in stable operation. These wharfs include the private wharfs of the petroleum enterprises like Cartagena, Barranquilla and Barrancabermeja. These cargoes are mainly of petroleum, petroleum product, coal, cement, etc., the transport volume of which accounts for more than half of the total transport volume of the Magdalena River. The development space of such wharfs is greatly affected by the social and economic development.

Public wharfs are the general wharfs serving the society, which are part of the public infrastructures and can meet the demand for transporting, loading and unloading of most of the cargoes needed by the society. Generally, the public wharfs are suitable for the loading and unloading operation of general bulk cargoes, such as bulk grains, agricultural products, steels, construction materials and containers. At present, only 6 public wharfs on the Magdalena River are provided with normal berths. Except that the Galan Port in Barrancabermeja is a newly-built port in recent years (not completed yet), other ports like Capulco, Berrio and Salgar Ports were constructed before 1940s. With the storage yards and warehouses lacking maintenance and expansion and the site limited, it is difficult for these ports to become regional logistics centers.

3) Lack of supporting facilities for the public wharfs

Most of the public wharfs are not provided with special loading and unloading equipment. Antique stationary cranes still exist at some wharfs. After several decades of downturn of the waterway transport, pieces of equipment have been abandoned at some ports, such as the Barrancabermeja Port and Beiiro Port. At present, the loading and unloading equipment used at these wharfs are auto cranes, which are high in unit cost and limited in efficiency. In addition, due to the lack of horizontal transport equipment at the wharfs and complete and high-efficient loading and unloading process has not taken shape, the time for ship loading and unloading operation is extended and the ship operation cost is increased, further making the water transport enterprises unwilling to expand the public wharf businesses.

4) Irrational geographical locations of some wharfs in the cities and newly-built wharfs lagging behind in development

Most of the ports are age-old. Along with urban development, ports have gradually become the centers of cities and the external access of the wharfs has been affected by urban transportation. The original public wharf in Barrancabermeja was near the office of CORMAGDALENA in the past and it has been abandoned now. A new port named Galan Port was constructed at the bridge downstream. This is the only newly-built port in recent 10 years. Other ports like Berrio and Salgar Port are still in the old urban area. Berrio Port is located in the city center and the distribution of cargoes must go through several blocks of the city. Since the urban traffic has already been heavy, the expansion of port handling capacity will certainly bring pressure on urban traffic. Salgar Port is located at the bridgehead and close to No. 45 trunk highway. However, the carrying capacity of the bridge is limited and the bridge is in the status of saturation and overload operation at present. If the backland of Salgar Port expands to the cities on the left bank, the carrying capacity of the bridge will be a bottleneck.

5.1.4 Current Situation of Ships and Shipping

According to the statistical data in 2002, the number of transport ships in possession is 3,371 in the Magdalena River Basin, with a total load capacity of 260,000 t, including 238,000 t for barges. Inland water freight transport is mainly done by pusher fleets, accounting for more than 90% of the total ship transport capacity. The barges mainly include those especially for transport of petroleum, petroleum products, dry bulks and containers.

The powers of pushers are mainly divided into 800 H.P., 1,440 H.P. 1,920 H.P. and 2,100 H.P., the specification of the loading tonnage of barge varies from 400 t to 1,200 t, and the organization types are from one pusher / one barge to one pusher / six barges. Pusher fleets are mainly engaged in the transport with the voyage distance of greater than 400 km, accounting for more than 70% of the total freight volume on the Magdalena River. Other medium-distance and short-distance transports are mainly carried out by small motor-driven barges, accounting for a small proportion of the total freight volume. Among the cargoes transported via the Magdalena River, 91% are petroleum and petroleum products, which are transported by a total of 30 pushers and 131 barges, with the total load capacity as high as 188,500 t. Currently, there are 24 water transport enterprises in the whole basin. The transport volume of the 4 largest ones of these enterprises takes up 50% of the inland water transport, with the ship load capacity accounting for 66% of the total load capacity.

The passenger ships mainly serve for the short-distance traveling of the people in the regions without convenient road transport on both banks, and the main ship type is speed boat with less than 50 seats.

In recent years, the possession of ships and transport capacity in the basin have been in slow growth and the a few changes have been made to the ship type and the operation organization modes. Although the government has developed some polices to encourage the small ship transport, the effect is not obvious. The transport ships in the basin are mainly found with the following features:

a) Pusher fleet is the leading cargo transport mode.

At present, the transport ships in the water transport market within the Magdalena River Basin are dominated by pusher fleets and there are no large-tonnage motor-driven ships. The proportion of the net load capacity of pusher fleets in the total load capacity of inland water transport ships of the whole society is always kept at more than 90%. Transport by pusher fleet is very economical and it is also the ship type most recognized by local enterprises. By virtue of its huge carrying capacity, it is especially suitable for the transport of stable bulk cargo supplies.

b) Transport business of bulk cargoes is stable while the transport business of medium and small scale LCL (less than container load) cargoes shrinks gradually.

The most stable cargo supplies in the Magdalena River Basin are petroleum and petroleum products and more than 70% of the transport ships are used to transport this type of cargo. The shipping enterprises are most enjoyed to do this transport business because of the perfect wharf and loading & unloading processes of the petroleum companies, safe and convenient ship berthing and fast speed in cargo loading & unloading. For other cargo types such as coal, containers and construction materials, which have unstable cargo supplies, poor wharf conditions and the lack of organization for stable supplies by logistics companies, most of the shipping enterprises are unwilling to engage in the transport of these cargoes. In recent years, due to the increase in the petroleum transport business, even some flat deck barges have been transformed into oil barges for petroleum transport, resulting in the shortage of ships for transporting other cargoes. The most obvious case is Berrio Port. This port was still engaged in some container and coal transport businesses a few years ago, but not in recent two years. The reason is that no ships can be used to transport this type of cargo and the original ships have been transformed for petroleum transport.

c) Except for liquid barge, there are a few types of other barges with low degree of specialization.

The main types of barges in the basin are deck barge and liquid barge. The latter one is mainly used for the transport of petroleum and petroleum products. Other types of cargoes, such as containers, dry bulks and construction materials, are transported by deck barges with low degree of specialization.

5.1.5 Current Situation of Transport Volume

In 2011, 2.11 million passengers and 2.24 million tons of cargos were transported via waterway of the Magdalena River, respectively accounting for nearly 1.0% and 1.4% of the corresponding comprehensive transport volumes of the whole country in the corresponding period. The major types of cargo by water transport via the Magdalena River are large bulk cargos like petroleum products and machinery equipment, with the petroleum products taking up the largest proportion. In 2011, the transport volume of petroleum products took up 91.8% of the total water transport volume, including 83.5% for crude oil and 2.3% for machinery & hardwares. Bulk cargos like coal, grain and construction materials are also traditional important types of cargoes.

The following are characteristics of passenger and freight volumes by water transport via the Magdalena River in recent 10 years.

a) The total level of passenger and freight volumes is in steady development. The transport volume of petroleum and petroleum products has been dominant for a long time and the total transport volume is almost kept stable. In contrast, the total transport volume of other cargoes by water transport shows a declining trend.

Since 1980s, petroleum and petroleum products have always been the most important cargoes for water transport on the Magdalena River. The transport volume of this type of cargo has been dominant for a long time and the transport ship route is mainly from Barrancabermeja to Cartagena. With the advantage of stable cargo supplies, the private wharf and loading & unloading equipment of the petroleum enterprises are well maintained. Thus, petroleum transport has become the most important business of water transport enterprises and all resources in the society have inclined to it. In order to pursue higher efficiency and profit, both the shipping enterprises and petroleum companies hope to improve the grades of waterway, so that transport cost can be reduced by using larger ships and fleets.

Other types of cargos, such as coal, steels and grains are bulk cargoes without stable supplies. Due to the poor conditions of public wharfs and the lack of substantial improvement in recent years, all logistics enterprises are unwilling to engage in the transport of such cargoes, so that the total transport volume of these cargoes shows a declining trend.

b) Coal will be another important cargo type by water transport besides petroleum.

At present, there are no inland river wharfs for coal transport from the coal-producing areas to the coal export ports of Cartagena and Barranquilla. With step-by-step improvement of the road transport conditions, coal transport mode will be changed to road transport. In addition, with the crowding-out effect of petroleum transport, the shipping companies will focus on the business of petroleum transport and the coal transport by waterway will decline. In 2011, there was nearly no record about coal transport by waterway. Coal is a kind of large bulk cargo very suitable for water transport. Besides, Colombia is a major coal producer and exporter. Therefore, coal transport by waterway is the largest potential in water transport development of the Magdalena River.

c) Container transport by waterway is in its initial stage.

Because of the convenience in loading & unloading and transferring, container transport has become a more and more important logistics organization method in the world, especially suitable for the land-and-water transport mode. Containers are important cargo supplies in all countries with developed water transport and the trend in continuous and rapid development of container transport is obvious. To adapt to container transport, regional logistics transfer centers have been constructed at many inland ports, integrating the container businesses like unpacking, transferring, storage and customs declaration. At present, the Magdalena River lacks mature container wharfs, but container transport by waterway is tried every year. In addition, some shipping companies have planned to construct modernized container wharfs in the mainland. All these facts indicate that container will be an important cargo supply for water transport. This is also the general trend for current inland water transport development in the world.

d) Transport of mineral building materials is not fully developed temporarily due to the effects of port conditions and ship equipment.

There are abundant sand and gravel resources in the Magdalena River, but the freight volume of mineral building materials only takes up a small proportion in the total freight volume of the river. However, the prices of sand and gravel are not cheap on both banks. The major reason for this is the absence of special sand dredgers and sand & gravel wharfs. In addition, the sand and gravel exploitation market is in its initial stage, also affected by the market demand to some extent. Along with the infrastructure construction development of the country, the demand for sand and gravel will increase and the government will give proper guidance on wharf construction, so that the transport of mineral building materials like sand and gravel will be developed.

5.1.6 Current Situation of Support System

a) Navigational and ancillary facilities

The inland river navigational aids are the important navigational facilities for ships to safely navigate on inland river, and are primarily used to mark orientation, boundaries and obstructions of the waterway, disclose relevant information of the waterway, and provide a safe and economic waterway for navigation of ships.

The waterways with complete navigational aids within the Magdalena River Basin mainly include Dique Canal and the waterway section from the downstream of Barranquilla of the Magdalena River to the sea entrance, with a small number of mileposts. As for other sections, only some of bridges and culverts are provided withmarks, and other marks for indicating the orientation, boundaries and obstructions are in a very limited number.

The ancillary facilities for waterway are the necessary conditions for maintenance of waterway. The ancillary facilities include station houses, service ships, etc., for the waterway maintenance departments to carry out the works such as maintenance and observation of waterway, maintenance of navigational aids, waterway improvement, structures inspection and maintenance, waterway protection, etc.

The CORMAGDALENA is responsible for the waterway maintenance works of the Magdalena River. In terms of survey, the station houses along the waterway are in a limited number, some of the station houses are under the administration of Waterway Transportation Department of the Ministry of Transport, and the number of service ships for the waterway is unknown. Thus, it can be seen that the maintenance system for waterway is to be completed for standardization.

b) Current situations of safety supervision facilities and industry informationization

Complete safety supervision and management network for water transportation is the necessary component for modern water transportation. Some regions with developed water transportation have special maritime sectors, special patrol ships, safety supervision vehicles, etc., and have video monitoring systems in the water areas subject to a heavy traffic. At present, local military and police forces are responsible for the safety & rescue and patrol of the Magdalena River. As the ship transport on the Magdalena River develops, the safety supervision system will be further completed and improved.

Currently, the water transport informationization system of the Magdalena River primarily includes the special SNS satellite navigation system, which has been completed in the last 10 years. The special SNS satellite navigation system has brought about good effects, mainly embodied as shortening the navigation cycle of ships, reducing grounding accidents and propeller damage accidents, saving fuels and increasing the waterway utilization rate. However, generally, there is still a gap with the modern water transport industry; for example, the e-government, e-commerce, e-port, information sharing and intercommunication between governmental departments and major port shipping enterprises, etc., still have much development space.

5.1.7 Existing Problems

The water transport of the Magdalena River will greatly impact on the economy of Colombia, and Colombia government is paying more attention to the construction of ship transport on the Magdalena River, so as to make better use of the Magdalena River as the large waterway. Currently, there are the following major problems:

a) The Magdalena River Waterway is basically in natural state, most of the river channels are unstable in river regime, and the input for maintenance of waterway is insufficient and has lagged.

In recent years, the CORMAGDALENA has always been committing to the improvement and maintenance works of the Magdalena River Waterway, to maintain the 2.1m-deep waterway at 631 km-long main stream and at 114 km-long Dique Canal downstream of Barrancabermeja. In 1980s, the Dique Canal Waterway was deepened to 2.1 m. The maintenance works for the main stream waterway of the Magdalena River are dominated by dredging, namely, the dredging is conducted for the silting in some places of the river channel, and the large-scale improvement works for removal of obstruction of waterway are relatively small in number, such as curve cutoff of waterway, systematic improvement of river channel, etc. The banks of the Magdalena River are characterized by poor scouring resistance and subject to very serious bank collapses, giving rise to horizontal swing of river channel, developed distributary and densely distributed islands. Generally, the waterway may be redirected due to a flood. The unstable bank slopes can not only worsen the waterway conditions, but also increase the sediment content in water flow, and threaten housing and farm land safety of residents on the banks. Such problems of this section of the river channel will be fundamentally solved by the improvement works of the waterway from Salgar to Barrancabermeja. The implementation of the improvement works of the waterway from Salgar to Barrancabermeja will also provide experiences for improvement of downstream river channel. The channel regulation is the fundamental solution for solving the silting problem of Dique Canal and reducing the quantities of maintenance works for waterway. The unstable waterway will cause low navigation dependability, rise of navigation risk of ships and increase of cost of shipping companies, and fundamentally restrict the development of shipping business. Generally, the systematic waterway improvement works are subject to a huge investment and cannot bring about the direct economic benefits. In the countries with developed water transport, this kind of investment is generally directly made by government, and ahead of the ship transport development demand.

b) Generally, ports are relatively undeveloped, and large-scale port areas and specialized wharfs are in limited numbers

There are many ports, wharfs and docking points along the Magdalena River, but most of them are not under intensive and scale management. Except the specialized wharfs of petroleum enterprises are satisfactory, the other public wharfs are relatively undeveloped, most of them were built before 1940s, and in recent years, only one public wharf is being built at the Barrancabermeja port, and has not been completed yet; besides, the ancillary facilities are insufficient, equipment is relatively simple, stevedoring technology is relatively backward, and the port has a very low mechanization and specialization level. Most of the ports and wharfs can only undertake simple stevedoring business, and ports only have single function, and cannot provide necessary cargos stockpiling, storage and integrated port services. The overall port industries arrangement has not been started yet, and ports have not played obvious supporting and prompting role in industrial development of cities along the Magdalena River. In some regions, water transport is becoming marginalized in the regional comprehensive transport network.

c) Low capability of support facilities and security situation of the society impact the development of shipping market to a some extent.

The support system of water transport of the Magdalena River is relatively undeveloped, cannot adapt to the characteristics of rapidity and safety of modern logistics and is far behind the standard of unimpeded information, effective supervision and rapid response. The infrastructure and technical equipment start from a low base, and the informatization construction is in its initial stage; the water area monitoring and communication means are insufficient, so that the prevention capability is relatively poor; and the construction of water emergency command and rescue system is in its initial stage, so that the emergency command and rescue forces are relatively limited. It is relatively clear that most of the shipping companies have to give up the shipping business at night due to the insufficiency of navigational aids at night and unsatisfactory public security, so that the shipping cycle is relatively long, the operating cost of ships is increased and the logistic transport cycle is extended.

d) The ship type is single and outmoded; the shipping companies are short of transport capacity, and the shipping market is in a low developing rate.

It seems like that the insufficiency of transport capacity of shipping companies is a common problem, as well as in the Mississippi River, America. On the Magdalena River, Berrio Port is relatively obviously subjected to the insufficiency of transport capacity, that is to say, the shipping companies do not have enough ships to transport the goods stockpiled at this port. The reason is that the shipbuilding cost is increased due to the risen international steel price and the shipbuilding cycle is relatively long, so the shipping companies would have to undertake a relatively high risk for improvement of transport capacity. As for the above-mentioned problem, governments offer subsidies to the shipbuilding companies in some other countries of the world, so as to prompt the development of shipping market. Since the water transport is characterized by low energy consumption, so it is worthy to do so for energy saving and carbon emission reduction.

5.1.8 Recognitions on Navigation

a) The Magdalena River Waterway is the most important oil export way in Colombia, and cargo types such as coal, container have a great space for development.

The inland river transport is advantaged in large transport capacity, low cost, small occupied area, etc. The Magdalena River is a natural waterway with very good shipping conditions, and has been being the important foundation for social and economic development in this basin historically. In particular, the Magdalena River plays an important role in transportation of petroleum and petroleum products, prompts the development of petroleum industry in Colombia, provides a large petroleum export way, and holds a relatively stable market share in the petroleum transportation market in Colombia. In 2011, more than 2 million tons of petroleum-related large-batch liquid bulk cargo were transported through the Magdalena River. Along with the improvement of waterway conditions and improvement of shipping efficiency, the transportation cost will be further reduced, so that the petroleum industry of Colombia will be more competitive in the international market.

Coal is the most important export resources in the Magdalena River Basin besides petroleum, and is the traditional large bulk cargo most suitable for water transport. At present, the coal transport on Magdalena River is only in the initial and trial stage, the annual transport volume of coal is only tens of thousands tons; and based on the forecasts made by the Ministry of Mines and Energy, the coal to be exported through the Magdalena River will reach 16 million t in 2019.

The container transport is the new logistic transport mode arisen in recent years, and is becoming the new transport mode suitable for inland river transport. The important cities such as Bogota, Medellin, etc., lie in the middle reaches and upper reaches of the Magdalena River Basin. The container transport ports are located at Cartagena and Barranquilla, and the Magdalena River becomes the most important bond for linking these cities together, so the container transport is also an important part for development of ship transport of the Magdalena River. The bulk cargos to be imported, such as steel and machines, can also be transported through the Magdalena River. Thus, it can be seen that the Magdalena River has a huge development space for ship transport, and will play a more important role in optimization of transport system and reduction of transport cost in Colombia.

b) The implementation of improvement works for the Magdalena River Waterway is the new opportunity for the development of ship transport of the Magdalena River

In history, the Salgar/La Dorada Port and the Berrio Port were both the important land-water transport ports. In recent years, due to the development of road transport and lack of effective improvement and maintenance of the Magdalena River Waterway, the waterway has been worsened, and road transport has been gradually prevailing, while the ship transport has been gradually shrinking. In 2013, the Colombian government decided to conduct the improvement works for the 256 km-long waterway from Salgar to Barrancabermeja on the Magdalena River. So far, relevant authorities have already approved these works. With these works to be implemented, the 887 km-long waterway on main stream of the Magdalena River downstream of Salgar will be deepened to 2.1 m, which can undertake kiloton-order ships fleets. Then Salgar and Berrio will become two new important land-water transport centers, and can attract the materials transfer business between large cities such as Bogota and Medellin, and Cartagena and Barranquilla at Atlantic coast, so that the major coal-producing areas in the middle reaches of the Magdalena River Basin can be connected to the Atlantic seaports through water transport, the most economic way, and the transport business of coal and containers on the Magdalena River can be greatly promoted. The implementation of these works will improve the waterway conditions, make the inland river transport market prosperous and drive the development of shipping industry. The river channels in middle and lower reaches of the Magdalena River are similar to plain river channels, in which the bank slopes are all in natural states, and less than 10% of the bank slopes have been artificially stabilized. The implementation of these works will also benefit the stabilization of the river channels, reduce soil erosion on banks, reduce sediment content in water flow, increase land utilization rate along the river, and provide engineering experiences for improvement of river channels downstream of Barrancabermeja and the Dique Canal.

c) The water leisure tourism has been gradually being developed, and water transport is becoming the important support for the development of scenic spots and tourism cities in the basin.

Many towns along the Magdalena River were formed and are developed upon the water transport of the Magdalena River, with long histories and beautiful sceneries, representing the glorious history of Colombia and being the hot tourism regions including cities like Cartagena, Mompos, Honda and Girardot. In recent years, more and more port cities have been intending to build scenery zones with cultural characteristics along the Magdalena River, improve urban style and develop the urban leisure sightseeing zones along the Magdalena River. Although the inland river passenger transport is impacted by rapid development of road and passenger transport distribution, the gradually developing water leisure and sightseeing tourism will drive the development of water passenger transport, so that the inland river transport will become the important support for the development of tourism resources in scenic regions and cities and for development of water leisure tourism.

5.2 ForecastForecast of Transport Volume and Port Handling Capacity

5.2.1 Analysis on Hinterland Economy

a) Current situation and plan of economic development of Colombia

Colombia is at the medium level in economic development in Latin America, and its economic development generally holds in the stable growth trend and its average economic growth rate is higher than that in most of the Latin American Countries.

The major industries of Colombia include agriculture, mining industry, manufacturing industry, service industry, etc. The agriculture mainly includes plantation, animal husbandry, fishery, forestry, etc., and coffee and flowers are relatively important export commodities. The manufacturing industry mainly includes sugar refinery, coffee production, textile, metallurgy, machine manufacturing, automotive assemble, cement, chemistry, oil refining, petrochemical industry, etc. The mining industry mainly includes coal, petroleum, gold, emerald, other precious metals, etc.

The main trade surplus countries of Colombia are America, Venezuela, Ecuador and Peru, and the main trade deficit countries are China, Mexico, Brazil, Argentina and Japan. In 2010, the total volume of foreign trade of Colombia was USD 80.5 billion, in which the total export volume was USD 39.82 billion, growing by 21.2% year on year; and the total import volume was USD 40.68 billion, growing by 23.7% year on year.

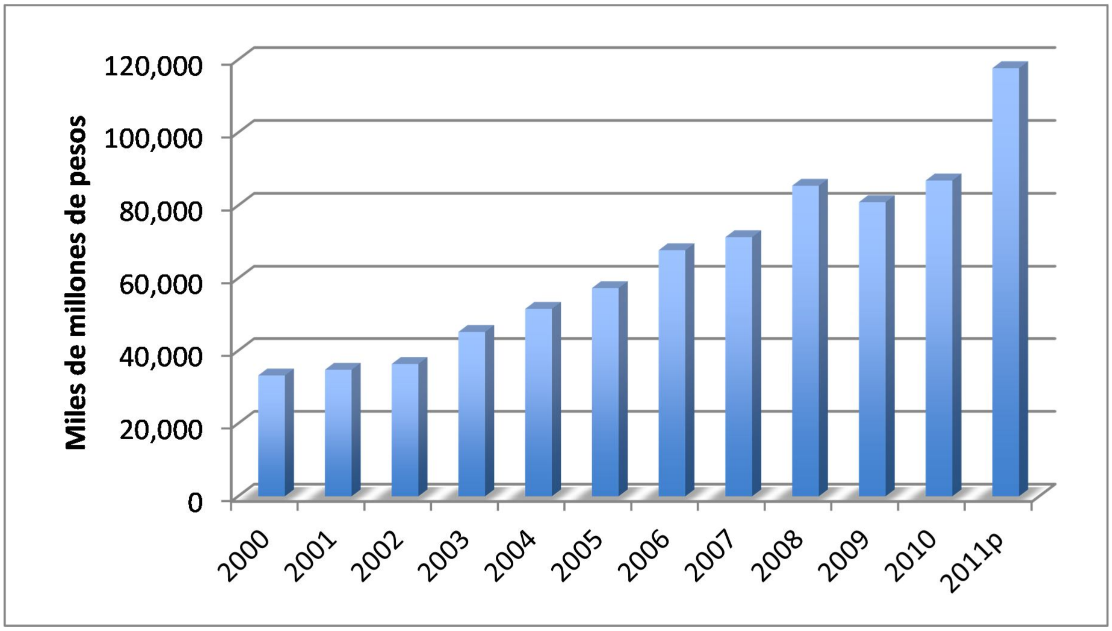


Fig. 5.2-1 Trend of Gross Foreign Export Values during 2000 ~ 2011

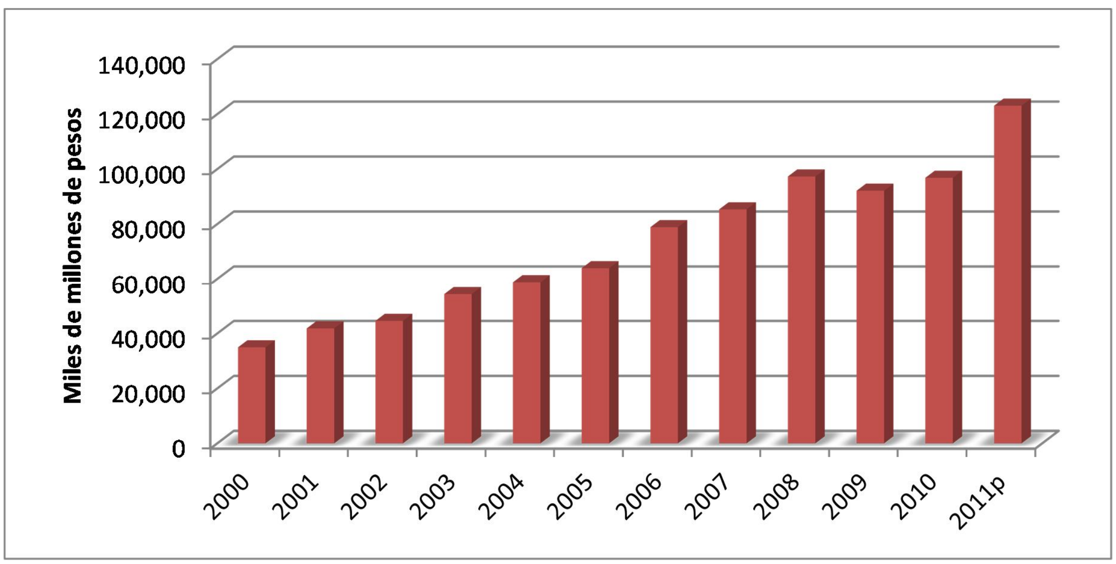


Fig. 5.2-2 Trend of Gross Foreign Import Values during 2000 ~ 2011

The main export products include petroleum and petroleum products, coal, coffee, nickel, textile and clothing, chemical product, food and beverage, metal products, mechanical equipment, etc. The petroleum and its byproducts account for a large proportion in export volume, and coal and nickel exports show the declining trend. The major countries to which Colombia exports goods are America, Ecuador, China, Venezuela, etc., and the export value to America accounts for more than 40% of the total export value. The import goods are dominated by intermediate products and raw materials, accounting for about 45% of the total import value, in which capital goods and building materials account for about 35%, and consumption import accounts for about 20%. The major countries from which Colombia imports goods are America, Brazil, Mexico, etc., and the import value from America accounts for about 30% of the total import value.

The economic development has always been one of the key tasks of recent governments. The economic policies of the current government are made on the basis of the purposes of "democracy and prosperity", in which agriculture, infrastructure, housing, mining and innovation are regarded as the five major engines for driving economic growth and prosperity of Colombia. As for investment, the current government will maintain the policies of being friendly to investors, so as to attract more foreign investments. The purposed foreign investments to be attracted will be increased from USD 7.17 billion in 2010 to USD 13.2 billion in 2014. The export value will be increased from USD 33 million in 2010 to USD 53 million in 2014. The coal output will be increased from USD 74 million in 2010 to USD 110 million in 2014.

b) Analysis on industries development environment in the basin

The major industries in this basin are petroleum, agriculture, tourism and mining. The petroleum and coal industries are directly related to ship transport of the Magdalena River. In 2012, the proved reserve of crude oil was more than 2 billion barrels, and the annual output was about 190 million barrels, accounting for about 5% of the total output of the whole Latin America. The main production areas of petroleum are centralized in east plain regions and middle and upper reaches of the Magdalena River Valley, mainly including Casanare Department, Arauca Department, Valle del Cauca Department, Meta Department and Santander Department. Coal is mainly distributed in La Guajira Department and Cesar Department in northeast region, and in Boyaca Department, Cundinamarca Department and Santander Department in upper and middle reaches of the Magdalena River Basin.

c) Analysis on transport development environment

Since the beginning of 1990s, Colombia has been actively improving the domestic infrastructures by opening market and attracting private investments. Foreign investors can be authorized and provide materials and services for joint venture and cooperation with state-owned enterprises, and can even merge state-owned enterprises to participate in the infrastructure construction of Colombia. In recent years, the government has been further increasing the input on construction of infrastructures in Colombia, and trying to attract foreign investors and provide business opportunities to them. Many large-scale infrastructure projects are about to be commenced. In 2009, the transport investment of the whole country was USD 31 billion, in which the road transport investment accounted for 87%.

Due to a very low transportation expense which is about 1/4 of transportation expense of road transport and about 1/2 of transportation expense of rail transport, water transport is the most suitable transport mode for the bulk commodities such as coal, petroleum and containers, and the improvement of infrastructures such as waterways and ports will cause that the transportation mode of bulk commodities will be changed from road transport to water transport, and the induced transport volume is the important factor which should be considered for the forecast of water transport volume.

5.2.2 Forecast of Passenger and Cargo Volume

a) Forecast method and basis of transport volume

The year for study is 2011, partially with data of 2010; 2020 is taken as the immediate level year, and 2030 is taken as the forward level year. The forecast study approach comprises: deeply analyzing the current development situation of cargos, current situation of infrastructures and variation trend of freight volume of the Magdalena River, and summarizing the development characteristics and existing problems of the Magdalena River; emphatically deeply analyzing and defining the macro economy, key industries and comprehensive transportation of the hinterland, development situation, future development plan and orientation of the Magdalena River Basin, and grasping the development orientation of ship transport of the Magdalena River; on the basis of qualitative analysis on national economy development level, industries forms, foreign trade structure and transportation demand characteristics of the hinterland, predicting the total freight volume of the Magdalena River by using various mathematic models such as modulus of elasticity, regression analysis, time serious and exponential smoothing; and predicting the freight volumes of major cargo types by using different forecast methods (including balance of production and marketing and container production coefficient method) for different demand characteristics and in combination with market research and resource distribution.

Forecast method: 1) according to the current situations and development trends of factors such as productivity layout the demand for transport of social and economic development, resource characteristics, transporting volume and directions of energy sources, raw materials and products, economic rationality of transport, comprehensive forecast on the transport volume can be conducted., 2) Performing the forecast analysis through the combination of macroscopic analysis and microanalysis (predominantly the macroscopic analysis) and the combination of quantitative analysis and qualitative analysis (predominantly the qualitative analysis). 3) Since the freight volumes of other ports (except the major ports) are very small, there is no relevant statistical data and the ship tonnage is small, which would not impact the navigation of large ships, the freight volumes of the Magdalena River mentioned in the report adopt the statistical data of the handling capacities of major ports on the Magdalena River. 4) The Dique Canal is primarily connected with the Cartagena Port, and the transport volume of the Dique Canal is basically equal to the handling capacity of the Cartagena Port, so it is not necessary to do the individual forecast analysis on the transport volume of the Dique Canal.

The bases for forecast include: economic and industrial development policies, national economic development plan and provincial development plan, statistical economic data in 2011, statistical yearbook on comprehensive transport, etc.

b) Forecast of total freight volume

The freight volume of the Magdalena River is closely related to the development of social and economic development of the hinterland, so the forecast of freight volume must be based on the social and economic development and be subject to a certain perspectiveness. Since the relatively single historical data cannot give a true representation of the comprehensive freight development of the hinterland market, the forecast with exponential smoothing, regression forecast method (correlation analysis method), grey system forecast method and elastic coefficient method is subject to a certain limitation. Refer to Table 5.2-1 for forecast results of handling capacity obtained through various models.

Table 5.2-1 Forecasts of Total Freight Volumes of the Magdalena River

Year of Forecast	2020 (Forecast) (10,000 t)	2030 (Forecast) (10,000 t)
Exponential smoothing	830	1230
Unitary linear recursive analysis	740	930
Grey forecast correction model	930	1500
Elastic coefficient method	780	1300
Weighted average of above forecasts	820	1240
Average growth rate	12.1%	4.2%
Predicted result of balance of production and marketing	1200	2600
Comprehensive average growth rate	16.5%	8.0%

In accordance with the above-mentioned predicted results obtained through different models and the characteristics of national economy, foreign trade and productivity layout of the hinterland, , the major cargo types are analyzed and predicted in detail through the methods such as cargos sources survey, balance of production and demand. On the basis of market research, giving consideration to rational division of freight transport system of the Magdalena River Basin and with reference to relevant inland waterway plan and development histories both in Colombia and foreign countries, a forecast level of freight volume relatively corresponding to reality is provided. In the far future, the economic development of the hinterland will give rise to the increaseing demand for ports, saturation of transportation capacity of ports around and deep promotion for construction of heavy industrial base, and considering the economic development of the hinterland of the Magdalena River, coal, mineral building materials, containers and passenger transport volume, etc. will be the new growth points of transport volumes on the Magdalena River in the future, besides petroleum-related products.

Based on comprehensive analysis, it is predicted that the freight volumes of the Magdalena River will respectively be 12 million t and 26 million t in 2020 and 2030, average annual growth rate from 2010 to 2020 will be 16.5% and average annual growth rate from 2020 to 2030 will be 8.0%.

c) Forecast of transport volumes of different cargo types

The cargos with relatively great development potentials in the basin include coal, petroleum products, containers, mineral building materials, cement, other agricultural products, etc. In accordance with the geographic location, natural conditions, development prospects and functional orientation of the Magdalena River Waterway, and the industries structure characteristics of the hinterland, the transport volumes of various cargos are predicted. Refer to Table 5.2-2 for the predicted results.

Table 5.2-2 Forecasts of Transport Volumes of Different Cargos

Categories of Cargos	2020 (Forecast)	2030 (Forecast)
Total freight volume (10,000 t)	1200	2600
Coal (10,000 t)	600	1400
Petroleum product (10,000 t)	400	600
Mineral building materials and cement (10,000 t)	40	100
Containers (10,000 t)	100	300
Others (10,000 t)	60	200
Passenger transport volume (10,000 person-times)	350	430

d) Forecasts of handling capacities of major ports

There are many ports along the Magdalena River, as the important compositions of the shipping system, in which the relatively important ports are Barranquilla Port, Cartagena Port, Gamarra Port, Barrancabermeja Port, Berrio Port and Salgar Port. Refer to Table 5.2-3 for collecting and distributing situations, functional orientations and covered areas of major ports.

Table 5.2-3 Summary of Collecting and Distributing Situations, Functions and Covered Areas of Major Ports

Port	Collecting and Distributing Situations	Functional Orientations	Covered Areas
Barranquilla Port	Dominated by waterway and road, supplemented by railway	Comprehensive hub ports dominated by containers, coal and petroleum products	Linked to inland, and exported to the world
Cartagena Port	Waterway and road	Comprehensive hub port dominated by petroleum products and containers	Linked to inland, and exported to the world
Gamarra Port	Waterway and road	Port for bulk cargo and container	Bolivar, etc.
Barrancabermeja Port	Waterway, road and railway	Port for coal, petroleum product and container	Santander, Bolivar, etc.
Berrio Port	Waterway and road	Port for bulk cargo and container	Santander, Caldas, etc.
Salgar Port	Waterway and road	Port for bulk cargo and container	Cundinamarca, Caldas, Tolima, etc.

In 2010, the total inland river handling capacity of the above-mentioned six ports reached 2.566 million t, accounting for 98.2% of the total handling capacity of ports in the Magdalena River Basin, and the same index accounted for 99.2% in 2011. Refer to Table 5.2-4 for summary of forecasts of handling capacities of major ports on the Magdalena River.

Table 5.2-4 Summary of Handling Capacities of Major Ports on the Magdalena River

Year	2010 (Actual) (10,000 t)	2011(Actual) (10,000 t)	2020 (Forecast) (10,000 t)	2030 (Forecast) (10,000 t)
Total	256.6	222.2	1160	2550
Barranquilla Port	21.9	13.0	200	400
Cartagena Port	116.2	102.4	350	850
Gamarra Port	5.6	3.4	60	200
Barrancabermeja Port	112.5	103.3	450	900
Berrio Port	0.4	0.1	50	100
Salgar Port	0.0	0.0	50	100

5.3 Planning Objectives and Development Concepts

5.3.1 Planning Objectives

Ship transport is a part of comprehensive utilization system of water resources of Magdalena River. The port, waterway, ship and support system should be prompted for complete development in accordance with the requirements in various aspects such as river channel regulation, shoreline utilization, environmental protection, so as to build an unimpeded, efficient, safe and green modern shipping system, and the ship transport of the Magdalena River will become the important composition of the comprehensive transportation system in the Magdalena River Basin or even the whole country, so as to facilitate and promote the sustainable development of economy and society in the basin.

The modern inland river ship transport system can make full use of advantages and potentials of water transport, optimize the comprehensive transport network and obviously improve the transport efficiency and energy saving and emission reduction capability, with obvious facilitation and promotion effects for economic development. In the regions developed in inland river transport around the world, generally the inland river transport is regarded as the important entry point to enhance the competitiveness of local mining industry and manufacturing industry, accelerate the local economy to participate in the cooperation with regions in Colombia and foreign countries and in industries division more completely and deeply and plan and deploy the development along river, industrial layout, development of zones close to port, etc., and the strategies of "port construction to promote urban economy" and "port-zone linkage" have been chosen by many port cities for economic and social development along rivers.

The Magdalena River has always been the large important waterway in history. With the gradually quick course of the globalization, the Magdalena River should be the powerful support for the integration of the basin into the global economic and trade circle, and the construction of unimpeded, efficient, safe and green modern inland river transport system is the urgent requirement to promote the economic development in the basin. According to the current development situation, development conditions, circumstances and requirements of water transport of the Magdalena River, the overall development objectives of water transport of the Magdalena River are studied and provided as follows:

A modern water transport system based on Cartagena Port and Barranquilla Port (both of them are international hub ports), by taking the Magdalena River and the Dique Canal as the backbones, centered by Gamarra Port, Barrancabermeja Port, Berrio Port and Salgar Port, supported by standard, specialized and large-scale transportation ships, guaranteed by advanced and complete support system and effectively linked and coordinated with the modes of transportation, such as maritime transport, road, railway, has been built in about 20 years.

2011 ~ 2020:

By 2020, the water transport of the Magdalena River will have been basically modernized, the advantages and potentials of water transport will have been relatively fully embodied, the transport business of coal and containers will have been obviously increased, the petroleum transport business will have been steadily increased, and the water transport will have been gradually prompting the development of inland industries. The inland river transport conditions of Cartagena Port and Barranquilla Port will have been improved, and the two ports will have been effectively linked with maritime transport; the waterways of main stream of the Magdalena River downstream of Salgar and Dique Canal will have been systematically improved and become the important compositions of comprehensive transport system in the region; a group of large-scale, specialized and modernized port zones will have been built at Gamarra Port, Barrancabermeja Port, Berrio Port, Salgar Port and important ports in some regions and effectively connected with road and railway, and these ports will be gradually built as the regional comprehensive logistic centers. The transport ships will have been basically standardized, specialized and expanded, and the average tonnage of transport ships on main stream will have been greater than 1,000 t. The advanced and complete safety supervision and rescue system for modern inland river transport will have been basically established, and the energy saving, emission reduction, service capacity and development level of industries will have been completely improved.

2021 ~ 2030:

By 2030, the water transport resources downstream of Salgar will have been reasonably developed and fully utilized, and the inland river transport advantages will have been fully embodied. This waterway will have undertaken most of the coal, petroleum and container transport business in the basin, become the major composition of the regional comprehensive transport system, and obviously promoted the development of economic industries along the Magdalena River.

5.3.2 Development Concepts

The next 20 years is the period of strategic opportunity for modernization of ship transport of the Magdalena River. According to plan objectives, current situation of ship transport and transport volume demand, the thoughts of development of "unimpeded waterway, river-sea linkage, land-and-water transport and efficient service" for ship transport of the Magdalena River are proposed, with the following specific contents:

a) Strengthen construction and management of waterway, ensure unimpeded waterway and expand high-grade waterway mileage.

The waterway is the foundation for development of inland river water transport and the key to promote development of inland river ports, ships and transport volume. The middle and upper reaches of the Magdalena River are close to the most important producing areas of major export commodities such as coal and petroleum and important industrial cities such as Bogota and Medellin in Colombia, and the lower reaches are linked to Barranquilla Port and Cartagena Port (two international hub ports), so the Magdalena River can be the bond for Colombia inland to blend into the world trade circle, and construction of unimpeded Magdalena River Waterway is the primary task for development of inland river transport. The government-leading policies for construction of waterway should be insisted, input and construction intensities should be strengthened, and the high-grade waterway (including the Dique Canal) downstream of Barrancabermeja should be kept unimpeded; the improvement works for waterway section from Salgar to Barrancabermeja should be carried out as soon as possible, and the high-grade waterway should be extended to Salgar; and the advanced mode in which waterway construction and hydropower development upstream of Salgar are integratedshould be actively explored, the water transport hinterland should be gradually expanded to the regions upstream of the Magdalena River, and the service range of water transport of the Magdalena River should be gradually enlarged.

b) Promote river-sea linkage and undertake international industrial transfer through international hub ports.

The development of port and water transport economies can not only effectively reduce the logistics costs in the hinterland, in particular for the manufacturing enterprises of coal and petroleum and export-oriented manufacturing enterprises along the Magdalena River, strengthen the international competitiveness of products and promote the local economy to participate in cooperation with regions in Colombia and foreign countries and in industries division more deeply, and also promote the development of relevant service industries such as port and shipping, commerce and trade, finance, information service. Promoting the river-sea linkage is the fundamental way for ship transport of the Magdalena River, namely, the inland river transport is seamlessly linked with maritime transport on the basis of Barranquilla Port and Cartagena Port (two international hub ports), and the international freight routes are directly introduced to the inland, so as to greatly increase transport efficiency, reduce the transshipment time and shorten the distance between inland industrial economy and international commercial trade. The river-sea linkage ports should be built on the basis of the existing infrastructures and development environment; the service capacity of inland river transport business of two hub ports should be improved; guidance and support should be made by policies, and international industrial trans-shippment should be undertaken.

c) Complete the construction of inland ports and supporting infrastructures, and promote land-and-water transport and port-and-city transport, so as to drive the development of regional economy

The construction of specialization, scalization and modernization of important inland ports such as the Gamarra Port, Barrancabermeja Port, Berrio Port, Salgar Port should be accelerated; the specialized development plan of important ports should be prepared as soon as possible, and the supporting facilities of ports should be gradually completed, so that ports will be seamlessly linked with land transport system such as road, railway, pipeline. The specialized transport systems for container, coal, liquid bulk cargo, etc. should be gradually built, and ports should further play the role of being transport hubs and foundation platforms for resource optimization allocation, so as to give rise to the establishment of storage bases, logistic parks and industrial parks close to ports, and promote the economic and social development in the basin.

d) Build an efficient inland river transport service system, and raise service capacity and level of modernization

Building an efficient inland river transport system is the fundamental way to enhance the industrial capability and make full use of water transport advantages. At present, the Magdalena River is subject to a relatively low transport volume and slow development, so the construction of high-grade waterway and modern ports must be strengthened while the support system should be completed at the same time. The 24-hour navigation should be achieved for important waterway sections; the inland "E-port" should be built to improve the comprehensive service capacity of inland ports, the public information service system of water transport should be completed; the market-oriented policies should be insisted, and the construction of upscaling, standardization and specialization of ships is accelerated based on the policy guidance and industrial macro-control. The water leisure and tourism transportation should be actively developed.

5.4 Ship Type Planning

5.4.1 Development Trend of Ship Types

a) Development situation and experience of inland river transport in foreign countries

The countries or regions relatively developed in inland river transport around the world mainly include China, European countries, America, etc., and the standardization process of ship types in these countries or regions is worthy to be referred to for many experiences and lessons, since the standardization construction of ship types is the necessary composition for construction of inland ship transport.

1) Inland river transport in China

There are many inland river systems in China, and a wide variety of ship types in different regions. In recent years, it has been showing an obvious trend of upscaling and standardization of transport ships; government has been investing a lot to accelerate the standardization process of ship types, and that is to say, the government has been providing subsidies for discard of outmoded ship types, and proportion of standard ship types and average loads of ships have been gradually increasing year by year.

2) Inland river transport in European countries

The inland waterway network in European countries is primarily centralized in Netherlands, Germany, France, Belgium, etc., and formed primarily based on the river system of the Rhine basin. Since the inland river transport is most suitable for sustainable development, each country pays much attention to the development of inland river transport, and basically all cargo ships are upscaled ships. In Germany, the inland annual transport volume is about 300 million t; most of the ships are motor ships, and there are about 3,000 ships including cargo ships, cargo pushers and oil tankers, with the total load capacity of more than 3 million t, and the average load capacity of cargo ships of 1,100 t.

3) Inland river transport in America

The inland river transport in America is dominated by Mississippi river system and water system of the Great Lakes. The Mississippi water system has the largest volume of freight, accounting for more than 60% of total inland volume of freight in America. The government has been actively building the high-grade waterway; now the waterway navigable for 2,000 t-order ships has reached 40,000 km long, and the average load capacity of motor ships has reached 1,700 t.

b) Analysis on development trend of ships

At present, pusher fleets are primarily adopted for large-scale freight transport on the Magdalena River, in which the largest barge has a load capacity of 1,250 t, and there are only small motor ships with the load capacity of lower than 25 t. The ship transport is administrated by Inland Transport Bureau of the Ministry of Transport, and operated by the private companies with licenses. The largest inland river transport company possesses 75 tractor tugs and 235 barges, with the total load capacity of 160,000 t. The transport business of the 4 biggest shipping companies accounts for 50% of the total inland river transport volume, and the load capacity of ships accounts for 66% of the total load capacity. There are 30 tractor tugs and 131 barges in total participating in petroleum and petroleum product transportation, with the total load capacity of about 188,500 t.

Currently, the waterway with the depth of not less than 2.1 m on the Magdalena River is about 745 km long (631 km-long section from Barrancabermeja to Barranquilla and 114 km-long Dique Canal), and will be extended to Salgar by 2023, be 1,000 km long in total. One-pusher/six-1000t-order-barges fleet is the mature fleet most suitable for the Magdalena River Waterway. Along with the improvement of waterway conditions in the future, the shipping demands will be continuously rising, and the one-pusher/eight-1000t-order-barges fleet or one-pusher/nine-1000t-order-barges fleet may be gradually developed. The large-sized ships have obvious economic effects. Upon increase of freight volume and further improvement of waterway conditions, the 2,000 t-order or 3,000 t-order ship types should be researched on the basis of the 1,000 t-order fleet.

Along with the improvement of waterway and ports conditions, the transport business of coal, containers, petroleum, etc. will grow relatively rapidly and it will be hard for the ship types with simple structuresto adapt the rapid and efficient development requirements; therefore, the specialized ships for containers, bulk cargo and dangerous liquid chemicals should be energetically developed as well as the development of standardization and upscaling of ships.

5.4.2 Selection of Ship Types

According to the waterway and port conditions of the Magdalena River, summarizing of existing shipping experiences and analysis on technical and economic feasibilities of different programs are conducted, finally the technically advanced ship types which are economically rational in operation are selected. For the collected statistical data of ship types are incomplete, or the statistical works for relevant data of ships have not been carried out yet, in this plan, the preliminary analysis is made with reference to the demonstration mode of China's Transport Organization of Ships.

a) The pusher fleet is advantaged in high navigation safety, high speed and less occupation on waterway, and is currently dominating on the Magdalena River. Due to good transport benefit and characteristics, the pusher fleet will be the major ship type to be developed in the future. It is recommended that there will be one-pusher/eight-1000t-order-barges fleet, one-pusher/six-1000t-order-barges fleet, one-pusher/three-1000t-order-barges fleet and one-pusher/two-1000t-order-barges fleet .

b) The 1,000 t-order single ship has flexible advantages of high trafficability and adaptability, and has been quickly developed in other countries. However, the 1,000 t-order single ship is barely used on the Magdalena River. In this plan, the 1,000 t-order cargo ship is regarded as the design ship type for reference.

c) The container transport is the general trend for development of logistics industry, so in this plan, the 30TEU and 60TEU container ships are included in the design ship types. The economic analysis and comparison indicate that the operation proposal with one-pusher/six-1000t-order-barges fleet and one-pusher/four-1000t-order-barges fleet is relatively satisfactory, due to low unit transport cost and necessary transport cost; due to flexibility and trafficability, the 1,000 t-order cargo ships and 500 t-order cargo ships have relatively large development space, and will be the major ship types (fleet) in the future. Giving consideration to the demand for specialized transport and the requirement of container transport development in the future, the 60TEU container ships are regarded as the recommended ship types for the master plan. Refer to Table 5.4-1 for operation organization.

Table 5.4-1 Operation Organization on the Magdalena River

Operation Organization		Total Length (m)	Molded Breadth (m)	Draft (m)
one pusher/six barges	Scale of fleet	238.0	21.6	2.0
	1,000 t-order barge	67.5	10.8	2.0
one pusher/four barges	Scale of fleet	167.0	21.6	2.0
	1,000 t-order barge	67.5	10.8	2.0
one pusher/two barges	Scale of fleet	160.0	10.8	2.0
	1,000 t-order barge	67.5	10.8	2.0

Table 5.4-1(Continued)

Operation Organization	Total Length (m)	Molded Breadth (m)	Draft (m)
1,000 t-order cargo ship	85.0	10.8	2.0
500 t-order cargo ship	67.5	10.8	1.6
30TEU container ship	51 ~ 53	10	1.5 ~ 2
60TEU container ship	62 ~ 64	10.6	2 ~ 2.5

Note: the above-mentioned table only lists the operation organization modes, and the data on ship types and scales are from the China's ship type and scale data, for reference only.

5.5 Waterway Planning

5.5.1 Waterway Scale

a) Total freight volume and representative ship types

In accordance with the predicted result of freight volume, in 2020, the transport volume of the Magdalena River will reach 12 million t, and in 2030, the transport volume of the Magdalena River will reach 26 million t.

Most of the operating ships are pusher fleets. Based on the sizes of pusher wheels, various organization modes such as R-B, R-2B, R-B-B, R-2B-2B, R-2B-2B-2B, R-3B-3B, R-2B-2B-2B-2B and R-3B-3B-2B (R represents pusher wheel and B represents barge) have been developed. The barge has the maximum load capacity of about 1,250 t, and the design draft is 1.83 m.

The designed ship types adopted in two designs of improvement works of Salgar-Barrancabermeja waterway section have some differences. The fleet adopted in the design of Berrio-Barrancabermeja waterway section is R-2B-2B-2B, and has a total length of 254 m and a width of 26 m. The fleet adopted in the design of Salgar-Berrio waterway section is R-2B-2B-2B-2B, and has a total length of 280 m and a width of 27 m. However, the widths of straight sections of waterway in the two designs are taken as 60 m based on R-3B-3B. The waterway depth is taken as 2.1 m, based on the design draft of ships, plus underkeel clearance of 0.3 m.

As for this master plan, in accordance with the results of above-mentioned two designs and the field survey, the representative fleet is taken as R-2B-2B-2B, with the total length of 254 m and width of 27 m, and it should be considered that other organization modes of fleets can also navigate in relatively good water level conditions.

b) Waterway depth

The waterway depth is the result of design draft of fleet plus underkeel clearance. For the waterway for navigation of kiloton-order fleet, the underkeel clearance can be taken as 0.3 m ~ 0.4 m; and for cobble and rock riverbed, the underkeel clearance can be taken as 0.4 m ~ 0.6 m, specifically, the underkeel clearance should be taken as a relatively high value in the water basin with a relatively high flow velocity or relatively strong wind wave; otherwise, the underkeel clearance should be taken as a relatively low value. For dredging works, the dredging depth of waterway should be design water depth plus 0.3 m, or the overdredging depth should be calculated in accordance with the actual sediment accumulation rate against the sediment accumulation of waterway.

The Magdalena River Waterway is the only water transport channel connecting the inland with the Atlantic Ocean, but this waterway has relatively simple commodities categories and ship types. At present, the major navigation reach is from Barrancabermeja to Atlantic coast, and upon the implementation of improvement works of the waterway section from Salgar to Barrancabermeja, the 887 km-long reaches downstream of Salgar can be available for navigation, with the waterway depth of 2.1 m. Currently, the reach from Neiva (K1300) to Salgar is only available for navigation of small passenger ships, and may be developed to high-grade waterway along with the construction of hydropower projects.

The cargos transport on the Magdalena River is centralized from the inland cities along the waterway to coastal port cities, Cartagena or Barranquilla for foreign trade, , including petroleum export, coal export, import of steel and finished industrial products, etc. Due to a relatively small number of big cities along the Magdalena River and developed road transport, the freight transshipment quantity among the inland cities on the Magdalena River is in a very low number. Setting different waterway standards for different sections has little significance in freight volume on the Magdalena River; for example, assuming that the waterway section from Neiva to Salgar is available for navigation of about 500 t-order ships, and the commodities of Neiva are primarily transported to coastal areas, the proposals of either arranging 500 t-order ships for the whole 1,300 km-long waterway or adopting 1,000 t-order ships at Salgar will cause the increase of cost. The transport expense of the waterway in the regions developed in road transport is not competitive with that of road transport when the tonnage of ship is less than 1,000 t. Therefore, the depth of waterway from Neiva to Salgar is also planned as 2.1 m. However, during this master plan period, the improvement works for this waterway section are not taken into account, and navigation structures will be built in accordance with the standard of the waterway for hydropower projects on this reach.

In conclusion, during this master plan period, the water depths of 1,300 km-long waterway downstream of Neiva are all planned as 2.1 m, in which the water depth of waterway downstream of Barrancabermeja is kept as 2.1 m; the water depth of waterway from Salgar to Barrancabermeja will reach 2.1 m around the year of 2023 upon the completion of improvement works; the water depth of waterway from Neiva to Salgar is planned as 2.1 m, and the construction time should depend on the construction of hydropower projects and the economic development conditions.

c) Waterway width and turning radius

Different waterway widths should be adopted in accordance with different bending degrees and numbers of ways of the waterway. The width of straight one-way waterway can be calculated with the following formula:

$$B_1=B_F+2d$$

$$B_F=B_s+L\sin b$$

Where, B_1 - width of straight one-way waterway (m);

B_F - width of track belt of ship or fleet (m);

d - safety distance between outboard of ship or fleet and waterway edge (m); for fleet, the safety distance can be taken as 0.25 ~ 0.30 times of the width of track belt, and for cargo ships, the safety distance can be taken as 0.34 ~ 0.40 times of the width of track belt;

Bs - width of ship or fleet (m);

L - length of pusher fleet or length of cargo ship (m);

β - drift angle of ship or fleet (°), taken as 3° for the Magdalena River Waterway.

Through calculations with the above-mentioned formula, the width of straight one-way waterway of the Magdalena River Waterway is about 60 m ~ 65 m.

The width of straight two-way waterway can be taken as twice of the width of straight one-way waterway.

The width of waterway at bending section should be increased on the basis of the width of straight waterway section , and the increase value can be determined through analytic calculation or experimental study according to landform, intervisibility conditions, operating performance of ships, etc. The minimum bending radius at bending section should be taken as 3 times of length of fleet. For a relatively high improvement difficulty, the waterway can be widened and bending radius can be reduced appropriately, but the bending radius cannot be reduced to be less than 2 times of length of the fleet.

As for the waterway scale of Dique Canal, in addition to the above-mentioned reference values, the section modulus should not be less than 6. The section modulus is the ratio of area of water cross section of waterway to the area of wetted cross section of ships.

d) Navigation capacity of waterway

The theoretical navigation capacity of waterway can be estimated with the following formula:$C=24n1000V_{(upstream)}TSQ_C/(m+1)L_C$

Where. C - annual two-way navigation capacity of waterway (t);

n - daily working coefficient of waterway, n=1 for full-time work;

$V_{(upstream)}$ - upstream velocity of ship (fleet), taken as 10 km/h;

T - annual navigable calendar days, taken as 350;

S - the number of ships (fleets) simultaneously on the same cross section of the waterway, calculated with the following formula: $S=BH/(b+1.5\Delta b)(t+\Delta t)$, where, B and H are respectively width and depth (m) of the waterway, b and t are respectively the width and draft (m) of ship (fleet), Δb and Δt are respectively the margin width and depth; according to the current situation and degree of busyness of the Magdalena River Waterway, S is taken as 1;

Qc - rated load capacity of standard ship, taken as 6,000 t;

m - longitudinal distance coefficient between ships (fleets), m=1 for upstream shift, m=2 ~ 5 for downstream shift, depending on velocity of flow; taken as 2;

Lc - length of ship, taken as 254 m;

The design navigation capacity of waterway can be estimated with the following formula:

$$Cs=PK_oK_fK_gC/K_d$$

Where, Cs - design navigation capacity of waterway;

P - navigation dependability, taken as 90% according to situation of the Magdalena River Waterway;

K_o - proportion of cargo ships in all ships in navigation, taken as 0.85;

K_f - average loading coefficient of fleet, taken as 0.65;

K_d - uneven coefficient of arrival of fleet, taken as 3;

K_g - uneven factor of compositions of fleet or reduction factor of standard fleet, taken as 0.75;

Refer to Fig. 5.5-1 for calculated results of annual navigation capacity of the waterway.

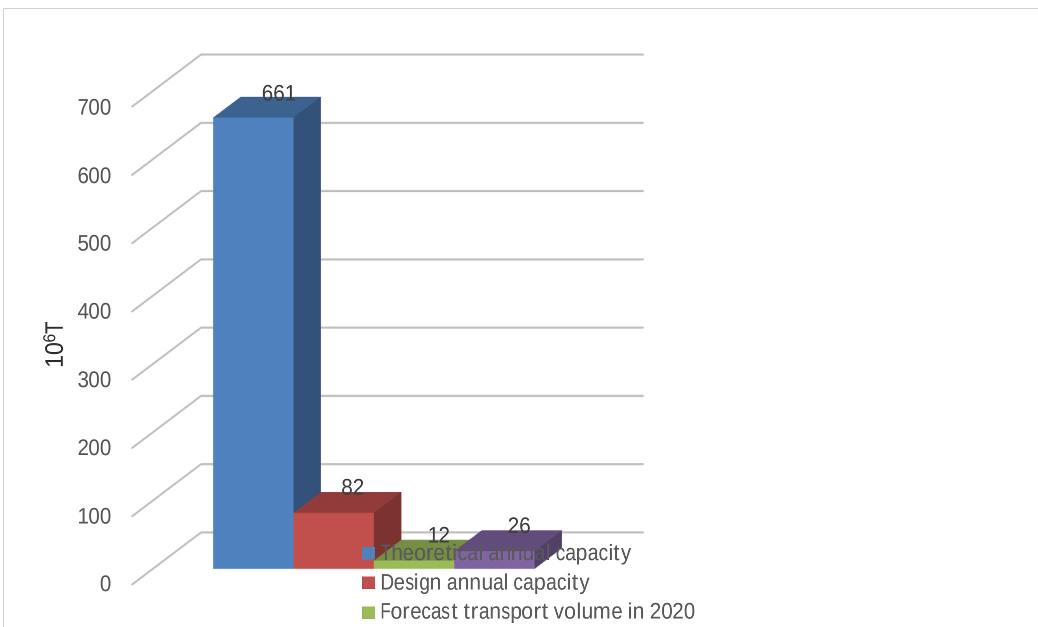


Fig. 5.5-1 Calculated Results of Annual Navigation Capacity of Waterway

According to the forecast of density of freight flow, the freight volume of the Magdalena River will reach 26 million t in 2030. The above-mentioned calculation and analysis indicate that the navigation capacity of the waterway can reach 82.22 million t, which will meet the requirement of transport volume growth.

e) Improvement and maintenance measures of the waterway

In order to maintain and increase the waterway scale, improve the navigation conditions, expand the navigation capacity, increase the navigation distance and improve the economic benefit and social benefit of water transport, the navigation-obstructing shoals must be treated. The structural measures to be adopted are the waterway works. The major waterway works include improvement works, dredging works, canalization works, runoff regulation, etc.

According to natural conditions of the Magdalena River Waterway, the reaches upstream of Salgar are subject to a relatively steep slope, which is suitable for canalization works in combination with the hydropower development; the river channel from Salgar to Barrancabermeja has the lowest stability, with the most navigation-obstructing shoals as a result, this river channel should be subject to improvement works, so that river channels can be gradually stabilized, branches can be reduced and water depth of waterway can be increased; and the reaches downstream of Barrancabermeja should be subject to dredging works, so as to keep the water depth of waterway, and partial unstable navigation river branches should be subject to appropriate regulation works for fixation of navigation river branches.

5.5.2 Canalization and Shiplock Sizing

The navigation channels of the Magdalena River have a total length of about 1,300 km (from Neiva to Atlantic coast), and according to the current navigation situation, can be divided into upper reaches, middle reaches and lower reaches. At the lower reaches, the 631 km-long section from Barrancabermeja to Barranquilla has the highest freight volume, and the water depth of 2.1 m (navigation dependability: 90%), for perennial navigation of kiloton-order fleets. At the middle reaches, the 256 km-long waterway section from Salgar to Barrancabermeja has a water depth of 1.35 m (navigation dependability: 90%) (1.8 m for wet season), for seasonal navigation of kiloton-order fleets. So far, the improvement works and dredging works have been commenced, and the water depth of the waterway will reach 2.1 m upon completion of these works. At the upper reaches, the waterway from Neiva to Salgar is 413 km long, and is less than 0.9 m in water depth; this waterway is basically not for navigation of large cargo ships, but only for navigation of small passenger ships and small cargo ships with the load capacity of lower than 50 t.

Upon completion of improvement works, the waterways downstream of Salgar can all achieve the objective of water depth of 2.1 m, thereby meeting the ship transport requirements during the plan period, so in this master plan, the cascade canalization is temporarily not proposed for the waterways downstream of Salgar.

The waterway section from Neiva to Salgar is part of the upper reaches of the Magdalena River, and is characterized by relatively steep slope. Due to the existence of Honda torrent, this waterway is not for navigation of large cargo ships at present. Along with the construction of cascade hydropower projects, the reaches will be gradually canalized, so that there will be a possibility for navigation of large cargo ships; and due to relatively big cities in upper reaches, such as Neiva and Girardot, the development of ship transport resources in these reaches will be good for social development. As a result, it is necessary to develop ship transport as well as hydropower development. In view of the purpose of development of hydropower resources as well as canalization of river channel, there will be 10 cascades for the reaches from Neiva to Salgar in this master plan. Upon completion of cascades, the waterway conditions will be greatly improved, so as to drive the development of ship transport. Generally, the hydropower cascades, as well as the ship transport, will greatly increase the investment of hydropower project and drop the economic indicators of the hydropower project, and in the initial stage of cascade canalization, the freight volume is relatively low and the ship transport benefit is not significant, so the attraction for investors is limited. With reference to the experiences of countries developed in ship transport, government is giving subsidy to construction of hydropower project in accordance with the length of river channel subject to cascade canalization and improvement on ship transport, so as to expand the high-grade waterways as well as development of hydropower.

The shiplock is the primary structure for ships to pass through dam, the design ship types is related to the scale and investment for construction of shiplock, in which over-large ship type will cause the investment waste and loss of electric energy, and over-small ship type will not promote the development of ship transport. Since the most economic operation organization for the Magdalena River is one-pusher/six-1000t-order-barges fleet, in view of freight volume of the waterway, the manner of de-queuing and making ships pass through the shiplock one by one should be adopted at the hub, and the one-way shiplock has an annual navigation capacity of about 3 million t, which can basically meet the requirements of freight volume. Therefore, it is recommended that the design ship type for the shiplock should be one-pusher/one-1000t-order-barge fleet, with the length of 110 m, width of 13 m and draft of 1.8 m; and as for the scale of shiplock, it is recommended that the lock chamber have an effective length of 120 m, a width of 16 m, a water depth at gate sill of 3 m ~ 3.5 m, a length of straight upstream and downstream approach channels of 250 m respectively, and a navigable clearance of 10 m.

5.5.3 Dique Canal Improvement Planning

The Dique Canal is an important freight line for linkage between Cartagena and the inland. More than 90% of petroleum is exported from Colombia through the Dique Canal. In addition, the Dique Canal is also connected with many freshwater lakes along the Dique Canal, so as to maintain the ecological balance of wetland, prevent the sea water encroachment, provide freshwater to cities along the Dique Canal, etc.

The current problem of Dique Canal is the serious sediment accumulation, the dredging works are carried out every year so as to maintain the unimpeded waterway; besides, the sediment accumulation also exists in freshwater lakes, the wetland area is reducing, and the Cartagena bay is gradually encroached by sediment year by year, which would impact the operation of ports.

The Colombian government pays high attention to the problems of Dique Canal, and the CORMAGDALENA has conducted multiple deep studies, and proposed many valuable scientific solutions and proposals. There are two relatively mature proposals: as for the first proposal, shiplocks should be built at Calamar and Cartagena at two ends of the Dique Canal, so as to regulate the sediment flowing to the Dique Canal, and to further achieve the purpose of reducing the sediment and maintaining the rational flow of water body; as for the other, channels with reduced cross sections should be built at inlet, middle and sea entrance of the Dique Canal, so as to reduce the flow and sediment flowing to the Dique Canal, keep the water level of the Dique Canal and maintain the water depth necessary for navigation and meet the requirements of water flow of wetland.

The root of the problem of Dique Canal is sediment, and to fundamentally solve the sediment problem of Dique Canal, the sediment content in water flow should be reduced, and in the long run, the sediment control works should be conducted through the ways of protecting vegetation in the basin, reducing the soil erosion; however, this is a long process. At present, the major cause of the sediment accumulation in the Magdalena River is high content of sandy soil in soil mass in the basin, frequent human activities, vegetation damage and serious soil erosion. The middle and lower reaches of the Magdalena River are subject to relatively poor improvement effects, so they are subjected to serious river bank collapse and high migration frequency, so that the Dique Canal has a relatively high sediment content. The relatively effective control measures for sediment accumulation include: energetically conducting the improvement works to stabilize the river channel, building hydropower cascades at upper reaches, blocking sediment, etc. Besides, the problem that the sudden drop of sediment content in water at the lower reaches of the cascade may cause the continuous undercutting of the channel at lower reaches and further bring about impacts on many aspects should be taken into account.

In recent years, the proposal of reducing the water flow with high sediment content to the Dique Canal, and trying to guide the sediment to flow into Atlantic Ocean through another outlet may be considered.

The sediment accumulation problem of Dique Canal is a systematic problem, and will be subject to the deep studies in many aspects. The sea entrances of rivers in other countries and regions are also subject to the problem of sediment accumulation, and dredging and guiding are relatively direct measures. It is recommended that the relatively mature engineering proposals should be further studied during the plan period, and the sediment control ways of other countries around the world should be researched and used as reference, so that the sediment control works can be implemented as soon as possible; and besides, the hydrologic sediment observation and study should be strengthened, so as to provide guidance to the engineering proposal. It is recommended that the input to improvement works of river channels as well as maintenance and flood control works of waterway at the upper reaches should be increased, so as to stabilize the river channels. Along with the development of hydropower cascade, sediment should be blocked from the head, thereby gradually implementing the sustainable development of the Magdalena River.

5.5.4 Cauca River Waterway Planning

The Cauca River is the most important tributary of the Magdalena River, and is currently available for seasonal navigation of one-pusher/four-500t-order-barges fleet, on the 187 km-long waterway from Pinillos to Caucasia of which the downstream 100 km-long river reach has the similar landform with Pinillos, and is wetland and flood plain. The rest 87km-long river reach is plain region. And the 187km-long channelhas a width of about 100 m ~ 300 m. The middle and upper reaches of Cauca River have abundant resources for hydropower, and there are many hydropower cascades planned, some of which are under construction.

Due to the underdeveloped land transport, the waterway at lower reaches of Cauca River is the important transport channel for residents in Caucasia and regions along the Cauca River. Caucasia is a relatively important city, with abundant coal resources around, and the Cauca River becomes the important channel for the export of coal.

The transport volume data of Cauca River has not been collected for this master plan, so the forecast of freight volume cannot be carried out temporarily. The Colombian government has already started to pay high attention to this waterway section, and is currently conducting the investigation and study on conditions of the waterway. Through the comprehensive analysis on the previous studies, transport demands, development conditions and difficulty degree of waterway upgrading and improvement of Cauca River, it is planned in this master plan that the 187 km-long waterway at lower reaches of Cauca River should have a water depth of 1.35 m (navigation dependability: 90%), and would be available for perennial navigation of one-pusher/four-500t-order-barges fleet. In the near future, the protection and management works of waterway resources should be strengthened; and in the far future, the construction of waterway should be carried out for the purpose of perennial navigation of one-pusher/four-1000t-order-barges fleet.

5.6 Port Planning

5.6.1 Layout of Ports

The water transport commodities of the Magdalena River mainly include the bulk cargos such as petroleum and petroleum products, coal, containers, agricultural products and machinery, in which petroleum, coal and containers have the best development potentials. The above-mentioned bulk cargos are all related to foreign trade, and subject to a relatively low internal circulation demand. For example, petroleum and coal are mainly for export and containers are mainly imported, so the ship transport of the Magdalena River should be the important channel for foreign trade in the basin. The Cartagena Port and Barranquilla Port are international hub ports and the transfer stations for all import and export freights, and are regarded as the Class-I ports in this master plan. Inland river ports-sea transport of all the bulk cargos should be conducted through these two hub ports. These two ports will undertake the transport of all cargo resources of the inland region, and foreign businesses covering the whole world through the sea transport, and will be the important support for great development of ship transport of the Magdalena River. The Gamarra Port, Barrancabermeja Port, Berrio Port and Salgar Port are the important central ports of inland region, and connected to Atlantic Ocean through the Magdalena River and the Dique Canal, and connected to the hinterland through road and railway. These ports are the important links for linkage between water transport system and land transport network. Ports, waterways and land transport network form the comprehensive transportation system together.

In this master plan, the riverside ports are divided into Class-I ports, Class-II ports and Class-III ports in accordance with the transport condition of the location, functions, development potential, etc., of each port, so that the classification guidance and industrial management can be conducted during development and construction of ports.

Class-I ports:

In the master plan, there are two Class-I ports, which are Barranquilla Port and Cartagena Port. Both of the two ports lie in the Atlantic coast, at very important geographic locations, and are the key water-and-sea transport nodes for linkage between the hinterland of the basin and the Atlantic Ocean. All commodities for foreign trade through water transport in the basin should be through the two hub ports, with a relatively high handling capacity. These two ports can widely impact the regional economic development, and are the important supports for resources development, productivity layout and regional economic development of the hinterland. The distance between the two ports is about 120km, and have their own historical and current characteristics. In the future development, advantages of each port shall be fully exploited to develop them complementarily and with emphasis placed on different aspects.

The Barranquilla Port relies on the Magdalena River Waterway and possesses relatively rich coastal resources. At present, the exploited shoreline accounts for half of the total length of deep water shoreline. The port also has the potential to develop deepwater port by taking advantage of open seas. The port is connected with the inland through main stream waterway of the Magdalena River. The bearing capacity of inland waterway is huge and has the space to be developed into waterway of even higher class. The types of goods currently mainly include coal, containers, and machinery and equipment, etc. Due to the low degree of development and population density at the right bank of Barranquilla section of the Magdalena River, it is suitable to develop a general cargo wharf which occupies a large area and is affected by certain degree of dust pollution. Therefore, for the development direction of inland water transportation of Barranquilla Port, emphasis should be placed on transportation of coal, containers and other general cargos.

The available shoreline for Cartagena Port mainly refers to the east bank of Cartagena Bay with a high degree of development. The Port is connected with the main stream waterway of the Magdalena River through Dique Canal and the development space of the waterway is limited. At present, the types of goods of the Port mainly include bulk liquids (such as petroleum), containers and other bulk cargos. Due to limited shoreline and land resources and high population density of Cartagena Bay, it is not suitable to develop the types of goods which occupy a large area and have serious pollution effect. Therefore, for development direction of the inland water transportation, emphasis should be placed on the transportation of petroleum and containers

Class-II ports:

In the master plan, there are four Class-II ports, which are Gamarra Port, Barrancabermeja Port, Berrio Port and Salgar Port. These four ports relying on the important cities along the Magdalena River have good economic foundations, developed railway and road transport, wide coverage on development of economy, society and comprehensive transport of surrounding regions and good conditions for development of ports, and are the regional transportation organization centers for passengers and cargos transport.

Class-III ports:

The Class-III ports mean the ports other than major ports and regional important ports, and are characterized by dependency on medium and small cities, wide distribution, relatively low handling capacity, limited coverage, relatively simple functions, etc. The relatively typical Class-III ports include Calamar Port, El Banco Port, Mompos Port, Maganque Port, Girardot Port, Neiva Port, Caucasia Port, etc.

5.6.2 Development Scheme of Ports

a) Barranquilla Port

The Barranquilla Port lies on the left bank of the Magdalena River, is 22 km away from the estuary of the Magdalena River, has a waterway with the depth of 11 m to the sea, is available for navigation of 30,000 t-order seagoing vessels and is connected with the inland through kiloton-order waterway of the Magdalena River, with convenient road transport.

The Barranquilla Port has busy maritime transport business, in which the major commodities include petroleum, containers, coal, machinery, building materials, etc., and can not only meet the local demands, but also meet the inland demands through road. In 2010, the handling capacity of this port was 4.0916 million t, in which the inland handling capacity was 219,000 t, including 117,000 t general cargos and 102,000 t petroleum. At present, the mode of transport of the Barranquilla Port is that maritime transport is linked with road transport for coverage of inland, but the advantages of inland water transport have not been embodied yet. The main reasons are that the current wharfs are almost saturated in capacity; all of them are participating in the maritime transport business; the wharfs suitable for the inland river ship operation are in a very limited number; the existing facilities are notcomplete; there are no specialized river-and-sea transport berths, and maritime transport and inland river transport have not been effectively linked yet. According to the industrial development trend in Colombia, the coal export demands have been steadily growing, and the foreign trade demands for containers, machinery, building materials, etc., of the inland, could also be realized by water transport by gradually replacing the current road transport mode, and the inland river transport of the Magdalena River has obvious advantages for linkage between Barranquilla Port and sea.

As predicted, handling capacity of inland river freight at Barranquilla Port will be 3 million t in 2020 and 7 million t in 2030, among which coal accounts for 5.5 million t, oil products 800,000 t, containers 600,000 t (an equivalent to 60,000 TEU) and other goods 100,000 t. This requires twenty 1000 t-order berths for inland river transportation and a total wharf length of about 790m.

During the plan period, for the types of goods for Barranquilla Port, coal, containers and other general cargos are mainly considered. Emphasis should be placed on new construction or reconstruction of modern water-and-sea transport wharfs by integrating and optimizing existing wharfs infrastructures and under the condition that marine transport business is guaranteed, so as to save operation costs, improve transport efficiency and drive the development of inland water transportation

b) Cartagena Port

Cartagena is the seaport city of the Atlantic Ocean, and the important industrial and commercial center in Colombia, and is developed in petroleum industry. Cartagena lies at the month of Dique Canal, has convenient road transport, and is connected to the inland through No. 90 Highway and connected with Barranquilla through No. 90A Highway.

The Cartagena Port is the most important petroleum export base and container transshipment center in Colombia. The Cartagena Port has many wharfs and busy transport business. The seaport business mainly includes containers, petroleum, coal .etc. In 2010, the container throughput was 1.581 million TEU, covering each of major cities in Colombia, such as Bogota, Medellin. Most of the inland river transport business is petroleum transport. In 2010, the petroleum throughput was 1.162 million t, in which the petroleum and petroleum products throughput was 1.15 million t, accounting for 99%.

Depending on the international commercial center position of Cartagena, the huge demands for maritime transport of container and petroleum will be continuously kept, which will be the opportunity for the development of inland river transport. So far, a close cooperation has been established between inland river petroleum transport and oil refinery, and the seamless connection has been implemented between inland river transport and maritime transport. In the future, it will focus on developing the inland river transport of containers.

Based on forecast, the inland river freight throughput of Cartagena Port will be 2.5 million t in 2020 and 5.5 million in 2030, including 2.6 million t of petroleum products, 1.2 million t of containers (equivalent to 120,000 TEU), 500,000 t of coal, , 400,000 t of mineral building material and cement, and 800,000 t of other commodities. There will be fifteen 1,000t-order inland river freight berths needed, and the length of wharf will be about 1,950 m.

At present, the shorelines of Cartagena Bay are relatively saturated in business, the existing infrastructures of wharfs should be fully integrated and optimized, and the river-and-sea transport business of container should be energetically developed, so that the industrial chain will be transferred and extended to the inland.

c) Gamarra Port

The Gamarra Port lies on the right bank around k500 point in the middle reaches of the Magdalena River, and is about 15 km from Aguachica. Cesar Department and Norte de Santander Department on the right bank of the Magdalena River are the main compositions of hinterland, including the respective capital cities of Aguachica and Cucuta. The Capulco Port lies about 5 km upstream of Gamarra. In this master plan, the two ports are both named the Gamarra Port, with two kiloton-order berths. The facilities at wharfs are relatively simple; the yard area for cargos piling is limited, and the road outside the port is connected with No. 45 Highway, however, this road is in a relatively low road classification, and may be easily impacted by flood. According to the statistical data of the Ministry of Transport, in 2010, the handling capacity of Gamarra Port was 56,000 t, and in 2011, that of Gamarra Port was 34,000 t. All of the cargos are machinery equipment.

Based on forecast, the handling capacity of Gamarra Port will be 600,000 t in 2020, and 2 million t in 2030, including 1.3 million t of coal, 500,000 t of containers (equivalent to 50,000 TEU), and 200,000 t of other cargos. There will be four 1,000 t-order inland river freight berths needed, and the length of wharf will be about 320 m.

The Gamarra region is characterized by low population density, good waterway conditions and relatively good conditions for development of the port, so it has the potential to undertake the industrial transfer for coastal areas and to be the logistic transshipment center. During the plan period, the container business, as well as the bulk cargos, such as coke, coal, machinery should be energetically developed for the Gamarra Port based on the favorable conditions such as two capital cities with relatively high population densities and agricultural producing areas. On the basis of the existing wharfs, the storage area should be enlarged, access to road should be improved and rebuilt, and stevedoring process and equipment should be upgraded, so that the Gamarra Port will gradually become a modern comprehensive port, so as to promote the regional industrial development.

d) Barrancabermeja Port

Barrancabermeja lies at the K631 point in the middle reaches of the Magdalena River, and is the most important petroleum industry city in Colombia, with the most important petroleum producing areas around. At present, this Barrancabermeja Port is undertaking the shipment for 90% of petroleum transport on the Magdalena River to Barranquilla and Cartagena. Barrancabermeja is developed in urban road transport, and has high-grade highways connected to Bogota, Medellin, Bucaramanga, etc., has good waterway conditions at port (with the water depth of 2.1 m (navigation dependability: 90%)), and is available for perennial navigation of one-pusher/six-1000t-order-barges fleet. At the Barrancabermeja Port, the specialized wharfs for petroleum are developed and facilities are complete, but the public wharfs suitable for bulk cargos such as coal and containers are lagged in development. Although the public wharf berths have been newly built, the storage yard and stevedoring equipment are in poor conditions, so the Barrancabermeja Port is hardly available for stockpiling and large-scale stevedoring. In 2010, the handling capacity of the port was 1.125 million t, including 1.096 million t of petroleum products.

Depending on the petroleum industry city and developed road network, and due to adjacency to coal producing areas of Santander Department and Cundinamarca Department, the development of Barrancabermeja Port should focus on petroleum, containers and coal. Based on forecast, the handling capacity of Barrancabermeja Port will be 4.5 million t in 2020, and 9 million t in 2030. There will be twenty-five 1,000 t-order inland river freight berths needed, with the length of wharf of about 1,950 m. Petroleum will continuously be the major commodity of the Barrancabermeja Port, and the development of petroleum wharfs should be ensured. The container transport has a huge development potential. The storage yard, warehouse, stevedoring process and other supporting facilities at the Galan Port should be energetically completed; the specialized container ports should be developed; the port service level should be improved; the service items such as port storage, customs declaration, inspection & quarantine should be completed, and through the river-and-sea transport port of Barranquilla Port and Cartagena Port, the container business for foreign trade could be undertaken, so that the inland cities such as Bogota, Medellin, Bucaramanga can be directly linked to international markets through the Galan Port. Coal transport is the urgent need for coal industry in the inland regions. At present, the coal transport condition is almost the bottleneck restraining the development of coal industry of the inland. Developing water transport is the most rational solution. In the near future, the specialized wharf for coal should be built at the Barrancabemeja Port, so as to support the rapid development of coal industry in the basin.

e) Berrio Port

Berrio (K731) lies in Antioquia Department, is close to Medellin and is developed in road transport. The Berrio Port has five kiloton-order berths, but the storage yard and warehouse area are relatively small. Besides, since the Berrio Port lies in the center of Berrio, the external access conditions are restrained by Berrio city. At present, the freight volume is relatively low. In 2010, the handling capacity was only 3,600 t (mineral and coal).

With the favorable conditions of adjacency to Medellin and mainproducing area of coffee, the Berrio Port should be developed mainly for containers and other general cargos, and undertaking foreign trade business through Barranquilla Port and Cartagena Port. Based on forecast, the handling capacity of Berrio Port will be 500,000 t in 2020, and 1 million t in 2030. There will be three 1,000 t-order inland river freight berths needed, with the length of wharf of about 245 m.

Along with the implementation of improvement works for the waterway section from Salgar to Barrancabermeja, the water transport conditions of Berrio Port will be more and more favorable, so that the transport demands will be rapidly developed. Due to the long history, the existing wharfs have already been surrounded by cities and their collecting and distributing transport conditions have been being worsened day by day; during the plan period, construction of new modern ports should be considered, so as to drive the development of economy and society of the hinterland.

f) Salgar Port

The Salgar Port (K887) lies in Cundinamarca Department, is the port on the Magdalena River which is closest to Bogota and is available for navigation at present, and is also relatively close to the coal producing area of Cundinamarca Department. Along with the completion of "Ruta del Sol", the transport from Salgar to Bogota is more convenient. Depending on big cities and primary coal producing areas, the Salgar Port should be developed mainly for coal, container and other bulk cargos.

The existing wharfs were built in 1935, and the rear road is connected with No. 45 Highway. Restricted by waterway conditions, the handling capacity is very low at present. In 2010, the handling capacity was only 200 t of agricultural products. Upon the implementation of improvement works for waterway section from Salgar to Barrancabermeja, the waterway conditions will be greatly improved. Based on forecast, the handling capacity will be 500,000 t in 2020, and 1 million t in 2030. Due to a long history and restricted by urban development, the existing wharfs can hardly meet the requirements of scalization development of modern ports. During the plan period, construction of new port in another place should be considered, so that Bogota and coal producing area can be directly connected with international markets through water transport, so as to promote the development of regional economic industries.

g) Development plan of Class-III ports

The Class-III ports include Calamar Port, Mompos Port, El Banco Port, Girardot Port, Neiva Port, Caucasia Port, etc. During the plan period, the wharfs for passenger transport should be improved primarily to serve the local residents. For the ports subject to relatively distinctive local economic development and relatively rapid demand development, construction of specialized freight wharfs should be considered.

5.7 Support System Planning

5.7.1 Auxiliary Navigation Facilities and Monitoring System

In order to ensure the navigation safety of ships on the Magdalena River, the navigational aids system characterized by rational distribution, equipment in good conditions and efficient functions should be established on the Magdalena River. This system should be capable of simply and clearly indicating safe, economic and convenient waterway for navigation of ships.

a) Distribution principle of navigational aids

As for the distribution of navigational aids, attention should be paid to effective combination of shore beacons and buoys, so as to make full use of each of the navigational aids. Since the shore beacons have a high reliability and far less influencing factors of the nature giving rise to unavailability than buoys, the shore beacons should be used primarily.

Besides, different distribution schemes for navigational aids should be taken according to different characteristics of geographic conditions, hydrologic conditions, etc.:

The middle and upper reaches of the Magdalena River are mountain rivers, which are characterized by narrow and bending waterways, a large number of navigation obstructing shoals, steep slope, high flow rate, large variation amplitude of water level and relatively poor flow regime. The distribution of navigational aids of the Magdalena River must consider these characteristics.

The middle and lower reaches of the Magdalena River are plain rivers, so the waterways in these reaches are prone to navigation obstructing shoals. On the shoal waterway at the transition section, generally the crossing marks are set at two ends of both banks of the river-crossing way. A couple of side buoys should be set at each of the entrance and exit leading to upstream and downstream deep troughs on the shoal crossing waterway. Any obstructions in the shoal waterway should be marked by one or several side buoys as the case may be. The waterway in the river center is marked by the side buoys which are primarily used to mark the boundaries of waterway.

The ships basically navigate along the center of river in the dense waterway net region. The side buoys should be set at the navigation estuary, river flat, bank protrusion, extremely bending shore and the places to prevent ships from going to tributary, etc. The relatively unimpeded and straight waterways in good conditions can be free of navigational aids. The side buoys or navigational aids for left or right-side navigation should be set at upstream end and downstream end of the sandbank in dense waterway net region as the case may be. Destination board can be additionally set at the branching place of two waterways.

The waterways in bridge zone should be mainly provided with marks of bridges and culverts, and selectively provided with side buoys to mark the navigable bridge openings as the case may be.

A conspicuous side shore beacon should be set at each of the heads of upstream and downstream training jetties at shiplock on the waterway. Signal lights for navigation should be set at the entrance and exit of approach channel or around upstream and downstream gates. Boundary marks should be set at the boundaries at two ends of the effective length of the shiplock chamber. Signboard should be set in the berthing region of shiplock, so as to mark the berthing boundaries of ships.

The fixed signs on shore such as lighthouse, light beacons should be set on the vantage ground at tidal estuary, and connected with navigational aids on the coastal shipping line.

b) Distribution of navigational aids

In accordance with requirements of maintenance and management works of inland river waterway, it is planned that the whole waterway downstream of Salgar (including Dique Canal) should be provided with navigational aids. In order to implement the 24-hour navigation of waterway, the navigational aids should be provided with lights. In daytime, the navigational aid should be capable of being viewed from the last navigational aid, and at night, the lighting navigational aid should be capable of being viewed from the last lighting navigational aid.

The waterway in good conditions may be free of navigational aids; however, the information given by each navigational aid should be consistent with the information given by the next navigational aid. The navigational aids should be set in the reaches where the navigation is difficult and in some individual places, so as to mark the obstructions.

All of the navigational aids throughout the waterway should be provided with wireless telemetering and remote control functions, so that the navigational aids can be automatically monitored. For the failure of lights of navigational aids or displacement of navigational aids, warning signals can be sent out, so that the management staff of navigational aids can arrange the repair in time, and the management modernization of navigational aids can be implemented.

5.7.2 Maintenance and Service Facilities of Waterway

The maintenance and service facilities of waterway include necessary comprehensive service area and service ships.

The comprehensive service area is the supporting service facilities of waterway for providing integrated comprehensive services to transport on the Magdalena River, and is provided with the functions of refueling sips, adding water for ships, simple maintenance, emergency rescue, collecting and treating ship garbage, etc.

At present, the ships managed by the Shipping Sector for the Magdalena River are in a very small number. In order to meet the development requirements for maintenance and management of waterway, the ships such as buoy tenders, marine administration speed boat, tug should be provided.

5.7.3 Security System

The safety monitoring management and emergency ship salvage command and dispatching system is the necessary composition of modern ship transport system, and includes monitoring and salvage command center and supporting equipment for salvage. The system should be provided with sensitive and efficient organizing, dispatching and commanding functions, and clear and rapid levels used for management.

The monitoring and salvage command center is provided with the information technologies such as GPS, mobile communication, electronic geographic information system, internet to make rapid response to the water accidents.

The supporting equipment for salvage includes the necessary communication facilities, rescue boats, tug, salvage ships, oil suction machine, oil fence, etc.

5.7.4 Information Management System

The management business of waterway, maritime and riverside ports on the the Magdalena River is regarded as the information sources of the port and waterway information management system, and the port and waterway information management system covers all regions around the Magdalena River and is used to collect, store, analyze and apply the port and waterway management information for the whole society, thereby providing integrated information and decision making support for the works such as port and waterway planning, construction, management, maintenance, maritime supervision, statutory inspection of ships, transport administration, imposing of expenses. The port and waterway information management system consists of the information management subsystems, such as waterway, maritime, ship inspection, transport ship, port, waterway operation management, dealing with the emergency, disaster relief, and cargo and passenger transport information service system.

5.8 Implementation Opinions

To achieve the development goal of water transport modernization of the Magdalena River, the guiding role of government and the basic functions of market allocating resources must be given full play. Meanwhile, overall construction and coordinated development of inland waterway, ports, transport ships and support system should be promoted by concerted efforts.

The inland waterway is the basis of the development of water transport, and the key to promote the development of inland ports, ships and transport. The construction of support system is related to public service capability and safety supervision level of the water transport industry. Moreover, as the waterway facilities and the support system are public welfare infrastructures, the competent government department should be responsible for their construction and daily maintenance management. The government should be the investor of construction of the waterway and the support system, and should increase the input of public financial fund to positively guide the shipping development. Therefore, the construction of inland waterway and support system are listed as the key of implementation in this master plan.

The inland port is the basic platform, which provides connection of the inland river transport to the cargo owners and other transport means like road, railway, pipeline.It has dual natures of public welfare infrastructure and commercial infrastructure. Meanwhile, considering the important roles of port and wharf in improving the external access conditions of an area, guiding the industrial layout along the river, reducing the logistics cost of enterprises and increasing the competitiveness of local enterprises, related port operation enterprises and cargo owners should be responsible for the construction of inland ports. The governments at all levels should provide certain investment and policy support for the public infrastructures, such as access roads to ports and ports, so as to accelerate the enhancement of comprehensive capacity and development level of service-based economy of ports.

The transport ships are commercial facilities, which should be constructed and operated by various social enterprises or individual operators. The government department should be mainly responsible for industrial management such as formulation of development policy, management of public resources, market access and safety supervision.

According to related development plan of inland waterway, port, transport ships and support system, and in combination with key fields and arrangement principle of investment of the government funds, the development of inland river transport should be implemented by stages as follows:

a) Comments on implementation during 2011~2020

As the water transport of the Magdalena River has suffered from a long downturn, the voice from all sectors of society for the renaissance of shipping of the Magdalena River is rising. Therefore, the period from 2011 to 2020 is the period of strategic opportunities for the redevelopment of inland river transport of the Magdalena River, as well as the gradualrecovery stage. The input of government fund should be increased in short term, and the focus should be put on the support and construction of high-grade waterway and support system. Meanwhile, the positive support should be given to the construction of infrastructures of the public wharfs, with proper support given to the development of planned ship types. The construction of waterway downstream Salgar should be completed in accordance with the plan standard, and the study and construction progress of the improvement of the Dique canal should be accelerated, and the guiding roles of governments at all levels should come into play. The focus should be put on the construction of 6 Class-I and II ports including the Barranquilla Port, the Cartagena Port, the Gamarra Port, the Barrancabermeja Port, the Berrio Port and the Salgar Port, while Class-III ports including Calamar Port, Magangue Port, El Banco Port, etc., should be positively constructed. The project of support system of water transport should be started, so as to basically complete a smooth and efficient support system of inland river transport, which can safely operate. Encouragement and support should be continuously given to the small and medium-sized barge development, so as to make the shipping market prosperous. Meanwhile, encouragement should also be given to the renovation and transformation as well as elimination of old ships and non-standard ships, and research on new ship types suitable for the waterway of the Magdalena River should be accelerated.

1) Completing the improvement works of waterway section from Salgar to Barrancabermeja, and maintaining smoothness of the waterway downstream Barrancabermeja

   The improvement works of the waterway section from Salgar to Barrancabermeja will make the water depth of 256 km-long waterway reach 2.1 m (with navigation dependability of 90%), which will be commenced in 2014 as planned. After the implementation of the works, the monitoring of the reaches with navigation obstruction should be strengthened, and the improvement effect should be evaluated.

Appropriate measures should be taken to continuously improve the reaches which have not reached the standard, so that the goal on waterway can be achieved at the end of this plan period as much as possible.

The waterway downstream Barrancabermeja is 2.1 m deep. However, no slope protection is available for most part, with serious collapse of banks. During the plan period, the depth of the waterway should be maintained by dredging, meanwhile stabilization works of bank slopes should be gradually conducted. River channel regulation should be carried out in combination with flood control for protecting arable land, reducing sediment content in water flow and flood disasters.

2) Advancing the studies on improvement of the Dique canal and improvement measures of waterway of the Cauca River

Several options on improvement of the Dique canal have been preliminarily formulated. At this stage, deep study should be continuously carried out based on the existing study results. Due to wide range of influences of the works, model test is appropriate. The project risks and effect should be evaluated so as to determine effective structural measures.

The Cauca River is an important regional waterway. It relies on export sales of coal to guarantee perennial navigation of the waterway so as to produce better economic and social benefits. The study on improvement measures of the waterway should be completed during the plan period.

3) Focusing on construction of 6 Class-I and II ports including the Barranquilla Port, the Cartagena Port, the Gamarra Port, the Galan Port, the Berrio Port and the Salgar Port

The inland ports of the Magdalena River are generally at low development level, which is the weak link in the shipping development of the Magdalena River. The ship route ends at the Barranquilla Port and the Cartagena Port, and both of the ports show sound development momentum of marine transport business. However, there is a major shortage of inland river wharfs with other large-scale cargos besides petroleum, so that the overseas business and the inland river transport cannot be effectively connected. The Gamarra Port and the Barrancabermeja Port have the advantages of high-grade waterways. However, the functions as regional logistics centers cannot come into play due to the restriction of access road, infrastructure on the wharf and equipment on the wharf, etc. During the plan period, 6 main ports should be newly constructed or reconstructed. In the overall plan of port, the public infrastructure construction of the port should be included in the corresponding city construction plan, like access roads and railways to the ports, water and power supply, communication, port anchorage, and waterwayproviding access to the port. The plan of port-vicinity industry and logistics park should be accelerated, and policies for promoting the rapid development of port should be formulated and introduced, so that the facilities and equipment on the existing wharfs can be completed before 2020. Meanwhile, the inland wharfs of the Barranquilla Port and the Cartagena Port can be properly constructed in advance.

4) Constructing some Class-III ports with urgent development demand and relatively good construction conditions in good time

Ports such as Calamar Port, Mompos Port, Magangue Port, El Banco Port are Class-III ports, and they are located in the wetland area on the middle and lower reaches of the Magdalena River. With undeveloped land transport, the water transport is the main means of transport of the city, and the living supplies are imported through waterway. Therefore, the construction of these ports is beneficial to the people’s livelihood. The reconstruction or new construction works of the ports should be properly started in short term, and the focus should be placed on the improvement of passenger terminals and general cargo terminals.

5) Basic completing a smooth and efficient support system of inland river transport which can safely operate

According to general requirements of waterway development and industrial management, before 2020, the following works should be completed: to focus on the implementation of navigation aids works of high-grade waterway downstream Salgar, to establish and improve waterway monitoring and management network, to study and construct water service area for inland river shipping, and to build the water level measurement and data reporting system, to basically complete the modernized information network for waterway transport, which is based on computer technology, communication technology and network technology, to realize effective delivery and interconnection of the waterway transport inside and outside the industry, and to achieve leapfrog development.

6) Positively promoting standardization progress of ship types in the river basin and studying new ship types suitable for water transport of the Magdalena River

Standardization of ship types is conducive to the improvement of utilization rate and efficiency of facilities of the port and waterway and the achievement of maximization of economic benefit. The in-service ships on the Magdalena River are slightly insufficient at present, and a lot of barges have been being operated for a long time. Therefore, the government should introduce relevant policies in good time, so as to encourage the updating of ships, introducing or studying of ship types with higher efficiency.

b) Comments on implementation during 2021~2030

The period from 2021 to 2030 is the stage of consolidation and preliminary improvement of development of inland river transport of the Magdalena River. Centering on the stage development goals, the input should be continuously increased; the range of channel regulation should be expanded in combination with flood control, and the navigation conditions of high-grade waterway downstream Salgar (including Dique canal) should be further improved. In addition, the following works should be completed: to conduct study of improvement of the waterway upstream Salgar, to improve navigation conditions of the Cauca River, to continuously construct and improve main ports and important regional ports, and based on the development direction of “smooth waterway” and “efficient water transport”, to continuously construct and improve support system of inland river transport according to the main line of development of guaranteeing safe operation of water transport, improving service capability of water transport and improving industrial management efficiency.

1) Further improving navigation conditions of high-grade waterway downstream Salgar, as well as gradually conducting improvement works of river reaches downstream Barrancabermeja

By 2020, the 256 km-long waterway from Salgar to Barrancabermeja will basically reach a depth of 2.1 m (navigation dependability: 90%). From 2021 to 2030, the improvement results should be strengthened based on the waterway improvement during the first 10 years, so that the maintenance cost can be reduced, and some reaches without reaching the standard should be continuously improved by taking measures. Further channel regulation and shoreline stabilization should be conducted for the key reaches downstream Barrancabermeja, so as to improve the navigation conditions and the navigation dependability.

2) Conducting studies on improvement of the waterway upstream Salgar in combination with the construction of hydropower projects

   The shipping market will gradually become prosperous by the recent development. With improved shipping demand in Neiva, Girardot and other cities, the improvement scheme of waterway should be researched in combination with hydropower cascade construction on the reaches from Neiva to Salgar.

3) Improving navigation conditions of the Cauca River

   The navigation conditions of 187 km-long lower reaches of the Cauca River should be further improved, so as to reach the goals of smooth and stable navigation.

4) Improvement of the Dique canal

   The silting problem existing in the Dique canal will be basically solved and the quantities of some maintenance dredging works could be reduced, so that the wetland along the canal can be well developed.

5) Gradually completing the construction of planned ports

   The professional service level of the ports should be continuously improved, so as to form a batch of professional coal wharfs, container wharf, general cargo wharf, etc. The supporting facilities of the ports should be further improved, and regional logistics transfer centers should be preliminarily formed.

5.9 Recommendations on Policies and Measures

a) Increasing the financial input from the government and raising fund for construction of water transport via multiple channels

   The financial input should be increased. The financial department of the government should arrange special funds for the construction of waterway, port and support system and for guiding the standardization of ship types.

   The fund raising channels for water transport should be expanded, with diversification of the main investors to be promoted and new investment and financing platforms for the development of water transport to be researched. For public welfare and quasi-public water transport construction projects, the construction funds can be raised by loan with project entity as the borrower, financial discount and other methods. The efforts to attract investment should be strengthened, and guidance should be provided for various social capitals to participate in the construction and maintenance of infrastructures and commercial facilities of water transport, with encouragement and support given to ports and shipping enterprises as well as bulk cargo suppliers to construct ports and wharfs and logistics parks. According to actual construction conditions of ports, the ports enterprises should be entrusted to conduct unified development in bundle for the ports, waterway and surrounding land. Part of the revenue from development should be used for the water transport construction.

Various preferential policies to promote the development of water transport should be introduced, so as to encourage various social capitals to participate in the development and construction of water transport market. The coordination and cooperation among the government, the enterprises, the banks and the insurance companies should be strengthened. Practicable investment and financing mechanism of inland river transport market should be researched and formulated, with financing channels to be opened. Meanwhile, loan interest privilege should be provided to the ship owners by means of ships mortgage, and the construction and updating of shipping capacity of ships should be accelerated. The ship trading market should be developed and made prosperous, with ship registration system to be further improved and registration problems of mortgaged ships under construction to be solved. Logistics development policies should be introduced to encourage the railway-water transport and road-water transport. Policy of fiscal subsidies should be carried out for the shipping companies and freight forwarding agents, with the development progress of water transport market to be accelerated. Such preferential policies as financial tax, land, talents should be introduced to encourage the development of port-vicinity industries, with support to be given to the development of port-vicinity industries.

Pilot work of paid use of infrastructures for water transport constructed by loan should be carried out. Aiming at improving the transport conditions of waterway, fund can come from loan so as to construct the waterway, the ports and other facilities for the waterway transport. The imposing methods of toll of ships should be researched.

b) Advancing the comprehensive development of navigation and hydropower and promoting shipping development

Due to slow construction of waterway facilities of the Magdalena River, the input must be increased to accelerate the development, so as to adapt to the requirements of regional economy and society development. In case of insufficient input in shipping construction and lack of stable construction fund channel at present, only withsystem innovation and creation of good shipping investment environment, the social resources can be allocated by the market to participate in the development and operation of the shipping of inland rivers. The competent government department should positively create conditions and mobilize social resources to promote the development of hydropower resources of the Magdalena River. The completion of hydropower projects can make the watercourse channelized and waterway upgraded. Meanwhile, the revenues from the hydropower development can be used for the maintenance of waterway, so that the waterway construction can be accelerated. For the navigation and hydropower project, the government can provide proper preferential policies for the approval, land acquisition, resettlement, tax, electricity price and other aspects of projects, to create a better external environment for the shipping development, so as to form a new hydropower development mode mainly aiming at shipping and hydropower generation.

c) Preparing development plan of main ports, strengthening the port construction and advancing the port-city and port-park interactive development

Along with the development of economy and society, the development of ports should be appropriately advanced, so as to meet the requirement of export-oriented economy development of cities along the river. At present, for the inland ports, due to weak management of the shoreline, low specialization and small scale of wharfs, as well as backward integration of ports and cities, strengthening the plan and management of ports isneeded badly and urgently. The situations that most ports have no available plan and the coordination of ports construction is relatively passive at present should be changed as soon as possible,. Special attention should be paid to the main hub ports and important regional ports; as the great change in cities which these ports depend on will have a significant impact on the accesses to the ports, the plan of ports development should be conducted by the port management department, so as to coordinate and connect with the overall city plan, the comprehensive transport plan as well as the industrial development and land utilization plan, to effectively protect the shoreline resources of ports, to promote the sound port-city interactive development and to satisfy the requirements of economy development of the hinterland. The investment of the government in specialized wharfs for container, coal, oil products, etc., and tourism wharfs of main ports should be increased, with policy support to be strengthened. The construction of infrastructures of important ports should be included in the state and local financial budget plans. The cooperative enterprises related to the port services should be encouraged to participate in the construction and operation of ports, so as to solve the insufficient fund of the port and expand and stabilize the cargo sources for the port transport.

d) Advancing the progress of standardization and upscaling of ship types

Scaling up and standardization of ships is either an inevitable choice for the improvement of transport efficiency and industrial competitiveness of inland river transport, or an objective requirement for the modernized development of inland river transport. Along with the comprehensive improvement of water transport conditions and development of other transport means, the process of scaling up and standardization of ship types should be accelerated. The government should research and establish a series of ship types and models with good technical characteristics and suitable for the navigation conditions of the Magdalena River. Meanwhile, the government should also research and formulate the plan and arrangement for eliminating the backward ships. Relevant subsidy policies for the ships should be researched and formulated. Appropriate subsidies should be given to the elimination and improvement of old and non-standard ships, with support to be given to the procedures of approval (report and filing) of shipping capacity and inspection of ships.

e) Strengthening the preliminary work of the project, and meeting the demand of shipping construction

The preliminary research of the project should be strengthened. In the next 10~20 years, the construction of inland river transport will be a heavy task, which is involved with various industries, and is featured with heavy coordination task and long preliminary work period. Multiple specialized technologies problems should be tackled due to extremely complex engineering technologies of some construction projects. For example, the improvement of Dique canal is featured with wide coverage, very complex terrain and water system, complex and varied water and sand conditions as well as relation of rivers and lakes, and being involved with water quality and water environment problems for the production and living of several million people in Cartagena, as well as such significant problems as protection of important wetlands and ecological protection. Therefore, multiple key technical issues including construction scheme and protection of water and ecological environment should be deeply researched. Therefore, emphasis must be put on the complex and arduous preliminary work of the construction project of water transport. The preliminary work of the construction project, together with the input and coordination for preliminary work, should be strengthened. Relevant properly-simplified approval procedures for the construction projects of water transport should be established, with preliminary work period to be shortened. According to appropriate advancing principle, provision of preliminary work plan of the construction project should be made, and reserve system of the project should be gradually established.

6 Hydropower Planning

6.1 Hydropower Resources and Development Situation

6.1.1 Hydropower Resources

According to the research results of UPME in 2011, for each hydropower station with an installed capacity of 100 MW and above in Colombia, the exploitable hydropower capacity is more than 93,000 MW; the exploitable hydropower capacity is about 47,862 MW without considering the existing hydropower stations and those to be constructed in the protection area; the exploitable capacity is further decreased to 33,077 MW after the ecological flow is discharged as per the requirements made by the Ministry of Environment of Colombia. Refer to Fig.6.1-1 for the distribution of hydropower resources in Colombia.

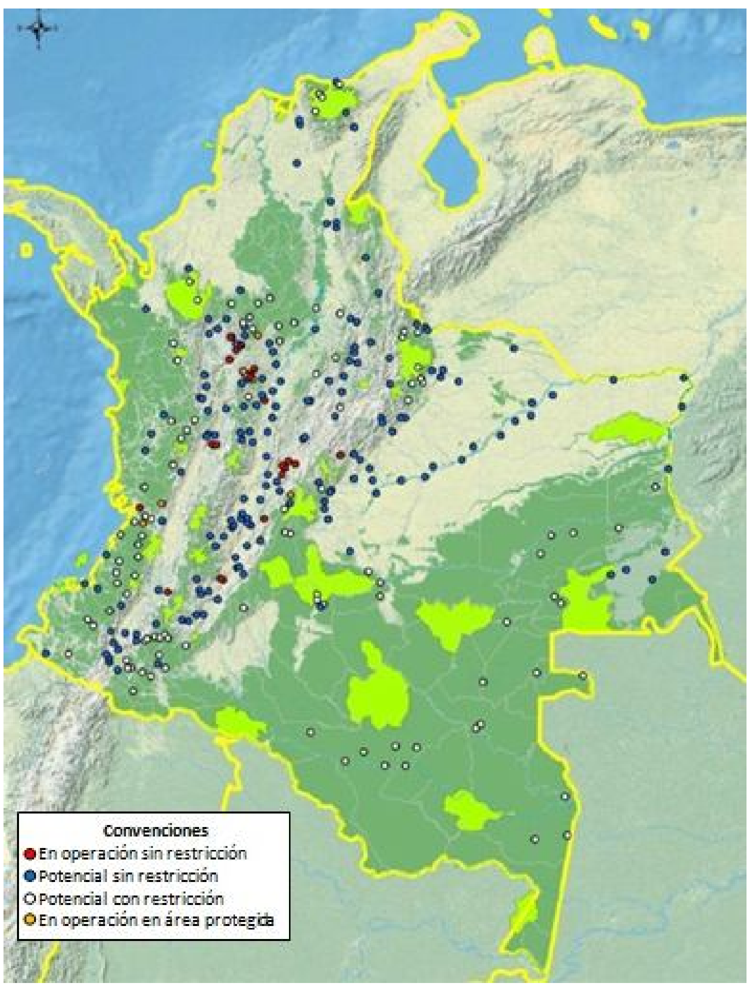


Fig.6.1-1 Distribution of Origins of Hydropower Resources

As is known from the figure, the origins of hydropower resources in Colombia are mainly distributed in the Magdalena River Basin, while the hydropower resources of the Magdalena River Basin are mainly concentrated on the main tributaries in the basin. According to the general investigation in 1978, the exploitable installed capacity of the Magdalena River Basin is 35,440 MW, among which 6,821 MW is from the main streams, accounting for 19.2% of the whole basin.

6.1.2 Current Situation and Existing Problems

The Magdalena River Basin is rich in hydropower resources, most of which are distributed on the tributaries. The main stream, constrained by various conditions, is underdeveloped and has only two hydropower stations (one is completed and the other under construction) with a total installed capacity of 960 MW, accounting for 10% of the theoretical hydropower potential of the main stream.

The existing Betania cascade hydropower station is located about 42 km upstream of Neiva and was put into operation for power generation in 1987. It has a live storage of 8.05×10^8 m^3 and is capable of yearly regulation; it has an installed capacity of 540 MW and an average annual energy output of 2,105 GWh. The El Quimbo hydropower station under construction is at the cascade upstream of Betania; it has a live storage of 1.824×10^9 m^3 and is capable of multiyear regulation, with installed capacity of 420 MW and annual energy output of 2,216 GWh. It is expected to be put into operation in 2014.

According to the current situation, there are the following problems in the development of hydropower resources of the Magdalena River:

a) In the early 1970s~1980s, general investigation of the hydropower resource of the Magdalena River Basin , research on key comprehensive utilization works of main stream and the cascade plan of navigation and power generation at some reaches of the Magdalena River were conducted. However, these works have been done for over 30 years and the economic and social conditions have gone through fundamental changes, with significant variation occurred to the concepts in reservoir inundation, environmental protection and other aspects concerning project development. In addition, new requirements have been put forward for the comprehensive utilization of hydropower resources. Therefore, it is necessary to optimize and make adjustment to the cascade development scheme.

b) Colombia is abundant in electricity power with surplus at present and its surrounding countries have the needs to purchase power from it. In recent years, the electricity industry in Colombia has been developing rapidly while the power load grows slowly, resulting in oversupply in the domestic power market. Nevertheless, from the view of the whole South America, Ecuador, Venezuela and other countries around Colombia are restricted by their own conditions and have the demand for purchasing power from Colombia. Meanwhile, due to unbalanced grid structure in Colombia and mismatching of power supply points and load centers, although local areas in Colombia imports power from its surrounding countries in some periods for some areas, Colombia is an electricity exporting country in general.

c) The hydropower energy accounts for a large proportion in Colombia, however, only a few of hydropower stations have good regulation performance. In 1990s, the hydropower energy accounts for as much as 80% in Colombia. Affected by El Nino in 1992~1993, the country is suffered from power crisis due to large-area drought all over Colombia and limited regulating reservoirs. Accordingly, it is proposed that the proportion of hydropower energy in Colombia will be reduced to 60% in the next few years. In fact, the power crisis is caused by insufficient live storage instead of large proportion of hydropower energy.

d) Limited conditions for the arrangement of key comprehensive utilization reservoirs on the main stream of the Magdalena River. Restricted by topographic conditions, except for the cascades where projects are completed and under construction, the possible locations for regulating reservoirs are mainly upstream of Neiva and at the upper and middle reaches confluence of Honda. However, the upstream of Neiva has relatively low runoff (accounting for about 5% of the Magdalena River) and therefore, its live storage is only enough to improve the power quality of the downstream cascade. Although the Honda reaches is qualified to build large-sized reservoir in both topographic and geological conditions, it has large inundation loss and relatively low flood control effect for its lower reaches.

e) The river reaches upstream of Betania reservoir enjoys good hydropower resources.

However, it is located in the high earthquake-intensity area and has relatively complex geological conditions, which should be given primarily consideration in the design and construction of cascade.

6.2 Power Market Analysis

6.2.1 Current Situation of Power Sources

By the end of 2009, the total installed capacity in Colombia was 13,543 MW, among which 9,001MW (66.46%) was for hydropower, 3,759 MW (27.76%) was for gas power, 700 MW (5.17%) was for coal power, 83 MW (0.61%) was for cogeneration, wind power and oil fired power plants. The per capita installed capacity was 300 W.

Refer to Fig.6.2.1-1 for the variation in installed capacity during 2003~2009. Refer to Fig.6.2.1-2 for power structure in the end of 2009.

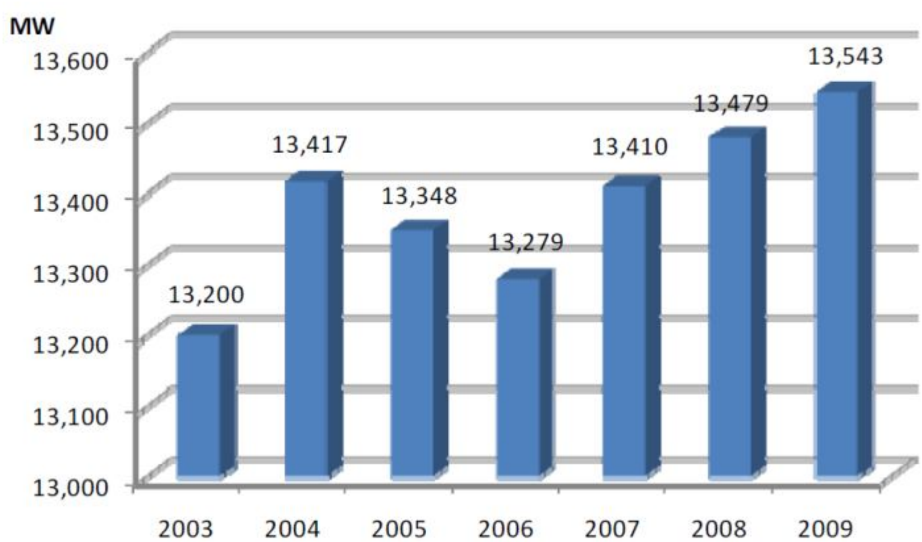


Fig.6.2.1-1 Variation in Installed Capacity during 2003~2009

(Source: Plan de Expansión de Referencia Generación – Transmisión 2010-2024)

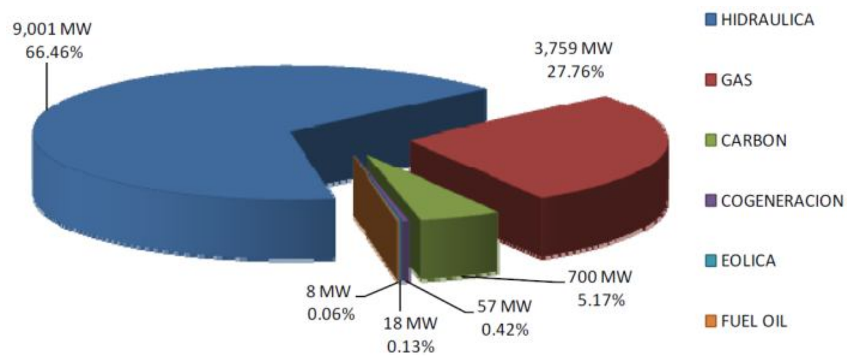


Fig.6.2.1-2 Power Structure in the end of 2009

(Source: Plan de Expansión de Referencia Generación – Transmisión 2010-2024)

6.2.2 Power Consumption Level and Composition

In 2009, the power consumption in Colombia was 54,679 GWh and the per capita power consumption was 1,216 kWh. The annual growth rate of power consumption during 2004~2009 was 1.50%~4.07%, with an average annual growth rate of 3.01%. Affected by international financial crisis in 2008 and 2009, the annual growth rate of power consumption was below 2%. The power consumption in each month in the whole year was relatively balanced. Refer to Fig.6.2.2-1 for power consumption during 2003~2009. Refer to Table 6.2.2-2 for monthly power consumption in each year.

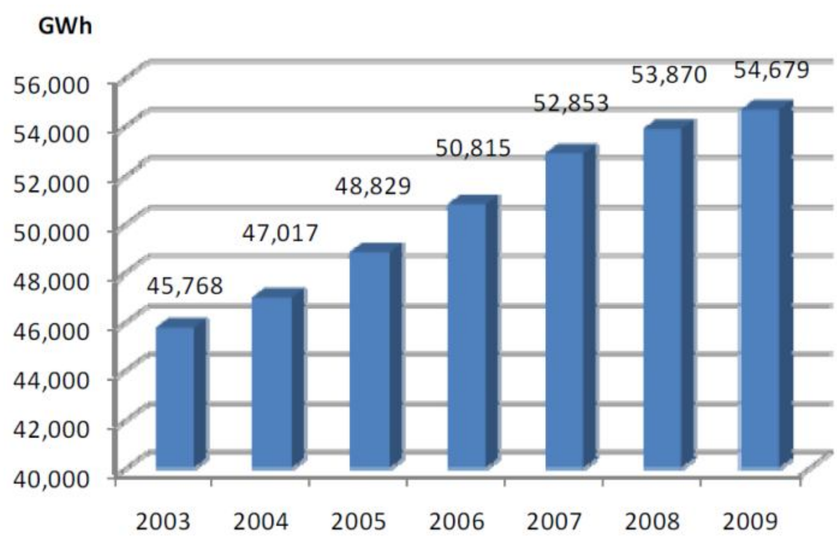


Fig.6.2.2-1 Power Consumption during 2003~2009

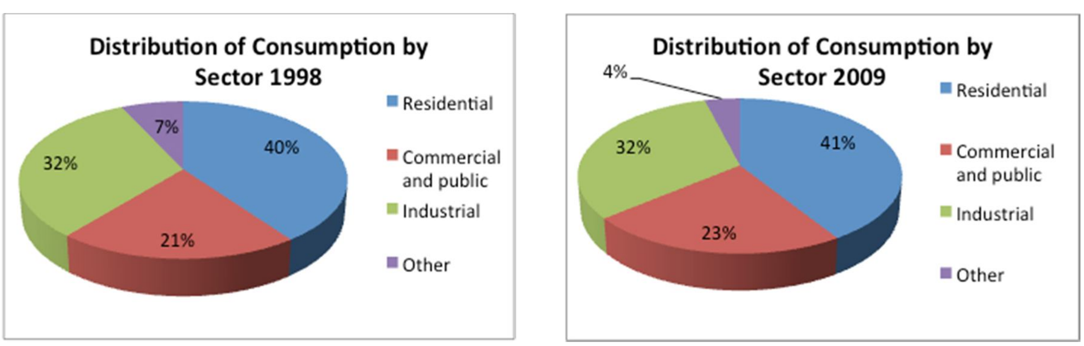
(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

Table 6.2.2-2 Monthly Power Consumption during 2003~2009 (Unit: GWh)

Month	2003	2004	2005	2006	2007	2008	2009
1	3774	3810	3947	4097	4309	4418	4465
2	3539	3744	3709	3881	4067	4315	4177
3	3891	4028	4089	4269	4511	4364	4560
4	3694	3791	4056	4040	4243	4470	4406
5	3887	3931	4111	4287	4475	4513	4587
6	3642	3836	4004	4152	4315	4378	4414
7	3903	3937	4090	4325	4469	4595	4653
8	3887	4027	4196	4369	4508	4547	4649
9	3836	3904	4136	4282	4415	4544	4681
10	3942	4000	4167	4428	4542	4683	4737
11	3810	3922	4084	4272	4454	4460	4608
12	3964	4088	4241	4413	4547	4584	4741
Total	45768	47017	48829	50815	52853	53870	54679

Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024.

Refer to Fig.6.2.2-3 for changes of power consumption structure in Colombia in 1998 and 2009. According to the figure, the residential power consumption has always been taking the dominance in Colombia, and basically no change has ever happened in residential and industrial power consumption in the recent 10 years, while the power consumption for commercial and public services becomes slightly higher.



Note: the data is from UPME and SUI.

Fig.6.2.2-3 Changes in Power Consumption Structure of Colombia

6.2.3 Load Characteristics and Forecasting

In 2009, the maximum load was 9,290 MW, increased by 2.32% over the previous year, with the utilization hours of maximum load to be 5,155 h. The annual growth rate of the maximum load during 2004~2009 was -0.15%~3.78%, with an average annual growth rate of 2.42%. Refer to Fig.6.2.3-1 for the changes in maximum load during 2003~2009.

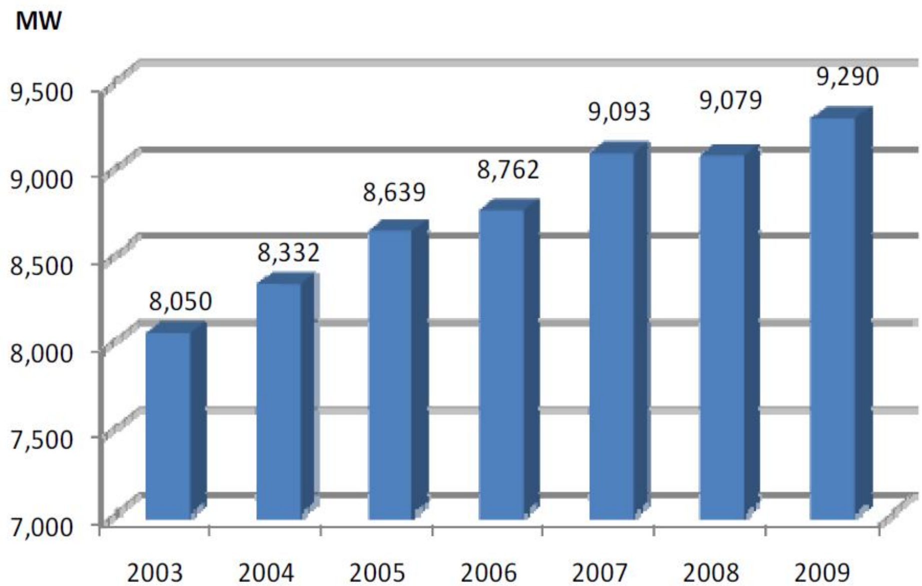


Fig.6.2.3-1 Maximum Load during 2003~2009

(Source: Plan de Expansión de Referencia Generación – Transmisión 2010-2024)

Refer to Table 6.2.3-1 and Fig.6.2.3-2 for the characteristics of the annual load during 2003~2009. Refer to Fig.6.2.3-3 for typical daily load curve in 2009. According to the figures and the table, the maximum load over the years always occurs in December when festivals and celebrations are more than usual. However, the seasonal unbalance coefficient ρ is about 0.95 in each year and the change in load among each month of the year is small, with seasonal load less than 10%. The daily load characteristic curve shows that the daily load is significantly unbalanced, and the minimum load rate is about 58%, mainly caused by large proportion of residential and commercial power consumption in the power consumption structure.

Table 6.2.3-1 Maximum Load in Each Month during 2003~2009 Unit: MW

Month	2003	2004	2005	2006	2007	2008	2009
1	7570	7817	7797	8113	8429	8474	8493
2	7548	7970	7943	8104	8509	8678	8568
3	7806	8221	8085	8165	8503	8529	8500
4	7835	7925	8103	8183	8515	8638	8596
5	7705	8081	7999	8196	8505	8707	8637
6	7452	7883	7928	8074	8411	8541	8630
7	7500	7813	7951	8225	8373	8524	8640
8	7549	7773	8107	8266	8419	8540	8807
9	7514	7761	8109	8413	8614	8709	8926
10	7653	7797	8078	8494	8784	8763	8920
11	7768	7969	8228	8447	8833	8800	9139
12	8050	8332	8639	8762	9093	9079	9290
Maximum	8050	8332	8639	8762	9093	9079	9290

Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024.

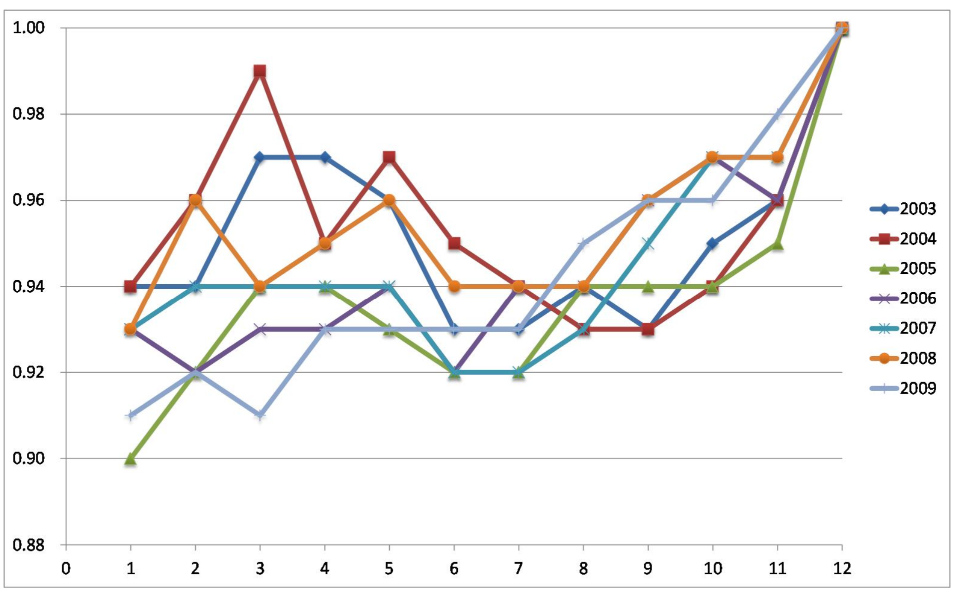


Fig.6.2.3-2 Annual Load Characteristic Curve during 2003~2009

(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

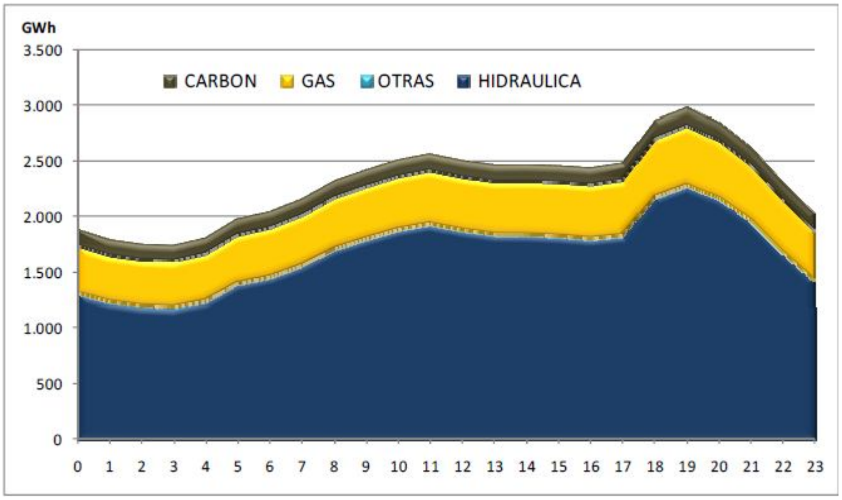


Fig.6.2.3-3 Typical Daily Load Characteristic Curve in 2009

(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

In the *Plan de Expansión de Referencia Generación – Transmisión 2010-2024*, UPME takes 2008 as the reference year, and makes the three types of forecast plan of high, medium and low types. Therefore, it is predicted therein that the maximum loads in 2020 are 14,781 MW, 12,974 MW and 11,386 MW respectively, with the average annual growth rates to be 4.15%, 3.02% and 1.90% during 2009~2020 respectively; the maximum loads in 2030 are 21,678 MW, 17,588 MW and 14,074 MW, with average annual growth rates to be 3.90%, 3.09% and 2.14% respectively. The average annual growth rates of the maximum load in the high, medium and low cases during 2009~2030 are expected to be 4.04%, 3.05% and 2.01% separately. Refer to Table 6.2.3-2 and Fig.6.2.3-4 for the results of load forecast.

Table 6.2.3-2 Forecast of Maximum Loads (UPME) during 2015~2030

Year	Forecast of Maximum Load Demand (MW)			Forecast of Average Annual Growth Rate		
	High	Medium	Low	High	Medium	Low
2008 (actual)	9079	9079	9079			
2015	11,783	10,956	10,212	3.79%	2.72%	1.69%
2020	14,781	12,974	11,386	4.64%	3.44%	2.20%
2025	18,001	15,133	12,603	4.02%	3.13%	2.05%
2030	21,678	17,588	14,074	3.79%	3.05%	2.23%
Average	-	-	-	4.04%	3.05%	2.01%

Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024.

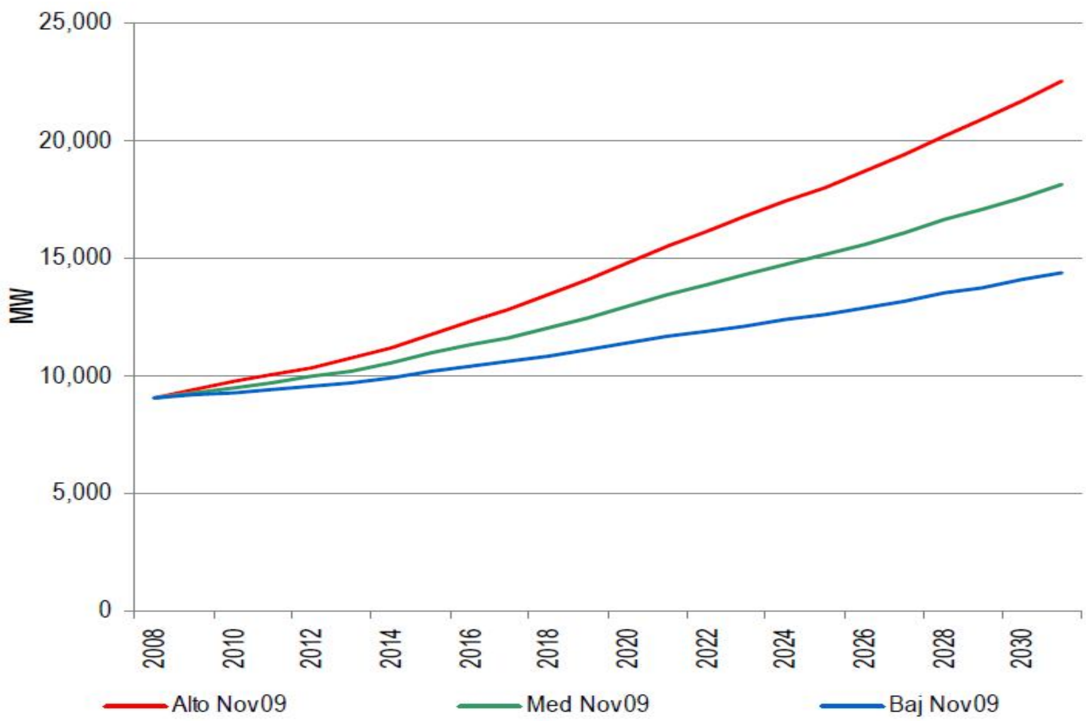


Fig.6.2.3-4 Results of Load Forecast in Colombia

(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

6.2.4 Power Source Planning

All power supply points to be constructed in Colombia should be registered in UPME as required, and the phases (pre-feasibility study, feasibility study or commencement for construction) of the hydropower stations should be clearly identified. However, the grid connection depends on the actual implementation during the later period of hydropower station. According to the *Plan de Expansión de Referencia Generación – Transmisión 2010-2024*, by the end of June, 2010, a total of 70 power stations have made registration at UPME, including 38 hydropower stations with a total installed capacity of 7,723 MW, coal generation stations with a total installed capacity of 3,259 MW and gas generation stations with a total installed capacity of 1,099 MW, all of which totaled at 12,204 MW. The actual total installed capacity at the construction phase is 4,372 MW, in which the total installed capacity of hydropower stations is 3,833 MW.

At present, the hydropower energy accounts for 2/3 in the power supply structure of Colombia. According to the energy structure and hydropower development potential, considering the reduction in carbon emission and other factors, the hydropower energy is still the main trend in the development of power supply in the future. Meanwhile, proper development of gas power generation, coal power generation and new energy should be made so as to form a multifunctional, complementary and rational power source structure. As there are only a few of hydropower stations with good regulation performance in the current system, the reliability of power supply may be subject to the impact of extreme climate to greatest large extent. Therefore, importance should be attached to the construction of hydropower stations with regulation performance, so as to enhance the resistance capability of the system against the extreme climate.

6.2.5 Electricity Trade with Neighbouring Countries

In recent years, the electricity industry in Colombia has been developing rapidly, resulting in oversupply in the power market. Since March, 2003, Colombia has begun to export power to Ecuador, Venezuela and other countries. The export volume of electric energy in 2005 reached 1,760 GWh. In October, 2009, the electricity exported to Ecuador reached 280 GWh. According to the official forecasting in Colombia, the exported electricity will increase at a rate of 5% per annum. According to the estimate results of power exchange of UPME, before 2017, the electricity exported from Colombia to Ecuador will be 120 GWh~300 GWh per month. Upon the completion of Coca Code hydropower station (with a total installed capacity of 1,500 MW) in Ecuador in 2017, the demand of power import from Colombia will decrease. However, along with the economic and social development in Ecuador, it is still expected that the electricity exported from Colombia to Ecuador will increase year by year. The annual distribution of electricity exported to Ecuador shows that the electricity export is mainly concentrated in November. According to the forecasting, it is expected that Colombia will sell about 200 GWh electricity to some countries in Central America in 2014. Refer to Fig.6.2.5-1 & 6.2.5-2 for forecasting results of electricity export from Colombia to Ecuador and Central America.

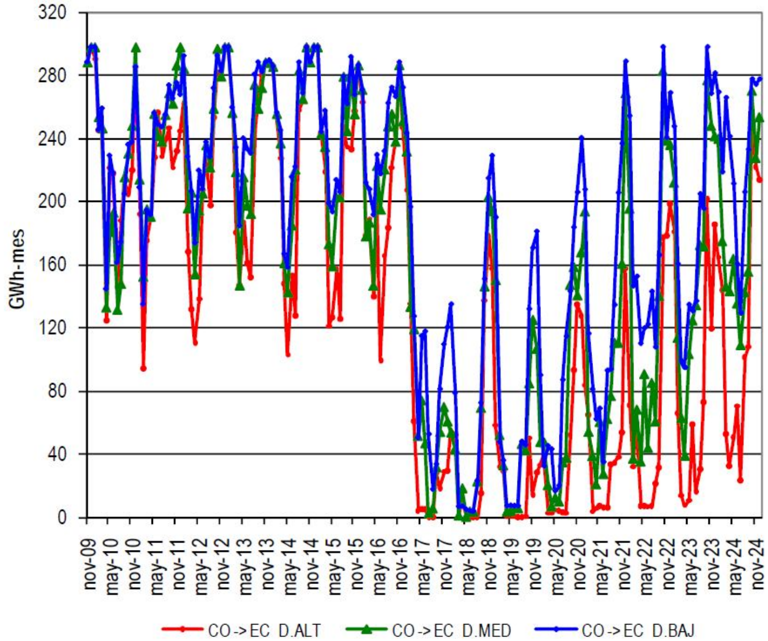


Fig.6.2.5-1 Forecasting of Electricity Export from Colombia to Ecuador
(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

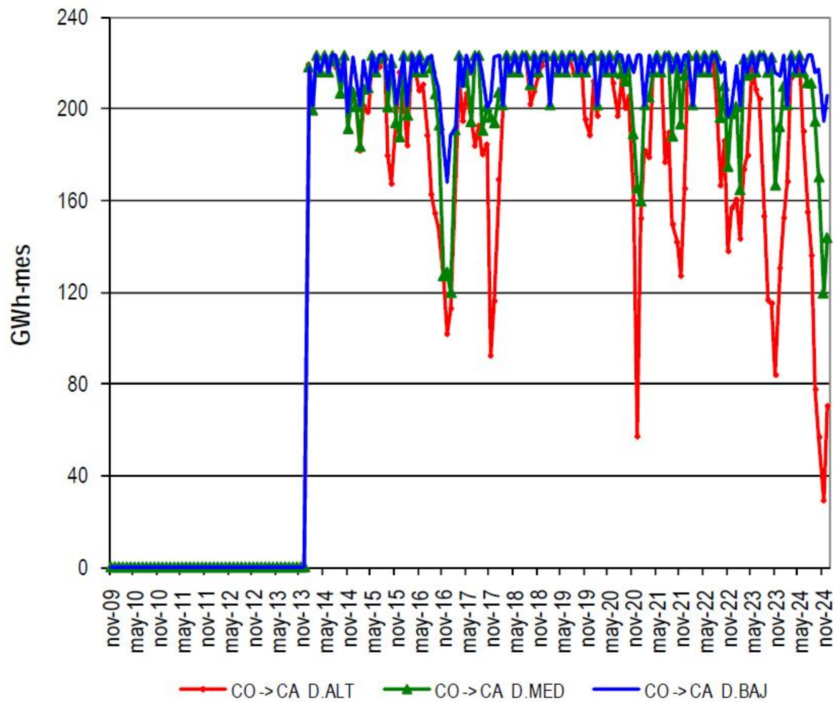


Fig.6.2.5-2 Forecasting of Electricity Export from Colombia to Central America
(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

Although the electricity in Colombia is generally in surplus, due to its unbalanced load distribution and development of power market, some areas still need to import electricity from Ecuador or Central America in special periods. As is known from the situation of electricity import and export, Colombia is still an electricity exporting country as it exports about 100 GWh electricity to Ecuador and Central America per month on average. Refer to Fig.6.2.5-3 & 6.2.5-4 for the forecasting of electricity import.

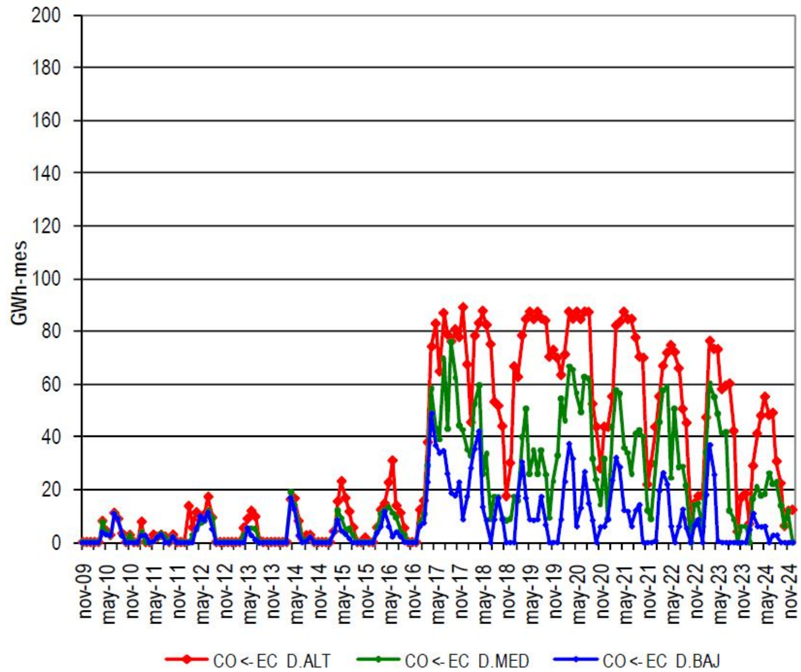


Fig.6.2.5-3 Forecasting of Imported Electricity from Ecuador to Colombia

(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

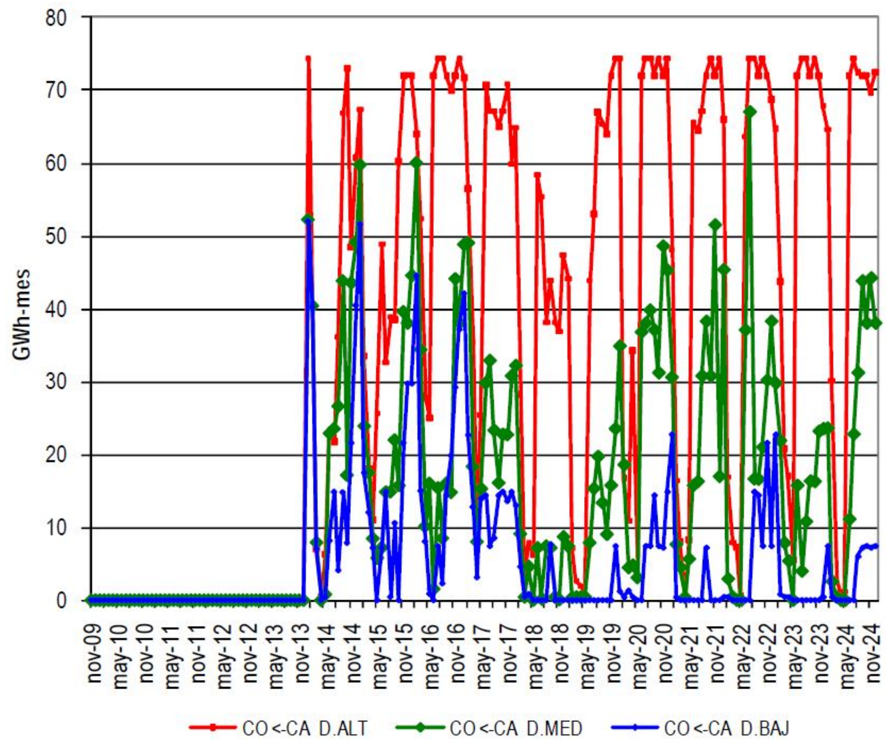


Fig.6.2.5-4 Forecasting of Electricity Import from Central America to Colombia (Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

6.2.6 Power Market Space

According to the report of power market analysis of CORMAGDALENA, the hydropower stations under construction in Colombia includes Mie II (with an installed capacity of 35 MW, completed in 2013; similarly hereinafter), Cucuana (60 MW, in 2014), El Quimbo (420 MW, in 2014), Ituango (1200 MW at phase I , in 2018), Sogamoso (800 MW, in 2014). Upon the completion of the above hydropower stations, by 2018, no newly constructed hydropower station will be required in Colombia. Nevertheless, after 2018, power production will be made to generate a capacity of 1900 MW for power supply so as to ensure reliable system capacity. If some hydropower stations working for 30 years are to be decommissioned however, the required capacity will be about 2,050 MW. According to the analysis results of UPME, thermal power stations with a total installed capacity of 600MW are required to be newly constructed in 2020 so as to reduce the fragility of power system. Therefore, by the planning target year (2020) in short term, there will be about 1300

MW~1450 MW capacity reserve in Colombia.

At present, the per capita power consumption level in Colombia is low, with the residential power consumption dominating in the power consumption structure and the tertiary industry dominating in the industry structure. The surplus electricity under low power consumption level is temporary, there is a large space for the power development in the future. Along with the economic and social development, upgrade industries and structural adjustment, it is expected that the power consumption in the industrial and mineral industry and the tertiary industry will rapidly increase in the near future. Meanwhile, along with the improved living standard of residents and widespread use of household appliances, there will be a continuous and rapid growth period for power demand, and significant changes will happen in the power consumption structure and the power load characteristics. Therefore, to meet the increasing power demand in domestic and international markets, it is necessary to positively boost the hydropower development according to the energy structure, resource endowment and development potential in Colombia.

6.2.7 Power Grid Planning

Based on *Plan de Expansión de Referencia Generación – Transmisión 2010-2024*, refer to Fig.6.2.7 for the geographical wiring diagram of the power grid in Colombia in 2024. According to the figure, the power grids in Colombia are widely distributed, basically covering the whole Magdalena River Basin. The substations on the main stream are mainly located on the middle reaches and estuary, with relatively fewer located in other areas.

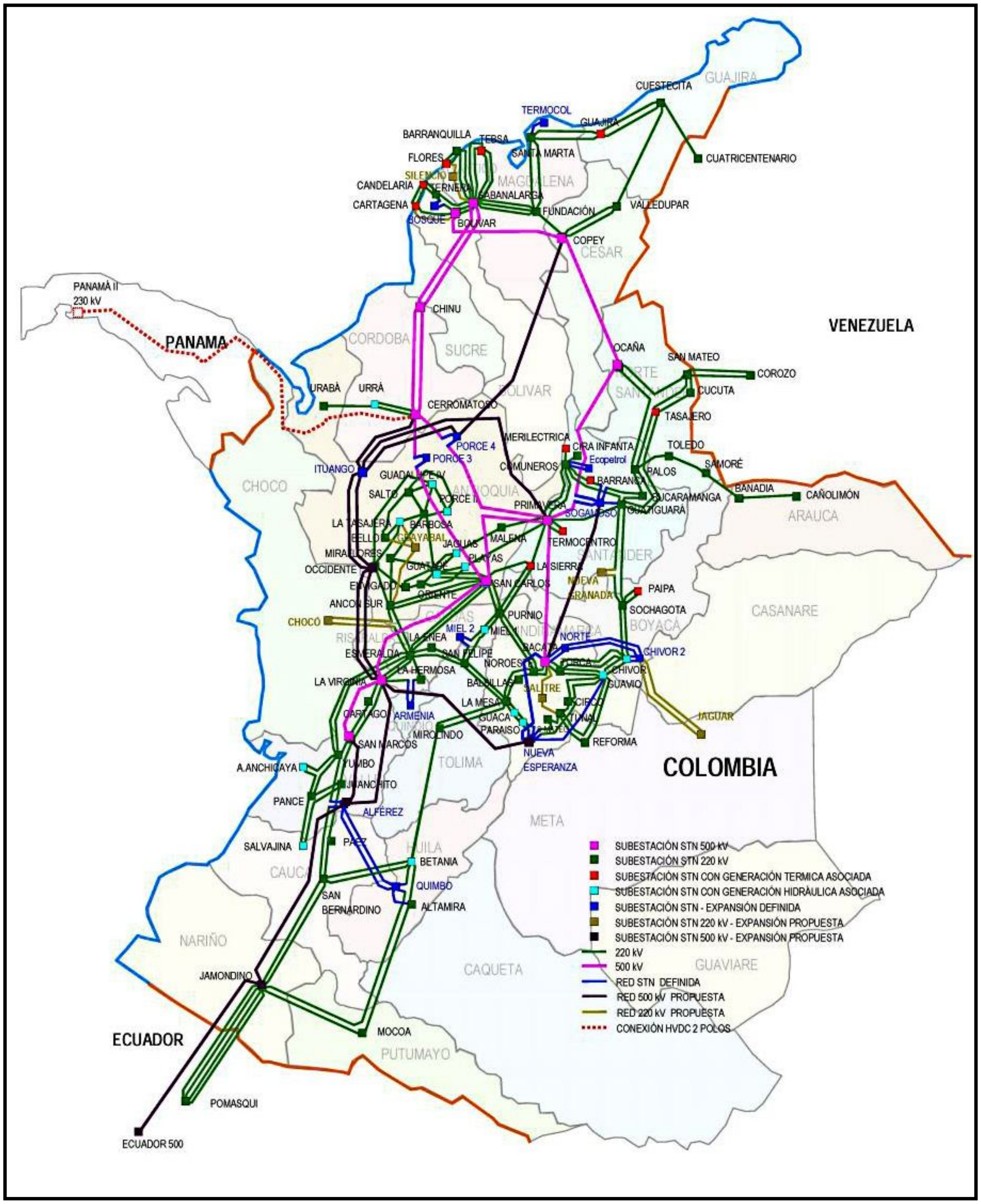


Fig.6.2.7 Plan Geographical Wiring Diagram (2024)

(Source: Plan de Expansión de Referencia Generación–Transmisión 2010-2024)

6.3 General Considerations

a) Guidelines

According to geological conditions of all reaches of the main stream of the Magdalena River, the distribution characteristics of hydropower resources, as well as conditions of arable land, population, protection area and other sensitive objects, and considering the new situations and requirements, importance should be attached to the handling of the relations between the development and the protection, the whole and the part, the needs and the possibilities, the short term and the long term, the upper reaches and the lower reaches, etc., in accordance with the principles that the hydropower development should adapt to the ecological environmental protection, the energy and power development, as well as the social and economic development of the basin.

b) Purposes

Based on the comprehensive consideration of the physical geographical characteristics, the resource and environment features, the strategic position, the demand for economic and social development and the requirements on ecological environmental protection of the Magdalena River, through analysis, investigation and research and in combination with characteristics of the planned reaches, the development tasks of the planned cascade in this plan are proposed, which are hydropower generation, navigation, flood control, irrigation, etc.

c) Scope

The scope of hydropower plan includes the river reaches where cascades will be arranged and the scope of power supply.

Since the territorial scope of this comprehensive plan covers 128 cities and towns under the jurisdiction of Cormagdalena, including the main stream of Magdalena River, Dique Canal, 187km-long river reach downstream of the largest tributary Cauca River and the downstream confluence reaches of other tributaries. Taking into consideration that the tributaries involved in the scope of plan are all the relatively short section at the estuaries, and that most sections have steep slope and dense population, these areas are unqualified for hydropower station arrangement. Therefore, the cascade layout scheme for the main stream only of Magdalena River is considered in this hydropower plan.

Due to the relatively low level of economic and social development in the area upstream of the Magdalena River, the power load is small there and the electricity volume of the projects at the planned cascades cannot be completely consumed. At present, the national power grid takes the dominance in Colombia, while the Magdalena River Basin is within the service area of the national power grid. According to the analysis of power consumption demand in Colombia and its surrounding countries, the hydropower supply range of the Magdalena River is connected to the national power grid in Colombia, and can be transmitted to the surrounding countries by the grid.

6.4 Formulation of Cascade Development Alternatives

6.4.1 Development Conditions of Hydropower Resources

6.4.1.1 Overall distribution of hydropower resources

The main stream of the Magdalena River is 1613 km in total length, with total drop of 3685 m. As a whole, the slope of river 110 km downstream the river head is relatively steep, with a drop of about 2800 m, accounting for 76% of the total drop.

The river reach from the river head to the Sombrerillo tributary confluence is located in gorges flanked by middle mountains, where the river valley is of V-type and is about 60km long, with a drop of up to 2,422m and an average slope about 40‰; The river reach from the Sombrerillo tributary confluence to the Betania dam site is mountain river, where the river valley is of “V” type and the slopes become gentle; the river reach is 193 km long, with a drop of about 777 m and an average slope of about 4‰. The reach from the Betania dam site to the Wilches Port is 741 km long, with a drop of 424 m and an average slope of about 0.6‰.

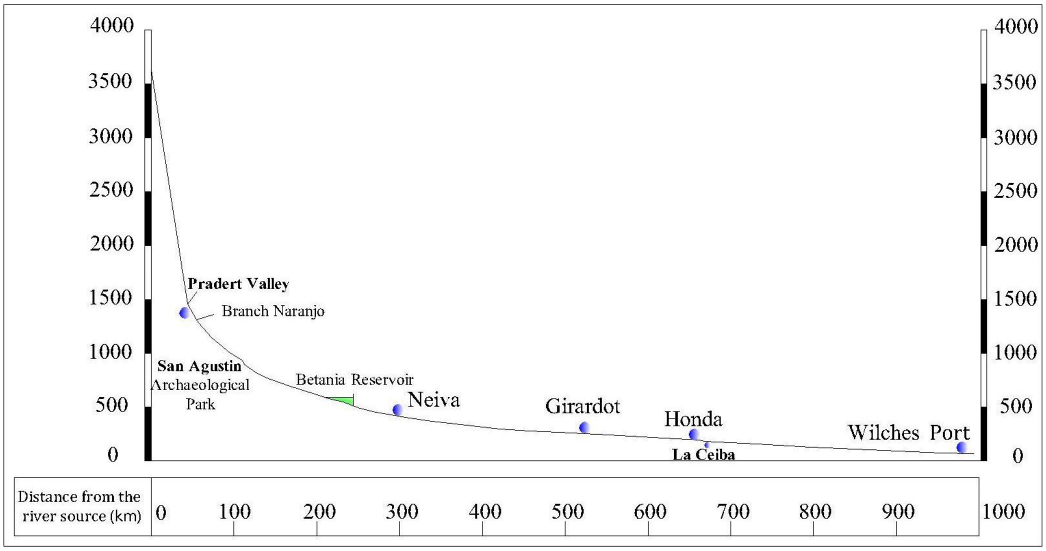


Fig.6.4.1-1 Slope of Reaches from Main Stream Head to Wilches

The theoretical hydropower potential of the main stream of the Magdalena River is 8965 MW, among which 3935 MW, 3746 MW and 1284 MW are for the upper, middle and lower reaches respectively. As the river downstream of the Wilches Porthas wide surface, gentle slope and dense marshes and wetlands and the theoretical hydropower potential of upstream of the port is 6,491 MW (accounting for more than 72% of the total), it is concluded that the river reaches with the value of hydropower development is mainly located at the upstream of Wilches on the main stream of Magdalena River.

According to field investigation and the topographical and geological conditions, runoff and slope along the banks, in combination with navigation, environmental protection and other requirements on comprehensive utilization, the main stream river reaches upstream of Wilches of the Magdalena River are divided into the following three areas following the principles of orderly development and sustainable utilization:

1) Reaches upstream of Sombrerillo tributary confluence: the reaches are 60 km along, with an average slope of 40‰. The about 45km long river section upstream the Pradera Gorge is within the area of river head, where few people reside and unique gorge, falls and other natural landscapes exist. The river section from the Pradera Gorge to Sombrerillo tributary confluence, located in the gorges flanked by deep

mountains and close to the San Agustin Archaeological Park, is of “V” type river valleys and is suitable for traveling and drifting. Taking into account of the natural ecology, the landscape and the cultural value, no cascade should be considered on the reaches.

2) Reaches from La Ceiba (located about 8km downstream of Honda): the reaches are 321 km long, with a drop of 120 m and an average slope of 3.7%. The reaches are basically plain watercourses, with gentle slope and wide banks. If a cascade is constructed on such river reaches, the area to be affected by the reservoir inundation will be large and therefore, embankments are required around the reservoir for protection while the conditions for hydropower development are relatively poor. The river section downstream of Salgar is capable of navigation throughout the year and therefore, comprehensive benefits as power generation and shipping etc., can be obtained by combining cascade development and channelized waterway. As the Colombian government has approved the project in 2013 to solve the navigation problem of the river reaches downstream of the Salgar Port by treatment and dredging, comprehensive development of navigation and power generation is of little necessity during the plan period. Therefore, it is suggested that the layout of cascades within this river reach should not be considered in this plan. If the social and economic development reaches a certain level in the future when new requirements are proposed for the development and utilization of the reaches, the study can be conducted again.

3) Reaches from Sombrerillo tributary confluence to La Ceiba: as is known from the general conditions of the hydropower resource of the main stream, the reaches from the Sombrerillo tributary confluence to La Ceiba enjoy good hydropower resources conditions and can be selected as the subject in the research of this hydropower cascade plan. The reaches are 612 km in total length, accounting for 62% of the total length for the reaches upstream of Wilches.

6.4.1.2 General geological conditions of the river reaches for cascade hydropower plan

According to topographical and geological features, the river reaches for cascade hydropower plan (Sombrerillo tributary confluence ~ La Ceiba) can be divided into 3 sections:

1) From Sombrerillo tributary confluence to Betania dam site

This river section, located in mountain valleys, winds and zigzags and is mainly of V-shaped valley and partially of U-shaped ones. It first flows to the southeast before turning to the east, and then it turns to the northeast. River bends are seen at part of the river reaches.

River terraces are developed on part of the reaches upstream Timana tributary confluence. The surface of Terrace I is generally 8 m~12 m higher than the river surface, with a width of less than 150m in general. Some terrace surfaces are 300 m~400 m wide. Terraces II and III are seen developed on some river sections as well. Wider river terraces and flood plains are developed on the reach from the downstream of Timana tributary confluence to the Betania dam site.

The stratum lithology is mainly of the metamorphic rocks and the sedimentary and volcaniclastic rocks, etc. from the Paleozoic to the Cenozoic, with a larger area of granodiorite and volcanic rocks exposed. The metamorphic rocks of the Precambrian are also distributed on the right bank; the lithology is mainly of schist, quartzite, phyllite, etc.

The fracture is mainly developed in NE and NEE directions, and is of thrust fault nature. With large scale, the fracture is regional main fracture. The main representative regional fracture includes Falla de Algeciras, Falla de Granadillo-Timana, Falla de Betania and Falla Oritoguaz. Most of the Falla Oritoguaz thrust faults are developed along the river. Besides, the fracture is also developed in NW direction, with the development controlled by the fracture in NE direction. Refer to Fig.6.4.1-2 for fracture structure and active volcano distribution of the Magdalena River Basin. Seismic peak ground acceleration with probability of exceedance of 10% during 50 years of the reaches is 0.30 g~0.35 g, and the corresponding basic earthquake intensity is VIII.

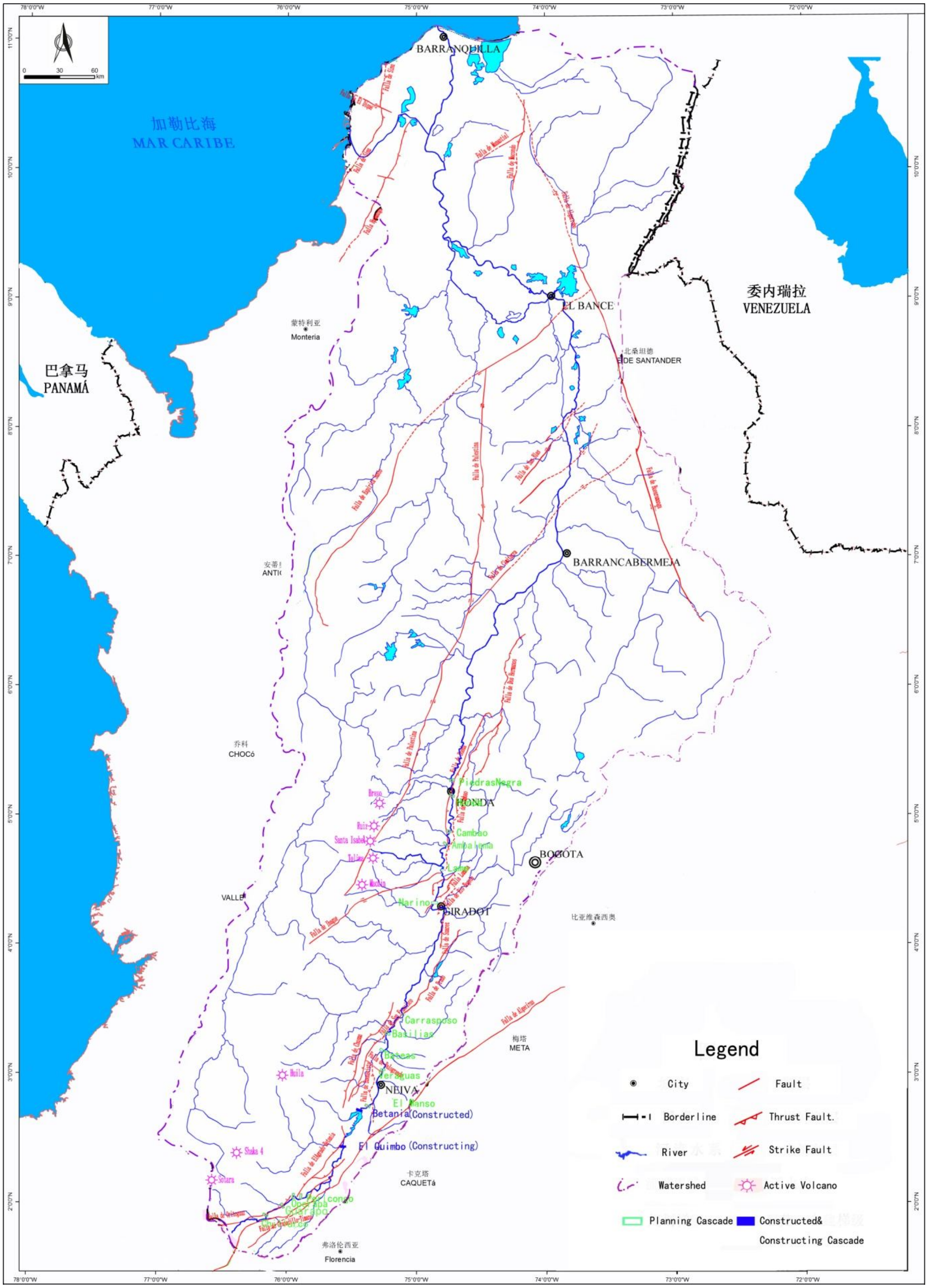


Fig.6.4.1-2 Distribution of Fracture Structure and Active Volcano on the Magdalena River Basin

2) Reaches from Betania dam site to Girardot

In comparison with the reaches upstream of the Betania reservoir, this reaches is gentler on the whole. The river generally flows towards the north-northeast, with river bends and relatively developed tributaries. The terraces on both banks are mostly wide and gentle. The mountain on the right bank is generally at the elevation of 1000 m~2000 m a.s.l, and the highest mountain is at an elevation of 3630 m a.s.l, while the elevation of the middle mountain on the left bank is more than 3000 m a.s.l. Nevado del Huila is the highest active volcano, with an elevation of 5365 m a.s.l. Seen from the physiognomy, the in-shore physiognomy of the reaches is basically hills or low mountains and hills as well as rivers and deposit. Both banks at most of the river sections are wide, with river bends, flood plains and terraces developed. Most of the terraces are grasslands or farmlands.

The stratum is mainly of Paleozoic metamorphic rocks, sedimentary and volcaniclastic rocks, etc. In addition, the river valleys are distributed with a large area of Mesozoic and Cenozoic strata, which are widely covered with volcaniclastic rocks and pyroclastic flow.

The mostly developed fracture is of thrust nature in NNE direction to NE direction, which is large-scale and is regional main fracture. The main representative fault includes Falla de Prado and Falla de San Francisco. In addition, a few small-scale fractures are developed in NW direction, with development controlled by the fracture in NE direction. See Fig.6.4.1-2. Compared with the reaches upstream Betania reservoir, the seismic peak ground acceleration with probability of exceedance of 10% during 50 years of the reaches is smaller, which is about 0.25 g~0.30 g.

3) Reaches from Girardot to La Ceiba

For the reaches, although the slope is low, low mountains and hills as well as flood plains and river valleys are alternately distributed along both banks. There are two narrower river valleys. One is downstream Girardot, with a length of about 40 km. The reaches have relatively strong mountains on both banks, and occasionally distributed with some narrow terraces (mainly including glass lands and farmlands); a provincial road on the right bank stretches along the river. The other one is located in the gorge upstream Honda City, with a length of about 8 km. For the reaches, a country road on the left bank is constructed along the river, and there is basically no farmland in the reaches, with a few residences.

Cenozoic sandstone, clay rocks and sandy conglomerate are exposed along the river valleys. Lots of the Quaternary pyroclastic debris and flow are distributed on the left side of the river valley. Five active volcanos including Nevado del Ruiz, etc., are distributed about 60 km~70 km from the west side of the river, in which Nevado del Ruiz is the existing active volcano.

Regional Falla de Honda is developed on the reaches, which is more than 100 km long and is in near SN direction generally. The fault turns from the north to the east on the Honda reaches by riverbed. See Fig.6.4.1-2. Seismic peak ground acceleration with probability of exceedance of 10% during 50 years of the reaches is 0.15 g~0.20 g, and the corresponding basic earthquake intensity is VII~VIII.

6.4.2 Previous Studies

Three studies about the hydropower of the main stream of the Magdalena River were conducted. The first time was the prefeasibility study of construction of large-sized comprehensive reservoir on Honda reaches, which was conducted by Medellin AEI Engineering Consulting Co., Ltd. in 1970. The second time was general hydropower resources investigation conducted in 1978, with 28-cascade development proposed for the main stream of the Magdalena River. The third time was cascade development study of 450 km-long reaches in the middle of the Magdalena River from Girardot to the Wilches Port, which was conducted by the original State Power Corporation in 1983 and proposed 10-cascade development for the reaches.

a) Honda high dam option

Medellin AEI Engineering Consulting Co., Ltd. conducted prefeasibility study of construction of large-sized comprehensive reservoir on Honda reaches in 1970, and proposed *Report on Hydropower Development Potential of Honda River Reaches* in 1972. In the report, the development tasks for Honda cascade were put forward, including power generation, navigation, flood control, irrigation and recreation. Two full supply levels of high and low were proposed for comparison. In the high inundation option, the dam height was 98 m, the full supply level was 280 m, the installed capacity was 1800 MW, 563 km^2 land were inundated, and about 2,000 households (13,000 people) in two cities (Ambalema and Beltrán) and four towns (Paquiló, Cambao, Pajonales and Ménez) were involved. The investment per kilowatt is USD 4383/kW.

Although the inundation loss in the high inundation option is large, great comprehensive benefits could be brought to the area, for example, a total installed capacity of 1800MW and the 8800GWh electricity could be provided for the system; the navigation base flow on the lower reaches could be greatly improved from 540 m^3/s to 1300m^3/s; 6 m flood storage space above the full supply level could retain and store about 3.1 billion m^3 flood; reliable irrigation water source could be provided for the irrigated area close to the lower reaches; the recreation development of the area could be promoted. By comprehensive comparison in terms of cost, revenue, social and economic benefit and other indicators in the two options, high inundation option was proposed in the study report at the premise of relatively abundant fund. However, high dam option of the Honda reservoir was not used in the general hydropower resource investigation results in 1978.

b) 28-cascade development option for the main stream of the Magdalena River

In 1978, during the general investigation of hydropower resources,, the original State Power Corporation of Colombia once planned the main stream of the Magdalena River, with the plan range from the upper reaches with riverbed elevation at 1,440 m a.s.l to the Wilches Port (with riverbed elevation at about 60 m a.s.l) on the middle reaches. The total drop of the planned reaches was about 1,380 m. Following the principle of full utilization of hydropower resources, 28-cascade development for the main stream of Magdalena River was planned, with a total installed capacity of 6,821 MW.

According to the characteristics of river slope, the Honda is the boundary of the upper and lower reaches. The upstream reaches are 20-cascaded, with a total installed capacity of 4,051 MW and an annual energy output of 23,569 GWh, while the downstream reaches are 8-cascaded, with a total installed capacity of 2,770 MW and an annual energy output of 17,504 GWh. The full supply level of Honda Hydropower Station is 220m and the installed capacity is 374MW.

c) 10-cascade option for the middle reaches of the Magdalena River

After the general investigation of hydropower resources was completed by the electric power department in 1978, to further optimize the project and meet the requirements in the guidance for the general policy of middle reaches utilization on the Magdalena River, the Department of National Plan (DNP) conducted technical cooperation with the German government in 1980 to make comprehensive plan of the navigation and power generation on the upper middle reaches of the Magdalena River from Girardot to the Wilches Port (k600~k1042). The *General Policy of Utilization of Middle Reaches of the Magdalena River* was completed in 1983. In view to reduce inundation loss and development difficulty, 10-cascade development option with incomplete cascade connection and local channelization was proposed based on comprehensive comparison, accompanied by waterway improvement and dredging. Meanwhile, specific implementation plan was also formulated, but was not put into effect. The planned total installed capacity was 2,174 MW, with annual energy output of 14,111 GWh.

The three study above have been made for many years. Due to the significant changes in technical economy, social need and environment, etc., the results and conclusions of these studies are only for reference.

6.4.3 Formulation of Cascade Development Alternatives

In this cascade development plan, the hydropower resources of the main stream of the Magdalena River are carefully studied and the hydropower generation plan results are put forward according to comprehensive investigation, field survey and data collection and in combination with the specifications and experience of hydropower development in China, as well as new situations and new requirements of reservoir inundation, flood control, power, navigation and environmental protection, etc.

6.4.3.1 Main factors considered in the cascade development proposal

1) The cascade development should adhere to the principle of ecological protection first so as to realize the proper coordination of the relation between the hydropower development and the forest reserve, important fish protection area, scenic spots for

leisure travel, aboriginal residential area, reservoir inundation loss as well as ecological flow of watercourse downstream the dam.

2) Reasonable connection with existing cascades and cascades under construction should be fully considered.

3) In case of shipping demand of the reaches downstream Neiva, requirements on shipping should be considered in the cascade proposal.

4) Due to the fact that the uppermost reaches with fish migration of the main stream of the Magdalena River are close to Neiva, fish pass should be provided for the cascade downstream Neiva.

5) Considering the requirements for flood control and disaster mitigation of the middle and lower reaches as well as the navigation improvement, the feasibility of arrangement of general-purpose hydropower project should be studied.

6.4.3.2 Division of reaches

Due to the fact that the river reaches for plan are relatively long and the difference of physical conditions along the reaches varies greatly, for the better analysis and study, in combination with comprehensive investigation and field survey, the river reaches are divided into the three sections, i.e. from Sombrerillo tributary confluence to Betania dam site, from Betania dam site to Girardot, and from Girardot to La Ceiba, following the principle of being beneficial to avoiding impacts on important cities and towns and large-scale arable land as well as environmentally sensitive objectives, to the cascade arrangement and the study and comparison of development options and to the reasonable distribution of resources based on regions, etc. Meanwhile, the division of reaches should also not affect the integrity of the cascade plan reaches.

Refer to Table 6.4.3-1 for main characteristics of all reaches.

Table 6.4.3-1 Main Characteristics of Three Reaches of the Main Stream

Planned reaches	From Sombrerillo Tributary Confluence to Betania Dam Site	From Betania Dam Site to Girardot	Girardot ~ La Ceiba
Length of reaches (km)	193	259	160
Measured water level (m)	1263 ~ 486	486 ~ 255	255 ~ 183
Drop (m)	777	231	72
Average river slope ‰)	4.03	0.89	0.45
Remarks	Small population and few arable land, relatively large slope and good hydropower resource conditions	Few large cities/towns, multiple farmlands and small towns along the river	Relatively dense population, and multiple large towns distributed in the section

6.4.3.3 Analysis on the arrangement of regulating reservoirs

At present, the main stream of the Magdalena River has two regulating reservoirs including Betania (the completed one) and El Quimbo (the one under construction). According to the comprehensive consideration of requirements on reasonable allocation of regulation storage, economical efficiency of hydropower development, rational utilization of water resources of the basin and flood control and disaster mitigation, etc., and in combination with topographical and geological conditions, the reaches upstream of El Quimbo reservoir head and the reaches located in the gorge close to Honda are suitable for the arrangement of regulating reservoir.

6.4.3.4 Cascade development proposal

a) Reaches from Sombrerillo tributary to Betania dam site

The reaches are 193 km long, with a drop of 777 m and an average slope of 4.03‰. Enjoying good topographic conditions and concentrated drops, the reaches are part of the main stream of the Magdalena River having relatively good hydropower resources as the reaches are sparsely populated along the river and therefore, will have relatively small environmental and inundation impacts involved in the cascade development. Part of the reaches is suitable for the construction of high dam.

Currently, the water head of 220m at the lowest reaches with the best development conditions has already been developed and utilized. Meanwhile, as the reaches (with head of 114 m) from El Quimbo reservoir backwater zone to the Timana tributary confluence are the ancient Indian relics protection area, the cascade is not considered during this plan. Therefore, the actual plan area of the reaches is from the Sombrerillo tributary confluence to the upper reaches of the Timana tributary confluence, with a natural drop of 436 m.

According to the preliminary analysis, the reaches should be developed in 6 cascades, i.e. Guarapo (1220 m) + Chillurco (1125 m) + Oporapa (1015 m) + Perícongo (870 m) + Quimbo (720 m, under construction) + Betania (561 m, completed). The full supply level of the Guarapo dam site at the cascade I should be controlled to an extent that no impact will occur to the city of Pitalito. The cascade 4 Perícongo is located about 500 m upstream of the Timana tributary confluence. See Fig.6.4.3-1.

b) Reaches from Betania dam site to Girardot

The reaches from the Betania dam site to Girardot are about 259 km long, with a drop of about 231 m and a slope of 0.89‰. Compared with the reaches upstream the Betania reservoir, the watercourse is more gentle. In the view of physiognomy, the reaches are basically located in river valleys flanked by hills, with both banks wide and broad and endowed with grasslands or farmlands. Hills 100m higher than river surface exist only on the banks about 22km upstream of the city, where the river course is slightly narrow. The main large city along the reaches is Neiva, the provincial capital of Huila Department, with a population of about 310,000. The elevation of the street on the river side is about 10 m a.s.l away from the water surface in dry season, and the lower reaches are involved with a number of cities/towns and large-scale farmlands. Constrained by the impact of inundation, power station at this river reach should better be of the water retaining type with low water head.

1) Neiva is the key in the inundation control for such reaches. The reaches from Neiva to the Betania dam site are 42 km long, with a drop of 65 m. Limited by the topographies of both banks and the inundation conditions, the reaches are not suitable for the construction of dam; only the reaches close to El Manso are relatively suitable for dam construction of, and capable of annual regulation as this river section is close to the Betania reservoir, , better benefited from impoundment in high water period and water replenishment in low water period. For the river section from the lower reaches of El Manso dam site to Neiva, both banks are flat, flood plain and river

terraces are developed, with many farmlands. Due to the heavy loss likely to be caused by inundation and the poor conditions for dam construction, cascade development is not considered for the 28 km reaches (with a head of 43 m) tentatively.

2) The section from Neiva to Los Cardes (dam site of the Carrasposo Cascade) basically belongs to the physiognomy of hills and denuded peneplains, with developed flood plains and terraces. Therefore, the potential sites with good conditions for dam construction are few. In combination with the topographic conditions of the watercourse, the four dam sites of Veraguas, Bateas, Basilias and Carrasposo are selected, among which the full supply level of the Veraguas Cascade should be 420m as is controlled to an extent that no impact will occur to the upstream Neiva. For the rest of the cascades, they are planned in a way to meet the demand of future navigation in the river reaches and the selection of the full supply level is based on the reasonable connection between cascades, with some overlaps of water heads.

3) For the reaches from Los Cardes to Girardot, both banks are gentle and wide, the topographic conditions for the construction of dam are poor. In addition, large-scale farmlands are distributed alternately along both banks. Therefore, no cascade should be considered during this plan. If the social and economic development reaches a certain level in the future when new requirements on navigation and irrigation are proposed for the development and utilization of the reaches, the study can be conducted again.

In summary, in combination with the topographic and geological conditions and field survey of the reaches, it is preliminarily proposed that the reaches from the Betania dam site to Girardot are developed in 5 cascades, i.e. El Manso (485 m) + Veraguas (420 m) + Bateas (399 m) + Basilias (378 m) + Carrasposo (357 m).

c) Reaches from Girardot to La Ceiba

La Ceiba is located about 8 km downstream Honda Town. The reaches from Girardot to La Ceiba are 160 km long, with a drop of 72m and an average slope of 0.45‰. For the reaches, although the slope is low, low mountains and hills as well as flood plains and river valleys are alternately distributed.

Girardot is the major city in Cundinamarca Department, with a population of about

100,000. As the distance of the elevation of the riverside street is less than 10 m a.s.l from the water surface in dry season, this street is the key point in the inundation control throughout the reaches. In addition, some small towns and villages are also distributed on both banks of the reaches.

The two river reaches with narrow valleys between Girardot and La Ceiba are the only reaches suitable for reservoir construction at the lower reaches of the completed Betania reservoir. Affected by the inundation impact of Girardot, only the reaches in gorges upstream Honda are suitable for the construction of regulating reservoir. The control elevation of Girardot is about 260 m a.s.l. Such a control elevation enables the Honda gorge section a topographic and geological conditions to have a live storage of about 9.0×10^9 m^3 and become a multi-purpose project serving for such functions as navigation, irrigation, recreation and power generation, etc. However, such cities/towns as Narino, Cambo, Ambalema, Pureto Rico, La Vega De Los Padres, Vindi, Barrialosa, Guataqui, etc., as well as large-scale grassland and farmland distributed along the banks of the reaches from Girardot to Honda will be affected.

According to the topographic features and the analysis of field survey , the locations on the reaches suitable for the construction of dam include Nariño, Lame, Ambalema, Cambao, Honda, Piedras Negras, etc. Based on degree of inundation impact, high, medium and low inundation options are proposed for Honda, while high and low inundation options are proposed for Lame for comparison. Meanwhile, due to the max. slope of up to 5‰ at the Honda reach under the rapid flow condition, this reach is navigation controlled and it is suggested that a cascade should be arranged at La Ceiba to channelize the rapid flow at Honda.

In conclusion, the following combination options are proposed for the Girardot ~La Ceiba reaches for comparison:

Option I (low inundation option): Nariño (260 m) + Lame (244 m) + Ambalema (232 m) + Cambao (221 m) + Honda (214 m) + Piedras Negras (192 m);

Option II (medium inundation option): Lame (260 m) + Ambalema (232 m) + Honda (221 m) + Piedras Negras (192 m);

Option III (high inundation option): Honda (260 m) + Piedras Negras (192 m).

According to the characteristics analysis of the above-mentioned three reaches, in combination with the topographical and geological conditions, reservoir inundation, environmental impact, demand of navigation and other factors, the following three options are proposed for the main stream of the Magdalena River for comparison:

Option I: 17 cascades of Guarapo (1220 m) + Chillurco (1125 m) + Oporapa (1015 m) + Perícongo (870 m) + Quimbo (720 m, under construction) + Betania (561 m, completed) + El Manso (485 m) + Veraguas (420 m) + Bateas (399 m) + Basilias (378 m) + Carrasposo (357 m) + Nariño (260 m) + Lame (244 m) + Ambalema (232 m) + Cambao (221 m) + Honda (214 m) + Piedras Negras (192 m) are under development in total;

Option II: 15 cascades of Guarapo (1220 m) + Chillurco (1125 m) + Oporapa (1015 m) + Perícongo (870 m) + Quimbo (720 m, under construction) + Betania (561 m, completed) + El Manso (485 m) + Veraguas (420 m) + Bateas (399 m) + Basilias (378 m) + Carrasposo (357 m) + Lame (260 m) + Ambalema (232 m) + Honda (221m) + Piedras Negras (192 m) are under development in total;

Option III:, 13 cascades of Guarapo (1220 m) + Chillurco (1125 m) + Oporapa (1015m) + Perícongo (870 m) + Quimbo (720 m, under construction) + Betania (561m, completed) + El Manso (485 m) + Veraguas (420 m) + Bateas (399 m) + Basilias (378 m) + Carrasposo (357 m) + Honda (260 m) + Piedras Negras (192 m) are under development in total. Refer to Table 6.4.3-2 for detail.

Table 6.4.3-2 Comparison of Cascade Development Options

<table>
<tr><th rowspan="2">Name of Cascade</th><th colspan="2">Option I
(17 cascades)</th><th colspan="2">Option II
(15 cascades)</th><th colspan="2">Option III
(13 cascades)</th></tr>
<tr><th>S/N</th><th>Full supply level (m)</th><th>S/N</th><th>Full supply level (m)</th><th>S/N</th><th>Full supply level (m)</th></tr>
<tr><td>Guarapo</td><td>Cascade 1</td><td>1220</td><td colspan="2" rowspan="9">The same as Option I</td><td colspan="2" rowspan="9">The same as Option I</td></tr>
<tr><td>Chillurco</td><td>Cascade 2</td><td>1125</td></tr>
<tr><td>Oporapa</td><td>Cascade 3</td><td>1015</td></tr>
<tr><td>Perícongo</td><td>Cascade 4</td><td>870</td></tr>
<tr><td>El Quimbo (under construction)</td><td>Cascade 5</td><td>720</td></tr>
<tr><td>Betania (completed)</td><td>Cascade 6</td><td>561</td></tr>
<tr><td>El Manso</td><td>Cascade 7</td><td>485</td></tr>
<tr><td>Veraguas</td><td>Cascade 8</td><td>420</td></tr>
<tr><td>Bateas</td><td>Cascade 9</td><td>399</td></tr>
</table>

Table 6.4.3-2(continued)

Name of Cascade	Option I (17 cascades)		Option II (15 cascades)		Option III (13 cascades)	
	S/N	Full supply level (m)	S/N	Full supply level (m)	S/N	Full supply level (m)
Basilias	Cascade 10	378	The same as Option I		The same as Option I	
Carrasposo	Cascade 11	357				
Nariño	Cascade 12	260	-		-	
Lame	Cascade 13	244	Cascade 12	260	-	
Ambalema	Cascade 14	232	Cascade 13	232	-	
Cambao	Cascade 15	221	-		-	
Honda	Cascade 16	214	Cascade 14	221	Cascade 12	260
Piedras Negras	Cascade 17	192	Cascade 15	192	Cascade 13	192

Refer to Fig.6.4.3-1 for geographic locations of the planned cascades. Refer to Fig.6.4.3-2 for longitudinal section of the cascade.

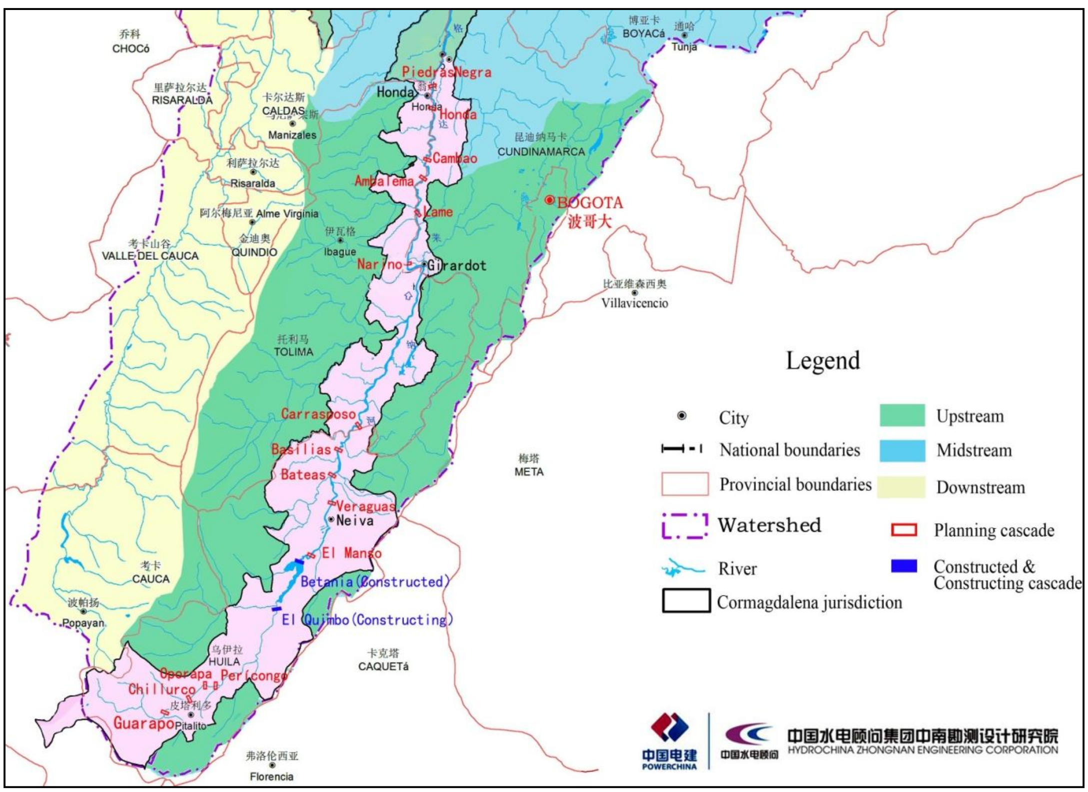


Fig.6.4.3-1 Geographic Positions of Dam Site of Cascade Plan Options

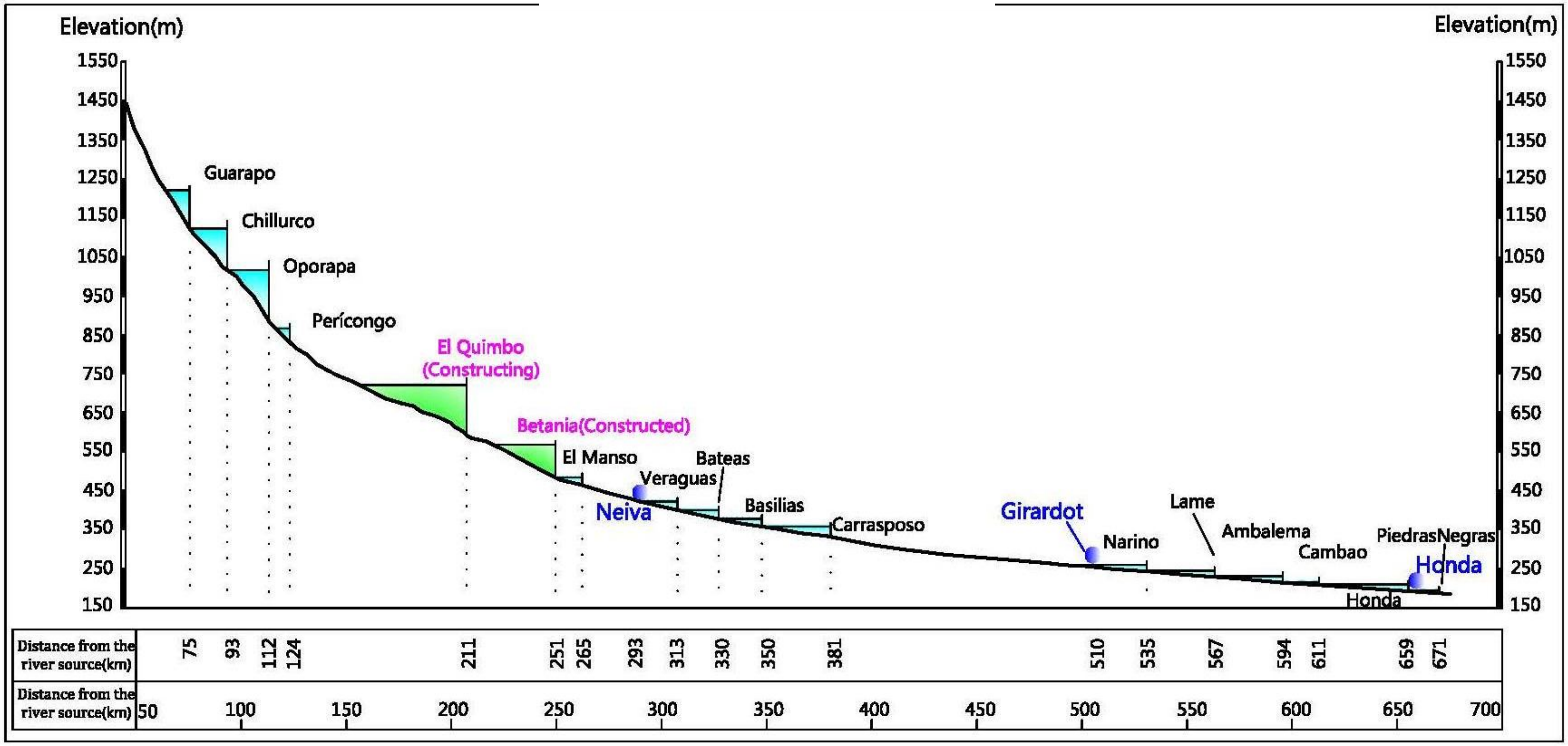


Fig.6.4.3-2 Longitudinal Section of Planned Cascades on the Main Stream of the Magdalena River

6.5 Conceptual Design of Cascade Hydropower Projects

6.5.1 Hydrology and meteorology

The hydrometeorological characteristics of all planned cascades are based on the basic data of the hydrometeorological stations provided by CORMAGDALENA and classified by IDEAM, which are obtained after being classified and analyzed. If a hydrometeorological station exists near the cascade, the hydrometeorological characteristic value of the station is used as the design basis for the site at the cascade; if no hydrometeorological station is set near the cascade, the data from the station nearby is used for analysis and calculation. Refer to Tables 6.5.1-1~6.5.1-4 and Fig.6.5.1-1 & 6.5.1-2 for hydrometeorological characteristic values of all cascades.

Table 6.5.1-1 Statistics of Annual Mean Values of the Meteorological Elements near the Cascades

Name of Cascade	Annual Rainfall (mm)	Maximum 24h Rainfall (mm)	Average Annual Temperature (□)	Extreme Maximum Temperature (□)	Extreme Minimum Temperature (□)	Relative Humidity (%)
Guarapo	1258	172.0	20.2	32.5	7.5	81
Chillurco	1258	172.0	20.2	32.5	7.5	81
Oporapa	1240	120.9	22.2	39.6	14.2	84
Perícongo	1240	120.9	22.2	39.6	14.2	84
El Manso	1362	248.0	26.6	40.6	14.0	73
Veraguas	1346	160.3	27.7	41.0	16.6	66
Bateas	1131	181.4	28.0	40.5	12.4	67
Basilias	1142	121.0	28.4	40.0	12.6	66
Carrasposo	1466	146.6	28.0	41.0	13.4	70
Nariño	1180	136.0	28.5	41.8	16.4	69
Lame	1003	129.7	28.0	40.4	14.6	69
Ambalema	1346	140.2	28.7	42.0	2.6	--
Cambao	1346	140.2	28.7	42.0	2.6	--
Honda	1442	128.0	28.1	40.6	2.1	75
Piedras Negras	1442	128.0	28.1	40.6	2.1	75

Table 6.5.1-2 Average Monthly & Annual Discharge (m^3/s) at the Dam Sites of each Cascade

Name of Cascade	Catchment Area (km^2)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Guarapo	2358	68.7	77.9	88	117	143	181	196	149	110	102	104	88.2	119
Chillurco	2983	80.0	90.3	101	135	163	203	220	168	124	117	120	100	135
Oporapa	3249	86.7	96.8	109	144	173	216	235	179	132	125	129	109	145
Perícongo	3387	90.2	100	113	149	178	221	242	185	136	129	133	113	149
El Manso	13883	300	305	339	397	488	539	538	436	318	330	385	393	398
Veraguas	16270	373	385	435	508	605	645	660	530	390	403	495	500	495
Bateas	17990	397	409	471	550	641	676	686	551	407	430	544	543	526
Basilias	19901	423	437	511	597	682	711	715	575	425	461	599	591	561
Carrasposo	23256	472	488	583	683	756	773	767	618	458	516	698	679	625
Nariño	48051	844	868	1070	1380	1490	1320	1210	963	790	1010	1410	1280	1140
Lame	49052	855	882	1090	1410	1520	1340	1220	974	804	1030	1430	1290	1150
Ambalema	51048	878	904	1120	1450	1570	1370	1240	992	828	1060	1470	1330	1190
Cambao	52805	897	924	1140	1480	1620	1400	1260	1010	849	1100	1500	1360	1210
Honda	54211	913	940	1160	1510	1660	1420	1280	1020	866	1120	1530	1380	1240
Piedras Negras	55328	930	959	1180	1540	1690	1450	1310	1040	883	1140	1560	1410	1260

Note: data for the cascades downstream of El Manso is from 1987~2011.

Table 6.5.1-3 Design Flood Peak Discharge (m3/s) at each Frequency for the Dam Site of each Cascade

Name of Cascade	Catchment Area (km^2)	Design Peak Discharge at each Frequency									
		0.02%	0.05%	0.1%	0.2%	0.5%	1%	2%	5%	10%	20%
Guarapo	2358	2670	2490	2360	2220	2030	1880	1730	1530	1360	1185
Chillurco	2983	2760	2580	2450	2320	2140	1980	1830	1630	1460	1280
Oporapa	3249	2850	2670	2530	2390	2200	2050	1890	1690	1510	1330
Perícongo	3387	2900	2710	2570	2430	2240	2080	1930	1720	1540	1350
El Manso	13883	5400	5000	4690	4370	3960	3630	3310	2870	2530	2170
Veraguas	16270	5790	5370	5040	4700	4270	3920	3580	3120	2750	2370
Bateas	17990	6060	5620	5280	4930	4470	4120	3770	3280	2900	2500
Basilias	19901	6330	5880	5520	5170	4690	4320	3960	3450	3060	2650
Carrasposo	23256	6780	6300	5930	5550	5050	4660	4280	3740	3320	2880
Nariño	48051	9350	8720	8250	7770	7120	6630	6120	5420	4870	4280
Lame	49052	9430	8810	8330	7850	7190	6690	6180	5480	4920	4320
Ambalema	51048	9600	8960	8490	7990	7330	6820	6300	5590	5030	4420
Cambao	52805	9750	9100	8620	8120	7450	6940	6410	5690	5120	4500
Honda	54211	9860	9210	8720	8220	7540	7020	6490	5760	5190	4570
Piedras Negras	55328	9950	9290	8800	8300	7620	7090	6560	5820	5240	4620

Table 6.5.1-4 Average Monthly & Annual Sediment Discharge (k.t/d) of Suspended Load at Dam Site of each Cascade

Name of Cascade	Catchment Area (km^2)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Guarapo	2358	1.87	3.05	3.39	4.68	5.87	5.76	5.83	2.82	1.36	2.87	3.02	2.78	3.61
Chillurco	2983	2.4	3.91	4.35	6.01	7.53	7.39	7.48	3.62	1.75	3.68	3.88	3.56	4.63
Oporapa	3249	2.65	4.32	4.8	6.63	8.32	8.16	8.25	4	1.93	4.06	4.28	3.94	5.12
Perícongo	3387	2.78	4.52	5.03	6.95	8.7	8.54	8.64	4.18	2.02	4.25	4.48	4.12	5.36
El Manso	13883	7.8	6.78	8.11	9.45	15.5	32.3	17.9	7.53	5.45	6.83	16.6	14.2	12.4
Veraguas	16270	8.63	7.63	9.43	10.8	17.4	34	19.5	8.81	6.2	7.77	18.4	15.5	13.7
Bateas	17990	9.43	8.71	11.7	13	19.5	32.1	20.7	11	7.26	9.14	20.1	16.5	14.9
Basilias	19901	10.32	9.92	14.1	15.3	21.8	29.9	22	13.5	8.45	10.65	22.1	17.6	16.3
Carrasposo	23256	11.86	12.02	18.4	19.4	26	26.3	24.3	17.8	10.5	13.31	25.4	19.5	18.8
Nariño	48051	18.1	24	29.7	46.6	55.4	36.7	30.5	22.2	15.9	32.4	46.5	39.3	33.1
Lame	49052	20.3	25.2	32.9	51.7	59.7	38.6	31.1	22.3	17.2	35.7	53.1	42	35.9
Ambalema	51048	24.6	27.6	39.3	61.9	68.4	42.2	32.1	22.3	19.7	42.2	66.3	47.5	41.2
Cambao	52805	28.5	29.7	44.9	70.8	76.1	45.3	33	22.4	21.9	48	78	52.4	46
Honda	54211	31.5	31.4	49.4	78	82.2	47.9	33.7	22.4	23.6	52.5	87.3	56.2	49.7
Piedras Negras	55328	33.7	36.7	53	80.3	87.6	53.7	40	28.3	25.2	53.6	89.1	63.5	53.8

Note: data for the sediment at cascades downstream of El Manso is from 1987 to 2011.

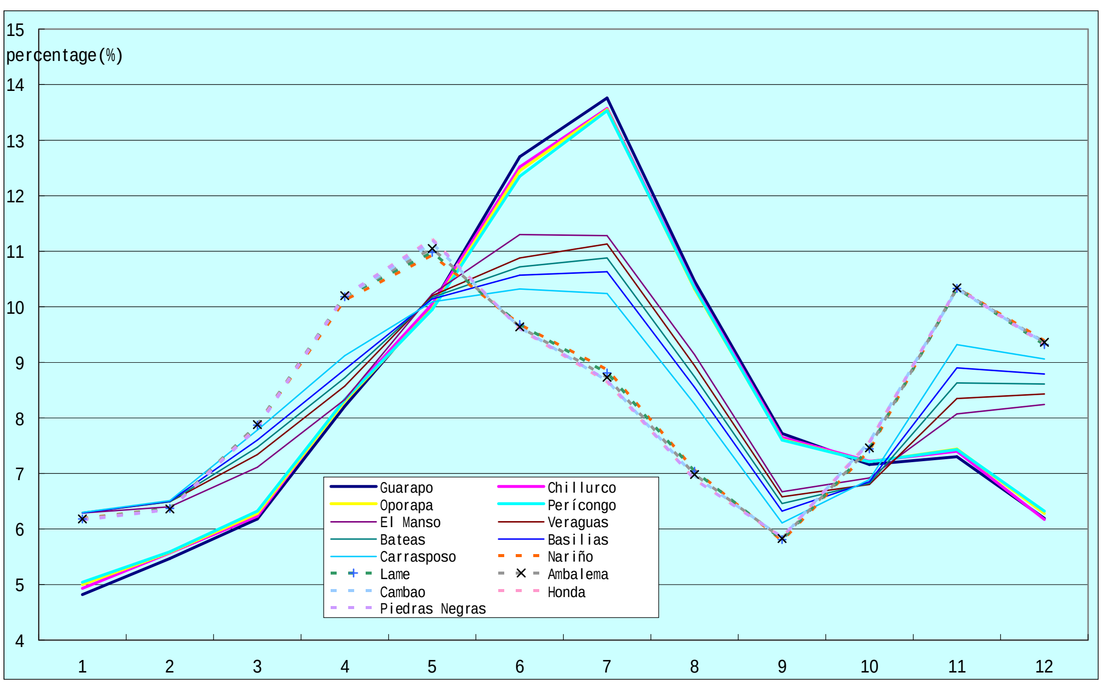


Fig.6.5.1-1 Cascade Runoff Distribution Within a Year

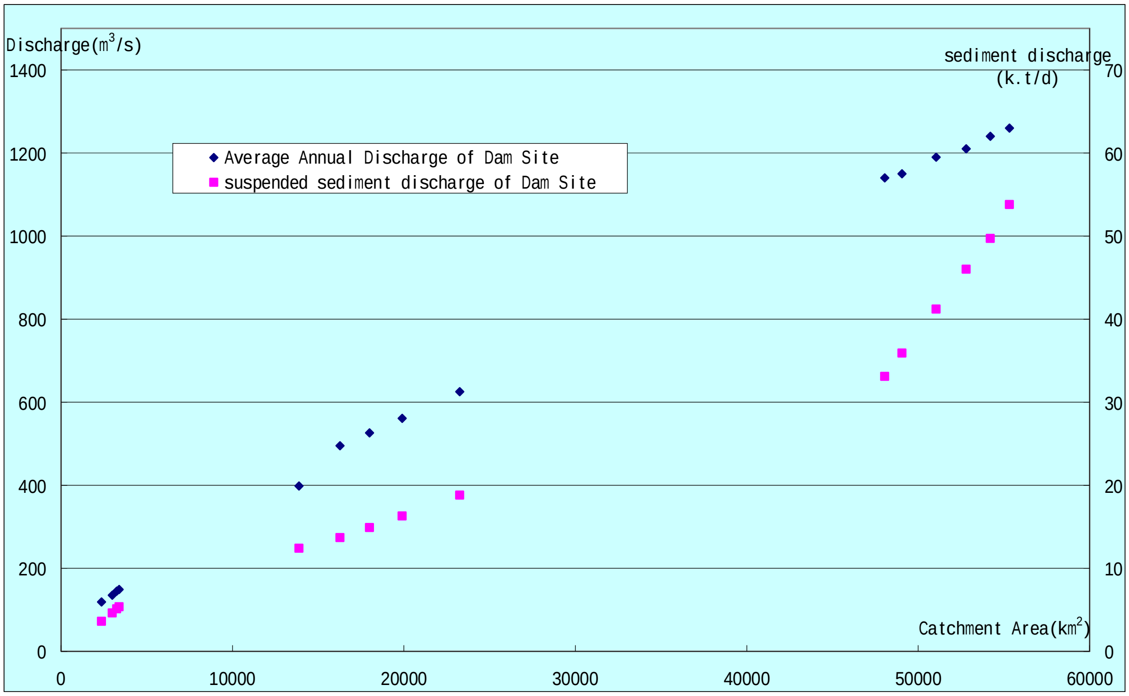


Fig.6.5.1-2 Relation of Catchment Area and Annual Mean Discharge as well as Sediment Discharge

6.5.2 Hydropower Analysis

a) Basic data

The relation curve between the runoff and the water level at the dam site uses the hydrological analysis results.

Storage curve: it is measured and calculated with topographic map (1:10,000) drawn based on topographic map (1:25,000) (IGAC) and measured data in the plan.

Head loss: with dam-toe type development used for the planned cascade, the head loss is relatively low. The average head loss of each cascade is considered to be 0.5 m~1m.

Water loss: the water losses of navigation lock and fish pass structure are mainly considered. It is temporarily determined as 5 m^3/s at the plan stage.

Coefficient of integrated output: according to comprehensive analysis of the range of operating heads of each cascade hydropower station and the available unit type, the coefficient of integrated output for the hydropower station is temporarily considered as per 8.5.

Ecological flow: the cascades are developed by dam-toe type or gated dam and have longer utilization hours of installed capacity are high. Therefore, for the cascades capable of regulation, the ecological flow can meet the requirements on downstream ecological water by adjusting the flow passing through the unit; for the cascades incapable of regulation, the operation of hydropower station does not change the runoff characteristics. Therefore, the impact of discharged ecological flow on energy index is excluded during the runoff regulation calculation.

b) Determination of characteristic water level

According to the dam construction conditions, in conformity with the reasonable connection between cascades, the full supply level for each cascade should be preliminarily proposed based on the principle that the inundation loss should be as small as possible and inundation should be avoided especially for the important cities and towns as well as natural reserves. Guarapo, Chillurco and Oporapa are capable of seasonal regulation, while Honda (260 m) is capable of over year regulation. For the rest of the cascades, the minimum operation levels should be preliminarily proposed as per a 2 m drawdown.

c) Installed capacity proposal

In order to economically and rationally utilize the hydropower resources of the reaches, the installed capacity should be proposed according to utilization degree of the hydropower resources under joint operation of the cascades on the reaches.

The power supply structure in Colombia is hydropower-dominant. Due to small seasonal variation in power load within a year and the high requirements of power system on the balance of hydropower generation, as well as peak regulation task to be undertaken by the hydropower station, the utilization hours of installed capacity for a hydropower station are generally high. During this plan, the utilization hours of installed capacity of each cascade hydropower station are proposed as 5500h.

d) Runoff regulation and energy index calculation

In the planned cascades, Guarapo (cascade 1), Chillurco (cascade 2) and Oporapa (cascade 3) are capable of seasonal regulation, and the runoff regulation of Perícongo (cascade 4) is considered as per the joint operation with the above cascades. The completed Betania and El Quimbo Cascade under construction are separately capable of annual and over year regulation, with certain compensation to the downstream hydropower stations incapable of regulation. The impacts of regulation and storage of the upstream reservoir are considered in the runoff regulation calculation of each downstream cascade. In addition, Honda Cascade (260 m) has overyear regulation storage, while the runoff regulation of PiedrasNegras Cascade should be considered as per joint operation with Honda Cascade.

Refer to Table 6.5.2 for main characteristic parameters and energy index results of each option.

Table 6.5.2 Main Characteristic Parameters of each Cascade Option

Cascade Option	Name of Cascade	Catchment Area	Average Discharge	Full supply level at Dam Site	Full supply level	Min. Operation Level	Backwater Height of Dam	Storage at Full supply level	Regulation Storage	Regulation Performance	Installed Capacity	Average Annual Energy Output	Dam Type	Unit Type	Preliminarily Proposed Main Development Task
		km^2	m^3/s	m	m	m	m	10^8 m^3	10^8 m^3	-	MW	GWh	-	-	-
Dam site 1	Guarapo	2358	119	1125	1220	1205	95	1.52	0.75	Seasonal regulation	140	774	Concrete faced rockfill dam	Francis turbine	Power generation
Dam site 2	Chillurco	2983	135	1015	1125	1105	110	3.58	1.84		180	1009			
Dam site 3	Oporapa	3249	145	898	1015	995	117	2.87	1.26		220	1190			
Dam site 4	Perícongo	3387	149	829	870	868	41	-		Incapable of regulation	80	432	Concrete gravity dam		
Dam site 7	El Manso	13883	398	463	485	483	22	-			140	593	Concrete gravity dam + homogeneous earth dam	Bulb tubular turbine	
Dam site 8	Veraguas	16270	495	398	420	418	22	-			130	723	Gravity dam + earth-rock dam		Power generation, navigation, irrigation and recreation
Dam site 9	Bateas	17990	526	377	399	397	22	-			140	779	Gravity dam + earth-rock dam		
Dam site 10	Basilias	19901	561	356	378	376	22	-			140	787	Concrete gravity dam		
Dam site 11	Carrasposo	23256	625	334	357	355	23	-			170	970			
Dam site 12	Nariño	48051	1140	243	260	258	17	-			200	1140	Concrete gravity dam + rockfill dam		
Dam site 13	Lame (low inundation)	49052	1150	231	244	242	13	-			160	894	Concrete gravity dam		
	Lame (high inundation)				260	258	29	-			400	2206		Kaplan turbine	
Dam site 14	Ambalema	51048	1190	220	232	230	12	-			160	885		Bulb tubular turbine	
Dam site 15	Cambao	52805	1210	213	221	219	8	-			100	577			
Dam site 16	Honda214	54211	1240	191	214	212	23	-			280	1577			
	Honda221				221	219	30				400	2200		Kaplan turbine	
	Honda260				260	240	69	130.43	88.82	Over year regulation	1000	5583		Francis turbine	Flood control, navigation, power generation, irrigation, recreation, environmental protection, etc.
Dam site 17	PiedrasNegras	55328	1260	183	192	190	9	-		Incapable of regulation	100	689/650		Bulb tubular turbine	Navigation and power generation

Note: the water levels listed in the table are the actually measured results; the electricity of PiedrasNegras are the results under the two conditions of joint operation and independent operation; the utilization hours of the El Manso Cascade is considered to be the same as that of the upstream Betania Cascade, which are about 4200 h.

6.5.3 Land Acquisition and Resettlement

The backwater impact is not considered tentatively at this stage. The reservoir inundation area is mainly the area below the full supply level of the reservoir. According to the cascade plan results, refer to Table 6.5.3 for the reservoir inundation area of each cascade.

Table 6.5.3 Inundation Area of Cascade Development Options

Reaches	Cascade Option	Name of Cascade	Full supply level	Backwater Height of Dam	Corresponding reservoir area
			m	m	km^2
Upstream of Betania	Dam site 1	Guarapo	1220	95	6.51
	Dam site 2	Chillurco	1125	110	9.07
	Dam site 3	Oporapa	1015	117	7.61
	Dam site 4	Perícongo	870	41	2.23
Reaches from Betania to Girardot	Dam site 7	El Manso	485	22	5.77
	Dam site 8	Veraguas	420	22	9.74
	Dam site 9	Bateas	399	22	22.31
	Dam site 10	Basilias	378	22	23.73
	Dam site 11	Carrasposo	357	23	41.60
Reaches from Girardot to La Ceiba	Dam site 12	Nariño	260	17	7.63
	Dam site 13	Lame244	244	13	9.82
		Lame260	260	29	36.10
	Dam site 14	Ambalema	232	12	32.00
	Dam site 15	Cambao	221	8	10.45
	Dam site 16	Honda214	214	23	48.66
		Honda221	221	30	75
		Honda260	260	69	571
	Dam site 17	PiedrasNegras	192	9	2.03

Due to the restriction of data and work depth at this stage, the inundated land type of each cascade and corresponding area, population and other indexes cannot be accurately determined.

The upper reaches of Betania are basically mountain rivers, the dam sites of the cascades are located in gorges flanked by middle and lower mountains. Although the dam height is big, the reservoir inundation area is relatively small, and a fewer farmers and farmland on both banks in the reservoir area, the inundation loss of each cascade is small.

With low backwater and limited reservoir inundation area, the plan cascade on the reaches from Betania to Girardot enjoys good sunlight, heat, water and earth conditions, and is the main area for agricultural development. As stretches of fertile farmland have been formed along the bank, during the cascade arrangement, the impact on arable land should be minimized. However, the impact cannot be completely avoided for such cascades as El Manso, etc.

Both ends of the reaches from Girardot to La Ceiba are relatively narrow, while the middle is composed of multiple terraces, with relatively fewer arable lands and relatively dense residential areas along the banks. The cities/towns with large population include Narino, Ambalema, Cambao, Pureto Rico, La Vega De Los Padres, Vindi, Barrialosa and Guataqui, etc. In the cascade plan options 1 & 2, the impacts on the main cities/towns (Cambao, Ambalema) in the reaches should be avoided to the largest extent. As there are many residential areas in the section between the Narino dam site and the Lame dam site, if the 260 m option at Lame is used, a population of nearly 2000 in four towns (La Vega De Los Padres, Vindi, Barrialosa, Guataqui) will be affected. If the 260 m option at Honda is used for the reaches, a population of more than 10,000 will be involved.

6.5.4 Environmental Protection

In the planned cascades, except that the high dam option at Honda (which may have a low-temperature water impact) is stratified reservoir, the reservoirs of the remained cascades are mixed or transition type.

The environmentally sensitive factors of each cascade hydropower station are analyzed by Tremarctos warning information system of Colombia. Important endangered (critically endangered or vulnerable) animals are involved in the four planned cascades (Perícongo, Bateas, Basilias and PiedrasNegras). In addition, the Basilias cascade may be also involved with one local natural park (La Tatacoa). The five cascades (Bateas, Basilias, PiedrasNegras, Veraguas and Carrasposo) have higher ecological compensation factor (8~9), with relatively large ecological compensation area. The remained 9 planned cascades are insensitive in terrestrial ecological environmental impact.

The PiedrasNegras Cascade has an impact on fish spawning ground and migration channel. Meanwhile, the high dam option at Honda has a significant impact on fish migration. Therefore, according to the comments on environmental impact assessment, the development of such cascades as Perícongo, Bateas, Basilias and PiedrasNegras should be delayed, while the high dam option at Honda should be further studied.

During the plan of all cascades, except that the Guarapo, Chillurco and Oporapa reservoirs are capable of seasonal regulation, and reservoir in the high dam option at Honda is capable of over year regulation, the remained cascades are incapable of regulation. The impact on hydrological regime is small, and the unfavorable environmental impact is mainly on obstructing the migratory fishes, which can be released and effectively controlled by habitat protection, breeding and releasing, fish pass structure, combined ecological regulation of cascade reservoirs, control of pollution sources, ecological compensation, etc.

6.5.5 Project Layout

a) Cascade 1-Guarapo

The dam site of the Guarapo Cascade is located about 4.8 km downstream the Guarapo tributary confluence. The drainage area upstream of the dam site is 2358 km^2, the average annual flow is 119 m^3/s, the full supply level of the reservoir is 1220 m, the backwater height is 95 m, and the installed capacity of the station is 140 MW. This cascade is of seasonal regulation property.

The landform of the project area is featured by gorges flanked by middle mountains. The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.35 g at the dam site, belonging to areas of high seismic intensity. Both banks in the reservoir area are surrounded by middle mountains, with wide dividing ridge, of which the lithology is mainly dominated by clasolite and volcanic lava. However, there may exist leakage due to soluble rocks distributed on the right bank of the dam site; local earth bank slopes of the reservoir banks may be prone to collapse;

there are certain sediment runoff sources. The river valleys at the dam site are cross-valleys, with thin riverbed overburden. Both banks are of steep terrain, and the river valleys are narrow. The bedrocks at the dam site are mainly dominated by marlstone and granodiorite, with hard to relatively hard rocks. The dam site has topographic and geological conditions suitable for the construction of dam, with available natural building materials.

The project layout follows such a pattern that a water retaining structure is provided in the main riverbed, an open spillway and a headrace system are arranged on the right bank in a centralized manner and a ground powerhouse arranged on the terrace at the right bank downstream the dam. The water retaining structure is concrete faced rockfill dam, with a crest elevation of 1225.0 m, a crest width of 8.0 m, the maximum dam height of 108 m, a dam axis length of 340.90 m. The upstream and the downstream dam slopes are 1: 1.4 and 1: 1.5 respectively. The flood discharge and energy dissipation structure consists of the intake channel, control section, chute, ogee connection section, flip bucket, etc., with a full length of 488.0 m and a discharge volume of 2322 m^3/s at full supply level. The headrace system of the hydropower station is of pressure diversion type with one tunnel shared by two generators. The headrace structure mainly consists of bank-tower intake, headrace tunnel, surge shaft and penstock. The powerhouse of the hydropower station is of riverside type, mainly comprising main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber, central control building and turnaround.

The dam site enjoys good site access conditions, with a secondary highway on the left bank connected to the location near the dam site. The highway mileage is about 9.5 km, of which the simple road (earth road, with subgrade width of about 4 m) is 8.0km. Construction diversion adopts such modes as one-time riverbed interception, tunnel diversion and over-the-year water retaining by cofferdam. The diversion standard at the early stage is based on the 10-year flood while the flood control standard for the dam is considered as per the 50-year flood in flood seasons. The diversion tunnel is arranged on the right bank. The total construction period of the project is 43 months.

b) Cascade 2-Chillurco

The dam site of the Chillurco Cascade is located about 1000 m downstream the

Bordones tributary confluence in the west of the Timana Town. The drainage area upstream the dam site is 2983 km^2, the average annual flow is 135 m^3/s, the full supply level of the reservoir is 1125 m, the height of the backwater is 110 m, and the installed capacity of the station is 180 MW. This cascade is of seasonal regulation property.

The landform of the project area is featured by gorges flanked by middle mountains. The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.35 g at the dam site, belonging to areas of high seismic intensity. Both banks in the reservoir area surrounded by middle mountains, with wide dividing ridge, of which the lithology is mainly dominated by tuff and volcanic lava. The regional fault Oritoguaz is developed along the river valley, which is the possible leakage channel. The natural bank slopes are relatively stable on the whole, with certain sediment runoff sources. The bank slopes of the river valleys at the dam site are relatively gentle, with thin riverbed overburden. The Tertiary tuff and breccia are exposed on both bank sides, with relatively soft rocks. The regional fault Oritoguaz runs through the left bank of the dam site, the activity of which will be further demonstrated. Natural aggregates are available near the dam site.

The main structures of the project include a concrete faced rockfill dam, the water releasing structure, headrace structure and surface powerhouse. The dam has a crest elevation of 1130.0 m a.s.l, a crest width of 12.0 m, the maximum dam height of 140 m, a dam axis length of 660.0 m. The upstream and the downstream dam slopes are 1: 1.4 and 1: 1.5 respectively. The water releasing structure is a riverside spillway on the right bank, comprised of upstream entrance channel, control section, chute, flip bucket, etc. The impervious structure for the main structures is composed of impervious curtains at the dam and on both banks. The headrace structure is arranged in the mountain on the left bank; it follows a pressure diversion pattern of 1 tunnel shared by 2 generators, mainly comprised of a bank-tower intake, a 1,015m-long headrace tunnel, a surge shaft and a penstock. The powerhouse of the hydropower station is of river-side type on the left bank, mainly comprising main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber, central control building and turnaround. The dimensions of the main powerhouse are preliminarily determined to be 77.0m×23.5m×46.7m (L × W × H).

The dam site enjoys good site access conditions, with a secondary highway on the right bank connected to the location near the dam site. The highway mileage is about 3.0 km.

Construction diversion adopts such modes as one-time riverbed interception, tunnel diversion and over-the-year water retaining by cofferdam. The diversion standard at the early stage is based on the 10-year flood while the flood control standard for the dam is considered as per the 50-year flood in flood seasons. The diversion tunnel is arranged on the right bank, with a length of 1395.00 m. The total construction period of the project is 49 months.

c) Cascade 3-Oporapa

The dam site of the Oporapa Cascade is located about 6.5 km downstream the Oporapa Town. The drainage area upstream the dam site is 3249 km^2, the average annual discharge is 145 m^3/s, the full supply level of the reservoir is 1015 m, the height of the backwater is 117 m, and the installed capacity of the station is 220 MW. This cascade is of seasonal regulation property.

The landform of the project area is featured by gorges flanked by middle mountains. The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.35 g at the dam site, belonging to areas of high seismic intensity. With good closed topographical and geological conditions, the reservoir basically has no leakage, part of the reservoir bank may be prone to collapse. There are certain sediment runoff sources. It is a cross valley at the dam site, with thin riverbed overburden. Both banks are topographically symmetrical The rocks at the dam site are marlstone and quartz sandstone. The dam site has topographic and geological conditions suitable for the construction of dam, with available natural building materials.

The main structures of the project include a concrete faced rockfill dam, water release structure, headrace structure and ground powerhouse. The dam has a crest elevation of 1020.00 m, a crest length of 385.29 m and the maximum dam height of 145.0 m. The slope ratio of the upstream face is 1: 1/40, and that of the downstream face is 1: 1.50. The water release structure is river-side open spillway on the left bank, comprising circular arc entrance channel, control section, gentle slope chute, parabolic connection section, steep slope chute, flip bucket, etc. It has a full length of 580.70m, and is capable of ski-jump energy dissipation, with the maximum discharge capacity of 3570 m^3/s. The impervious structure for the main structures is composed of impervious curtains at the dam and on both banks. Arranged in the mountain on the left bank, the headrace structure employs a pressure diversion mode of one tunnel shared by two generators, mainly comprising a bank-tower intake, a headrace tunnel, a surge shaft and a penstock. The water diversion route is about 1.6 km long. The powerhouse at the hydropower station is of surface type with headrace system and is arranged on the right bank. The structure in the plant area consists of main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround. The dimension of the main powerhouse is preliminarily determined to be 83.0m×21.0m×48.2m (L × W × H).

The dam site enjoys good site access conditions, with a secondary highway connected from the left bank. A simple bridge, crossing one tributary, reaches the dam site. The highway mileage is about 4.5 km.

Construction diversion adopts such modes as one-time riverbed interception, tunnel diversion and over-the-year water retaining by cofferdam. The diversion standard at the early stage is based on the 10-year flood while the flood control standard for the dam is considered as per the 50-year flood in flood seasons. The diversion tunnel is arranged on the right bank, with a length of 756.00 m. The total construction period of the project is 49 months.

d) Cascade 4- Perícongo

The dam site of the Perícongo Cascade is located about 500 m upstream the Timana tributary confluence in the north of the Timana Town. The drainage area upstream the dam site is 3387 km^2, the average annual flow is 149 m^3/s, the full supply level of the reservoir is 870 m, the height of the backwater is 41 m, and the installed capacity of the station is 80 MW.

The landform of the project area is featured by gorges flanked by middle mountains. The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.35 g at the dam site, belonging to areas of high seismic intensity. Both banks of the reservoir are surrounded by middle mountains, with wide dividing ridge, of which the lithology is mainly dominated by limestone and glutenite, and the topographically closed conditions are good. With soluble limestone distributed in the reservoir area, relatively impervious sandy conglomerates are distributed at the dam site and around the reservoir, therefore, there is no leakage in the reservoir; local bank slopes may be prone to collapse; there are certain sediment runoff sources.

It is a diagonal river valley at the dam site, with thin riverbed overburden. Both banks are topographically steep on the lower reaches and gentle on the upper reaches, with single lithology and simple geological structure. The rocks at the dam site are mainly conglomerates and clay rocks, the strength of which is medium, thus the geological requirements of the dam foundation can be satisfied. There are available natural sand-gravel materials.

The main structures of the project include a concrete gravity dam and a powerhouse at the dam toe. The gravity dam is provided with structures for flood discharge, diversion and sand flushing, with energy dissipation structure arranged at the dam toe. The dam has a crest elevation of 873.00 m a.s.l, a maximum dam height of 61.00 m, and a crest length of 241.0 m. The section of the dam is typically triangular, of which the upstream face is vertical, the slope ratio of the downstream face is 1: 0.7, the crest widths are 6.0 m and 20.0 m. The flood discharge structure is open overflow weir with 3 surface bays, having a weir crest elevation of 859.00 m a.s.l, an orifice width of 11.00 m. There are 2 bays for sand flushing in total, arranged separately on the left and right sides of the flood discharge section. The invert elevation of the intake is 829.00 m a.s.l. The impervious structure for the main structures is composed of impervious curtains at the dam and on both banks. The headrace structure of the hydropower station mainly consists of an intake and penstocks in the dam, which follows the pattern of 1 tunnel for 1 generator. The intake is arranged closely to the left side of the overflow monolith. The surface powerhouse at the dam toe is arranged on the left bank, consisting of main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround.

The dam site enjoys good site access conditions, with a No.45 secondary highway connected from the right bank. A simple bridge, crossing the Timana tributary, reaches the dam site. The highway mileage is about 1.5 km.

Construction diversion adopts such modes as one-time riverbed interception, tunnel diversion and over-the-year water retaining by cofferdam. The diversion standard at the early stage is based on the 10-year flood while the flood control standard for the dam is considered as per the 50-year flood in flood seasons. The diversion tunnel is arranged on the right bank, with a length of 530.00 m. The total construction period of the project is 41 months.

e) Cascade 7-El Manso

The dam site of El Manso Cascade is located 14 km downstream Betania Hydropower Station. The drainage area upstream the dam site is 13,883 km^2, the average annual flow is 398 m^3/s, the full supply level of the reservoir is 485 m, the height of the backwater is 22 m, and the installed capacity of the station is 140 MW.

The landform of the project area is featured by low-maintains, hills and broad valley. The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.30 g at the dam site, belonging to areas of high seismic intensity. Both banks of the reservoir area are of low-mountains and hills. With a closed terrain, the relatively impervious glutenite, siltstone and tuff sandstone are distributed around the reservoir, therefore the leakage towards the adjacent valleys will not take place for the reservoir. However, the terrace near the dam section is wide, and terrace deposits are very thick, the anti-seepage treatment should be properly conducted for both banks; the area near the dam reservoir bank is dominated by earth bank slope, and bank sloughing might occur to some riverbank. The river valley at the dam site is broad, with a thick overburden. The subterrane is mainly glutenite and red siltstone interbeds, belonging to relatively soft rock, and the strength of the weakly weathered bedrock meets the requirements of concrete dam foundation; Natural sand-gravel material is available.

The project layout follows such a pattern of riverbed concrete gravity dam + homogeneous earth dam of both banks + water retaining type powerhouse. The concrete dam has a total length of 200 m, a crest elevation of 490.00 m, a maximum dam height of 48 m, consisting of 6 water release dam sections, 3 powerhouse dam sections and 3 non-overflow dam sections. The flood discharge and energy dissipation structure is a weir gate of 5-bay open spillway type, with orifice dimensions of

12.0m×11.0m (width × height). The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround. The main powerhouse has preliminarily proposed dimensions of 102.0 m×20.0 m×52.4 m (L × W × H) and is arranged with three units of bulb tubular turbine generators, with a total installed capacity of 140MW. The terrace of left and right banks is homogeneous earth dam, having a maximum dam height of 37 m, the crest length of the earth dam on the left bank to be 665 m and the crest length of the earth dam on the right bank to be 300 m. The homogeneous dam has the slope ratios for the upstream and downstream dam faces of 1:2.75 and 1:2.2 respectively and a crest width of 7.0 m.

The access at dam site is connected with the secondary highway on left bank, and the highway mileage is about 2.0 km. The open channel diversion mode is adopted for construction diversion. The flood standard for diversion design is selected as per the 10-year flood. The diversion open channel is arranged on the right bank, with a length of 772.00 m. The total construction period of the Project is 44 months.

f) Cascade 8-veraguas

The dam site of Veraguas Cascade is located 19 km downstream Neiva City. The drainage area upstream the dam site is 16,270 km^2, the average annual flow is 495 m^3/s, the full supply level of the reservoir is 420 m, the height of the backwater is 22 m, and the installed capacity of the station is 130 MW

The landform of the project area near the bank is featured by hills, and the seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.30 g at the dam site, belonging to areas of high seismic intensity; both banks of the reservoir area are distributed with floodplain and terrace, while the terrace near the dam section is wide, with low terrain and flat landform, and the ground elevation around the reservoir is higher than the full supply level, and the reservoir is topographically and geologically closed; the reservoir bank is dominated by earth bank slope, and bank sloughing might occur to some river bank after impounding; a certain amount of sediment runoff sources are provided; the regional fracture of the reservoir area, Palogrande, passes through the upstream of the dam site, with no seismic record, therefore the possibility of reservoir induced earthquakes is fairly slim.

The riverbed at the dam site is narrow. Both the riverbed overburden and the terrace deposits on the left bank are relatively thick, and there are strongly weathered bedrock outcrops exposed on the right bank side. The river valley and the subterrane of the left-bank terrace are dominated by glutenite, belonging to relatively soft rock, and the strength of the weakly weathered bedrock can meet the requirements of concrete dam foundation. Natural sand-gravel material is available.

The main structures of the station include the ship lock, the sluice gate, the water retaining type powerhouse and the earth and rockfill dam of right bank. The crest elevation is 425 m and the total length of the dam crest is 611.6 m. The flood discharge and energy dissipation structure is of 4-bay open type overflow weir, with the dimensions of the orifices being 15 m×15 m (width × height), and the elevation of weir crest is 410.000 m. The powerhouse is of water retaining type, composed of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, switching station, central control building and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 94.1 m×20.5 m×44.5 m (L × W × H). The navigation structure is of ship lock type, arranged on the left bank of the river channel. The right side is connected with the sluice gate, and the effective dimensions of the gate chamber are 120 m×16 m×4 m (length × width × water depth at gate sill). The maximum navigation water level at upper reaches is 420 m, and the minimum navigation water level at lower reaches is 397 m. The maximum lifting height is 23 m. The earth and rockfill dam of right bank is of concrete core wall type, with the maximum dam (gate) height being 30.0 m, and the dam crest width being 8.0 m. The slope ratio of upstream face is 1:2.75, the slope ratio of downstream face is 1:2.50, and the concrete cut-off wall is 0.4 m thick.

The external access conditions at dam site are relatively good, with secondary highway passing by the right bank of the dam site. Construction diversion of the project is of open channel type and adopts the 10-year flood as the design flood standard in diversion. The open channel is arranged on the right bank, with a length of 684.00 m. The total construction period of the Project is 40 months.

g) Cascade 9-Bateas

The dam site of Bateas Cascade is located 6 km upstream Villavieja. The drainage area upstream the dam site is 17,990 km^2, the average annual flow is 526 m^3/s, the normal water level of the reservoir is 399.00 m, the height of the backwater is 22 m, and the installed capacity of the station is 140 MW.

The landform of this area is featured by low hills, and the seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.30 g at the dam site, belonging to areas of high seismic intensity; the topographic condition of the reservoir is closed; the reservoir is dominated by earth bank slope, and bank sloughing might occur to some river bank after impounding; a certain amount of sediment runoff sources is provided. The riverbed at the dam site is relatively wide. Both the riverbed overburden and the terrace deposits are relatively thick. The river valley and the terrace subterrane on both banks are dominated by glutenite, belonging to relatively soft rock. The engineering geological condition at the dam site can basically meet the requirements of buildings foundation, and natural sand-gravel material is available.

The project layout from left to right follows the sequence of left bank earth and rockfill dam, left bank water retaining dam, three dam sections of run-of-the-river powerhouse, eight dam sections for flood discharge, ship locks, right bank water retaining dam and right bank earth and rockfill dam. The crest elevation is 403.00 m, the maximum dam height is 46 m, and the total length of the dam crest is 1,389 m. The maximum dam height of the earth and rockfill dam on both banks is 30 m, the crest length of the earth dam on the left bank is 591 m, and crest length of the earth dam on the right bank is 438 m. The slope ratio of upstream dam face of the earth dam is 1:2.75, and the slope ratio of downstream dam face is 1:2.2. The crest width is 7.0m. The flood discharge and energy dissipation structure is a weir gate of 7-bay open overflow spillway, with the orifice dimensions being 12.0 m×9.0 m (width × height). The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, switching station, central control building and turnaround. The size of the main powerhouse is 96.8 m×21.0 m×44.9 m (L × W × H). The ship lock is arranged on right side of the river channel, and the effective dimensions of the gate chamber are 120 m×16 m×4 m (length × width × water depth at gate sill). The maximum navigation water level at upper reaches is 399 m, and that at lower reaches is 376 m. The maximum lifting height is 23 m.

The access at dam site can be connected with the secondary highway on the right bank, and the highway mileage is about 4.5 km. Construction diversion of the project is of open channel type and adopts the 10-year flood as the design flood standard in diversion. The diversion open channel is arranged on the right bank, with a length of 859.00 m. The total construction period of the Project is 44 months.

h) Cascade 10-Basilias

The dam site of Basilias Cascade is located about 12 km downstream Villavieja. The drainage area upstream the dam site is 19,901 km^2, the average annual flow is 561 m^3/s, the full supply level of the reservoir is 378 m, the height of the backwater is 22 m, and the installed capacity of the station is 140 MW.

The landform of the project area is featured by the alternation of alluvium and erosive hills, and the seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.25 g at the dam site; with a closed terrain of the reservoir, leakage towards the adjacent valleys will not take place; the reservoir bank is under overall stability; many tributaries and gullies with sandy gravels of alluvium and diluvium enter the main river channel, providing a certain amount of sediment runoff sources; the riverbed at the dam site is relatively narrow, and both the riverbed overburden and the terrace deposits are relatively thick; bedrock outcrops exposed on the left and right bank, which is mainly volcanic tuff, belonging to soft rock, and the strength of the weakly weathered bedrock can basically meet the requirements of concrete dam foundation; Natural sand-gravel material is available on the right bank of upstream of the dam site.

The main structures of the project include the overflow dam section, water retaining type powerhouse, ship lock and homogeneous earth dam. The crest elevation is 383m, and the total length of the dam crest is 1,651m. The overflow dam section has a total length of 98m and is arranged with 5 surface overflow bays, with a weir crest elevation of 366 m, orifice dimensions of 15 m×12 m (width × height). The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, switching station, central control building and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 100.0 m×21.7 m×45.6 m (L × W × H). The homogeneous earth dam on the left bank is 386 m long, and the homogeneous earth dam on the right bank is 1,023 m long. The effective dimensions for the gate chamber of the ship lock are 120 m×16 m×4 m (L × W × H). The maximum navigation water level at upper reaches is 378 m and that at lower reaches is 356 m. The maximum lifting height is 22 m.

The access conditions at dam site are relatively good, with No.45 trunk road passing by the left bank of the dam site. T Construction diversion of the project is of open channel type and adopts the 10-year flood as the design flood standard in diversion. The diversion open channel is arranged on the right bank, with a length of 724.00 m. The total construction period of the Project is 48 months.

i) Cascade 11-Carrasposo

The dam site of Carrasposo Cascade is located 24 km upstream Natagaima. The drainage area upstream the dam site is 23,256 km^2, the average annual flow is 625 m^3/s, the full supply level of the reservoir is 357 m, the height of the backwater is 23 m, and the installed capacity of the station is 170 MW.

Both banks at the reaches of the project area belong to a landform of alternately distributed alluvium and erosive low hills, and the seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.25 g at the dam site; the river floodplain and terrace are developed in the reservoir area; many tributaries and gullies with sandy gravels of alluvium and diluvium enter the main river channel, providing a certain amount of sediment runoff sources. The dam site is hills and gorges, belonging to erosive river valley. Bedrocks are exposed on both banks. The bedrock is mainly glutenite and red siltstone interbeds, belonging to soft rock, and the strength of the weakly weathered bedrock can meet the geological requirements of concrete dam foundation. On the left bank of the dam site, there is a saddle lower than full supply level, so an auxiliary dam should be constructed. The overburden of the riverbed is not very thick. Natural sand-gravel material is available.

The main structures of the project are composed of an overflow dam, a water retaining type powerhouse, ship locks and a non-overflow dam. Due to the existence of a saddle on the reservoir bank of the left side of the dam axis, an auxiliary dam should be provided. The auxiliary dam is a homogeneous earth dam, of which the dam slope at upper reaches is 1:2.8, and the dam slope at lower reaches is 1:2.0. The main dam is a roller-compacted concrete gravity dam, with a crest elevation of 362 m, the maximum dam height of 54 m and a crest length of 276 m. The flood discharge and energy dissipation structure is of 3-bay open type overflow weir, of which the weir crest elevation is 340 m, and the orifice dimensions are 15 m×17 m (width × height), with energy dissipation by hydraulic jump adopted. The water retaining type powerhouse is arranged on the right side of the river channel, consisting of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber, central control building and turnaround. The dimensions of the main powerhouse are preliminarily determined to be 111.2 m×20.5 m×46.5 m (L × W × H). The ship lock is arranged on the left side of the river channel, and the effective dimensions of the lock chamber are 120 m×16 m×4 m (length × width × water depth at gate sill). The maximum navigation water level at upper reaches is 357 m, and the minimum navigation water level at lower reaches is 332 m. The maximum lifting height is 25 m.

The access at dam site can be connected with No.45 trunk road on the left bank, and the highway mileage is about 7.0 km. Construction diversion adopts the pattern of one-time riverbed interception while tunnel diversion follows the pattern of all-the-year-round water retaining with cofferdam . The diversion standard is a 10-year flood; standard of 50-year flood return is adopted for the dam in flood seasons. The diversion tunnel is arranged on the right bank, with a length of 573.00 m. The total construction period of the Project is 45 months.

j) Cascade 12-Nariño

The dam site of Narino Cascade is located about 4 km upstream of Nariño Town, Girardot City. The drainage area upstream of the dam site is 48,051 km^2, the average annual flow is 1,140 m^3/s, the full supply level of the reservoir is 260 m, the height of the backwater is 17 m, and the installed capacity of the station is 200 MW.

The landform of the area is featured by low mountain and wide valley, and the seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.20 g at the dam site; both banks of the reservoir are surrounded by low mountains, with wide watershed, of which the lithology is mainly dominated by siltstone, argillaceous siltstone, and the topographic and geological closed condition of the reservoir is good, leakage will not take place; the most part of the reservoir bank is the earth bank slope accumulated by terrace, therefore bank sloughing might occur to some reaches of earth bank slope after the reservoir is impounded; the rock on the bank slope of the reservoir area is strongly weathered, with a wide distribution of terrace and pyroclastic flow. There are many sediment runoff sources. The riverbed at dam site is broad. Both the riverbed overburden and the terrace deposits on the right bank are relatively thick, and there are bedrock exposed on the left bank side. The river valley and the subterrane of the right-bank terrace are dominated by glutenite and argillaceous siltstone, belonging to relatively soft rock, and the strength of the weakly weathered bedrock can meet the requirements of concrete dam foundation. However, the bedrock on the right bank is buried relatively deep, so the anti-seepage treatment work quantities are quite large. There is no relatively large-scale available natural sand bank or available artificial aggregate within a certain range of the dam site, so it is recommended to take the terrace deposits on the right bank of upstream of the dam site as the natural sand-gravel material for exploitation.

The main structures of this cascade are composed of overflow concrete dam in the middle of the riverbed, the water retaining type powerhouse on the right side, ship lock on the left side and the non-overflow concrete dams on both banks. The dam has a crest elevation of 265 m, a maximum dam height is 47 m, and a dam crest length is 368 m. The flood discharge and energy dissipation structure is a 5-bay open overflow weir, of which the dimensions of the orifices are 15 m×15 m (width × height), with energy dissipation by hydraulic jump adopted. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 156.7 m×19.5 m×48.2 m (L × W × H). The effective dimensions of the ship lock chamber are 120 m long, 16 m wide and 3.5 m in water depth at gate sill. The straight section of upstream and downstream approach channel is 250 m long, with 10 m navigation clearance and 19.00 m maximum operating head.

The dam site is easily accessible and can be connected with the secondary highway on the right bank, with a 10m highway mileage. Construction diversion is performed by phases and the standard for design flood during diversion is a 10-year flood. The total construction period of the Project is 64 months.

k) Cascade 13-Lame

The dam site of Lame Cascade is located about 27 km upstream Narino Town. The drainage area upstream the dam site is 49,052 km^2, the average annual flow is 1,150 m^3/s. It is planned to make a comparison between high inundation and low inundation options for Lame Cascade. As for the Lame low inundation option, the full supply level is 244 m, the height of the backwater is 13 m, and the installed capacity of the station is 160 MW; as for the high inundation option, the full supply level is 260 m, the height of the backwater is 29 m, and the installed capacity of the station is 400 MW.

The landform of the project area is featured by erosive hills, and seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.15 g at the dam site. Many fault zone are developed in the reservoir area, with complex geologic structure; the reservoir is basically in the river channel, and no leakage towards the adjacent valley will take place; bank sloughing might occur to some part of earth bank slope after the reservoir is impounded; farmland of alluvial plain in the reservoir area might suffer from inundation in the low dam area, while inundation of GUATAQUI Town and local inundation of Narino Town might be caused by the high dam option; the rock on the bank slope of the reservoir area is strongly weathered, with a wide distribution of river terrace and pyroclastic flow, and there are many sediment runoff sources. Bedrocks are exposed on both banks at dam site, and the subterrane of both banks and riverbed are dominated by siltstone, glutenite, all belonging to relatively soft rock. The strength of the weakly weathered bedrock can meet the requirements of concrete dam foundation, and the topographical and geological condition of the dam site can meet the requirements of the Project. Natural sand-gravel material yard is available.

In the low inundation option (244 m), the main structures are composed of a concrete gate dam in the middle of the riverbed, the water retaining type powerhouse on the right side, the ship lock on the left side and the non-overflow dam on both banks. The dam has a crest elevation of 247 m, the maximum dam height of 32.0 m, and a crest length of 325.5 m. The flood discharge and energy dissipation structure is of 6 overflow surface bays, of which the weir crest elevation is 230 m, and the dimensions of the orifices are 15 m×14 m (width × height). The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, switching station, central control building and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 154.5 m×24.5 m×47.9 m (L × W × H).The effective dimensions of the gate chamber for the ship lock are 120 m×16 m×4 m (L × W × H). The maximum navigation water level at upper reaches is 244 m, and the minimum navigation water level at lower reaches is 229 m. The maximum lifting height is 15 m.

In the high inundation option (260 m), the main structures are composed of the concrete earth dam in the middle of the riverbed, the diversion dam section on the right side, the water retaining type powerhouse, the ship lock on the left side and the non-overflow dam on both banks. The dam has a crest elevation of 264 m, the maximum dam height of 57 m, and a crest length of 465 m. The flood discharge and energy dissipation structure is of 5 overflow surface bays, of which the weir crest elevation is 247 m, and the dimensions of the orifices are 15 m×13 m (width × height), with energy dissipation by hydraulic jump adopted. The total length of 4 diversion dam sections is 122 m. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, switching station, central control building and turnaround. The size of the main powerhouse is preliminarily determined to be 176.0 m×33.0 m×63.9 m (L × W × H). The effective dimensions for the gate chamber of the ship lock is the same with that of the low inundation option, of which the maximum navigation water level at upper reaches is 260 m, and the minimum navigation water level at lower reaches is 229 m and the maximum lifting height is 31 m.

The access at dam site can be connected with the secondary highway on the right bank with a 3.0km highway mileage. The construction diversion options for both the high and low inundation options are the same, with the open channel diversion mode adopted. The flood standard in diversion design adopts a 10-year flood, and a 1,077.00m-long open channel for diversion is arranged on the left bank. The total construction period of the high inundation option is 48 months while that of the low inundation option is 41 months.

l) Cascade 14-Ambalema

The dam site of Ambalema Cascade is located about 3 km upstream of Ambalema Town. The drainage area upstream of the dam site is 51,048 km^2, the average annual flow is 1,190 m^3/s, the full supply level of the reservoir is 232 m, the height of the backwater is 12 m, and the installed capacity of the station is 160 MW.

The landform of the right bank of the dam site is generally featured by low mountains and erosive hills, and that of the left bank is featured by river alluvium, with floodplain and terrace developed. The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.15 g at the dam site. Floodplain and terrace are developed on both banks of the reservoir area, and the closed topographic condition of the reservoir is not good. Certain earth bank slope exists in the reservoir, with rock slope in local part. The lithology is relatively soft, and the rock mass is relatively strongly weathered, so bank sloughing and collapse will take place after the reservoir is impounded. With wide accumulation of terrace and pyroclastic flow, the sediment runoff sources are rich. The overburden on both banks at dam site is not very thick, and the subterrane of both banks and riverbed are dominated by sandshale, mud shale, belonging to soft rock. The strength of the weakly weathered bedrock can meet the requirements of concrete dam foundation. Natural sand-gravel material yard is available.

The main structures of the project are composed of concrete sluice gate in the middle of the riverbed, water retaining type powerhouse on the right side, ship lock on the left side and the concrete non-overflow dams on both banks. The dam has a crest elevation of 235 m, the maximum dam height of 30 m and a crest length of 378.3 m (excluding the part of cut-off wall). The sluice gate is 140 m in total length, comprised of 7 overflow surface bays, with a weir crest elevation of 220 m and the dimensions of the orifice of 15 m×12 m (width × height). The energy dissipation by hydraulic jump is adopted. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, switching station, central control building and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 169.2 m×23.6 m×47.2 m (L × W × H). The effective dimensions for the gate chamber of the ship lock are 120 m×16 m×4 m (L × W × H). The maximum navigation water level at upper reaches is 232 m, and the minimum navigation water level at lower reaches is 218 m. The maximum lifting height is 14 m.

The access at dam site can be connected with the secondary highway on the right bank, and the highway mileage is about 0.2 km. Construction diversion of the project is of open channel type and adopts the 10-year flood as the design flood standard in diversion. The 600.00 m-long open diversion channel is arranged on the left bank. The total construction period of the Project is 48 months.

m) Cascade 15-Cambao

The dam site of Cambao Cascade is located 7.5 km upstream of Cambao Town. The drainage area upstream of the dam site is 52,805 km^2, the average annual flow is 1,210 m^3/s, the full supply level of the reservoir is 221.00 m, the height of the backwater is 8m, and the installed capacity of the station is 100 MW.

The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.15 g at the dam site, and the geologic structure is simple. Basically, leakage of the reservoir will not take place. Floodplain and terrace are developed on both banks of the reservoir area, of which the bank slope is mainly earth bank slope, with rock slope in local part. The lithology is relatively soft, and the rock mass is relatively strongly weathered, so bank sloughing and collapse might take place after the reservoir is impounded. With the river terrace, pyroclastic flow and debris flow relatively developed, the sediment runoff sources are rich. The dam site belongs to landform of corrosive low hills, and the river valley is broad, with a thick overburden. The bedrock is mainly glutenite and red sandshale interbeds, belonging to soft rock, and the strength of the weakly weathered bedrock can meet the requirements of concrete dam foundation; Natural material is available.

The main structures of the project are composed of the concrete sluice gate in the middle of the riverbed, the water retaining type powerhouse on the left side, the ship lock on the right side and the water retaining dams on both banks. The dam has a crest elevation of 226 m, the maximum dam height of 50 m, and a crest length 710 m. The sluice gate is 98 m in total length and comprised of 5 bays, having a weir crest elevation of 205 m and orifice dimensions of 15 m×16 m (width × height). Energy dissipation of hydraulic jump type is adopted. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, switching station, central control building and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 176.9 m×24.8 m×48.1 m (L × W × H). The effective dimensions for the gate chamber of the ship lock are 120 m×16 m×4 m (L × W × H). The maximum navigation water level at upper reaches is 221 m, and the minimum navigation water level at lower reaches is 211 m. The maximum lifting height is 10 m.

The access at dam site can be connected with the secondary highway on the right bank, and the highway mileage is about 0.5km. The open channel diversion mode is adopted for construction diversion, and the flood standard in diversion design is determined as per 10-year flood return. The diversion open channel is arranged on the left bank, with the length of 775.00 m. The total construction period of the Project is 45 months.

n) Cascade 16-Honda

The dam site of Honda Cascade is located about 4 km upstream of Honda Bridge. The drainage area upstream the dam site is 54,211 km^2, the average annual flow is 1,240 m^3/s. According to the key elements in inundation control, three options of high, middle and low inundation are proposed for the Honda Cascade to make comparison. As for the high inundation option, the full supply level is 260 m, the backwater height is 69 m, and the installed capacity of the station is 1,000 MW; as for the middle inundation option, the full supply level is 221 m, the backwater height is 30 m, and the installed capacity of the station is 400 MW; for the low inundation option, the full supply level is 214 m, and the backwater height is 23 m, and the installed capacity of the station is 280 MW.

The landform of the area is generally featured by low mountains and hills, and wide river alluvial terrace exists at some reaches. The seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.15 g at the dam site, and the regional Falla de Honda active fracture passes through the left bank at a distance of about 3 km from the dam site. Both banks of the reservoir are surrounded by low mountains, and the topographic and geological closed conditions of the reservoir are relatively good; reservoir banks of each inundation option are all earth bank slope, with rock slope in local part. The lithology is relatively soft, and the rock mass is relatively strongly weathered. Bank sloughing and collapse might take place after the reservoir is impounded; terrace is developed on both banks of the river, which might cause immersion of relatively low-lying areas. The riverbed at dam site is relatively broad, with terrace distributed on the left bank, and the riverbed overburden is not very thick. There is bedrock exposed on most part of both banks, of which the bedrock is mainly the glutenite, volcanic tuff or cinerite exists in local part, generally belonging to relatively hard to relatively soft rocks. The strength of the weakly weathered bedrock can meet the geological requirements of concrete dam foundation, but the influence of volcanic tuff or cinerite on strength must be taken into consideration; the stratum at dam foundation is mainly relatively impervious glutenite and sandstone, and the relative water-resistant layer is buried not very deep. The engineering geological condition of dam site can basically meet the requirements of each option, and natural sand-gravel material yard is available at upper and lower reaches of dam site.

In the low inundation option (214 m), the main structures of the project are composed of the overflow concrete dam in the middle of the riverbed, the water retaining type powerhouse on the left side, the ship lock on the right side and the non-overflow concrete dams on both banks. The dam has a crest elevation of 219 m, the maximum dam height of 56 m and a total crest length of 394 m. The overflow dam section is arranged with 5 bays and has a total length of 98 m; it has a weir crest elevation of 197.5 m and orifice dimensions of 15 m×16.5 m (width × height). Energy dissipation of hydraulic jump type is adopted. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 207.7 m×21.0 m×49.6 m (L × W × H), and 8 bulb tubular turbine generator units are installed inside. The effective dimensions for the gate chamber of the ship lock are 120 m×16 m×4 m (length × width ×water depth at gate sill), and the maximum operating head is 24 m.

In the middle inundation option (221 m), the main structures of the project are composed of overflow concrete dam in the middle of the riverbed, the diversion dam section on the left side, water retaining type powerhouse, ship lock on the right side and the non-overflow concrete dams on both banks. The crest elevation of the dam is 226m, with a maximum dam height of 63m, and a crest length of 405m. The overflow dam section is arranged with 5 bays and has a total length of 98m; it has a weir crest elevation of 214.5 m and orifice dimensions of 15 m×16.5 m (width × height). Energy dissipation of hydraulic jump type is adopted. The diversion dam section has a total length of 128 m. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 194.0 m×36.0 m×68.0 m (L × W × H). Four turbine generator units with a unit capacity of 100 MW are installed in the powerhouse. The effective dimensions for the gate chamber of the ship lock are 120 m×16 m×4 m (L × W × H). The maximum navigation water level at upper reaches is 221 m, and the minimum navigation water level at lower reaches is 191 m. The maximum lifting height is 30 m.

In the high inundation option (260 m), the main structures of the project are composed of the overflow concrete dam in the middle of the riverbed, the diversion dam section on the left side, the water retaining type powerhouse, the ship lock on the right side and the concrete non-overflow dams on both banks. The dam has a crest elevation of 265m, the maximum dam height of 100m, and a crest length of 638m. The overflow dam section is arranged with 5 bays and has a total length of 98m; it has a weir crest elevation of 243 m and orifice dimensions of 15 m×17 m (width × height). Ski-jump energy dissipation is adopted. The diversion dam section is 154m long. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround. The dimensions of the main powerhouse are preliminarily proposed to be 214.0 m×34.4 m×29.8 m (L × W × H) and 5 turbine generator units with a unit capacity of 200 MW are installed in the powerhouse. The ship lock is arranged on the right bank slope of the river channel, with the left side connected with the sluice gate. The effective dimensions for the gate chamber of the ship lock are 120 m×16 m×4 m (length × width × water depth at gate sill). The maximum navigation water level at upper reaches is 260 m, and the minimum navigation water level at lower reaches is 190 m. The ship lock is arranged in two stages, with single stage lifting height being 35 m.

The access at dam site can be connected with the trunk road (Honda City) on the right bank, and the highway mileage is about 1.0 km.

The construction diversion options for the three options are the same, with the open channel diversion mode adopted. The flood standard in diversion design adopts the 10-year flood and the 410 m-long open diversion channel is arranged on the right bank. The total construction periods of the low, middle and high inundation options are 73 months, 68 months and 81 months respectively.

o) Cascade 17-Piedras Negras

The dam site of Piedras Negras Cascade is located at a distance of 8 km downstream of highway bridge of Honda downtown, of which the drainage area upstream the dam site is 55,328 km^2, the average annual flow is 1,260 m^3/s, the full supply level of the reservoir is 192.00 m, the height of the backwater is 9 m, and the installed capacity of the station is 100 MW.

The landform of the area is featured by low mountain and wide valley, and the seismic peak ground acceleration with a probability of exceedance of 10% in 50 years is 0.15 g at the dam site. The regional Falla de Honda active fracture passes through the right bank of the dam site. Both banks of the reservoir are surrounded by low mountains, with wide watershed, of which the lithology is mainly dominated by clastic rocks, no low adjacent valleys exist on both banks. Therefore, the topographical closed conditions are good, and leakage of the reservoir will not take place. The stratum of the reservoir area is dominated by Quaternary terrace deposits (Qt), and great part of the reservoir bank is earth slope. With terrace and pyroclastic flow widely accumulated, collapse, slumping and reconstitution might occur to the reservoir bank. The sediment runoff sources are rich, and the certain siltation might form for the reservoir. The river valley at dam site is broad, with shallow and terrace developed on both sides of the river channel, and the terrain is flat and broad. The overburden at dam site is thick. Except the overflow dam, the sand gravel foundation can be used as the dam foundation for both banks, but the anti-seepage treatment work quantities is quite large. Natural sand-gravel material yard is available at upper and lower reaches of dam site.

The main structures of this cascade are composed of the concrete sluice gate in the middle of the riverbed, the water retaining type powerhouse on the right side, the ship lock on the left side and the non-overflow concrete dams on both banks. The dam has a crest elevation of 196 m, the maximum dam height of 32.0 m and a total crest length of 464.6 m. The sluice gate has 8 overflow surface bays and is 183.5 m in total length; it has a weir crest elevation of 180 m and orifice dimensions of 18 m×12 m (width × height). Energy dissipation of hydraulic jump type is adopted. The water retaining type powerhouse consists of the main powerhouse, auxiliary powerhouse, erection bay, main transformer chamber, GIS chamber and turnaround. The effective dimensions for the gate chamber of the ship lock are 120 m×16 m×4 m (L × W × H). The maximum navigation water level at upper reaches is 192 m, and the minimum navigation water level at lower reaches is 180 m. The maximum lifting height is 12 m.

The dam site is easily accessible, with No.45 trunk road passing by the left bank of the dam site. Construction diversion of the project is of open channel type and adopts the 10-year flood as the design flood standard in diversion. The 680m-long open diversion channel is arranged on the left bank. The total construction period of the Project is 47 months.

6.5.6 Cost Estimate

With reference to the current specifications and quota standards of hydropower industry in China, combining with the local practices in Colombia, this cost estimate is prepared based on the design quantities at this stage, construction organization design and price level in the 2nd quarter of 2013. See Table 6.5-6 for the results of cost estimate for each cascaded hydropower station.

Table 6.5-6 Cost estimate Results of Cascaded Hydropower Stations

Cascade		Total Project Investment				Investment per kilowatt	Investment per KWH
		Total	Investment in Hydroproject		Investment in Land Acquisition and Resettlement		
			Subtotal	Wherein: navigation structures			
		million USD	million USD	million USD	million USD	USD/kW	USD/kWh
1	Guarapo	351	334	-	17	2505	0.45
2	Chillurco	771	748	-	23	4283	0.76
3	Oporapa	501	481	-	19	2276	0.42
4	Perícongo	249	243	-	6	3116	0.58
7	El Manso	378	360	-	17	2697	0.64
8	Veraguas	546	517	74	29	4199	0.76
9	Bateas	606	539	69	67	4329	0.78
10	Basilias	644	573	73	71	4599	0.82
11	Carrasposo	694	569	80	125	4079	0.71
12	Nariño	542	523	45	18	2708	0.48
13	Lame (low inundation)	640	616	53	24	4000	0.72
	Lame(high inundation)	964	863	93	100	2410	0.44
14	Ambalema	834	756	51	77	5210	0.94
15	Cambao	779	754	43	25	7787	1.35
16	Honda214	1003	817	99	186	3581	0.64
	Honda221	1329	999	103	330	3323	0.60
	Honda260	5168	1817	173	3350	5168	0.93
17	Piedras Negras	789	781	49	8	7890	1.15/1.21

6.6 Selection of Cascade Development Alternatives

6.6.1 Comparison of Cascade Development Alternatives

Refer to Table 6.6.1 for the main indexes of the three plan options.

Table 6.6.1 Main Indexes of Cascade Plan Options

Options	Installed Capacity	Average Annual Energy Output	Total Investment	Investment per kW	Investment per KWH
	MW	GWh	million USD	USD/kW	USD/kWh
Option 1 (15 cascades)	2,340	12,980	9,327	3,986	0.719
Option 2 (13 cascades)	2,400	13,198	8,656	3,607	0.656
Option 3 (11 cascades)	2,440	13,529	10,697	4,384	0.791

Note: data of the 5^{th} cascade and the 6^{th} cascade (completed or under construction) are not listed in the table.

Engineering construction: among the 15 preliminarily selected cascades, most of them are provided with relatively low dam height. From the perspective of geology, except that regional fault should be paid attention for Cascade 2 and Cascade 17, major geological flaws having impact on dam construction are not found temporarily. The engineering layout and construction of all cascades have no major technical problems. Adjusting measures to local conditions, the local materials or concrete can be used to construct the dam. The regional road network is developed, and there is no big difference between access conditions at dam site.

Utilization of hydropower resources: Concerning the utilization heads, they are the same to three options; as for the installed capacity of each option, with the decrease in cascades, the utilization of the hydropower resources is sufficient and the total installed capacity and electric energy increases gradually. The installed capacities for Option I, Option II and Option III are 2,340 MW, 2,400 MW and 2,440 MW respectively while the electric energy are 12,980 GWh, 13,198 GWh and 13,529 GWh respectively. The difference in the total installed capacity and total electric energy among each option is only about 2%. Therefore, from the perspective of utilization degree of hydropower resources, difference among three options is not big.

Reservoir inundation: according to the site survey, many residential areas are distributed along the banks of the Girardot~Honda reaches. In Option I, inundation is controlled to an extent that cities and towns are not to be influenced as much as possible and therefore, the displaced people from the reservoir area are small in number. As for Option II, about 2,400 people from the four towns of La Vega De Los

Padres, Vindi, Barrialosa, Guataqui, will be affected by the Cascade 12 Lame (high inundation). In Option III, the Honda high dam is adopted, and more than 10,000 populations will be involved (refer to the chapter of “Land Acquisition and Resettlement” for the details of inundation of each option). Therefore, according to the degree of influence due to reservoir inundation on the towns along the banks, Option I suffers from the smallest influence, followed by Option II and Option III.

Environmental impact: the difference of the three Options lies in the Girardot~Honda reaches, where no environmentally sensitive factors are involved. Therefore, the environmental issue will not become the key element in the selection of the options.

Investment and economical efficiency: according to the cost estimate results, the average investments per kilowatt of Options I, II and III are 3,986 USD/kW, 3,607 USD/kW and 4,384 USD/kW respectively; the investments per KWH are 0.719 USD/kW·h, 0.656 USD/kW·h and 0.791 USD/kW·h respectively. Through the analysis on the economic indexes of each option, Option II is the best, followed by Option I. Option III is relatively poor.

6.6.2 Determination of Cascade Development Options

Through comprehensive comparison from technical, economical, social, environmental and other aspects, and integrated evaluation of hydropower development, ecological environmental protection, reservoir inundation, engineering construction conditions, investment and economical efficiency, Option I is tentatively recommended as the cascade development option for main stream of Magdalena River at this stage as this option has smallest inundation influence and implementation difficulty. Therefore, the main stream will be developed by the 17 cascades of Guarapo(140 MW)+ Chillurco (180 MW)+Oporapa(220 MW)+Perícongo(80 MW)+ElQuimbo(420 MW)+Betania(540 MW)+ElManso(140 MW)+Veraguas(130 MW)+Bateas(140 MW)+Basilias (140 MW)+Carrasposo(170 MW)+ Nariño(200 MW)+Lam (low inundation option) (160 MW)+Ambalema(160 MW)+ Cambao(100 MW) +Honda214(280 MW)+PiedrasNegras (100 MW), with a total installed capacity of 3,300 MW. Among them, two cascades are completed or under construction respectively, and the other 15 cascades to be built have an installed capacity of 2,340

MW, of which the investment per kW is 3,986 USD, the investment per KWH is 0.719 USD/kW·h.

Taking into consideration of the multi-purpose utilization of Honda Cascade in its high inundation option (including flood control, navigation, power generation and irrigation), this cascade is of great significance to the economic and social development in Colombia. Therefore, the development rationale and feasibility shall be studied based on the further investigation into the reservoir inundation impact and the demonstration on its comprehensive utilization benefits in the future so as to finalize the development option of Girardot~Honda reaches.

6.7 Implementation Opinions

Based on the comprehensive consideration of power market demand, development and construction conditions, ecological environmental protection, resettlement conditions, regional social and economic development and power transmission works etc, for the projects to be commenced in short term, priority should be given to four cascades having the best economic indicators among the recommended development options, which are Cascade 1 of Guarapo, Cascade 3 of Oporapa, Cascade 7 of El Manso and Cascade 12of Nariño. As the left bank of El Manso may involve large areas of farmlands, further investigation is needed.

According to conclusions of environmental impact assessment for each cascade, Perícongo, Bateas, Basilias and Basilias have bigger environmental influencing factors. Therefore, further study shall be made in the future to coordinate the relation between development and protection.

Regional fracture may exist in Chillurco Cascade, and the fracture activity is to be further proved; technical and economical index of the six cascades of Veraguas, Carrasposo, Lame (low), Ambalema, Cambao and Honda is relatively poor. These seven cascades can be developed in due time based on the requirements of economic and social development, construction conditions of the station and the technical and economical indexes.

7 Environmental Protection Planning

With relatively developed economy and high urbanization rate, the Magdalena River Basin is the area dominated by a majority of national population and industrial and agricultural production. Meanwhile, it is also faced with some prominent environmental problems. The water body in the basin is seriously affected by organic pollution with the average level of COD as high as 30mg/L; such aquatic habitats as lakes, marshes and wetlands in the basin gradually shrink; the connectivity between the river and the lake, marsh and wetland becomes poor; and the fish's living environment is threatened because the breeding and inhabitation space narrows and the migrating channel becomes blocked. The increased soil erosion area of the basin, the high content of sediment and the serious deposition of river course have had impacted some important habitats. In order to maintain river health, correctly handle the relation among management, exploitation and protection, promote the sustainable development of the economy and society, and solve the issues concerning water quality, aquatic ecosystem, soil erosion, etc., the protection of the quality of surface water should be strengthened; restoration of aquatic ecological environment should be consolidated; control of soil erosion and afforestation should be promoted; and environmental monitoring system should be established so as to form a relatively sound and complete environmental protection system.

7.1 Surface Water Environment Protection Planning

7.1.1 Current Situation of Water Quality and Existing Problems

a) Current Situation of Pollution Source

Main pollution sources include industrial, agricultural and domestic pollution sources along both banks of the river.

1) Industrial Pollution Source

At present, 80% of the industrial production area is located in the Basin. The discharge of COD by industrial enterprises in the whole basin is about 216t/d. The industrial wastewater discharged in the basin mainly comes from Cali, Bogota and Medellin located at the middle and lower reaches of the river. The industrial wastewater from those three areas causes serious impact on the water quality of the middle and lower reaches of the river.

The industrial pollution source within the plan scope mainly comes from processing of meat and dairy products, petroleum processing and exploitation, and gold mining. There are few other industrial pollution sources. The gold mining has accelerated the land destruction and soil erosion. According to field investigation, the quality of water along the banks of the river in Barrancabameija is extremely poor and the sludge is black with stinks due to serious influence from the discharge of wastewater by petroleum processing enterprises. As can be seen from PLAN DE DESCONTAMINACION AMBIENTAL DE BARRANCABERMEJA, FASE I, AÑO 2004 provided by Cormagdalena, 10 wastewater treatment plants have been planned in Barrancabameija city, but most of them are not in normal operation. With the development of industry, the pollution of water body in the basin by industrial wastewater will also become more and more serious.

2) Agricultural Pollution Source

Traditional agriculture and animal husbandry are the main forms of agricultural economy in the basin and the output from the two accounts for 70% of the total agricultural output of the country. The fertilizer (mainly nitrogen and phosphate fertilizers) used by farmers during land cultivation, pesticides, wastewater from breeding industry and excrement of animals enter into the river along with rainwater due to rain wash, and cause certain impact on the quality of water as they contain such main pollutants as N, P and coliform. According to PMC data, the discharge of N in the basin is 211,243t/d and the discharge of P is about 80,130t/d.

The middle and upper reaches of the basin is dominated by agricultural planting, especially coffee planting. The planting of crops and reclamation of land by destroying forests have resulted in destruction of most forests in Andes Mountains. Additionally, with the use of pesticides and fertilizers, surface water body is polluted to a certain degree and certain impact is exerted on the biological diversity, soil, water and other resources. The agricultural planting and animal husbandry in the middle and upper reaches as well as the delta area at estuary are relatively developed. The grazing density in the middle reaches is 1.5 cattle per hectare, higher than the average level

(0.5 cattle per hectare) of Colombia. The untreated pollutants produced from animal husbandry are directly discharged along with surface runoff into the water body, and the discharge amount accounts for 49.16% of the total from agricultural production in the whole basin.

With the increase of population, the demand for agricultural and animal husbandry products increases, and meanwhile the pollution of water body due to agricultural production also increases.

3) Domestic Pollution Source

The domestic pollution sources mainly refer to domestic wastewater and garbage from urban residents. According to VISION Cormagdalena 2019-AGOSTO, the domestic organic pollution load BOD_5 produced in Magdalena River Basin (The Cauca River excluded) is about 1,340t/d (2.68 billion EH/d), among which the domestic organic pollution load BOD_5 from urban sources is about 1035 t/d (2.07 billion EH/d), accounting for 77.3% of the total pollution load. The actual BOD_5 treatment capacity of existing wastewater treatment plants (86 of the wastewater treatment plants (PTARS) are subsidized by Cormagdalena) in the basin is 63.5 t/d (130 million EH/d), which accounts for only 6.14% of domestic organic pollution load. Since the treatment capacity is small, the efficiency is low, and wastewater discharge is not strictly carried out according to PSMV (planes de saneamiento y manejo de vertimientos), the urban wastewater treatment rate of the whole planned area is lower than 10%.

According to the data on disposal of domestic garbage of major cities of Colombia during 2011~2012, among those cities with a population of more than 1 million, the disposal capacities of Barranquilla and Medellin in 2012 were 1300.74t/d and 1414.94t/d, respectively. Among those cities with a population of 50,000~1,000,000, the disposal capacities of Neiva, Armenia and Popayan in 2012 were 262.05t/d, 119.00 t/d and 209.91 t/d, respectively. The daily garbage disposal capacity of those cities with a population of less than 50,000 was not high. On the whole, the urban domestic garbage disposal rate of the country is lower than 30%, and that of the planned area is about 23%. The percentage of coverage for garbage collection of most cities is quite low with garbage piled in disorder and under improper management. At present, the main approaches adopted for disposal of domestic garbage in Colombia is storage in open air and sanitary landfill.

b) Current Situation of Water Quality

According to the water quality monitoring data collected on rainy season in 2000, in the period from 2006~2007 and in 2011 as well as the PMC analysis data, although the quality of water has improved slightly, it is still relatively poor in general. The water quality of the upper reaches in the basin is relatively good with COD being 0mg/L~20mg/L; the water quality of upper middle reaches is slightly poor with COD being 21mg/L ~41mg/L; the water quality of lower middle reaches is the poorest with COD reaching 42mg/L~62mg/L; and the water quality of lower reaches has improved slightly with COD being 21mg/L ~41mg/L.The three tributaries which are the most seriously polluted include the Cauca River, the Bogota River and the Nechí River. The main pollutants include COD, BOD_5, nitrogen and phosphorus nutrients, heavy metal mercury, cyanide and coliform.

According to the monitoring data in rainy season of April ~ May in 2011, the water of the Magdalena River is alkalescent and the PH values are in the range of 7~8. The organic pollution of the Bogota River is very serious, followed by the rivers of Saldana, Sogamoso, Negro, Carare, Sitio Nuevo R11, Regidor and Opon. The heavy metal pollution of Negro and Bogota rivers is relatively serious, and the Carare, Clmitarra, Tacamocho rivers and Sitio Nuevo Section R11 are also suffering heavy metal pollution.

The average level of COD of water body in the basin is as high as 30mg/L. The BOD_5 load from domestic pollution source accounts for 78%, and BOD_5 loads from food and beverage industry, coffee processing industry, and animal husbandry account for 10%, 10%, and 2.2%, respectively. Thus, it can be seen that the main pollution sources of the basin are domestic pollution source followed by industrial, agricultural, and animal husbandry pollution sources.

c) Major Existing Problems

1) Although the population of the basin accounts for 80% of the national population, there are a few facilities for treatment of domestic wastewater and disposal of garbage. The wastewater treatment rate is less than 10% and centralized disposal rate of

domestic garbage is only 23%. The discharge of domestic wastewater and stacking of garbage have relatively large impact on the quality of water.

2) Since 80% of the industries of the country gather in the basin, the size of industrial wastewater treatment plants is small and their operation is abnormal, most of the wastewater from processing of food and beverage and coffee, from oil exploitation and processing and from mineral exploration and processing are directly discharged into the river without being treated, which causes certain impact on the quality of water.

3) The total output of agriculture and animal husbandry in the basin accounts for 70% of that of the country. The fertilizer used in agricultural production and especially the wastewater and excrement produced in breeding industry are discharged into the river course together with surface runoff. That causes relatively serious organic pollution of the water body.

7.1.2 ObjectiveObjectives and Layout

a) Objectives

There are 128 cities and towns distributed in the planned area and the urban population of 2020 will account for 79.75 % of the total population of the planned area. The main pollution sources are domestic wastewater and garbage. The plan objective mainly focuses on treatment of domestic wastewater and garbage.

Short-term objective: Firstly, control domestic pollution source. List the 20 cities, of which the population in target year is larger than 30,000 and the current pollution load density is more than 81 EH/km^2 or the control objective for pollution load density is obviously less than the current value, as planned city in short term according to the population of the planned area in target year, economic and social conditions, distribution diagram of current domestic pollution load density and diagram for control objective of pollution density. The urban population of those cities account for 65.44% of that of the 128 cities and towns in the planned area. The pollution load density of domestic pollution sources should decrease to 24EH/km^2~43EH/km^2, the urban wastewater treatment rate reach 80% and garbage disposal rate reach 70%. Secondly, control industrial pollution source, renovate production process, implement management works for project and gradually realize up-to-standard discharge of production wastewater. Thirdly, control non-point source pollution, upgrade the industrial structure, adjust agricultural cultivation mode, improve livestock stocking, implement projects for centralized treatment of wastewater and excrements from livestock breeding, and control the usage of pesticides and fertilizer to gradually reduce the discharge of the pollutants from non-point source.

Long-term objective: Carry out treatment of domestic wastewater and garbage of other 108 cities and towns gradually so as to make the urban domestic wastewater treatment rate reach 85% and garbage disposal rate reach 80% in the planned area. The non-point source pollution would be effectively controlled, and basically, pollutants from industrial pollution source would be discharged after treatment as per the required standard.

b) Plan Layout

Through the investigation and analysis of current water quality and pollution source of the basin and with requirement for the water quality of the river as objective, put forward the scheme for control of total discharge of wastewater into the river, accelerate the management of domestic pollution source in and around the cities and towns, construct urban domestic wastewater treatment plants and garbage disposal projects, implement industrial wastewater treatment projects, strengthen control of regional non-point source pollution and implement comprehensive improvement projects in agriculture and animal husbandry. With the control of ecological flow of the river as objective, rationally control the exploitation and utilization of water resources, strengthen the scheduling, operation and management of hydropower projects so as to ensure that the ecological flow and water quality of the control section satisfy the requirements of ecological environment. Take various measures to protect the quality of water environment of the basin.

To tackle the main existing problems in the planned area, formulate a plan for control of pollution source and proposal the scheme for control of wastewater discharged into the river and the plan for the protection of water source area. Considering that the domestic pollution load accounts for 78% of the total load, the plan focuses on the treatment of domestic wastewater and disposal of garbage in 128 cities and towns so as to effectively prevent the water pollution.

c) Water Function Zoning

No water function zoning has been put forward for the basin. To realize the objective of controlling the water quality of the planned area of the Magdalena River, the main stream and tributaries of the basin as well as surrounding large lakes and reservoirs should be divided into different specific function zones according to the plan of economic and social development and the exploitation and utilization of water resources, water quality and social needs of the area. On the one hand, the proposing of water function zone is to satisfy the requirements for the exploitation and utilization of water resources and on the other hand, the proposing of the objective of water quality in water function zone is to satisfy the requirements for protection of water resources.

The water function zoning is mainly to stipulate the pollutant discharge and water quality standards. Drawing on the experience and practice of China, two-level zoning can be adopted for water function zoning. The first-level zoning involves protected area, reserved area, exploitation and utilization area and buffer area with the main task of resolving contradiction in water consumption between regions. The second-level zoning is carried out in the exploitation and utilization area in first-level zoning, which involves seven types of zones, i.e., drinking water zone, industrial water zone, agricultural water zone, water zone for fishery, water zone for sightseeing and entertainment, transition zone and wastewater discharge control zone with the main task of resolving contradiction in water consumption between industries.

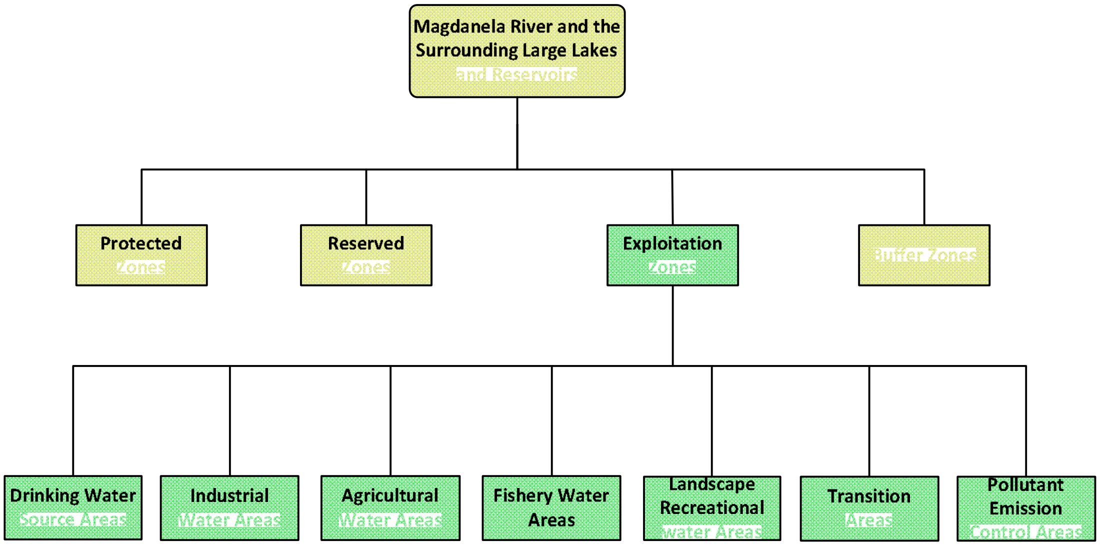


Fig. 7.1.2-1 Water Function Zoning The water function zoning of this time does not have enough relevant information and data, so the next step is to monitor the current water quality of Magdalena River Basin, understand the requirements for water function in terms of social needs and economic development status along the river, carry out investigation on the utilization of water resources and on this basis, conduct corresponding research on special topics. Relevant competent authorities should organize the water function zoning, and formulate a complete plan for protection of surface water environment based on the water function zoning. The complete plan involves 1) check calculation of pollution bearing capacity of the basin, forecast of the total discharge of pollutants into the river, and preparation of scheme for control of discharge of pollutants into the river; 2) layout of pollution discharge outlets to rivers, and scheme for management of pollution discharge outlets to rivers; 3) water source conservation and protection of drinking water source; 4) control of point source, non-point source and internal source (mainly referring to river bottom sediment); 5) water quality monitoring and comprehensive improvement.

7.1.3 Pollution Source Control Planning

7.1.3.1 Plan for Treatment of Urban Domestic Wastewater

a) Plan Thoughts

Propose the plan of expansion and renovation for existing wastewater treatment plants so as to provide the required treatment capacity and satisfy the requirements for wastewater discharge. For cities with no wastewater treatment plant, the scale of new wastewater treatment plants should be determined and requirements for up-to-standard discharge should be put forward. During the expansion and renovation as well as construction of new wastewater treatment plants, auxiliary wastewater collection pipe network should be constructed at the same time.

b) Drainage System

Fully combined sewer system is adopted as the current drainage system for treatment of wastewater in Colombia. Considering the characteristics of distinct dry and wet seasons, interceptive combined sewer system is adopted in the plan, i. e. constructing main sewers and overflow wells in the drainage ditch along the banks of urban area. During the dry season, the urban wastewater is collected by main intercepting sewer and carried to the wastewater treatment plant for centralized treatment; while during wet season, initial rainwater of high concentration and mixed rainwater and wastewater of low concentration are collected. In case the amount of precipitation is excessively large, the part that exceeds the pipeline transport capacity enters into the original river course in the form of overflow to alleviate the load of wastewater treatment plant.

c) Water Quality Standard and Wastewater Discharge Standard

Different water quality standards are formulated for different functions of water area in DECREE 1594 June 26, 1984 of Colombia. Corresponding water quality standard is executed according to the utilization of water resources of each river reach in the basin.

In terms of the wastewater treatment and discharge standards, stipulations in DECREE 1594 June 26, 1984 are executed. See Table 7.1.3-1.

Table 7.1.3-1 Municipal Wastewater Discharge Standards of Colombia

Referencia	Usuario Existente	Usuario Nuevo
pH	5 a 9 unidades	5 a 9 unidades
Temperatura	<40ºC	<40ºC
Material flotante	Ausente	Ausente
Grasas y aceites	Remoción >80% en carga	Remoción >80% en carga
Sólidos sus-Pendidos dométicos o industriales	Remoción >50% en carga	Remoción >80% en carga
Demanda bioquímica de oxígeno:		
Para desechos domésticos	Remoción >30% en carga	Remoción >80% en carga
Para desechos industriales	Remoción >20% en carga	Remoción >80% en carga

d) Treatment Capacity

Analyze the water quota, adopt the interceptive combined sewer system for drainage, set the objective of overage percentage of sewer pipe network at 70%~75% and wastewater discharge coefficient at 0.8, and determine the treatment capacity for urban wastewater according to the *Population Statistics of Cities and Towns throughout Colombia from 1985~2005 and Population Forecast from 2005~2020 (Poblacion por municipio_1985-2020 copia)* provided by Cormagdalena.

The wastewater treatment rate is planned and designed by three levels. See Table 7.1.3-2 for details. The comprehensive domestic water quota is determined by four levels. See Table 7.1.3-3 for details.

Table 7.1.3-2 Planning Objective of Wastewater Treatment Rate

S/N	Wastewater Treatment Rate	Planning Scope	Number of Cities and Towns
1	85%	Administrative center (provincial-level, principal, and medium-level)	5
2	75%	Regional center; urban residential area with residents more than 30,000	32
3	70%	Urban residential area with residents less than 30,000	91

Table 7.1.3-3 Planned Comprehensive Water Quota

S/N	Comprehensive Water Quota L/(d.person)	Design Scope
1	700	Administrative center
2	500	Regional center
3	400	Urban residential area with residents more than 30,000
4	300	Urban residential area with residents less than 30,000

1) Short-term Scale

To realize the planned objective, this plan involves expansion and reconstruction of existing wastewater treatment plants of the five cities for which there is only a small gap between the existing treatment capacity of plants and the required capacity. For those with a large gap, new wastewater treatment plants are planned. For the other 15 cities with no wastewater treatment plant, the treatment capacity is determined according to the amount of domestic wastewater. In short term, there will be 4.35 million urban populations by 2020 in the 20 cities. It is predicted that the urban domestic wastewater discharge will be 2.1695 million m^3/d, so it's planned to have 6 expanded and reconstructed wastewater treatment plants and 20 new wastewater treatment plants. The existing domestic wastewater treatment capacity is 139,000 m^3/d, which would increase to 1.886 million m^3/d by 2020 after the building and expansion of the wastewater treatment plants. The urban domestic wastewater treatment rate could reach 82%. It is suggested that enhanced class II wastewater treatment process be adopted. See Table 7.1.3-4 for the data of the five existing wastewater treatment plants. See Table 7.1.3-5 for the treatment capacity of the new urban wastewater treatment plants constructed for the other 15 cities with no wastewater treatment plant.

Table 7.1.3-4 Reconstruction and Expansion Scale of Existing Wastewater Treatment Plants

S/N	City Name	Urban Population in 2020 (Person)	Wastewater Discharge (m^3/d)	Wastewater Collection (m^3/d)	Existing Treatment Capacity (m^3/d)	Total Construction Scale (m^3/d)	Remarks
1	Honda	22,846	9,139	6,854	3,888	7000	Reconstructed and expanded
2	Espinal	56,977	22,791	17,093	12,614	18000	Reconstructed and expanded
3	Puerto Berrío	45,388	18,155	13,616	11,664	15000	Reconstructed and expanded
4	Aguachica	83,713	33,485	25,114	15,552	25000	Reconstructed and expanded
5	Barranquilla	1,235,186	691,704	587,949	94,867	600,000	2 places renovated and expanded
	Total	1,444,110	775,274	650,626	138,585	665,000	

Table 7.1.3-5 Scale of New Wastewater Treatment Plants

S/N	City Name	Urban Population in 2020 (Person)	Water Quota (L/d per Day)	Wastewater Discharge (m^3/d)	Wastewater Collection Rate	Wastewater Collection (m^3/d)	New Treatment Capacity (m^3/d)	Remarks
1	Neiva	329,624	700	184,589	85%	156,901	160,000	1 wastewater treatment plants to be newly constructed
2	Garzón	47,196	400	15,103	75%	11,327	15,000	1 wastewater treatment plants to be newly constructed
3	Pitalito	81,952	500	32,781	75%	24,586	30,000	1 wastewater treatment plants to be newly constructed
4	Puerto Salgar	15,061	400	4,819	75%	3,615	4,000	1 wastewater treatment plants to be newly constructed
5	Girardot	104,117	700	58,306	85%	49,560	50,000	1 wastewater treatment plants to be newly constructed
6	La Dorada	71,129	500	28,452	75%	21,339	25,000	1 wastewater treatment plants to be newly constructed
7	Barrancabermeja	172,459	700	96,577	85%	82,090	85,000	1 wastewater treatment plants to be newly constructed
8	Cartagena	1,006,994	700	563,917	85%	479,329	500,000	6 wastewater treatment plants to be newly constructed
9	Arjona	62,454	400	19,985	75%	14,989	15,000	1 wastewater treatment plants to be newly constructed
10	Magangue	84,233	400	26,955	75%	20,216	25,000	1 wastewater treatment plants to be newly constructed
11	Mompos	25,814	400	8,260	75%	6,195	7,000	1 wastewater treatment plants to be newly constructed
12	Plato	46,821	400	14,983	75%	11,237	15,000	1 wastewater treatment plants to be newly constructed
13	El Banco	35,174	400	11,256	75%	8,442	10,000	1 wastewater treatment plants to be newly constructed
14	Soledad	700,514	500	280,205	75%	210,154	250,000	1 wastewater treatment plants to be newly constructed
15	Malambo	123,408	400	39,491	75%	29,618	30,000	1 wastewater treatment plants to be newly constructed
	Total	2,906,950		2,160,952		1,129,598	1,221,000	

2) Long-term Scale

In long term, planned urban population of the 108 cities by 2030 will be 1.04 million. It is predicted that the domestic wastewater discharge will be 278,900 m^3/d and it is planned to construct new wastewater treatment plants for the 91 cities and towns with no wastewater treatment plant and reconstruct and expand the existing wastewater treatment plants of the 17 cities and towns with wastewater treatment plant. The domestic wastewater treatment capacity of existing wastewater treatment plants of the 108 cities and towns is 47,000 m^3/d, which would increase to 244,000 m^3/d by 2030 after the construction, expansion and reconstruction of wastewater treatment plants. The urban domestic wastewater treatment rate could reach 87.49%. The domestic wastewater treatment rate of the 128 cities and towns in the whole planned area could reach 87% by 2030.

Table 7.1.3-6 Scale of New Wastewater Treatment Plants for Cities and Towns in Long-term Plan

S/N	Department	City	Urban Population in 2030 (Person)	Wastewater Discharge (m^3/d)	Collection Rate of Pipe Network	Wastewater Collection (m^3/d)	Existing Treatment Capacity (m^3/d)	Total Construction Scale (m^3/d)
1	CAUCA	San Sebastián	1,369	329	70%	230		300
2	HUILA	Villa Vieja	2,432	584	70%	409		500
3	HUILA	Tello	6,878	1,651	70%	1,156		1,200
4	HUILA	Aipe	24,506	5,881	70%	4,117		5,000
5	HUILA	Rivera	12,201	2,929	70%	2,050		2,000
6	HUILA	Campo Alegre	27,752	8,880	75%	6,660	4,234	10,000
7	HUILA	Hobo	5,631	1,351	70%	946		1,000
8	HUILA	Gigante	22,329	7,145	75%	5,359	5,184	6,000
9	HUILA	Altamira	3,793	910	70%	637		1,000
10	HUILA	Elías	1,633	391	70%	274		300
11	HUILA	Timaná	7,273	1,746	70%	1,222		1,500
12	HUILA	Palermo	20,178	6,457	75%	4,843	2,246	5,000
13	HUILA	Yaguará	9,172	2,201	70%	1,541		2,000
14	HUILA	Tesalia	5,553	1,333	70%	933		1,000
15	HUILA	Paicol	2,576	619	70%	433		500
16	HUILA	Agrado	5,643	1,354	70%	948		1,000

Table 7.1.3-6(continue)

S/N	Department	City	Urban Population in 2030 (Person)	Wastewater Discharge (m^3/d)	Collection Rate of Pipe Network	Wastewater Collection (m^3/d)	Existing Treatment Capacity (m^3/d)	Total Construction Scale (m^3/d)
17	HUILA	Pital	5,319	1,277	70%	894		1,000
18	HUILA	Tarqui	5,673	1,361	70%	953	864	1,500
19	HUILA	Oporapa	5,321	1,277	70%	894		1,000
20	HUILA	Saladoblanco	3,065	736	70%	515		1,000
21	HUILA	Isnos	6,886	1,653	70%	1,157		1,500
22	HUILA	San Agustín	12,910	4,131	75%	3,098	1,296	4,000
23	TOLIMA	Suárez	2,097	503	70%	352		500
24	TOLIMA	Armero-Guayabal	7,188	1,726	70%	1,208	2,592	1,500
25	TOLIMA	Ambalema	4,352	1,044	70%	731		1,000
26	TOLIMA	Venadillo	14,845	3,563	70%	2,494		3,000
27	TOLIMA	Piedras	1,817	727	75%	545		1,000
28	TOLIMA	Coello	2,001	480	70%	336		500
29	TOLIMA	Flandes	26,123	6,270	70%	4,389	1,166	5,000
30	TOLIMA	Guamo	14,162	4,532	75%	3,399		4,000
31	TOLIMA	Purificación	18,356	7,343	75%	5,507	1,296	6,000
32	TOLIMA	Prado	2,676	643	70%	450		500
33	TOLIMA	Coyaima	4,628	1,110	70%	777		1,000
34	TOLIMA	Natagaima	13,749	3,300	70%	2,310	1,797	3,000
35	CUNDINAMARCA	Guaduas	24,611	7,876	75%	5,907		6,000
36	CUNDINAMARCA	Chaguaní	742	179	70%	125		200
37	CUNDINAMARCA	San Juan de Río Seco	2,876	690	70%	483		500
38	CUNDINAMARCA	Beltrán	510	123	70%	86		100
39	CUNDINAMARCA	Guataquí	1,517	364	70%	255		300
40	CUNDINAMARCA	Nariño	1,598	383	70%	268		300
41	CUNDINAMARCA	Ricaurte	5,252	1,260	70%	882		1,000
42	CALDAS	Victoria	2,962	711	70%	498	1,728	2,000
43	BOYACÁ	Puerto Boyacá	224	71	70%	50	691	302
44	SANTANDER	Puerto Wilches	16,440	5,261	75%	3,946		2,500

Table 7.1.3-6(continue)

S/N	Department	City	Urban Population in 2030 (Person)	Wastewater Discharge (m^3/d)	Collection Rate of Pipe Network	Wastewater Collection (m^3/d)	Existing Treatment Capacity (m^3/d)	Total Construction Scale (m^3/d)
45	SANTANDER	Puerto Parra	4,440	1,066	70%	746		500
46	SANTANDER	Cimitarra	25,667	8,213	75%	6,160		3,500
47	SANTANDER	Bolívar	1,076	259	70%	181		250
48	ANTIOQUIA	Yondó	12,383	2,971	70%	2,080		2,000
49	ANTIOQUIA	Sonsón	12,592	4,029	75%	3,022		2,000
50	ANTIOQUIA	Puerto Nare	8,867	2,129	70%	1,490	2,765	3,000
51	ANTIOQUIA	Puerto Triunfo	8,162	1,959	70%	1,371	1,037	2,000
52	BOLIVAR	Turbaná	15,845	3,803	70%	2,662		3,000
53	BOLIVAR	María La Baja	22,273	7,128	75%	5,346		6,000
54	BOLIVAR	Mahates	11,801	2,833	70%	1,983		2,000
55	BOLIVAR	Soplaviento	8,430	2,023	70%	1,416		1,500
56	BOLIVAR	San Estanislao	12,957	3,110	70%	2,177		2,500
57	BOLIVAR	Calamar	15,686	3,764	70%	2,635		3,000
58	BOLIVAR	El Guamo	4,259	1,023	70%	716		1,000
59	BOLIVAR	Zambrano	11,533	2,767	70%	1,937		2,500
60	BOLIVAR	Córdoba	3,008	721	70%	505		1,000
61	BOLIVAR	San Cristóbal	5,489	1,317	70%	922		1,500
62	BOLIVAR	San Juan de Nepomuceno	26,983	8,635	75%	6,476		10,000
63	BOLIVAR	Achí	5,167	1,240	70%	868		1,000
64	BOLIVAR	Pinillos	3,091	741	70%	519		1,000
65	BOLIVAR	Altos del Rosario	9,789	2,349	70%	1,644		2,000
66	BOLIVAR	Barranco de Loba	7,802	1,873	70%	1,311		1,500
67	BOLIVAR	San Martín de Loba	10,094	2,423	70%	1,696		2,000
68	BOLIVAR	Hatillo de Loba	3,510	843	70%	590		1,000
69	BOLIVAR	Talaigua Nuevo	5,403	1,297	70%	908		1,000
70	BOLIVAR	Cicuco	7,276	1,746	70%	1,222		1,500
71	BOLIVAR	San Fernando	3,231	776	70%	543		1,000
72	BOLIVAR	Margarita	1,972	473	70%	331		500

Table 7.1.3-6(continue)

S/N	Department	City	Urban Population in 2030 (Person)	Wastewater Discharge (m^3/d)	Collection Rate of Pipe Network	Wastewater Collection (m^3/d)	Existing Treatment Capacity (m^3/d)	Total Construction Scale (m^3/d)
73	BOLIVAR	El Peñón	5,008	1,201	70%	841		1,000
74	BOLIVAR	Morales	7,161	1,719	70%	1,203		1,500
75	BOLIVAR	Regidor	5,345	1,283	70%	898		1,000
76	BOLIVAR	Río Viejo	10,651	2,556	70%	1,789		2,000
77	BOLIVAR	Arenal	6,970	1,673	70%	1,171		1,500
78	BOLIVAR	Simití	10,873	2,610	70%	1,827		2,000
79	BOLIVAR	San Pablo	38,966	12,469	75%	9,352		15,000
80	BOLIVAR	Cantagallo	5,304	1,273	70%	891		1,000
81	CESAR	Tamalameque	5,152	1,237	70%	866		1,000
82	CESAR	La Gloria	4,680	1,123	70%	786		1,000
83	CESAR	Gamarra	11,188	2,686	70%	1,880		2,000
84	SUCRE	Guaranda	7,885	1,893	70%	1,325		1,500
85	SUCRE	Majagual	11,273	3,608	75%	2,706		3,000
86	SUCRE	Sucre	7,057	1,694	70%	1,186		1,500
87	MAGDALENA	Sitio Nuevo	18,440	5,901	75%	4,426		5,000
88	MAGDALENA	Remolino	4,817	1,156	70%	809		1,000
89	MAGDALENA	Salamina	3,425	821	70%	575		1,000
90	MAGDALENA	El Piñón	5,933	1,424	70%	997		1,000
91	MAGDALENA	Cerro de San Antonio	3,882	931	70%	652		1,000
92	MAGDALENA	Pedraza	2,454	589	70%	412		500
93	MAGDALENA	Zapayán	3,689	886	70%	620		1,000
94	MAGDALENA	Tenerife	5,744	1,379	70%	965		1,500
95	MAGDALENA	Santa Barbara de Pinto	8,746	2,099	70%	1,469		2,000
96	MAGDALENA	Santa Ana	15,721	3,773	70%	2,641		3,000
97	MAGDALENA	San Zenón	1,620	389	70%	272		300
98	MAGDALENA	San Sebastián de Buena Vista	5,672	1,361	70%	953		1,500
99	MAGDALENA	Guamal	8,995	2,159	70%	1,511		2,000
100	ATLÁNTICO	Sabanagrande	41,644	13,327	75%	9,995	4,320	15,000

Table 7.1.3-6(continue)

S/N	Department	City	Urban Population in 2030 (Person)	Wastewater Discharge (m^3/d)	Collection Rate of Pipe Network	Wastewater Collection (m^3/d)	Existing Treatment Capacity (m^3/d)	Total Construction Scale (m^3/d)
101	ATLÁNTICO	Santo Tomás	26,074	6,257	70%	4,380	10,368	6,000
102	ATLÁNTICO	Palmar de Varela	26,754	6,421	70%	4,495		3,000
103	ATLÁNTICO	Ponedera	14,210	3,410	70%	2,387		3,000
104	ATLÁNTICO	Campo de la Cruz	10,701	2,569	70%	1,798	5,184	2,000
105	ATLÁNTICO	Suán	7,077	1,699	70%	1,189		2,000
106	ATLÁNTICO	Repelón	21,326	5,119	70%	3,583		4,000
107	ATLÁNTICO	Manatí	16,949	4,067	70%	2,847		3,000
108	ATLÁNTICO	Santa Lucía	9,401	2,256	70%	1,579	518	2,000
	Total		1,036,394	278,881		201,000	47,287	244,052

7.1.3.2 Rural Wastewater Treatment around Urban Area

The rural population around the urban area in 2010 accounts for 20.48% of the total population of planned area. The domestic wastewater is not discharged concentratedly and the discharge is small. The treatment and treatment facilities of rural domestic wastewater around the urban area should satisfy the four basic requirements, i. e. low costs, less maintenance, being ecological and good effects. On the basis of prioritizing cut down of pollution sources and resource utilization and according to the principle of adjusting measures to local conditions, step-by-step procedures and guiding by categories, carry out the comprehensive treatment by combining decentralized and centralized treatment modes, control of urban and surrounding rural pollution, and control and prevention of pollution caused by rural living and production. Saving and recycling of water is gradually promoted so as to reduce the amount of wastewater generated. Penned livestock and excrement centralized treatment projects is implemented. The domestic wastewater is treated with septic tank, after that, wastewater is used for irrigation and waste residue is used as fertilizer as far as possible so as to reduce the rural pollution source load.

7.1.3.3 Industrial Wastewater Treatment

Control the pollution source. Adjust the industrial structure and industrial layout; develop and promote new technologies and equipment for saving water and reducing pollution; advocate clean production; reduce water consumption and increase repeated utilization factor of water; and save industrial water. Reduce the use of poisonous and harmful materials and adopt rational technological process and equipment to reduce the generation of poisonous and harmful substances. Carry out comprehensive treatment of pollutants in oil exploitation and mineral exploration in combination of soil erosion prevention and non-point source pollution control projects so as to reduce heavy metal pollution.

The industrial wastewater should be discharged after the treatment meets the standards. The corresponding treatment process should be adopted for treatment of characteristic pollutants from the petroleum and oil refining enterprises of Barrancabameija city, gold ore exploration enterprises at confluence of the Cauca River and meat (diary) processing enterprises of the urban area. The pollutants should be discharged after standards are met.

Strengthen supervision and implement the environmental permitsystem so as to realize increased output with no increase of pollution or reduced pollution.

7.1.3.4 Disposal of Urban Domestic Garbage

The generation of garbage from households is mainly determined by the population and per capita daily generation. The treatment capacity should be determined comprehensively after considering the clearing rate of garbage.

In the plan, the per capita daily garbage generation of the planned area is assumed based on the 2010 data of the three Departments, i. e. Antioquia, Atlantic and Valle del Cauca in Colombia with relatively high per capita daily garbage generation (0.82kg/d, 0.86 kg/d and 0.91 kg/d, respectively) and the technical specification for treatment of domestic garbage of China. The per capita daily garbage generation and garbage clearing rate are determined respectively according to the administrative level, population and economic and social development level of cities and towns.

a) Short-term Scale

In short term, it is planned to dispose the garbage in and around the 20 cities. The planned urban population of 2020 is 4.35 million and the generation of domestic garbage is predicted to be 6397 t/d and the collection and disposal amount is predicted to be 5242t/d. The current domestic garbage disposal capacity is 1739t/d, which may reach 60.03 million/d in 2020 after new construction, expansion and reconstruction of treatment facilities. The harmless disposal rate of urban domestic garbage could reach 81.95%. See Table 7.1.3-7 for the construction scale for disposal of garbage in each city.

Table 7.1.3-7 Construction Scale for Disposal of Urban Domestic Garbage in Short Term

S/N	City Name	Urban Population in 2020 (Person)	Garbage Generation (t/d)	Garbage Collection Rate (%)	Garbage Collection (t/d)	Existing Disposal Capacity (t/d)	Disposal Capacity (t/d)
1	Neiva	329,624	514.2	85	437	262	500
2	Garzón	47,196	61.4	75	46		58
3	Pitalito	81,952	106.5	75	80		100
4	Honda	22,846	29.7	75	22		21
5	Espinal	56,977	74.1	75	56		56
6	Puerto Salgar	15,061	19.6	75	15	10	18
7	Girardot	104,117	162.4	85	138	96	150
8	La Dorada	71,129	92.5	75	69		73
9	Barrancabermeja	172,459	269.0	85	229	30	230
10	Puerto Berrío	45,388	59.0	75	44	20	53
11	Cartagena	1,006,994	1570.9	85	1335		1500
12	Arjona	62,454	81.2	75	61		74
13	Magangue	84,233	109.5	75	82	56	90
14	Mompos	25,814	33.6	75	25	20	30
15	Aguachica	83,713	108.8	75	82		100
16	Plato	46,821	60.9	75	46	43	60
17	El Banco	35,174	45.7	75	34	20	40
18	Barranquilla	1,235,186	1926.9	85	1638	1182	1800
19	Soledad	700,514	910.7	75	683		900
20	Malambo	123,408	160.4	75	120		150
	Total	4,351,060	6397		5242	1739	6003

b) Long-term Scale

In long term, it is planned to provide new dispose capacity for garbage of the other 108 cities. The population serviced by 2030 will be 1.036 million, the generation of garbage 1259.2 t/d, the disposal amount 904t/d and constructed capacity 958t/d. In the long-term plan, the harmless disposal rate of domestic garbage of the 108 cities and towns could reach 71.79% and the domestic garbage disposal rate of the 108 cities and towns in the whole planned area in 2030 could reach 80.9%. For cities requiring small garbage disposal capacity, it is suggested to carry out proper centralized disposal according to the haul distance in the next step. See Table 7.1.3-8 for the construction scale of garbage disposal projects in each city.

Table 7.1.3-8 Construction Scale for Disposal of Urban Domestic Garbage in Long Term

S/N	Department	City	Estimated Urban Population in 2030 (Person)	Garbage Generation (t/d)	Garbage Collection Rate (%)	Garbage Collection (t/d)	Construction Scale (t/d)
1	CAUCA	San Sebastián	1,369	1.6	70	1.1	2
2	HUILA	Villa Vieja	2,432	2.8	70	2.0	2
3	HUILA	Tello	6,878	8.0	70	5.6	6
4	HUILA	Aipe	24,506	28.7	70	20.1	21
5	HUILA	Rivera	12,201	14.3	70	10.0	10
6	HUILA	Campo Alegre	27,752	36.1	75	27.1	28
7	HUILA	Hobo	5,631	6.6	70	4.6	5
8	HUILA	Gigante	22,329	29.0	75	21.8	22
9	HUILA	Altamira	3,793	4.4	70	3.1	4
10	HUILA	Elías	1,633	1.9	70	1.3	2
11	HUILA	Timaná	7,273	8.5	70	6.0	6
12	HUILA	Palermo	20,178	26.2	75	19.7	20
13	HUILA	Yaguará	9,172	10.7	70	7.5	8
14	HUILA	Tesalia	5,553	6.5	70	4.5	5
15	HUILA	Paicol	2,576	3.0	70	2.1	3
16	HUILA	Agrado	5,643	6.6	70	4.6	5
17	HUILA	Pital	5,319	6.2	70	4.4	5
18	HUILA	Tarqui	5,673	6.6	70	4.6	5

Table 7.1.3-8 (continue)

S/N	Department	City	Estimated Urban Population in 2030 (Person)	Garbage Generation (t/d)	Garbage Collection Rate (%)	Garbage Collection (t/d)	Construction Scale (t/d)
19	HUILA	Oporapa	5,321	6.2	70	4.4	5
20	HUILA	Saladoblanco	3,065	3.6	70	2.5	3
21	HUILA	Isnos	6,886	8.1	70	5.6	6
22	HUILA	San Agustín	12,910	16.8	75	12.6	13
23	TOLIMA	Suárez	2,097	2.5	70	1.7	2
24	TOLIMA	Armero-Guayabal	7,188	8.4	70	5.9	6
25	TOLIMA	Ambalema	4,352	5.1	70	3.6	4
26	TOLIMA	Venadillo	14,845	17.4	70	12.2	13
27	TOLIMA	Piedras	1,817	2.4	75	1.8	2
28	TOLIMA	Coello	2,001	2.3	70	1.6	2
29	TOLIMA	Flandes	26,123	30.6	70	21.4	22
30	TOLIMA	Guamo	14,162	18.4	75	13.8	14
31	TOLIMA	Purificación	18356	23.9	75	17.9	18
32	TOLIMA	Prado	2,676	3.1	70	2.2	3
33	TOLIMA	Coyaima	4,628	5.4	70	3.8	4
34	CUNDINAMARCA	Natagaima	13,749	16.1	70	11.3	12
35	CUNDINAMARCA	Guaduas	24,611	32.0	75	24.0	24
36	CUNDINAMARCA	Chaguaní	742	0.9	70	0.6	1
37	CUNDINAMARCA	San Juan de Río Seco	2,876	3.4	70	2.4	3
38	CUNDINAMARCA	Beltrán	510	0.6	70	0.4	1
39	CUNDINAMARCA	Guataquí	1,517	1.8	70	1.2	2
40	CUNDINAMARCA	Nariño	1,598	1.9	70	1.3	2
41	CALDAS	Ricaurte	5,252	6.1	70	4.3	5
42	BOYACÁ	Victoria	2,962	3.5	70	2.4	3
43	SANTANDER	Puerto Boyacá	224	0.3	70	0.2	1
44	SANTANDER	Puerto Wilches	16,440	21.4	75	16.0	17
45	SANTANDER	Puerto Parra	4,440	5.2	70	3.6	4

Table 7.1.3-8 (continue)

S/N	Department	City	Estimated Urban Population in 2030 (Person)	Garbage Generation (t/d)	Garbage Collection Rate (%)	Garbage Collection (t/d)	Construction Scale (t/d)
46	SANTANDER	Cimitarra	25,667	33.4	75	25.0	26
47	ANTIOQUIA	Bolívar	1,076	1.3	70	0.9	1
48	ANTIOQUIA	Yondó	12,383	14.5	70	10.1	11
49	ANTIOQUIA	Sonsón	12,592	16.4	75	12.3	13
50	ANTIOQUIA	Puerto Nare	8,867	10.4	70	7.3	8
51	BOLIVAR	Puerto Triunfo	8,162	9.5	70	6.7	7
52	BOLIVAR	Turbaná	15,845	18.5	70	13.0	13
53	BOLIVAR	María La Baja	22,273	29.0	75	21.7	22
54	BOLIVAR	Mahates	11,801	13.8	70	9.7	10
55	BOLIVAR	Soplaviento	8,430	9.9	70	6.9	7
56	BOLIVAR	San Estanislao	12,957	15.2	70	10.6	11
57	BOLIVAR	Calamar	15,686	18.4	70	12.8	13
58	BOLIVAR	El Guamo	4,259	5.0	70	3.5	4
59	BOLIVAR	Zambrano	11,533	13.5	70	9.4	10
60	BOLIVAR	Córdoba	3,008	3.5	70	2.5	3
61	BOLIVAR	San Cristóbal	5,489	6.4	70	4.5	5
62	BOLIVAR	San Juan de Nepomuceno	26,983	35.1	75	26.3	27
63	BOLIVAR	Achí	5,167	6.0	70	4.2	5
64	BOLIVAR	Pinillos	3,091	3.6	70	2.5	3
65	BOLIVAR	Altos del Rosario	9,789	11.5	70	8.0	9
66	BOLIVAR	Barranco de Loba	7,802	9.1	70	6.4	7
67	BOLIVAR	San Martín de Loba	10,094	11.8	70	8.3	9
68	BOLIVAR	Hatillo de Loba	3,510	4.1	70	2.9	3
69	BOLIVAR	Talaigua Nuevo	5,403	6.3	70	4.4	5
70	BOLIVAR	Cicuco	7,276	8.5	70	6.0	6
71	BOLIVAR	San Fernando	3,231	3.8	70	2.6	3
72	BOLIVAR	Margarita	1,972	2.3	70	1.6	2

Table 7.1.3-8 (continue)

S/N	Department	City	Estimated Urban Population in 2030 (Person)	Garbage Generation (t/d)	Garbage Collection Rate (%)	Garbage Collection (t/d)	Construction Scale (t/d)
73	BOLIVAR	El Peñón	5,008	5.9	70	4.1	5
74	BOLIVAR	Morales	7,161	8.4	70	5.9	6
75	BOLIVAR	Regidor	5,345	6.3	70	4.4	5
76	BOLIVAR	Río Viejo	10,651	12.5	70	8.7	9
77	BOLIVAR	Arenal	6,970	8.2	70	5.7	6
78	BOLIVAR	Simití	10,873	12.7	70	8.9	9
79	BOLIVAR	San Pablo	38,966	50.7	75	38.0	40
80	BOLIVAR	Cantagallo	5,304	6.2	70	4.3	5
81	CESAR	Tamalameque	5,152	6.0	70	4.2	5
82	CESAR	La Gloria	4,680	5.5	70	3.8	4
83	CESAR	Gamarra	11,188	13.1	70	9.2	10
84	SUCRE	Guaranda	7,885	9.2	70	6.5	7
85	SUCRE	Majagual	11,273	14.7	75	11.0	11
86	SUCRE	Sucre	7,057	8.3	70	5.8	6
87	MAGDALENA	Sitio Nuevo	18,440	24.0	75	18.0	20
88	MAGDALENA	Remolino	4,817	5.6	70	3.9	4
89	MAGDALENA	Salamina	3,425	4.0	70	2.8	3
90	MAGDALENA	El Piñón	5,933	6.9	70	4.9	5
91	MAGDALENA	Cerro de San Antonio	3,882	4.5	70	3.2	4
92	MAGDALENA	Pedraza	2,454	2.9	70	2.0	3
93	MAGDALENA	Zapayán	3,689	4.3	70	3.0	4
94	MAGDALENA	Tenerife	5,744	6.7	70	4.7	5
95	MAGDALENA	Santa Barbara de Pinto	8,746	10.2	70	7.2	8
96	MAGDALENA	Santa Ana	15,721	18.4	70	12.9	13
97	MAGDALENA	San Zenón	1,620	1.9	70	1.3	2
98	MAGDALENA	San Sebastián de Buena Vista	5,672	6.6	70	4.6	5
99	MAGDALENA	Guamal	8,995	10.5	70	7.4	8

Table 7.1.3-8 (continue)

S/N	Department	City	Estimated Urban Population in 2030 (Person)	Garbage Generation (t/d)	Garbage Collection Rate (%)	Garbage Collection (t/d)	Construction Scale (t/d)
100	ATLÁNTICO	Sabanagrande	41,644	54.1	75	40.6	41
101	ATLÁNTICO	Santo Tomás	26,074	30.5	70	21.4	22
102	ATLÁNTICO	Palmar de Varela	26,754	31.3	70	21.9	22
103	ATLÁNTICO	Ponedera	14,210	16.6	70	11.6	12
104	ATLÁNTICO	Campo de la Cruz	10,701	12.5	70	8.8	9
105	ATLÁNTICO	Suán	7,077	8.3	70	5.8	6
106	ATLÁNTICO	Repelón	21,326	25.0	70	17.5	18
107	ATLÁNTICO	Manatí	16,949	19.8	70	13.9	14
108	ATLÁNTICO	Santa Lucía	9,401	11.0	70	7.7	8
	Total		1,036,394	1259.2		904.4	958

7.1.3.5 Agricultural Non-Point Source Pollution Control

With the objective of reducing discharge of such pollutants as fertilizer and pesticide in farmland and excrement of livestock into the river course and alleviating agricultural non-point pollution source load, and according to the distribution characteristics of agricultural pollution sources, this plan gives priority to Pitalito~Garzón and Neiva of the upper section of the upper reaches, Puerto Berrío~Barrancabermeja of the middle reaches and Santa Barbara de Pinto and Repelón in the lower reaches in terms of taking measures to control agricultural non-point source pollution.

It is hard to formulate specific pollution control measures due to lack of current information about the agricultural non-point source pollution in the planned area, for example, the amount of pesticide and fertilizer used in different regions, the amount of waste discharged due to breeding of livestock, crop yield, use of straws and agricultural plastic mulching film and cultivation mode of crops. Considering the pollution of internal and non-point sources in the planned area, the following suggestions are put forward.

a) Pollution Control Technology

1) Promoting Ecological Agriculture Mode and Technology

The ecological agriculture modes and technologies mainly include three-dimensional intercropping in orchard, three-dimensional intercropping in farmland, three-dimensional breeding in water area, three-dimensional cropping and breeding in rural courtyard and biogas eco-agriculture mode.

(1) Three-dimensional intercropping in orchard - ecological agriculture mode applicable to Pitalito~Garzón, the upper section of the upper reaches.

(2) Three-dimensional intercropping in farmland, three-dimensional cropping and breeding in rural courtyard and biogas eco-agriculture - ecological agriculture modes applicable to Puerto Berrío~Barrancabermeja of the middle reaches.

(3) Three-dimensional intercropping in farmland, three-dimensional breeding in water area, three-dimensional cropping and breeding in rural courtyard and biogas eco-agriculture - ecological agriculture modes applicable to Santa Barbara de Pinto and Repelón of the lower reaches, etc.

See Fig. 7.1.3-1 for the plan and layout of ecological agriculture technologies.

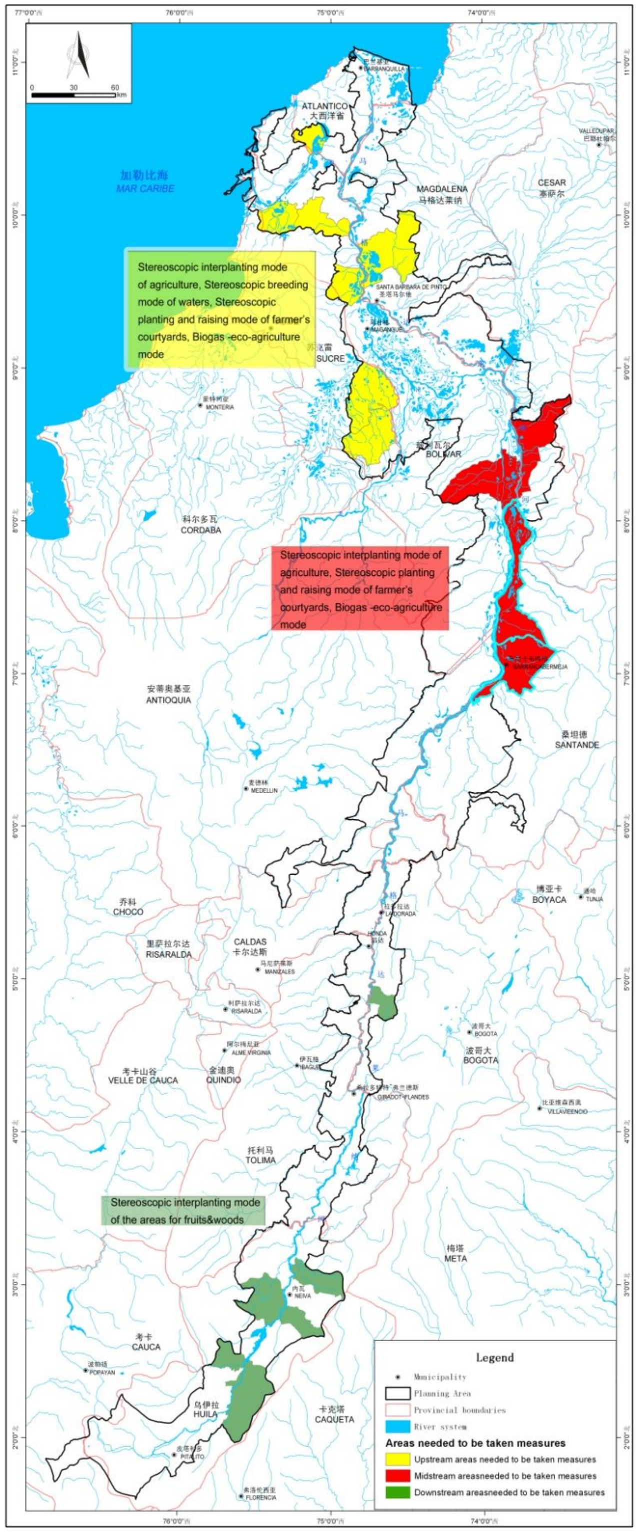


Fig. 7.1.3-1 Plan and Layout for Ecological Agricultural Technologies in Planned Area

2) Implementing Scientific Fertilization and Controlling Application of Pesticide

Promote mature fertilization technology, such as balanced fertilization, encourage application of organic fertilizer and improve the fertilization method and time; apply to the largest extent the organic fertilizer, such as excrements of livestock's in agricultural production and realize comprehensive utilization of excrements of livestock's by means of turning them into biogas; adopt the least harmful and non-poisonous pesticides and biological disinfection technology as far as possible; and before application of excrements and control of pollution, take various measures to reduce the total amount of pollutants so as to reduce the amount requiring to be disposed.

b) Adjusting Industrial Structure

Adjust the structure of agriculture and animal husbandry industries and put forward the control requirements of intercepting urban surface runoff during the initial stage of precipitation according to the non-point source pollution control objective and characteristics of industrial structure in this plan.

Replace the current decentralized livestock breeding mode with the mode of large-scale penned livestock. The excrement disposal or utilization of excrement as resource after centralized collection contributes to the realization of the above-mentioned recycling ecological agriculture mode.

Exploit the resource advantage of mountainous area in the planned area. Determine tropical, temperate and cold temperate zones in the planned area according to the various altitudes in the Andes Mountains area and forcefully implement diversified cultivation modes.

Strengthen construction of agricultural infrastructure; improve infrastructure for water conservancy; enhance the flood control and drought resistance ability; and take the path of agriculture with less cultivation, more harvest and high efficiency by improving the general conditions for agricultural production.

Reduce the dependence on land and promote in an all-round manner the production mode of intensive land utilization for penned livestock; reduce the occupation of pasture and promote returning of farmland and pasture for forest and grassland so as to increase vegetation coverage rate.

Support the development of economic forest and fruit industry in poverty-stricken areas that show relatively distinct development advantage. Through scientific analysis and reasoning, change the operation management mechanism to ensure the income of farmers. In addition, promote the overall development of husbandry, forestry and fishery based on stable development of planting industry.

c) Carry out comprehensive control of small basins, take comprehensive measures for prevention of soil erosion and control non-point source pollution in an all-round manner from such aspects as the control of source, blocking of transmission and catchment treatment.

7.1.4 Headwater Zone Protection Planning

According to investigation, no water source protection zone has been defined in the headwater area of the Magdalena River. Since this area has relatively high altitude, good vegetation, abundant precipitation, large catchment area, slight soil erosion and vulnerable ecological environment, it is suggested to define a certain area in the headwater area as the water source protection zone of the Magdalena River Basin, carry out plan of water source protection zone and put forward corresponding protection and control requirements including grading of and requirements for the protection zone. Main protection measures for the water source protection zone include management on closing the mountain for growth of forest, strict protection of the existing forests, cultivation of water conservation forest, forbidding of agricultural production and planting, isolation and protection inside the area, comprehensive control of pollution and ecological restoration.

7.1.5 Ecological Flow and Pollutants Control

a) Guarantee of Ecological Flow

The guarantee of ecological flow of the river is the key to the protection of ecological environment of the river. In this plan, requirements for control of flow are put forward for 13 sections. The ecological flow of each control section of Magdalena River is obtained with the two calculation methods provided by Cormagdalena and currently adopted by Colombia, i. e. based on 75% of the minimum year-to-year monthly mean flow of the control section (minimum mean monthly flow among the mean flow of 12 months) or based on mean daily flow corresponding to 97.5% of guarantee rate according to the curve for mean daily flow frequency for more than five consecutive years. See Table 4.4-1 for the control values. Ecological flow guarantee measures are taken for all construction projects and the implementation and supervision of such measures are strengthened. According to the requirements for control section, it is suggested in the plan that effective engineering and supervision measures be taken to guarantee the discharged ecological flow.

b) Control of Total Amount of Pollutants Discharged into River

Comprehensively determine the controlled amount of pollutants discharged into the river based on the water function zone and administrative level, according to the water quality, pollutants discharged into the river, pollution bearing capacity and requirements for social development in the plan reach and considering such factors as the uneven distribution of the pollution bearing capacity of rivers and lakes and requirements for water source protected area. With reference to the international and Chinese practices, and in consideration of the current existing water quality index data and relevant water quality protection Objectives of PMC, the indicators for control of pollutants are recommended to be COD, BOD_5 and NH_3-N.

The control scheme should be consistent with the Objectives of reducing discharge of pollutants in the area. Comments and suggestions for management and control of pollution source and adjustment of industrial structure should be given.

Since this plan lacks relevant technical data, it is suggested to carry out special research on the total controlled amount of pollutants discharged into the river in the next step according to the requirements for water quality of the plan reaches, economic and social development of the basin, industrial layout, urbanization progress and pollution control level.

7.1.6 Implementation Opinions

In short-term plan, 20 new wastewater treatment plants will be constructed for 20 cities and towns and six wastewater treatment plants will be reconstructed and expanded. The wastewater treatment capacity of 2020 could reach 1.886 million m^3/d. The urban wastewater treatment rate will be increased from less than 10% to above 80%

and will be 85% after implementation of the long-term plan.

In short-term plan, 20 comprehensive garbage disposal facilities will be constructed and the domestic garbage disposal capacity of 2020 could reach 60.03 million t/d, and the urban domestic garbage disposal rate will be increased from less than 30% to above 70% and will be 80% after implementation of the long-term plan.

With overall consideration of such factors as the location of 20 cities and towns, economic and social development conditions and attraction of the public and from the perspective of being favorable to the attainment of plan Objectives of water environment protection in the basin and the reduce of pollution load and cost of eliminating each type of pollutant, the construction of wastewater and garbage treatment projects will be prioritized for 12 cities and towns including Neiva, Honda, Puerto Salgar, Girardot, La Dorada, Barrancabermeja, Puerto Berrío, Magangue, Mompos, Plato, El Banco and Barranquilla. They are planned to be completed by 2019. See Table 7.1.6 and Fig.7.1.6.

Table 7.1.6 Key Projects Recommended in Short-Term Plan

S/N	City Name	Wastewater Treatment Capacity (m^3/d)	Garbage Disposal Capacity (t/d)
1	Neiva	160,000	500
2	Honda	7,000	21
3	Puerto Salgar	4,000	18
4	Girardot	50,000	150
5	La Dorada	25,000	73
6	Barrancabermeja	85,000	230
7	Puerto Berrío	15,000	53
8	Magangue	25,000	90
9	Mompos	7,000	30
10	Plato	15,000	60
11	El Banco	10,000	40
12	Barranquilla	600,000	1800
	Total	1,003,000	3065

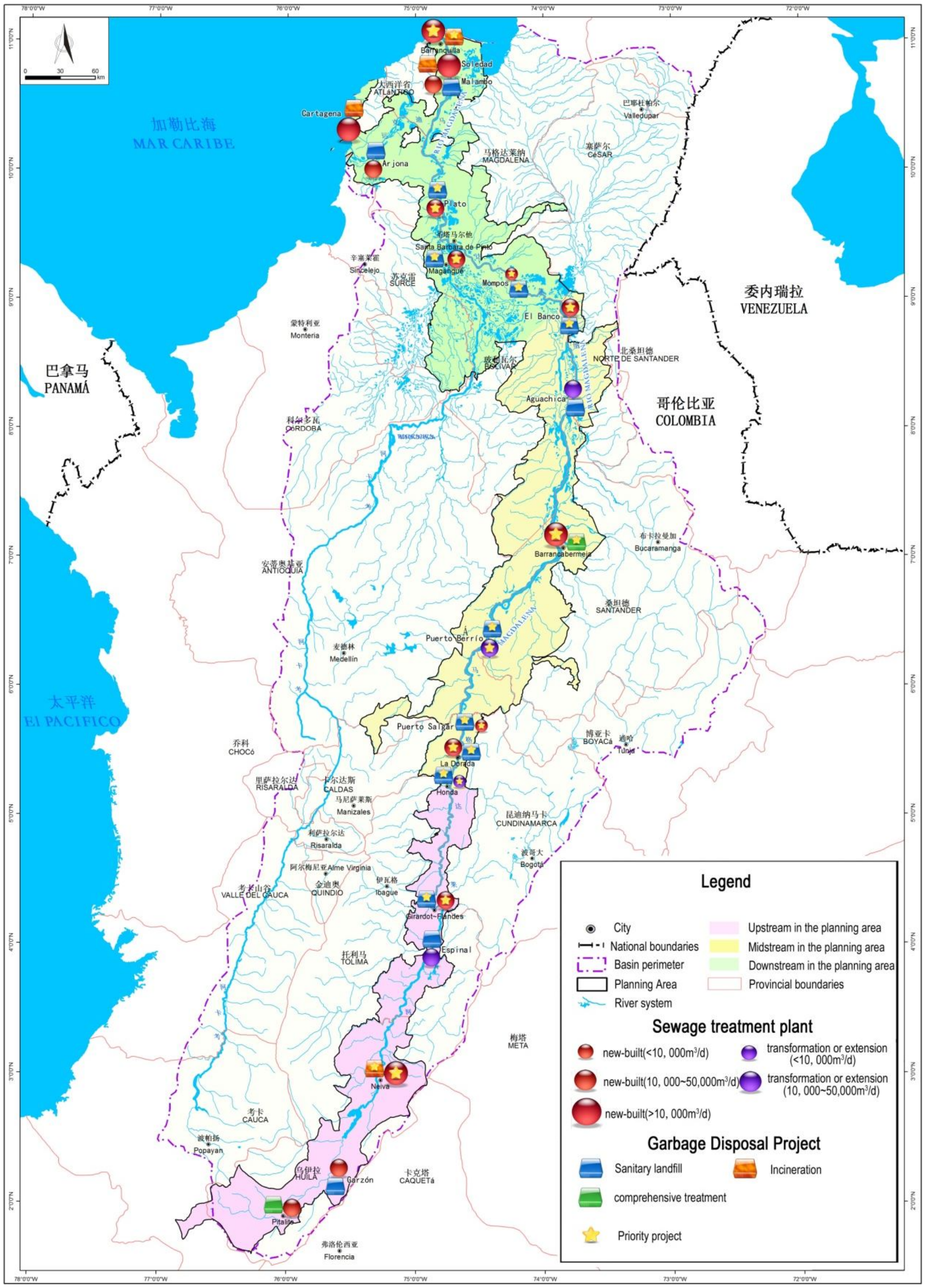


Fig. 7.1.6 Layout of Key Projects for Treatment and Control of Urban Domestic Pollution

7.2 Aquatic Ecological Protection Planning

7.2.1 Current Situation and Existing Problems

According to Portafolio_TNC, there are 112 species of waterfowls belonging to 10 orders and 23 families in the Magdalena River Basin, 202 species of fishes belonging to 11 orders and 39 families, 43 species of large benthonic animals, 81 families of large invertebrate animals, 321 species of phytoplankton, 49 species of zooplankton and 79 species of epiphytic organisms.

7.2.1.1 Fish Species

Magdalena River is abundant in fish resources and there are many reports on fish species. Red Data Book of Colombia Endangered Freshwater Fishes published by Mojica et al. (2002) has recorded 44 species of fishes including 23 in the Magdalena River. Among these fishes, two most important fishes are critically endangered (CR, i.e., Prochilodus magdalenae, Pseudoplatystoma fasciatum), four are endangered (EN, i.e., Ageneiosus caucanus, Rhizosomichthys totae, Ichthyoelephas longirostris and Sorubim cuspicaudus), eight are vulnerable (VU), nine are nearly endangered (NT). Besides, there are also 51 species of special fishes.

Table 7.2.1-1 List of Endangered Fishes of Magdalena River Basin

ORDEN	FAMILIA	ESPECIE	Nombres comunes	Categoría	Cuenca
CHARACIFORMES	Curimatidae	Curimata mivartii	Vizcaína, Cachaca, Sardina	VU	M
		Prochilodus magdalenae	Bocachico, Chico de Boca	CR	M, At
		Ichthyoelephas longirostris	Jetudo, Pataló, Besote	EN	M
	Characidae	Grundulus bogotensis	Guapucha	NT	M
		Carlastyanax aurocaudatus	Sardina	NT	M
		Salminus affinis	Picuda, Rayada, Rubia, Salmón	VU	M
		Hyphessobrycon poecilioides	Sardina	NT	M
		Genycharax tarpon	Boquiancho, Boquifarol	VU	M
		Microgenys minutus	Sardina	NT	M
	Anostomidae	Abramites eques	Totumito, Bonito	VU	M
	Hemiodidae	Parodon caliensis	Rollizo	NT	M
		Saccodon caucae	Rayado, Rollizo, Dormilón	NT	M

Table 7.2.1-1(continue)

ORDEN	FAMILIA	ESPECIE	Nombres comunes	Categoría	Cuenca
SILURIFORMES	Pimelodidae	Pseudoplatystoma fasciatum	Tigre, Rayado, Bagre Rayado, Pintadillo	CR	A, O, M
		Sorubim cuspicaudus	Bagre Blanco, Blanquillo, Paletón	EN	M
		Imparfinis macrocephala	Micudo, Chiribí	NT	M
	Callichthyidae	Callichthys fabricioi	Roño	VU	M
	Loricariidae	Cochliodon hondae	Cucha, Coroncoro	VU	Ct, M, At, P
	Ageneiosidae	Ageneiosus caucanus	Doncella, Niña, Gata, Fría, Señorita	EN	M, At
	Trichomycteridae	Trichomycterus caliense	Jabón, Guabino	NT	M
		Eremophilus mutisii	Capitán de la Sabana, Chimbe	NT	M
		Rhizosomichthys totae	Pez Graso, Runcho	EN	M
GYMNOTIFORMES	Gymnotidae	Ubidia magdalanensis	Caballo	VU	M
PERCIFORMES	Sciaenidae	Plagioscion magdalenae	Pácora, Burra, Corvina	VU	M

Cuencas Hidrográficas: A: Amazonas, O: Orinoco, M: Magdalena, Ct: Catatumbo, At: Atrato, P: Pacífico(Mojica, J. I., C. Castellanos, J. S. Usma y R. Álvarez (eds.). 2002)

There are 202 species of fishes belonging to 11 orders, 39 families and 102 genera in Magdalena River Basin. Among them, the Siluriformes order including 86 species ranks the first with a percentage of 42.6% among the total fish species. Then it is Characiformes order which includes 71 species with a percentage of 35.1%; Perclformes order which includes 17 species with a percentage of 8.4%; Gymnotlformes order which includes 11 species with a percentage of 5.4%; Cyprlnodontlforme order which includes 8 species with a percentage of 4.0%; Percesoclda order which includes 4 species with a percentage of 2.0% and Eloplformes, Isospondullda, Myllobatlformes, Salmonlformes and Synbranchiformes orders which include 1 species respectively. From the perspective of family, the Loricariidae family has the largest number of species, i. e. 27 species, followed by Cichlidae family with 14 species and Astroblepidae family with 13 species.

In August, 1999, 20 species of natural wild fishes (Especies de peces nativos capturados en el río Magdalena, Departamento del Huila marzo-agosto 1999) belonging to 8 families were caught at the upper reaches of the Magdalena River in Huila Department.

Table 7.2.1-2 Natural Wild Fishes Caught at Upper Reaches of Magdalena River in Huila Department in August 1999

Family	Species	Generic Name	Habitat	Length of Fish Caught (cm)
Ctenolucidae	*Ctenolucius hujeta*	aguja		
Curimatidae	*Curimata magdalenae*	madre bocachico		
Parodontidae	*Parodon suborbitale*	corunta	algas, detritus, invertebrados	
Erythrinidae	*Hoplias malabaricus*	dentón		
Characidae	*Prochilodus reticulatus* ✸	bocachico	algas, detritus	24.8±9.0
	Ichthyoelephas longirostris ✸	pataló	detritus, material vegetal	41.4±4.9
	Brycon moorei ✸	sardinata	detritus, material vegetal	
	Salminus affinis	dorada		
	Astianax fasciatum	sardina	algas, invertebrados	
	Argopleura conventus	sardinita		
	Charax magdalenae	juan viejo		
	Leporinus muyscorum	mohino		
Doradidae	*Centrochir crocodilii*	matacaimán		
Pimelodidae	*Pimelodus grosskopfii* ✸	capaz	detritus, insectos, mat. vegetal	19.8±3.1
	Pimelodus clarias ✸	nicuro	detritus, fragmentos animales	20.8±4.5
	Pseudopimelodus bufonius ✸	pejesapo		47.8±7.0
	Pimelodella chagresi	picalón		
Loricaridae	*Laciancistrus caucanus*	bebechiche	detritus	
	Loricaria gymnogaster ✸	zapatero	detritus, algas, invertebrados	27.0±8.0
	Panaque gibosus	coroncoro		

✸Peces de mayor interés comercial en el Huila commercial fish.

According to statistics of Lasso et al. in 2011, the main fish species and habitats in the Magdalena River are shown in Table 7.2.1-3.

Table 7.2.1-3 Main Fish Species and Type of Habitats in the Magdalena River

Taxa (Taxonomic Group)	Nombre común (Generic Name)	Hábito (Habitat)
Rajifomes		
Dasyatidae		
Dasyatis guttata(Bloch y Schneider1801)	Raya látigo, hocicona	M-E
Pristiformes		
Pristidae		
Pristis pristis(Linnaeus1758)	Pez sierra	M-E
Myliobatiformes		
Potamotrygonidae		
Potamotrygon magdalenae(Duméril1865)	Raya del Magdalena raya barranquilla	D
Elopiformes		
Megalopidae		
Megalops atlanticus Valenciennes1847	Sábalo, tarpón	M-E
Characiformes		
Anostomidae		
Leporinus muyscorum(Steindachner1900)	Dentón, dientón, quatrojo	D
Leporinus striatus Kner1858	Rayado, torpedo, tusa	D
Characidae		
Astyanax fasciatus(Cuvier1819)	Sardina colirroja, cola amarilla	D
Brycon henni Eigenmann1913	Sabaleta, sardina, toá	D
Brycon moorei Dahl1955	Dorada, mueluda, sardinata	D
Cynopotamus magdalenae(Steindachner1879)	Chango, mueluda	D
Salminus affinis Steindachner1880	Picuda, rayada, rubia	D
Triportheus magdalenae(Steindachner1878)	Arenca, arenga, sardina	D
Curimatidae		
Curimata mivartii(Steindachner1878)	Vizcaina, cachaca	D
Cyphocharax magdalenae(Steindachner1878)	Yalua, campaniz, campaniza	D
Erythrinidae		
Hoplias malabaricus(Bloch1794)	Mocholo, dormilon dentón,	D
Prochilodontidae		
Ichthyoelephas longirostris(Steindachner1879)	Besote jetudo	D
Prochilodus magdalenae Steindachner1879	Bocachico	D
Siluriformes		
Ariidae		

Table 7.2.1-3(continue)

Taxa (Taxonomic Group)	Nombre común (Generic Name)	Hábito (Habitat)
Notarius bonillai(Miles1945)	Bagre de río, chivo cabezón	D
Auchenipteridae		
Ageneiosus pardalis Lutken1874	Doncella, señorita, niña	D
Heptapteridae		
Rhamdia quelen(Quoy y Gaimard1824)	Liso, barbudo, barbilla	D
Loricariidae		
Chaetostoma fischeri Steindachner1879	Guacuco, corroncho cucha	D
Chaetostoma marginatum Regan1904	Guacuco, corroncho, cucha	D
Chaetostoma thomsoni Regan1904	Guacuco, corroncho, cucha	D
Chaetostoma milesi Fowler1941	Guacuco, coroncoro amarillo	D
Hypostomus hondae(Regan1912)	Coroncoro, cucho, cucha	D
Pterygoplichthys undecimalis(Steindachner1878)	Coroncoro negro, cucho, cucha	D
Pimelodidae		
Pimelodus“blochii” Magdalena Valenciennes1840	Nicuro, barbul, barbule	D
Pimelodus grosskopfii Steindachner1879	Capaz, barbudo	D
Pseudoplatystoma magdaleniatum Buitrago-Suárez y Burr2007	Bagre rayado, bagre pintado	D
Sorubim cuspicaudus Littmann, Burr y Nass2000	Blanquillo, bagre blanco	D
Pseudopimelodidae		
Batrochoglanis transmontanus(Regan1913)	Capitán, bagre sapo, photphot	D
Pseudopimelodus cf. bufonius(Valenciennes1840)	Bagre sapo, peje sapo, siete cueros	D
Pseudopimelodus schultzi(Dahl1955)	Bagre sapo, bagre pintado	D
Trichomycteridae		
Eremophilus mutisii Humboldt1805	Capitán, capitán de la sabana, chimbe	D
Trichomycterus spilosoma(Regan1913)	Salí, baloso	D
Trichomycterus taenia Kner1863	Salí, baloso	D
Gymnotiformes		
Sternopygidae		
Sternopygus aequilabiatus(Humboldt1805)	Viringo, veringo, mayupa	D
Perciformes order		
Cichlidae		
Caquetaia kraussii(Steindachner1878)	Mojarra amarilla, mojarra anzuelera	D
Caquetaia umbrifera(Meek y Hildebrand1913)	Mojarra negra, mojarra anzuelera	D
Sciaenidae family		
Plagioscion magdalenae(Steindachner1878)	Pácora, corvina	D
Subtotal 7 orders and 19 families	40	

Fuente: Lasso *et al*., 2011
Notes: M-E: marine estuary; D: freshwater.

7.2.1.2 Characteristics of Fish Distribution

According to the distribution of fishes in the basin, *Pimelodus grosskopfii, Pimelodus blochii, Hypostomus hondae, Ageneiosus pardalis and Hoplias malabaricus* are relatively widely distributed and the altitude of distribution water area could possibly exceed 1000m. *Potamotrygon magdalenae, Sorubim cuspicaudus, Pseudoplatystoma magdaleniatum, Caquetaia kraussii Brycon henni, Astyanax fasciatus and Leporinus striatus* are also relatively widely distributed, basically in the water area downstream of Neiva. *Megalops atlanticus, Notarius bonillai, Pseudopimelodus schultzi, P.cf hufonius, Pterygoplichys undecimalis, Prochilodus magdalenae, Cyphocharax magdalenae, Ichthyoelephas longirostris, Curimata mivartii, Triportheus magdalenae, Salminus affinis, Cynopotamus magdalenae, Brycon moorei and Leporinus muyscorum* are mainly distributed at the valley reaches near Honda and the water areas downstream of Honda. *Plagioscion magdalenae and Caquetaia umbrifera* are mainly distributed in the lakes and marshes with slow flow in the lower reaches. *Lutjanus griseus, Pomadasys crocro, Eugrres plumieri, Centropomus undecimalis, Mugil incilis, M. curema, Agonostomus monticola, Cathorops mapale, Pristis pectinate, Himantura schmardae, Dasyats guttata, Pristis pristis and Carcharhinus leucas* mainly live in the estuary and surrounding waters and do not swim upward exceeding the tidal reaches \. Chaetostoma niveum is only distributed at the Cesar River.

The fishes in the Magdalena River are mainly distributed in three different habitats, i. e. valley with rapid flow, wetland and plain reaches. Small fishes such as *babosos (Astroblepus spp) y capitanes y lauchas (Trichomycterus spp)* mainly live in valley area with rapid flow; such fishes as *viejito (Curimata magdalenae), la vizcaína (Curimata mivartii)* and *mojarras* live in wetland; and some other fishes are found in plain tracts, such as *v. gr., viejito, Curimata magdalenae; vizcaína Curimata mivartii; mojarra amarilla, Caquetaia kraussii. Mojarra azul* and *Aequidens pulcher (Cichlidae)* are special species of wetland. The species of fish in plain reaches is consistent with that of wetland including migrating fishes, such as *bocachico (Prochilodus magdalenae) and bagre pintado (Pseudoplatystoma fasciatum).*

7.2.1.3 Ecological Habit

As indicated by relevant research, the middle reaches from Honda to El Banco is the main reaches for spawning of fishes in flowing water and the migration passage, especially the reaches at the confluence with the Sogamoso River (a tributary of Magdalena) at Honda. Part of the fishes may swim upward to the reaches from Honda to Girardot for spawning. Since no specific data about the distribution of spawning grounds is available, preliminary judgment is made according to the river regime, river status and bottom characteristics of the river channel. Key spawning grounds are distributed at the tributary from Guarino to Berrio. After incubation, the fries are moved to the open river networks and marshes, wetlands and lakes at the lower reaches of the river for fattening.

The number of migrating fish species in the Magdalena River accounts for about 1/4 of the total. Seen from the water regime of the basin, the Magdalena River has two flood seasons every year, one around May and the other around November. The fish migration mainly occurs before the commencement of flood season. Generally, the fishes swim to deep river course through marshes, wetlands and lakes in dry season. Before the flood comes, they swim upward to the main river course for spawning. Young fishes swim downward with the current to the lower reaches of the river, lakes, marshes and wetlands for raising and fattening (Valderrama 1972, Kapestky et al. 1978, Valderrama & Zarate 1989). See Fig. 7.2.1-1 for the migrating route of fishes. According to the research of Jiménez-Segura (2010), at the first occurrence of flood after the new year, the group of fishes migrating for spawning is relatively large. During the second flood period, the group of spawning fishes is relatively small. Further research is yet to be conducted on whether the fishes spawn twice every year or whether two times of spawning are by different species group.

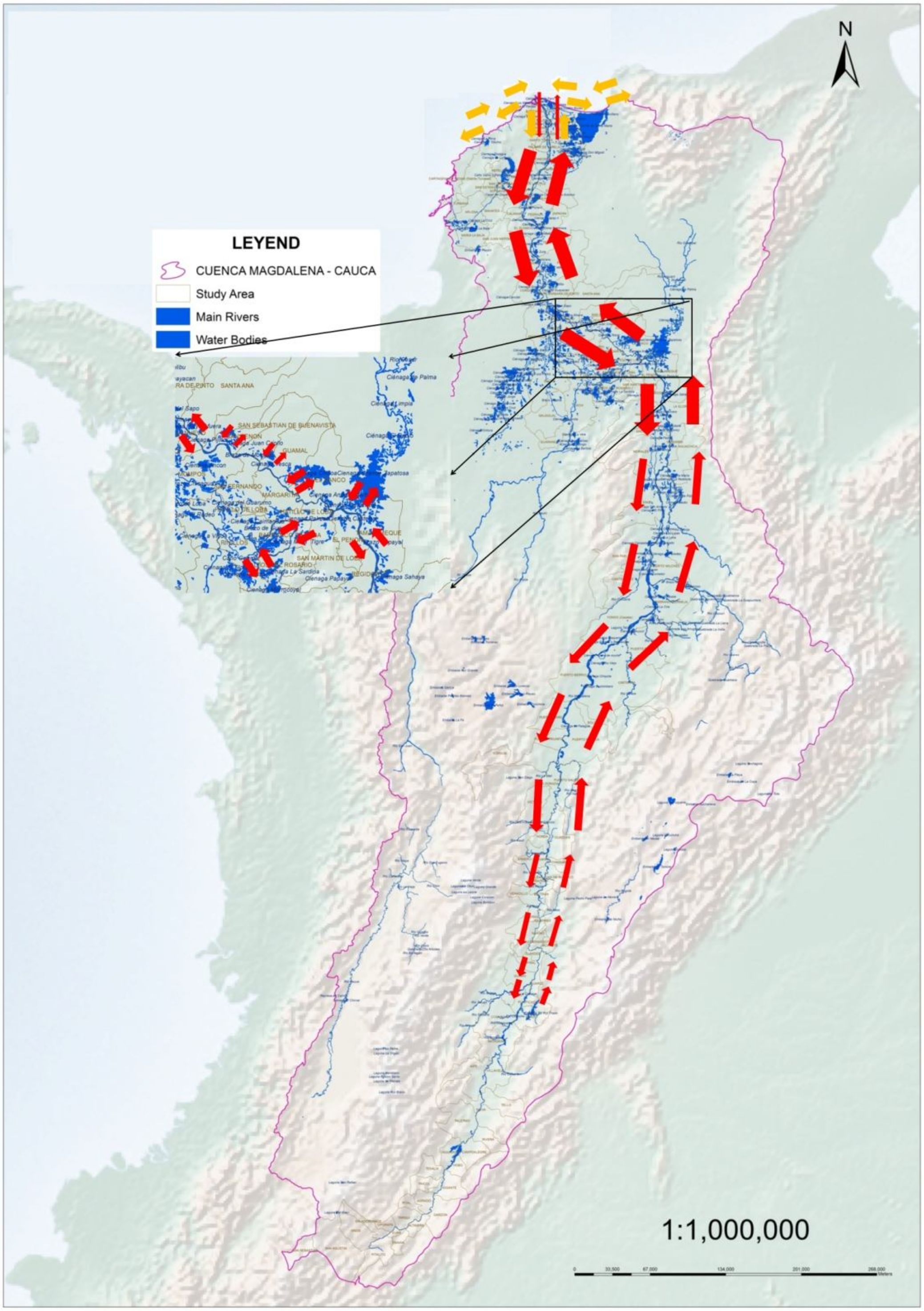


Fig. 7.2.1-1 Migrating Route of Fishes in Magdalena River

According to the migrating rules of fishes of the whole basin, the migrating characteristics of various fishes differ a lot. For the fishes living in coastal area and adapted to salty habitat, part of them enter into the confluence area of salty and fresh water at the estuary, but generally do not swim upward to the water area upstream of the tidal reaches. The fishes passing the estuary with weak swimming ability generally swim upward to El Banco in the main stream and to confluence of the Cauca River with the Zene River. Most of the fishes migrating to river and lake and part of the fishes migrating to the ocean can swim upward to the valley reaches with fast-flowing current near Honda. However, a few individual fishes can swim upward to the reaches near the Zene River. In addition, with the variation of water level during wet and dry seasons in rivers and lakes, the fishes also migrate in the local water area between rivers and lakes.

7.2.1.4 Major Existing Problems

With the development of human society and economy of the basin, threatening effect on the hydrological environment of the basin increases remarkably. Due to such reasons as the soil erosion, pollution of water quality, shrinkage of lakes, marshes and wetlands, overfishing, blocked connection among rivers, lakes and marshes, expansion of alien species and lack of effective supervision, the fishes are suffering narrowed reproducing and living space and more and more threat on their living environment, the fish resources are obviously in a downtrend.

7.2.2 Aquatic Ecological Protection Planning

7.2.2.1 Objectives

The Objectives is to protect the completeness of the habitat and biological structure of hydrological system of the basin and maintain the effective play of the functions of aquatic ecosystem. The upper reaches are the main area in the hydroelectric development plan, where the protection of aquatic ecology focuses on alleviating the impact of hydroelectric development on aquatic ecology through protection of aquatic environment of main and tributary streams, restoration of connection among rivers after blockage of dam, and breeding and releasing for protection and restoration of local fish resources. For the middle and lower reaches, the main Objectives is to maintain the connection among original river systems including rivers, lakes, marshes and wetlands and stable range of wetland, restore the damaged habitat in wetland by stages and batches, maintain and breed rare, special and economically important fishes, and rationally develop and continuously use the fishery resources.

Short-term Objectives: by 2020, to establish a sound mechanism for aquatic ecological protection, monitoring and management, strengthen protection of important biological species resources gradually restore the ecological connection between different water areas such as rivers and wetlands, protect the aquatic habitat of rare and special species, and ensure that the three important fish grounds, i. e. wintering ground, spawning ground and feeding ground, are not damaged by the exploitation and utilization of water resources so as to alleviate the situation that fish species are threatened.

Long-term Objectives: by 2030, to restore and breed the majority of rare and endangered species groups through aquatic ecological protection and restoration, and effectively implement the ecological restoration measures stated in different development plans so as to maintain the diversity and completeness of aquatic organisms of the basin.

7.2.2.2 Key Aquatic Ecological Protected Area and Objects

Through analysis from the protection of habitat, the four river systems, i. e. Cesar, Magdalena, Cauca and San Jorge in the basin form the inland delta river network, lakes, marshes and wetlands and possess relatively large biological productivity by collecting and transferring surface runoff, sediments and biogenic elements to Mompos lowland. Such areas are important water area for feeding, fattening, reproducing and inhabiting of fishes and thus are deemed as important water areas under protection.

Seen from the distribution of fish resources, migrating rules of fishes, important habitats where life history is completed and main water areas for fishing, the middle reaches are important reaches for the distribution of spawning grounds for fishes in flowing water. Thus, the protection of such reaches is extremely important for maintaining the fish resources of the basin. As the only passage for fishes passing the estuary to migrate and with complicated species of fishes, the confluence area of salty and fresh water in the estuary requires to be protected as key protection object.

Seen from the characteristics of habitat change, Canal del Dique requires to be protected and restored as key object since it is one of the sea exits of rivers, distributed with relatively large estuarine lakes, marshes and wetlands along the banks and with relatively big change of habitat in lakes, marshes and wetlands. The large mangrove wetland and the adjacent Ciénaga Grande wetland on the right bank of the sea exit in Barranquilla city have relatively obvious habitat change due to input of fresh water from river systems. Thus, they are deemed as wetlands under key protection of Ramsar Convention and should be defined as key protected areas in the plan. Since the upper reaches upstream of Honda are key water area for hydroelectric plan and the implementation of plan will have certain impact on the habitat in the area, a series of measures for aquatic ecological protection and restoration need to be taken to alleviate the impact of project construction and operation on aquatic ecosystem. Meanwhile, the accumulated and superimposed effects of the construction of plan hydropower station will affect the reaches downstream of Honda and cause relatively obvious habitat change, and moreover the reaches are important reaches for the breeding of fishes in flowing water and the migrating passage, thus requiring key protection. In addition, the Sogamoso hydropower station is being constructed about 70km upstream of the confluence with the Sogamoso River, a tributary of the middle reaches, which will affect the river network and wetlands downstream of the dam and even affect the important middle reaches for spawning of fishes. Therefore, alleviation measures need to be taken to maintain the structure and function of aquatic ecosystem.

The fishes listed in Red Data Book of National Endangered Fishes, economically important fishes and migrating fishes in rivers and oceans are considered as the key protection objects.

7.2.2.3 General Layout of Aquatic Ecological Protection Plan

a) Layout of Key Protected area

Short-term key protected areas are as follows. See Fig. 7.2.2-1 for details.

1) Wetlands under key protection of Ciénaga Grande Ramsar Convention;

2) Lakes, marshes and wetlands along the bank of Canal del Dique;

3) Lakes, marshes and wetlands at San Jorge estuary;
4) Lakes, marshes and wetlands at Cesar estuary;
5) Main river course downstream of Cauca and lakes, marshes and wetlands at the estuary;
6) Lakes, marshes and wetlands in the area from Sogamoso tributary confluence to E1 Banco main river course and river network;
7) Main river course from Honda to the confluence with the Sogamoso River where fish spawning grounds are located;
8) Hydroelectric plan reaches upstream of Honda;
9) Reaches, river networks and wetlands of the Sogamoso River downstream of Sogamoso hydropower station.

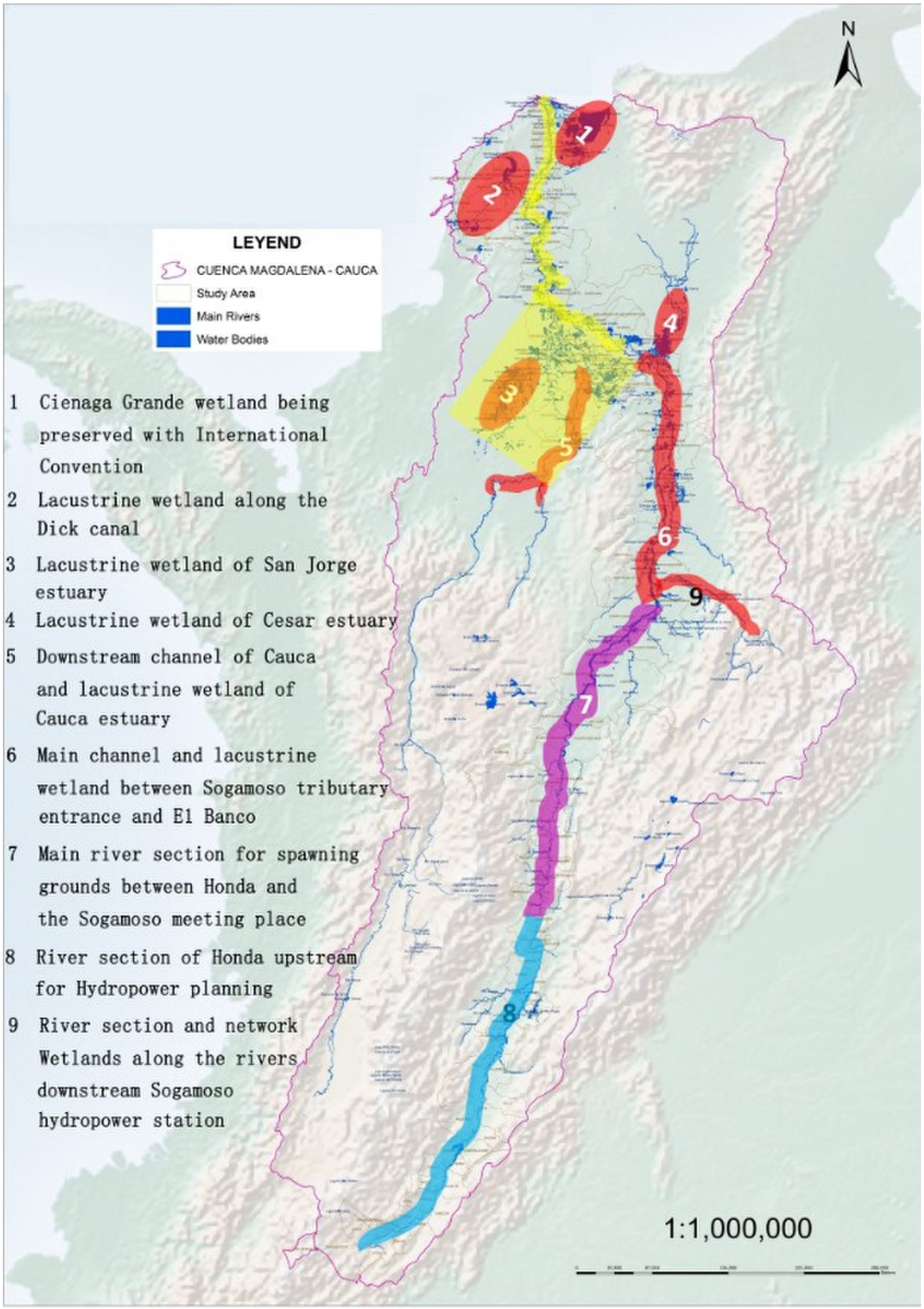


Fig. 7.2.2-1 Distribution of Short-Term Key Protected Area for Aquatic Ecosystem of Magdalena River

Among short-term key protected areas, area (1) is the wetland under protection of Ramsar Convention where research on the impact of river system connection and salinity change of wetland on mangrove forest will be carried out as key tasks and rational connection of river systems will be carried out to provide guarantees for the restoration of mangrove forest in wetland. Areas (2), (3), (4), (5) and (6) are lakes, marshes and wetlands, where the emphasis will be placed on the protection of the diversified habitats of rivers and lakes and the connection of river and lake systems, maintenance and stabilization of the area of rivers and lakes, restoration of the structure of aquatic biological population and quantity of resources, standardization of activities in fishery and promotion of sustainable utilization of fishery resources. Area (7) is an important reach for the distribution of fish spawning ground, where the emphasis will be placed on maintenance of the diversified habitat of the reach, conduct of relevant research on hydrological and hydraulic conditions for breeding of fishes and conditions of habitat of spawning ground and alleviation of impact of hydroelectric development on the breeding of fishes through ecological scheduling of hydropower stations on the upper reaches. Area (8) is an important reach for hydroelectric development, where the emphasis will be placed on the protection of running water habitat of main stream and tributaries, research on construction of fish pass downstream of Veragas hydropower station, implementation of breeding and releasing of fishes and promotion of protection and restoration of fish resources in the area. Area (9) is the tributary habitat affected by hydropower station. On the basis of systematic research on the impact of sluicing of Sogamoso Hydropower Station on downstream habitat, carry out plan of release of ecological flow and adopt such restoration technology and measures as ecological scheduling.

The long-term key protected areas include (10) main stream from Magangue to the estuary of Barranquilla River, wetland near the river network and estuarine delta wetland, and (12) river network, lakes, marshes and wetlands at Mompos inland delta.

b) Restoration of Connection among Lakes, Marshes and Wetlands

The emphasis of restoration of connection between rivers and lakes will be placed on the blocked lakes in areas (2) and (6). Such measures as reconstruction of gate, optimized scheduling, dredging of connection river course and construction of artificial natural bypasses are taken to restore the connection of river and lake systems.

c) Restoration of Connection of Rivers

Furnish fishway for Veragas Hydropower Station and hydropower stations downstream of it. Carry out research and demonstration on the objects of fish pass of each cascade hydropower station and the ecological habit so as to finalize the fish pass scheme and general layout.

d) Fish Breeding and Releasing Plan

Reconstruct the fish breeding and releasing stations and REPELÓN breeding farm of Cormagdalena and construct new fish breeding and releasing stations in Neiva, Girardot and Magangue.

7.2.2.4 Aquatic Ecological Protection Plan Scheme

Based on the habitat protection and restoration, the aquatic ecosystem protection plan is to maintain the diversity of aquatic habit, maintain the diversity of aquatic species through orderly utilization of aquatic organisms and breeding and releasing of important fish species, establish sound supervision organization and legal system and enhance the law enforcement level and ability so as to guarantee the protection of aquatic ecosystem and orderly implementation of the development and management and maintain the structure and function of aquatic ecosystem and river health of the basin.

a) Plan of Protection and Restoration of Aquatic Habitat

Formulate measures for protection and restoration of aquatic habitat by areas and stages with short-term and long-term key protection water areas as the main plan scope. Sort out the local protected area systematically based on the existing wetland under protection of Ramsar Convention, key wetland under national protection and nature reserves; Screen and determine key protected area according to the diversity of habitat and establish a sound habitat protection system for the basin.

1) Maintenance and Restoration of Wetland and Water Area

(1) Determine the aquatic habitat protection scope based on perennial flood level. The water areas, bottomlands and marshes below the perennial flood level all belong to national public resources. It is forbidden for enterprises or individuals to encroach the

wetland that is outcropped during dry season in flood plain below perennial flood level, and to reclaim land from lakes as farmland and for grazing.

(2) Marshes and wetlands, which are below the perennial flood level and have been developed for agriculture, forestry and animal husbandry, should be returned from farmland and pasture to lakes to restore the water area and wetland.

(3) Reduce sediment transport amount of the river based on control of soil erosion of the upper middle reaches of Magdalena River and Cauca River and comprehensive improvement of small basins so as to delay the silting up progress of lakes, rivers and marsh wetlands.

(4) Properly dredge the connection channel between rivers and lakes to avoid drying and shrinkage of lakes, marshes and wetlands due to silting up.

2) Protection and Restoration of Connection between River and Lake Systems

For the protection and restoration of the connection between river and lake systems, the emphasis should be placed on the reaches from BERRIO to EL BANCO (No. 7 water area under key protection in short term) and SOGAMOSO (No. 9 water area), MAGANGUE and MOMPOS reaches (water area under protection in long term) of Canal del Dique (No. 2 water area).The emphasis should especially be placed on the connection of river systems of lakes, marshes and wetlands along Canal del Dique, as Canal del Dique has been dredged for several times and the connection between the canal and the lakes and marshes along the canal is seriously damaged. Besides, after construction of hydropower stations on the reaches upstream of Honda (No. 8 water area under key protection in short term), obvious blocking impact will be caused on the habitat of main stream. Therefore, research on and implementation of technical measures for restoration of the connection is required.

(1) The current connection between river systems of lakes, marshes and wetlands should be maintained and such activities as constructing embankments and dams and blocking and narrowing connection channel of rivers and lakes should be strictly forbidden so as to maintain the connection between river network and river system.

(2) For water area with connection of river network and system damaged, proper dredging and expansion measures should to taken to connect the water channel; unnecessary barrage projects should be demolished; and abandoned embankments and

dams that obstruct the connection should be removed so as to restore the original connection of river network and system.

(3) For embankments and sluices that have blocked the rivers and lakes, construct fish pass mainly including artificial natural bypass so as to realize necessary connection of rivers and lakes.

(4) If a sluice cannot be provided with fish pass for the moment or it blocks the connection of river systems in some period or water areas, the sluice should be reconstructed to adapt to the behavior and habits of aquatic organisms and migrating rules of fishes; the sluice scheduling should be optimized; and such measures as opening the gate to let juvenile fishes into the lakes are taken during key migrating periods such as fish breeding and feeding so as to alleviate the blocking impact on fish migration between rivers and lakes.

(5) The No. 8 water area under key protection in short term is an important reach for hydroelectric development with the main research focused on fish pass for the project. It is suggested that fish pass mainly including fishway be constructed for hydropower stations downstream of Veragas Hydropower Station.

(6) Apart from blockage of river systems, the fishermen are accustomed to fishing in the connection river course between rivers and lakes all the year round. Although the use of large number of barring network and tools has not blocked the connection between river systems, it has seriously blocked the migrating of fishes between rivers and lakes. Therefore, such water area needs to be treated as forbidden area for fishing all the year round so as to restore the channel for migrating of fishes between rivers and lakes.

3) Maintenance of Habitat Diversity and Restoration of Microhabitat

(1) The general exploitation level of the basin is not high, especially the river network and wetland of lower middle reaches where the aquatic habitat diversity is relatively high. With extremely high habitat diversity, the water areas 3, 4, 5 and 6 are under key protection in short term which refer to the four estuarine water areas in the inland delta of Mompos lowland of Magdalena River, i. e. the Cesar, Magdalena, Cauca and San Jorge. In addition, the habitat maintenance of No. 7 water area is very important since it is a reach where important spawning grounds of fishes are distributed.

(2) For the construction of water-related projects such as flood control and management of channels, ports and river courses, systematic plan and prioritized design scheme should be provided based on the river regime, hydrological regime, characteristics of sediment erosion and deposition, and characteristics of aquatic habitat. Simple reinforced concrete hardening projects should be constructed as far as possible by use of ecological materials and methods. The structural measures that seriously destroy the aquatic habitat should be avoided such as straightening the bent pat of river course and cutting the bottomland to fill lakes so as to maintain the diversified layout of habitat with bending rivers, alternated shoals and ponds, and alternated slow and rapid rivers.

(3) The existing hardening projects such as embankment construction, slope protection and bank protection should be properly reconstructed for restoration with ecological materials and methods. Some river courses changed into channels should be gradually restored to almost natural river courses.

(4) The hydroelectric plan of hydropower station will change the river habitat. The microhabitat should be restored by taking reservoir scheduling and structural measures to protect the fish spawning ground for output of adhesive eggs.

4) Maintenance of Water Environment and Control of Water Pollution

(1) Based on wastewater treatment of large and medium cities and large industrial and mining companies, gradually implement standardized discharge and adjust the industrial structure. Water environment management should be implemented for some seriously polluted tributaries. In short term, emphasis is placed on controlling the discharge of point source pollutants so as to maintain the water quality of rivers.

(2) For some of the closed and half-closed lakes and marshes of the river network water area whose connection of river system is blocked and tend to eutrophicate, the rivers and lakes are reconnected, lakeside, marshes and wetlands as well as aquatic vegetation are restored, pollution and discharge of surrounding point and non-point source pollutants are controlled and polluting enterprises are forbidden to be constructed close to the river bank.

(3) For aquaculture in reservoir and lakes, the breeding scale is strictly controlled according to the bearing capacity of aquatic ecosystem; breeding on wide water

surface is promoted; and the breeding mode of bait casting is restricted to prevent pollution of water body by aquaculture.

b) Aquatic Organism Diversity and Resource Protection and Restoration Plan

1) Protection and Restoration of Important Habitats of Fishes

Magdalena River Basin has relatively abundant fish species and diversified ecotypes. The diversity of aquatic habitat is the basis for maintaining the diversity of fish species. Therefore, the protection and restoration of important habitats for fishes is based on the protection of aquatic habitat. Proper places for breeding, feeding and inhabiting as well as migrating channel should be provided through protection and restoration of the river connection and important water area under protection in short term.

2) Rational Utilization and Supervision of Fish Resources

(1) Identifying Protection Objects

Identify the key protection objects of the basin based on the rare and endangered level of fishes, the function in aquatic system and the commercial value. According to different protection levels of nation and local, improve the aquatic animal protection system, policies, and regulations, specify the protection requirements and implement graded management.

(2) Standardizing Fishing Behavior

Strictly implement the system for closed fishing period and area. The centralized fish spawning areas, brooding areas and important migrating channels (such as important connection channel between rivers and lakes) are determined as closed fishing areas. The closed fishing period and fishing area should be identified for different reaches of the basin according to the breeding and migrating habits of fishes.

The fishing tools and methods should be standardized. Such fishing tools and methods as dense fishing net and fishing by explosion should be banned. The fishing permit system should be implemented to effectively control the fishing intensity.

(3) Alleviating Pressure on Utilization of Fishery

Effective supportive policies should be adopted to guide some fishermen and land-lost farmers to transfer to other industry so as to effectively reduce the number of fishermen and alleviate the dependence of family life on fishing.

The industry chain of fished products should be expanded. The refrigeration, processing, transporting and marketing of fished products should be developed so as to increase the added value of products and improve the utilization efficiency of fishery products. The breeding in fishery should be developed to increase the breeding output.

3) Breeding and Releasing

(1) Object of Breeding and Releasing

According to the *Red Data Book of Endangered Freshwater Fishes of Colombia*, 23 species of fishes in the Magdalena River Basin belonging to species under key protection are listed. Therefore, the objects of breeding and releasing is the 23 rare and endangered species of fishes listed in the book, which should be adjusted and prioritized according to investigation on fish resources in the future.

(2) Releasing Quantity and Specification

According to the change of fishing output of Magdalena River Basin over the years, i. e. about 60,000 tons in 1970s, about 30,000 tons in 1980s and less than 20,000 tons at present, if the fishing output recovers to the level of 1990s in short term and to the level of 1970s in long term, then the short- and long-term fishing quantity will be increased by 10,000 and 40,000 tons. If calculation is based on an average weight of 3000g catch, the increased number of fishes caught is 33.33 million and 133.33 million respectively. A survival rate of 10% of fish fry artificially released is assumed in calculation. Considering that artificially releasing is only an auxiliary means for breeding of resources and natural breeding is the main means, the number artificially released is calculated based on 10% of the increased number. The number of fish fry annually released is about 35 million and 150 million in short term and long term, respectively.

There are two specifications for released fish species considering the actual situation of production and growth of different fish species. The first specification focuses on inch long fishes with a releasing quantity of 80%. For rare species, the releasing quantity is adjusted according to breeding quantity, i.e. the smaller the quantity, the smaller the proportion. The second specification focuses on fishes of that very year and the actual releasing specification is based on the specification by the end of the breeding year. The proportion of releasing quantity should not exceed 20%.

(3) Marked Releasing

Genetic management of domesticated wild population by breeding and releasing, parent fish bred artificially and artificially released population needs to be carried out. This involves establishing archive-based management mode, tracking change of genetic diversity, giving feedback and guidance, submitting annual report on genetic management and creating database. The fish species bred and released must be marked so as to facilitate evaluation of breeding and releasing effects when these species are re-caught. The marking method should be based on genetic marks, especially fishes released at small scale.

(4) Plan and Layout of Breeding and Releasing Station

Four breeding and releasing stations and one breeding farm are provided in the plan scope according to the distribution of fish resources and conditions for construction of stations in the plan scope. Fish breeding and releasing stations and REPELÓN breeding farm of Cormagdalena are reconstructed and new fish breeding and releasing stations in Neiva, Girardot and Magangue are constructed. For the fish breeding and releasing stations and REPELÓN breeding farm of Cormagdalena to be reconstructed and expanded, the domesticating and breeding breeds must be the breeding and releasing objects of the basin. The original function of improving fine breeds for aquatic breeding should be removed, especially breeding of alien species such as Tilapia mossambica. The releasing species of breeding and releasing station is designed to be 3~4 in short term and 5~6 in long term. The specific species to be bred and released are determined according to the distribution of fish resources. The scale of breeding and releasing station is designed to be such as to be able to release 15 million fish fries every year in the short term and 50 million fish fries in the long term.

4) Control of Invasion of Alien Species

Mechanism for monitoring and early warning of alien species, ecological safety and risk evaluation system and identification, quarantine and control system are established to strengthen management of alien species of aquatic animals and plants.

5) Strengthening of Construction and Management of Ecologically Sensitive Area

Supervision and management of existing fish spawning grounds, feeding grounds, migrating channels and important wetlands, and established ecologically sensitive area are strengthened. Sensitive areas of the reaches should be further divided in the implementation of the plan.

7.2.3 Implementation Opinions

With the main Objectives as protecting the integrity of aquatic habitat and population structure of the basin and maintaining the effective functioning of aquatic ecosystem, the aquatic ecological protection plan, which is based on restoration of aquatic habitats plus proper plan, puts forward the species resource protection measures focusing on facilitating natural breeding of endangered, special and economically important fish species and supplemented by artificial breeding and also covers supervision and scientific research support considerations.

In overall consideration of the current situation of aquatic ecological protection and main urgent problems, and based on such community benefits as completion of aquatic ecological protection objective, project costs, attraction to and acceptance of public, location of basin, partnership opportunity, traffic convenience of construction site, science popularization, nine protected areas under key aquatic ecological protection are planned to be constructed in short term; fishways or artificial natural bypasses are to be constructed; two blocked connection channels between the lakes, marshes and wetlands and the rivers are to be restored as the key task; three new fish breeding and releasing stations are to be constructed; and fish breeding and releasing stations of Cormagdalena, designed as prioritized projects in short term, are to be reconstructed and expanded.

The releasing objects of fish breeding and releasing stations of Cormagdalena are four fish species, i. e. *Bocachico, Bagre rayado, Brycon moorei* and *Sorubim cuspicaudus* and the short-term releasing scale is 15 million fishes. The comprehensive improvement and production facilities occupy 6ha in the plan. The comprehensive improvement facilities include two laboratories, one herbarium and multi-media academic halls and offices. The production facilities include 2 spawning induction basins, 3 FRP incubation tanks (clear dimensions 2.0m×0.8m×0.6m), 2 Yushchenko incubators for incubating sinkable and debonding fertilized eggs (clear dimensions

3.26m×0.85m×0.89m), 6 incubation barrels with a diameter of 0.86m, 24 small fry cultivation pots, inlet and outlet pipes and fry collection basin (1.2m×0.6m×0.6m).

7.3 Soil Erosion Control and Afforestation Planning

7.3.1 Current Situation of Soil Erosion

According to statistics based on field investigation and collection of materials from November ~ December in 2011, July ~ September in 2012 and March ~ April in 2013, and interpretation of satellite photos of 2005 and 2010 and with reference to the diagrams provided in *Overview of Magdalena River Basin* (2007), the area of the planned area with low scouring erosion is 56118.43km^2, accounting for 80.86% of the total area of land in the planned area. The area with extremely high scouring is 16217.36km^2, accounting for 23.37% of the total; the area with high scouring is 6154.04km^2, accounting for 8.67% of the total; the area with moderate scouring is 20896.80km^2, accounting for 30.11% of the total; and the area with low scouring is 12850.24km^2.In addition, there are also areas with extremely low scouring or no erosion with an area of 5947.21km^2 and 7332.66km^2 respectively. According to relevant research of IDEAM in 2001, the area with extremely high degree of erosion accounts for 22% of the total basin area. According the relevant research of Restrepo in 2005, the soil erosion modulus of the basin is 560t/ (km^2·a).

The soil erosion mainly exists in the middle and lower sections of the upper reaches and the lower reaches.

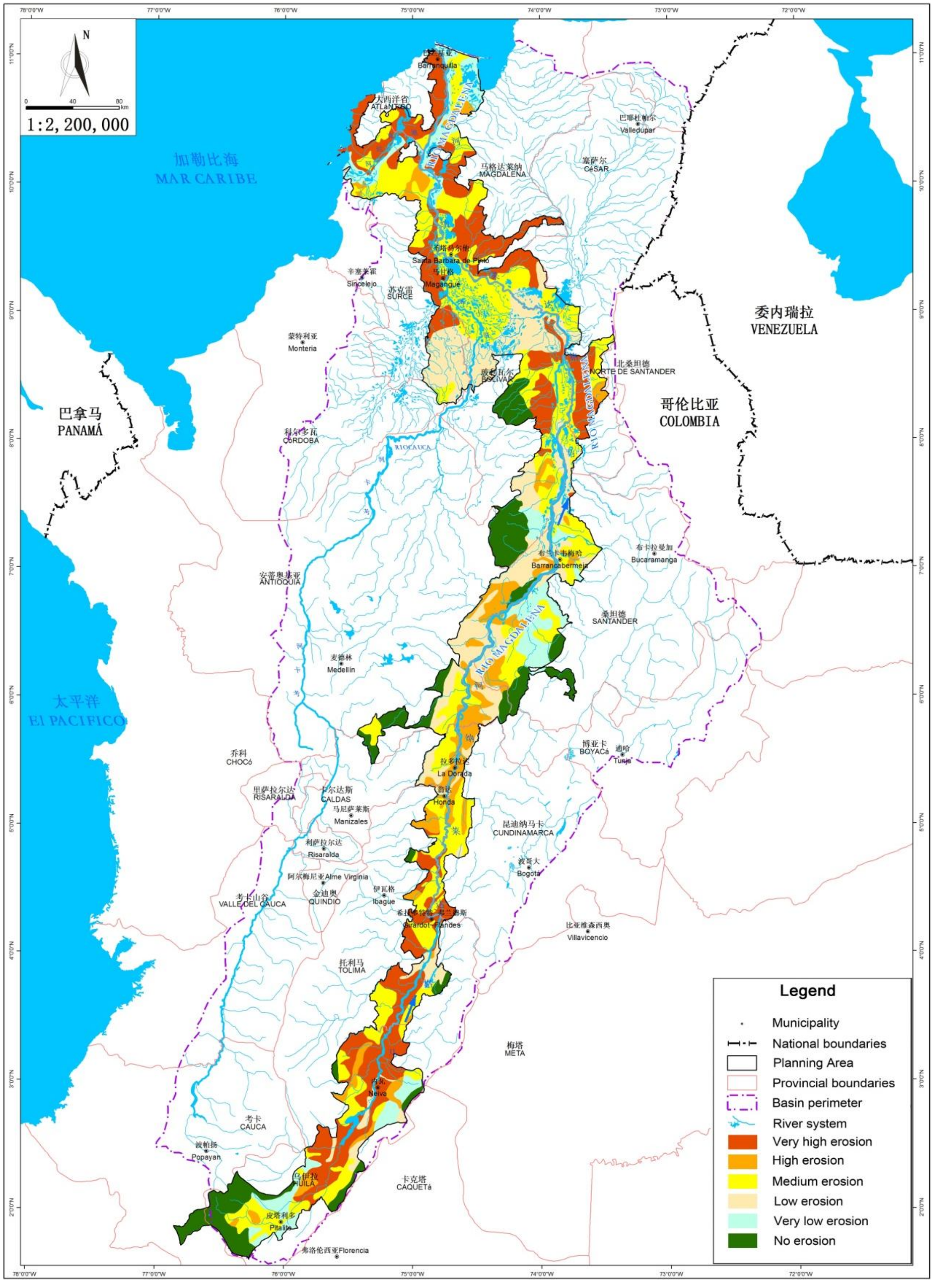


Fig. 7.3.1-1 Current Situation of Soil Erosion in Planned area (Reference: IGAC, 2007)

7.3.2 Current Situation of Soil Erosion Control and Afforestation

a) Current Situation of Soil Erosion Control

Relevant research on soil erosion of the basin is carried out, but no planning for systematic and general soil erosion control is formed. The current works for soil erosion control are relatively scattered. The implemented works mainly include renovation of slope surface, protection of river bank, management of ditches, ecological restoration and afforestation of small basins. Although certain effects have been achieved in soil erosion, this problem is still relatively serious.

Fig 7.3.2-1 shows some typical bank protection works scattered along the river bank in the field investigation. The scales are all small and the facilities are relatively simple.

Fig. 7.3.2-1 Photos of Typical Bank Protection Works Scattered along River Bank

b) Current Situation of Afforestation

The Regional Autonomous Company of Magdalena signed an agreement on scientific and technological cooperation with National Corporation for Forestry Research and Development (CONIF) with the purpose of developing cultivation of forest trees in the business area.

Cultivation of forest trees began since 2000 through the signing of the agreement between the Regional Autonomous Company of Magdalena and land owners.

In this basin, there are forest protection plantation and commercial plantation that mainly distribute at the lower reaches of Cordoba and Bolivar of Magdalena River and the upper reaches of the Magdalena and the Cauca River. In the jurisdiction area of Cormagdalena, there is 19528ha commercial plantation with 84.5% of it located at the lower reaches of Magdalena River and 15.2% at the middle reaches. The main plants cultivated include eucalyptus globulus, deodar, Mesua ferrea, Canarium album and alder (reference: CONIF, 2004).

Fig. 7.3.2-2 Protection Forest along Banks of Main Stream

Fig. 7.3.2-3 Protection Forest along Banks of Main Stream

7.3.3 Analysis on Causes and Evolutionof Soil Erosion

The causes of soil erosion in Magdalena River Basin include the following:

a) Natural Factors

The geological structure is relatively new and unstable. Landslide, rockfall and collapse occur frequently in local area.

Since the upper reaches have high and steep terrain, and weak and crushed stratum; the soil easily lost is widely distributed; there is a relatively large quantity of loose volcanic ashes left due to volcanic eruption; and there is an abundant rainfall and frequent occurrence of rainstorm, the soil erosion caused is relatively serious.

b) Human Factors

Large scale of disafforestation has resulted in lack of water conservation forests and protection forests. As indicated by the research of Colombia Meteorological and Environmental Research Institute, the forest area decreases by 4676778ha and coverage rate decreases from 42.6% to 25.4%. The irrational utilization of land resources, reclaiming of wasteland from steep slope, overgrazing and construction of industrial, mining and traffic infrastructure and no attention paid to the protection of environment have accelerated the soil erosion. Irrational mode of agricultural cultivation in local area and cultivation on steep slope has resulted in soil erosion. As the waste residue produced due to gold prospecting is randomly stacked and occupies the arable land and forest land making them waste lands, soil erosion is caused due to washing of rainfall and surface runoff.

7.3.4 Soil Erosion Control and Afforestation Planning

7.3.4.1 Plan Objectives and Scale

a) Plan Objectives

The general plan Objectives of soil erosion control is to rational utilize and protect the water and soil resources in the planned area and effectively control and prevent the current and new soil erosion so as to improve the ecological environment and curb the degeneration trend of the land function.

Short-term Objectives (2020): With emphasis placed on the middle and lower reaches of Magdalena River and small basin as the unit, carry out comprehensive treatment of soil erosion so as to finish the task of controlling 40% soil erosion of the whole basin and reduce the sediment discharged into the Magdalena River.

Long-term Objectives: On the basis of emphasis placed on the controlling of soil erosion of the lower reaches of Magdalena River, carry out controlling of soil erosion of the basin in an all-round manner so as to achieve preliminary control of above 75% soil erosion of the basin and remarkably improved ecological environment. Meanwhile, establish complete soil erosion control monitoring network system, carry out dynamic monitoring of soil erosion of the whole basin in due time and regularly publish soil erosion control information bulletin.

b) Control Scale

Lay down the control scale according to the plan Objectives of comprehensive control of each controlled zone. See Table 7.3.4-1 for details.

Table 7.3.4-1 Plan of Control Measures against Soil Erosion of Each Administrative Department

Administrative Department	Area inside Planned area (km^2)	Soil Erosion Area	Control Area	Comprehensively Controlled Area	Naturally Restored Area	Forest Restoration Rate
		(km^2)	(km^2)	(km^2)	(km^2)	(%)
ANTIOQUIA	5424.69	4309.62	3102.93	1551.46	1551.46	72.00
ATLANTICO	2456.47	1789.95	1235.07	802.79	432.27	69.00
BOLIVAR	18530.32	15150.32	11968.75	8856.88	3111.88	79.00
BOYACA	1517.72	1314.97	933.63	737.57	196.06	71.00
CALDAS	1131.23	1131.23	757.92	538.13	219.80	67.00
CAUCA	385.19	0.00	0.00	0.00	0.00	
CESAR	2547.35	2547.35	1885.04	1376.08	508.96	74.00
CUNDINAMARCA	2366.01	2366.01	1892.81	1306.04	586.77	80.00
HUILA	11670.18	7975.86	4466.48	2456.56	2009.92	56.00
MAGDALENA	7765.00	6862.55	5078.29	2996.19	2082.10	74.00
SANTANDER	7796.72	5073.87	3754.66	2740.90	1013.76	74.00
SUCRE	2423.81	2423.81	1890.57	1474.65	415.93	78.00
TOLIMA	5383.73	5172.91	2586.46	1422.55	1163.90	50.00
Total	69398.41	56118.45	39552.60	29664.45	9888.15	70.48

(Reference: Research on the Environment of Magdalena River-Cauca River, Cormagdalena- IDEAM)

7.3.4.2 Plan Zoning and General Layout

a) Plan Zoning for Control of Soil Erosion and Afforestation

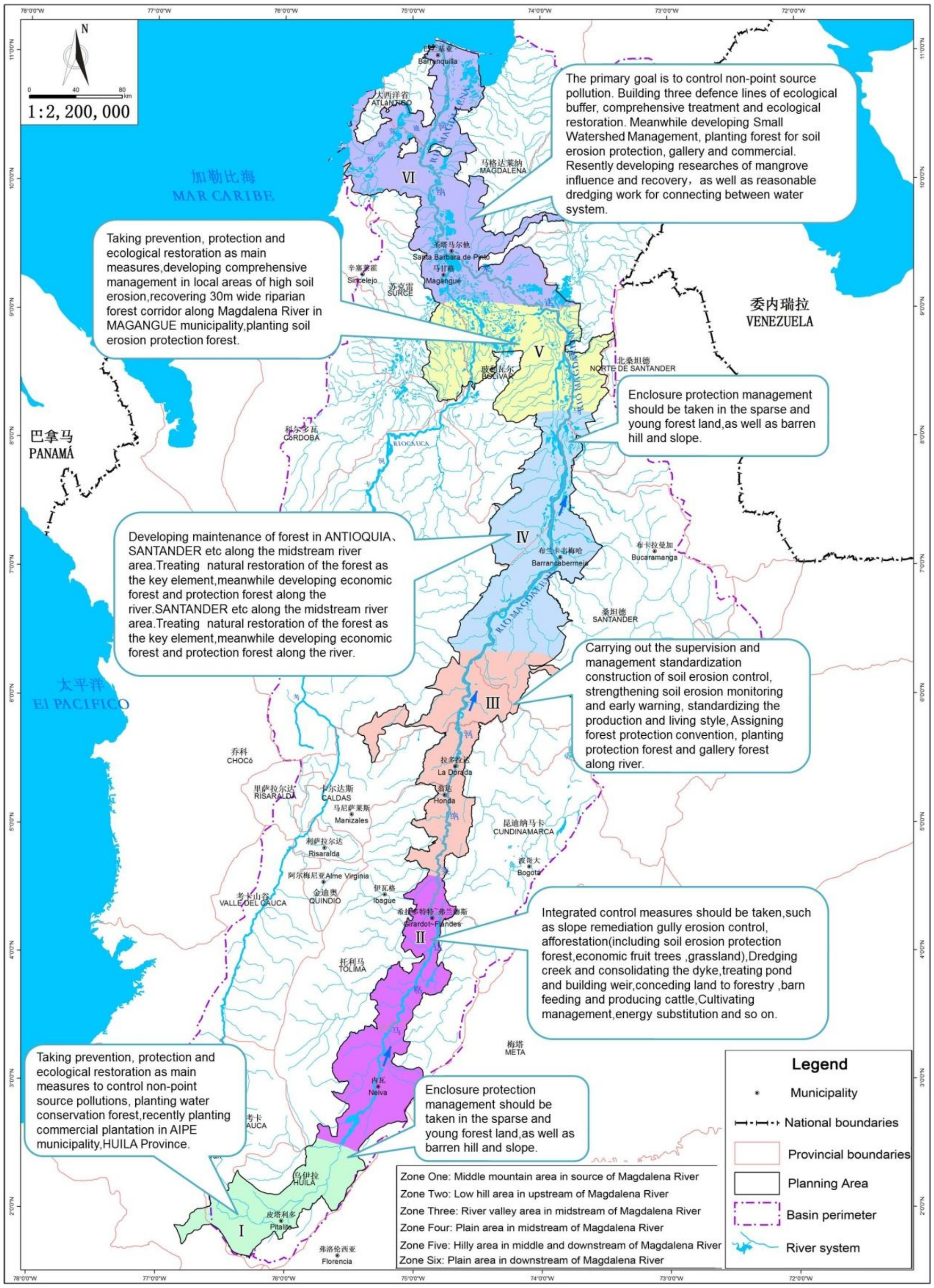


Fig. 7.3.4-1 Comprehensive Plan and Layout of Soil Erosion Control and Afforestation in Planned Area

Based on the distinct similarities in natural conditions, soil erosion and social and economic conditions and basic consistency of production and development directions, afforestation mode and layout of control measures, and with reference to the almanac of afforested forest zone of land in the plan scope (CONIF, 2004), the plan scope is divided into six plan zones for soil erosion control and afforestation, i. e. zone I, located in middle mountainous area at the source of the Magdalena River; zone II, hilly and mountainous area at the upper reaches of Magdalena River; zone III, located in hilly area of river valley at middle and upper reaches of Magdalena River; zone IV, located in the plain area of the middle reaches of Magdalena River; zone V, located in hilly area at the boundary of upper and lower reaches of Magdalena River; zone VI, located in alluvial plain area of the lower reaches of Magdalena River. See Fig. 7.3.4-1.See Table 7.3.4-2 for details on basic situation of each zone.

Table 7.3.4-2 Basic Situation of the Control of Soil Erosion and Afforestation in Zone

Planned Zone for Soil Erosion Control and Afforestation	Administrative Department	Landform and Physiognomy	Proportion of Soil Erosion Area in Total Area (%)	Agricultural Population Density (Person/km^2)
Zone I: Middle mountainous area at the source of Magdalena River	CAUCA, HUILA	Mainly middle mountains	51.82	26.1
Zone II: Hilly area of middle mountainous area at the upper reaches of Magdalena River	CALDAS, CUNDINAMARCA, HUILA, TOLIMA	Mainly middle mountains and hills, mixed with low mountains	96.33	17.6
Zone III: Hilly area of river valley at the middle upper reaches of Magdalena River	CALDAS , BOLIVAR, CUNDINAMARCA ,	Mainly valleys, low mountains and hills	82.66	10.3
Zone IV: Plain area at middle reaches of Magdalena River	ANTIOQUIA, BOLIVAR, BOYACA, SANTANDER CALDAS, CUNDINAMARCA	Mainly plains	70.04	26.6
Zone V: Hilly area at the boundary of middle and lower reaches of Magdalena River	SUCRE , BOLIVAR, CESAR, MAGDALENA, SANTANDER	Mainly hills	92.56	20.9
Zone VI: Plain area at lower reaches of Magdalena River	ATLANTICO, BOLIVAR, MAGDALENA	Mainly plains and hills	90	29.3

b) General Plan and Layout of Soil Erosion Control and Afforestation

1) Zone I: Middle Mountainous Area at the Source of Magdalena River

With the core task of controlling non-point source pollution and protecting water quality and by taking prevention, protection and natural restoration measures, carry out closing of mountains for growth of forest to strictly protect the existing forest, and carry out energy replacement locally to replace fuel wood, reduce deforestation and cultivate water conservation forest.

2) Zone II: Hilly and mountainous area at the upper reaches of Magdalena River

Such measures as closing the mountain for growth of forest, energy replacement, penned livestock and ecological relocation are taken in the plan to restrict irrational production and construction in the area, reduce human-caused destruction of ecological environment and cultivate protection forest against soil erosion.

3) Zone III: Hilly area of river valley at the middle upper reaches of Magdalena River

With the main Objectives of reducing erosion and sediment along the bank and in the surrounding areas of main stream, artificial control and natural restoration measures are taken to reduce to the largest extent the sediment discharged into the stream and cultivate protection forest for main stream and gallery forest.

4) Zone IV: Plain area at middle reaches of Magdalena River

The soil erosion is relatively moderate and part of the protected area is also involved. With emphasis placed on the prevention, protection and ecological restoration, carry out closing of mountains for growth of forest to strictly protect the existing forest, carry out energy replacement locally to replace fuel wood and thus reduce deforestation, and cultivate commercial forest and protection forest for main stream.

5) Zone V: Hilly area at the boundary of middle and lower reaches of Magdalena River

With emphasis placed on prevention, protection and natural restoration, carry out comprehensive control in the area with relatively serious soil erosion locally and cultivate protection forest for soil erosion.

6) Zone VI: Alluvial plain area at lower reaches of Magdalena River

With the primary Objectives of controlling non-point source pollution, arrange three lines of defense, i. e. ecological buffer, comprehensive control and ecological restoration, control soil erosion and non-point source pollution, cultivate protection forest for soil erosion, protection forest for main stream, gallery forest and commercial forest.

7.3.4.3 Plan of Soil Erosion Control and Afforestation

a) Plan of Measures for Soil Erosion Control

1) Prevention and Protection Measures

Prevention and protection measures are taken to maintain the ecological barrier function of the area. Closing in the whole year is carried out in the basin to close the area of remnant and sparse forests and gradually restore the vegetation with their self-restoration functions. Three ~ five years after the implementation of the measures, the canopy density should be above 0.7. For each closed area, boundary is defined and signboard is provided. Closing system (time and method) and opening conditions (closing and opening in turn) are formulated, publicity activities are carried out, and such behaviors as deforestation, destruction of grassland and reclaiming of wasteland from steep slope are forbidden.

2) Comprehensive Improvement Measures

Implement the following comprehensive improvement measures according to local conditions so as to control soil erosion and improve the ecological environment.

(1) Control of Slope Surface

On the arable land with gentle slope and relatively thick soil layer, reconstruct the slope into terrace, provide supporting slope surface water system, improve the roads to farmland and construct earth and stone banked terraced fields according to local conditions. Vegetation protection measures must be taken to protect the earth banked terrace. The slope surface water system includes such works as irrigation and drainage ditches, impounding basins and pits, and sedimentation basin. Carry out reconstruction of slope into grain terrace on the arable land with 5^0 ~ 15^0 gentle slope and reconstruction of slope into fruit terrace on the arable land with 15^0 ~ 25^0 slope. In the plan, the areas of sloped arable land reconstructed into grain and fruit terraces are 863,712 ha and 282,895 ha respectively, and the area of arable land returned to forest is 247, 81 ha.

Table 7.3.4-3　Slope Gradient and Reconstructed Area of Slope Surface of Key Management Area

Gradient	Area (ha)	Reconstruction of Slope Surface
>35°	247781	Reclaim arable land or grazing land to forests
20~35°	290916	Part of the slope reconstructed into fruit terrace
15~20°	191979	Slope reconstructed into fruit terrace
10~15°	276921	Arable land with gentle slope reconstructed into grain terrace
5~10°	586791	Arable land with gentle slope reconstructed into grain terrace
0~5°	2569552	
Total	396394	

(2) Protection of Ditch

Taking MORALES city of BOLIVAR Department as an example, carry out demonstration project for comprehensive improvement of small basins and implement plan of soil erosion control and afforestation, so as to restore the demonstration forest ecological system of small basin, control the soil erosion and remarkably improve the ecological environment. On the basis of obvious effects achieved for the demonstration project, duly carry out soil erosion control for the whole basin in an all-round manner. For protection of ditches, check dam groups are adopted for impoundment by multi-layers to prevent undercutting of ditches. For ditches with expanded ditch banks and ditch head seriously eroded, integrated vegetation measures, such as cultivation of local arbor, shrub and grass are provided so as to establish a complete and all-around protection system for the ditch.

(3) Closing of Mountains for Growth of Forest and Ecological Restoration

Closing in the whole year is carried out to close the area of remnant and open forests and gradually restore the vegetation with their self-restoration functions. Three ~ five years after the implementation of the measures, the canopy density should be above 0.7.

Carry out different types of ecological restoration of shrubbery, sparse and young forests, and barren mountain and provide plan and measures of ecological restoration type in small basins.

(4) Management and Construction of Pond

For existing ponds with serious silting, dredging should be carried out to unblock the drainage and irrigation ditches and new ponds should be constructed as required by irrigation of farmlands and in consideration of conditions for providing drinking water people and livestock in some places. This can not only improve the irrigation conditions for agricultural production but also effectively intercept the sediment.

(5) Flood Control Project along River Banks

In this plan, flood control and water log control projects and facilities are designed in 17 cities and towns with collapse of river bank and grave flood control situation, mainly to control flood and waterlog and meanwhile improve the resistance against erosion of river banks, so as to control collapse of river bank and reduce the sediment discharged into the river.

(6) Adjusting Industrial Structure

Properly prioritize and adjust the industrial structure of Magdalena River Basin according to the current situation and objective of the national economic development of Colombia and in consideration of the current natural environment of the country. Promote ecological agricultural technologies and carry out adjustment of industrial structure. Define tropical crop belts, temperate crop belts, and cold temperate crops belts according to different altitudes of Andes Mountains; promote in an all-round manner the production mode of intensive land utilization for penned livestock and the scientific fertilization; reduce the occupation of pasture and promote returning of farmland and pasture for forest and grassland so as to increase vegetation coverage rate. The plan of penned livestock is carried out in the representative city, i. e. PURIFICACION of HUILA Department in the early stage.

b) Afforestation Plan

1) Plan of Afforestation Objective, Area and Scale and Forest Species

As indicated by the current situation of soil erosion in the planned area and five quality objective diagrams about the control of soil erosion, and plan and afforestation of protected areas in PMC, there are mainly three afforestation plan objectives for the planned area, i. e. maintaining relatively good current situation of forest vegetation, restoring and monitoring of forest vegetation which has been destroyed in a certain degree, and carry out afforestation in areas that can be afforested. See Fig. 7.3.4-2 and Table 7.3.4-4 for the distribution and scale.

Table 7.3.4-4 Afforestation Objective and Scale

Area	Area (ha)
Forest currently retained	1188769
Forest restored and monitored	733852
Afforestation area	303385

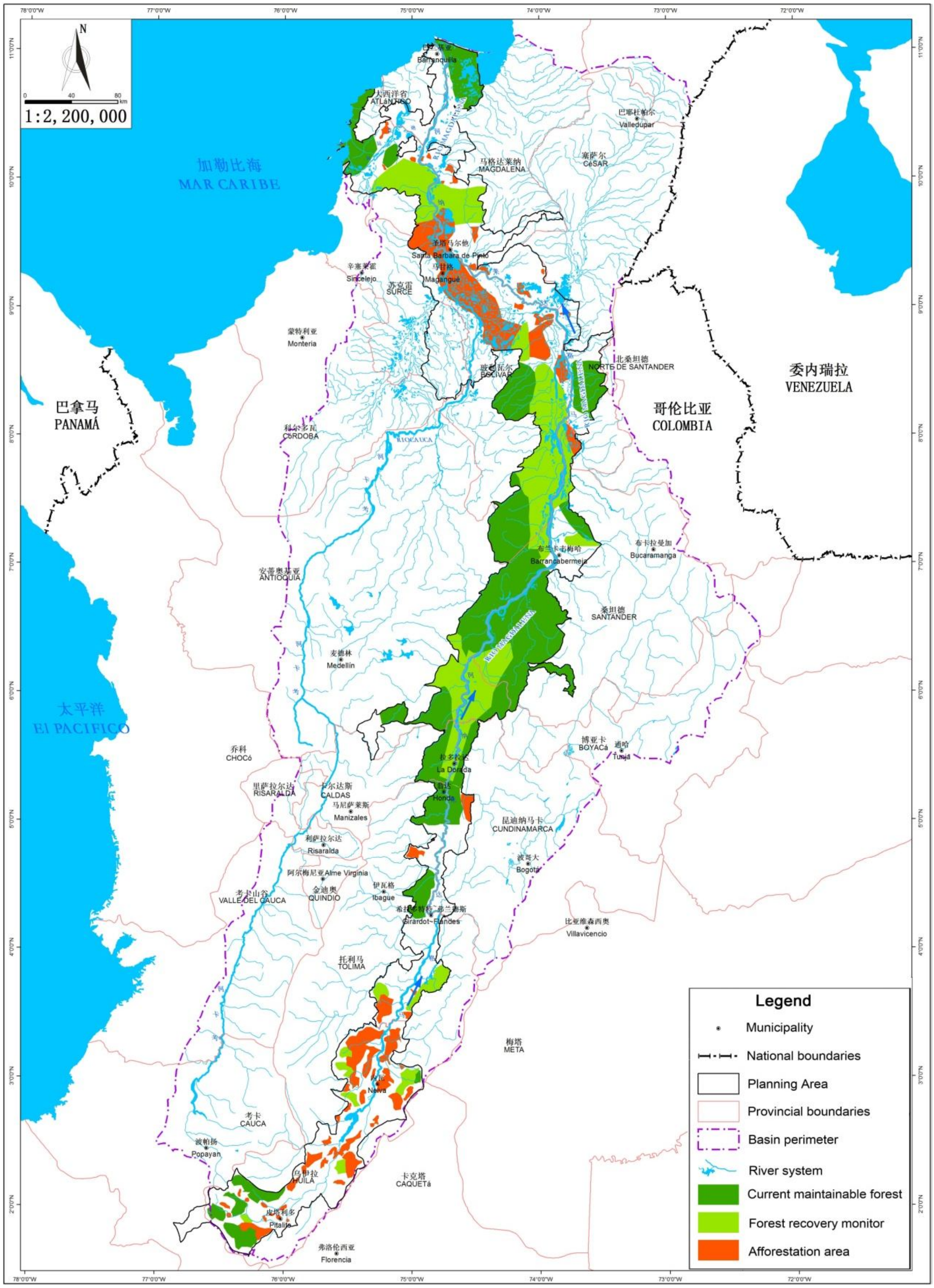


Fig. 7.3.4-2 Afforestation Plan Objective and Layout of Afforestation Area in Planned Area

Afforestation has been used as a means to control soil erosion. It is planned to cultivate commercial forest and protection forest against soil erosion and water conservation forest in forest lands, forest product supply areas, areas with serious or extremely serious soil erosion and areas where the land is determined to be bare, degraded and burned according to Colombia Corine Land Cover Projects ~ 2000, and cultivate protection and gallery forests in riparian zone of the river. Moreover, it is planned beyond the protected area (IGAC, 2002) so as to avoid adverse impact on the succession and development of natural vegetation in the protected area.

The protected area in the planned area is 1,880,933ha and mainly distributed in such places as SANTANDER and BOLIVAR, where emphasis is placed on natural restoration; whereas the unprotected areas are mainly distributed in such places as HUILA and CALDAS. Therefore, the afforestation area in the plan is designed beyond the protected area with an area of 1,260,199ha.See Fig. 7.3.4-3 for the distribution of protected area.

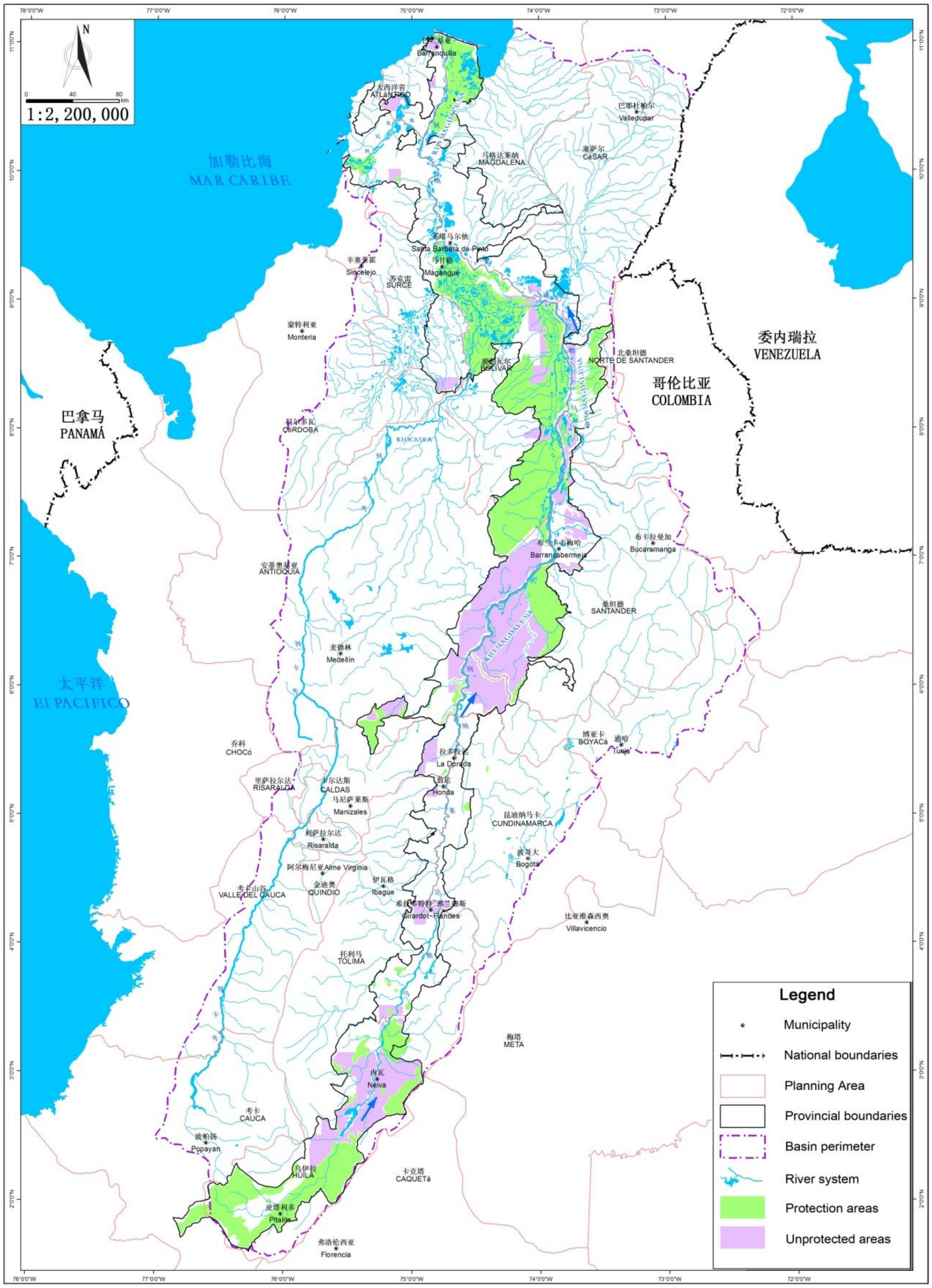


Fig. 7.3.4-3 Distribution of Protected Areas in Plan Scope

(1) Commercial Forest, Protection Forest against Soil Erosion and Water Conservation Forest

It is planned to cultivate commercial forest, soil erosion forest and water conservation forest at the upper and lower reaches of Magdalena River according to ecological site conditions of areas that can be afforested and the requirements for control of soil erosion in the planned area. The afforested area of middle reaches is relatively small. The cultivation of commercial forest, soil erosion forest and water conservation forest at upper reaches of Magdalena River mainly concentrates in HUILA, the south of TOLIMA Department and the east of CUNDINAMARCA Department; for the lower reaches of Magdalena River, in MAGDALENA and ATLÁNTICO; and for the middle reaches of Magdalena River, small part in the north of TOLIMA Department and west of CUNDINAMARCA Department. The area of commercial forest, protection forest against soil erosion and water conservation forest planned to be cultivated totals 303,385ha.

(2) Protection Forest for Main Stream and Gallery Forest

According to the diagram for control plan and objective of soil erosion of PMC, it is planned to cultivate 617km-long protection forest and 114km-long gallery forest for the main stream. The total length of forests to be cultivated is 731km. The gallery forest is mainly planned for the main stream and surrounding areas of BOLIVAR and MAGDALENA at lower reaches and a little is planned in such areas as ANTIOQUIA and SANTANDER at middle reaches.

According to "VISION COLOMBIA 2019: COLOMBIA SEGUNDO CENTENARIO" of Cormagdalena, it is planned to restore 1300km-long gallery forest along the bank. Therefore, 569km-long gallery forest along the bank is added in the plan in such areas as SANTANDER, BOLIVAR, BOYACÁ and ANTIOQUIA at middle reaches. The length of protection forest and gallery forest for the main stream is 1,300 km. According to ley 2811 de 1974, the width of protection forest is planned to be 30m, so the afforested area is 3,900ha. See Fig. 7.3.4-4 for the planned area of protection forest for main stream and gallery forest.

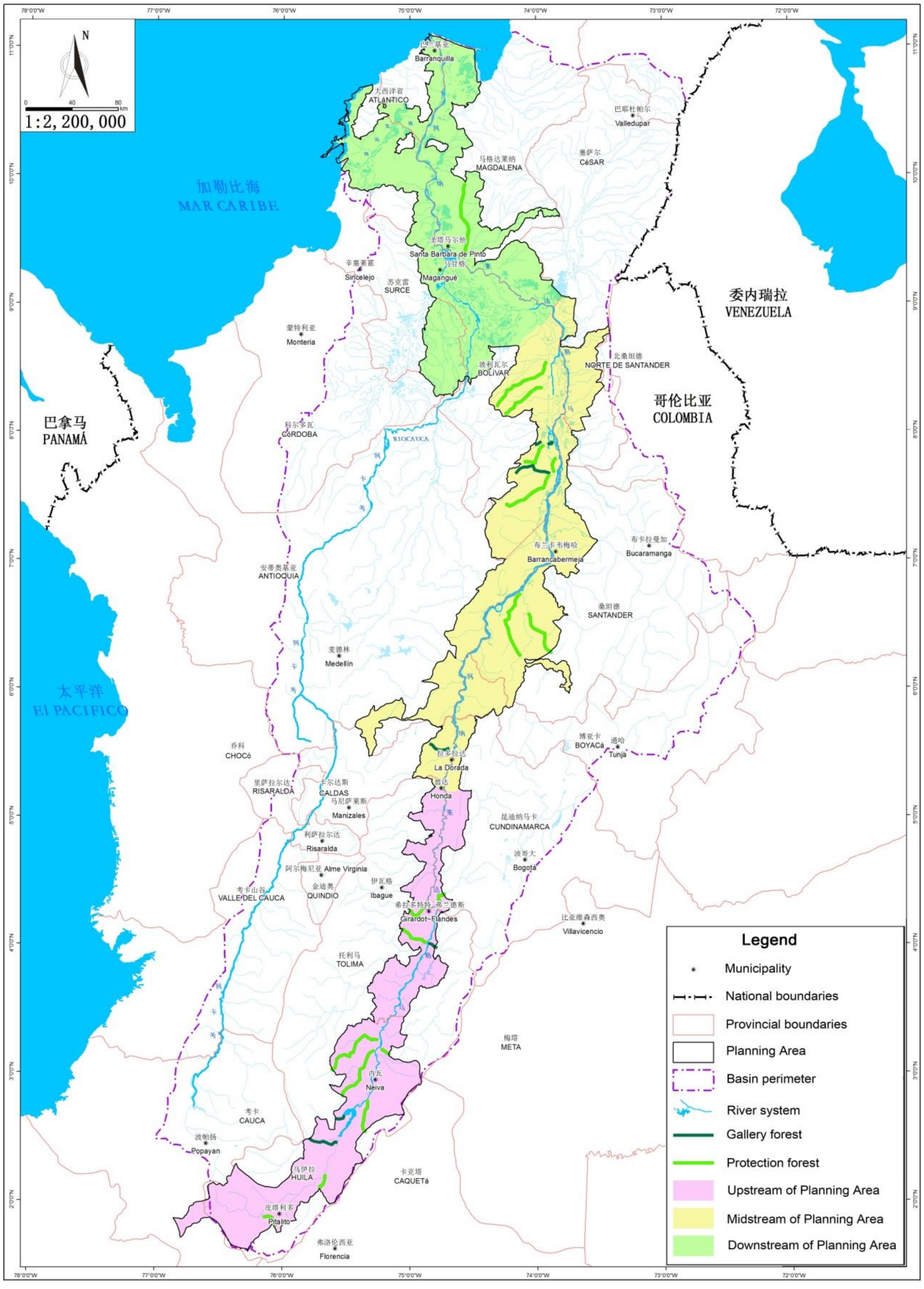


Fig. 7.3.4-4 Distribution of Protection Forests for Main Stream and Gallery Forests

2) Plan of Afforestation Zone

Zone plan needs to be carried out since the plan scope is large, the environmental difference is relatively large, and the difference between afforestation mode and tree species is also relatively large. The planned area is divided into 6 afforestation zones according to such conditions as the altitude, terrain, soil and climate of each zone in the plan scope, and proper tree species are selected based on different zones. See Fig. 7.3.4-5 for details.

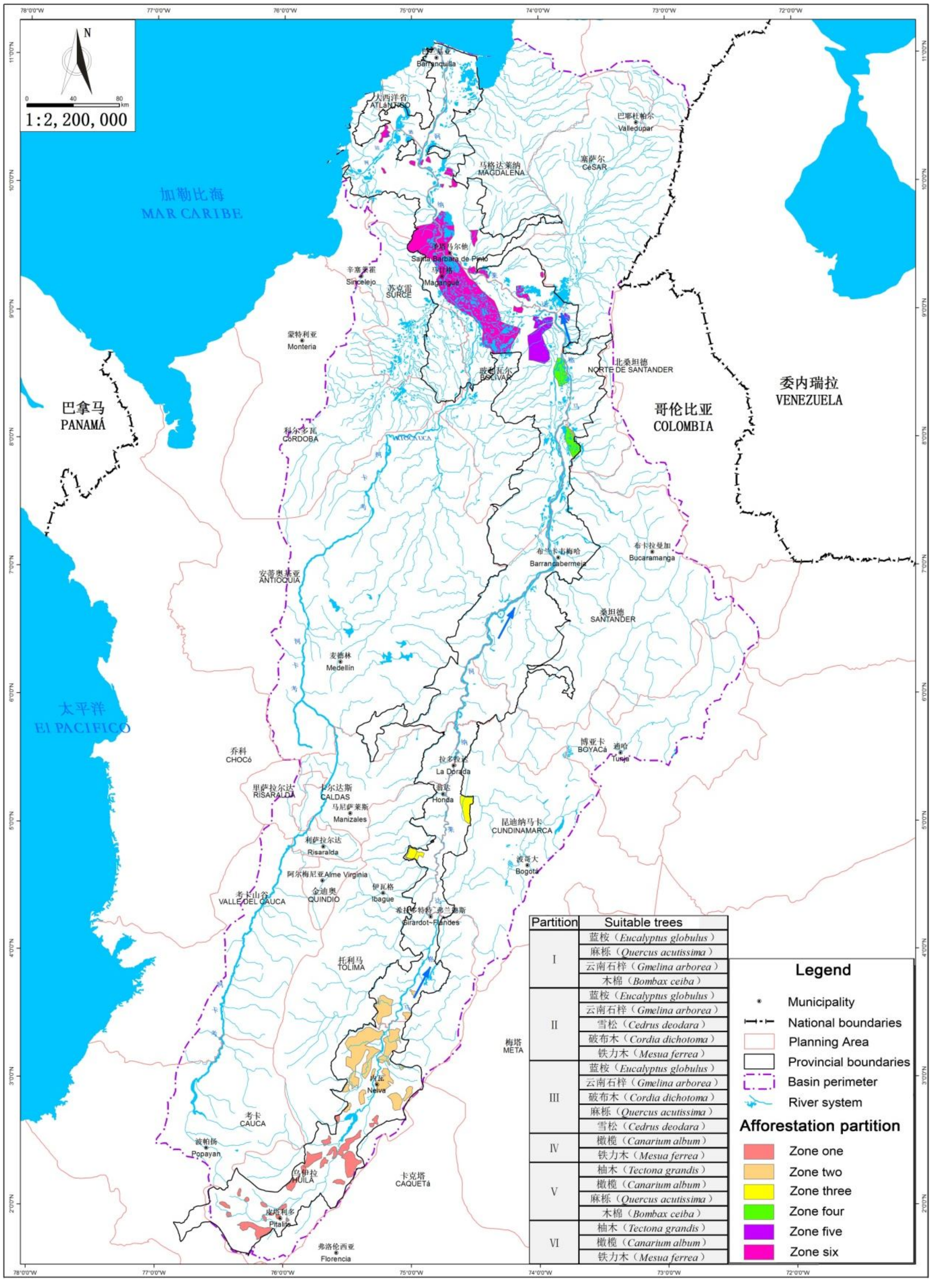


Fig. 7.3.4-5 Afforestation Zone and Species in Planned Area

(1) Zone I: Middle Mountainous Area at the Source of Magdalena River

This zone is located in the source area of the upper reaches of Magdalena River and the main purpose of afforestation is to improve the water conservation ability, and prevent and control soil erosion. Since there is relatively wide distribution of protected areas in the zone, the soil erosion degree is low and the ecological environment is relatively good, afforestation in this zone can further improve the quality of ecological environment of the source area.

Since this zone has a high altitude and relatively large difference in climatic conditions, the tree species suitable to be cultivated mainly include eucalyptus globules, *Quercus acutissima var. acutissima, Gmelina arborea and Bombax malabaricum.* Underplanting of *Indigofera hirsute, Mimosa pudica, Pennisetum alopecuroides, Brachiaria brizantha, Medicago and Andropogon gayanus* should be performed. The afforested area is planned to be 27,389ha. The main function of afforestation is to strengthen the water conservation ability.

(2) Zone II: Hilly and mountainous area at the upper reaches of Magdalena River

Located at the upper reaches of Magdalena River, this zone is one of the zones with the most serious soil erosion in the basin. As the forest in the north of the zone is destroyed, the soil erosion is extremely serious there. The afforestation sequence is determined to be at top grade according to the "intervention sequence determined for afforestation and erosion control indicators".

In consideration of the mountainous and hilly terrain of this zone and the relatively mild climate, such tree species are selected as Eucalyptus globules, Gmelina arborea, Cedrus deodara, Cordia dichotoma and Mesua ferrea. Underplanting of such herbaceous plants as Desmodium, Indigofera hirsut, Mimosa pudica, pennisetum, Brachiaria Griseb, Panicum, Medicago and Guyana Andropogon virginicus should be performed to form the three dimensional arbor-shrub-grass vegetation structure and better control soil erosion. The planned area is 74,978ha and the main type is protection forest against soil erosion.

(3) Zone III: Hilly area of river valley at the middle upper reaches of Magdalena River

This zone is located at the middle upper reaches of Magdalena River with only a few protected areas involved. The water and soil erosion degree is low and the afforestation priority of the zone is also low. However, since both banks of main stream, especially both banks of the river in Barrancabermeja City of SANTANDER Department lack necessary protection forest, large quantity of sediments are discharged into the river. Therefore, this zone is the key construction zone for cultivation of protection forest for main stream and gallery forest.

The afforestation area of this zone mainly concentrates in three areas, which can be divided into three subareas.

The first subarea refers to Ambalema and Venadillo in the south of the zone, where such plants as *Eucalyptus globules, Gmelina arborea, Cordia dichotoma* and *Erythrina variegate* are suitable to be cultivated.

The second subarea refers to such regions as Victoria and Guaduas in the middle part of the zone, where *Quercus acutissima var. acutissima* and *Cedrus deodara* are suitable to be cultivated.

The third subarea refers to such regions as Cimitarra, Bolívar, Cimitarra and El Peñón in the north of the zone, where *Cedrus deodara* is suitable to be cultivated.

The total afforested area of Zone III is 26,788ha. The main type of afforestation includes protection forest against soil erosion, protection forest for main stream and commercial forest.

(4) Zone IV: Plain area at middle reaches of Magdalena River

The soil erosion degree is relatively low and part of the protected area is also involved. The afforestation priority is at medium level. The trees suitable to be planted include *Canarium album and Mesua ferrea*. Underplanting of *Indigofera hirsute, Mimosa pudica, Pennisetum alopecuroides, Brachiaria brizantha, Medicago and Andropogon gayanus* should be performed. The total afforested area is 13,939 ha. The main type of afforestation includes commercial forest and protection forest for main stream.

(5) Zone V: Hilly area at the boundary of middle and lower reaches of Magdalena River

With extremely serious soil erosion, this zone is defined as the zone with the first priority of afforestation based on requirements for controlling soil erosion. The objective of afforestation is mainly to control the soil erosion. In the west of the zone, *Tectona grandis and Canarium album* are suitable to be planted while in the east *Bombax ceiba and Quercus acutissima var. acutissima* are suitable to be planted.

Underplanting of *Indigofera hirsute, Mimosa pudica, Pennisetum alopecuroides, Medicago and Andropogon gayanus* should be performed. The afforested area is 79,353ha and the main afforestation type is protection forest against soil erosion.

(6) Zone VI: Alluvial plain area at lower reaches of Magdalena River

This zone has a large area, relatively serious soil erosion and low-level of priority for afforestation, and involves a few protected areas. Meanwhile, certain degree of restoration of mangrove forest also requires to be carried out along the riparian zone of the area. The trees suitable to be planted in the zone include *Tectona grandis, Canarium album and Mesua ferrea*. *Rhizophora apiculata* should be planted in the coastal area. Afforestation in this zone is relatively scattered and the total afforested area is 80,938ha.Cultivation of commercial forest, protection forest against soil erosion, protection forest for main stream and gallery forest are mainly carried out.

See Table 7.3.4-5 for the natural conditions and afforestation scale of each zone. Different tree species are selected according to different natural conditions (elevation, terrain, soil, temperature, rainfall, climate, etc.) and the development of the area.

Table 7.3.4-5 Natural Conditions of Afforestation Area and Afforested Area

Zone	Involved Department	Physiographic Characteristics							Afforestation	
		Range of altitude (m)	Average rainfall (mm)	Main type of soil	Drought grade	Average temperature (^{0}C)	Sunshine duration (h)	Terrain	Afforested area (ha)	Trees suitable to be planted
□	HUILA	1000~3000	1000~2000	Dryland soil Hilly soil	Standard area to area with low frequency of precipitation	16~24	900~1700	Mainly middle mountains	27389	*Eucalyptus globules, Quercus acutissima var. acutissima, Gmelina arborea and Bombax malabaricum*
□	HUILA, TOLIMA	500~1000	500~1000	Mountain soil Hilly soil	Standard area to area with low frequency of precipitation	12~24	1300~2100	Mainly low mountains and hills	74978	*Eucalyptus globulus, Gmelina arborea, Cedrus deodara, Cordia dichotoma and Mesua ferrea*
□	TOLIMA, CALDAS, BOYACA, SANTANDER	500~2000	1000~3000	Hilly soil, highland soil, mountain soil	Standard area	24~28	1700~2100	Mainly hills	26788	*Eucalyptus globulus, Gmelina arborea, Cordia dichotoma. Quercus acutissima var. acutissima and Cedrus deodara*
□	BOLIVAR, SANTANDER, ANTIOQUIA, CESAR	50~250	2000~4000	Alluvial soil Mountain soil	Standard area	>28	1700~2100	Plain	13939	*Canarium album and Mesua ferrea*
□	BOLIVAR, CESAR	500~1500	3500~4000	Mountain soil Hilly soil	Standard area	>24	1700~2500	Mainly plains and hills	79353	*Tectona grandis, Canarium album, Quercus acutissima var. acutissima, Bombax ceiba*
□	MAGDALENA, BOLIVAR, ANTIOQUIA	0~150	1000~2000	Alluvial soil, mountain soil and soil on coastal terrain	Standard area to area with low frequency of precipitation	>28	2100~2500	Alluvial plain	80938	*Tectona grandis, Canarium album, Mesua ferrea and Rhizophora apiculata*

3) Afforestation Priority

It is planned to put forward afforestation priority in overall consideration of the afforestation situation of the basin, quality objective in the protected area and intervention priority determined for afforestation and soil erosion control.

Determine the afforestation priority in the planned area according to the soil erosion control objectives and requirements in the planned area and the soil erosion control and afforestation priority stated in PMC. For the afforestation priority, such areas as the north of HUILA Department, south of TOLIMA Department, east of TOLIMA Department and west of CUNDINA –MARCA Department are of top level; CALDAS is the main area of high level; the east of HUILA and BOLIVAR Departments are of medium level; and BOLIVAR and MAGDALENA Departments as well as a few areas in the north of SANTANDER Department at the lower reaches of Magdalena River are of low level. The afforestation area of high priority is 151,762 ha, which mainly distributes in Neiva of HUILA Department, the middle area of BOLIVAR Department and Honda city of TOLIMA Department. Three areas with high priority for afforestation are determined according to the degree of soil erosion. See Fig. 7.3.4-6 for the plan of afforestation priority.

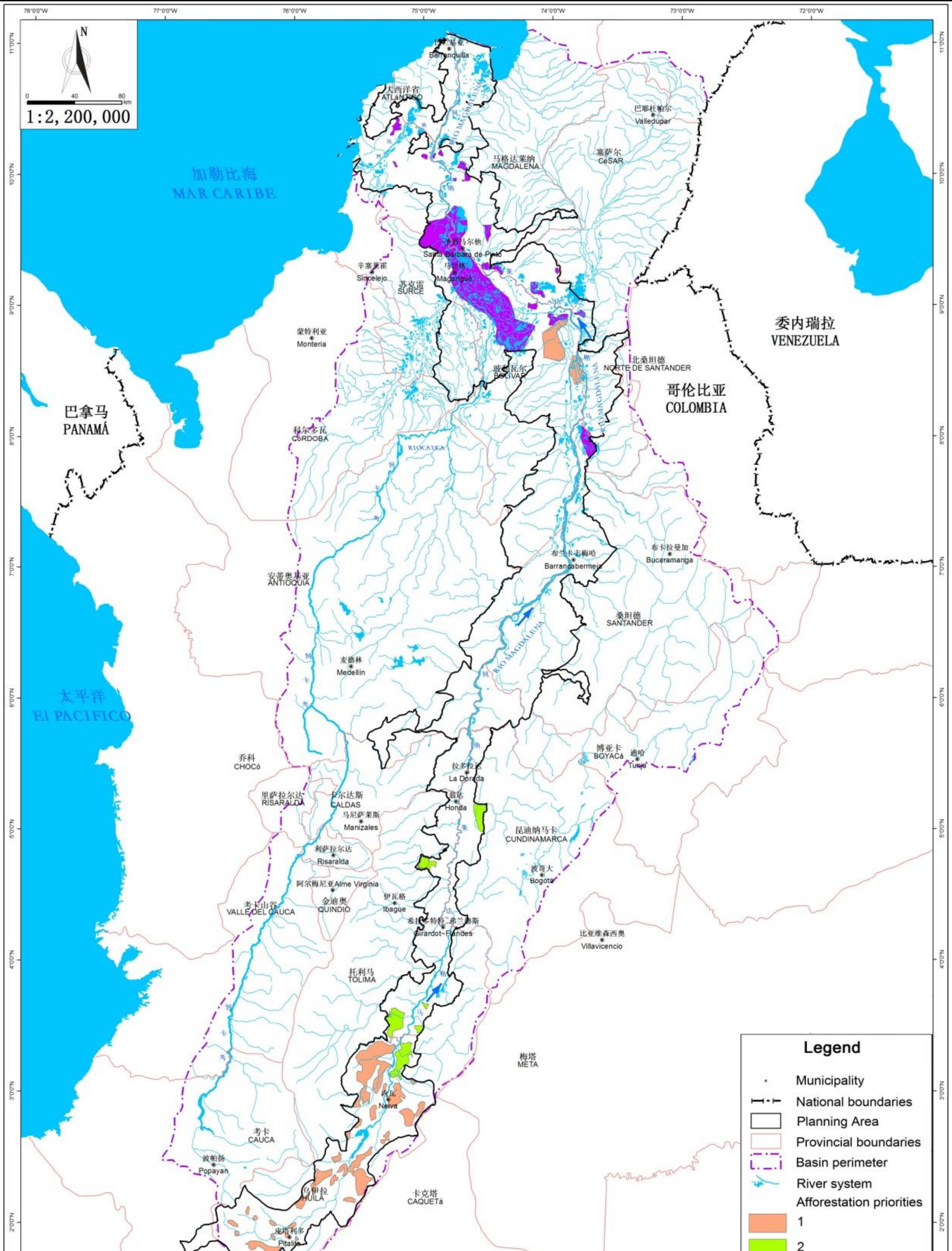


Fig.   7.3.4-6 Plan of Afforestation Priority

c) Other Plan

1) Plan of Forest Carbon Sink Project ($REDD^+$)

As the largest carbon pool of terrestrial ecosystem, the forest plays a very important and unique role in reducing the concentration of greenhouse gases in atmosphere and slowing down the global climate warming. The growth rate of forest in Colombia is higher than that in other areas at high latitude; the forest is more effective in absorbing carbon dioxide and releasing oxygen compared with other countries and regions at low altitude; and the carbon sink per unit area is higher than that in other non-tropical areas. Although the forest cover along the bank of the upper reaches of Magdalena River is well kept for years, it is suggested in the plan to design forest carbon sink project for areas surrounding the forest that tend to be threatened by human activities.

2) Supervision and Management Plan

Strengthen supervision and effectively prevent human-caused soil erosion. Strengthen investigation and management of existing forest lands, register by category and formulate conventions for protection of forest. Management and protection of items already restored should be strengthened and the responsibilities as well as responsible personnel of management and protection should be made clear based on the principle of "whoever benefits should carry out management and protection". Carry out construction of standardized supervision and management of soil erosion control, strengthen the supervision and management of the development and construction of large and medium-sized projects that are under construction or proposed to be constructed, and implement in an all-round manner the system for approval of soil erosion control scheme for those development and construction projects. The declaration rate and approval rate of the soil erosion control scheme meet the requirements of relevant regulations. Carry out supervision, inspection and acceptance of the implementation of soil erosion control scheme.

3) Plan for Demonstration and Promotion of Technologies for Soil Erosion Control and Soil Improvement

Carry out demonstration and promotion of technologies for soil erosion control and soil improvement from six aspects, i. e. technology for transforming slope into terrace, technology for control of agricultural non-point source pollution, technology for rapid restoration of vegetation in ecological degradation area, technology for comprehensive configuration and construction of biological embankment and technology for comprehensive utilization of biogas.

7.3.5 Implementation Opinions

In the planned area of the Magdalena River, 80.86% of the land is suffering soil erosion at different degrees, affecting water quality of the Magdalena River, fishery and wetland biodiversity to a certain extent. In accordance with the current situation of soil erosion and its control as well as utilization and protection requirements of land resources in the planned area, key preventive area and key treatment area for soil erosion are identified in the plan. Besides, according to the principle that there is similarity in natural conditions, soil erosion characteristics and social & economic conditions, that production development trend, afforestation method and preventive measure are basically consistent, and cluster development, the planned area is divided into 6 soil erosion control and afforestation planned areas. Based on the specific conditions of each area, corresponding soil erosion control and afforestation plan are proposed, including comprehensive treatment measures and plan, e.g., preventive & protective measures by closing hill for afforestation, management of small river basins and ditches, pond regulation, flood control works, industrial structural adjustment and supervision enhancement. When soil erosion control plan is made, economic benefits brought by afforestation are considered. According to ecological site conditions and land utilization trend of the six areas, corresponding afforestation plans, supervision and technical demonstration & promotion plans, and plan suggestions on forest carbon-sink are put forward.

Due to implementation of soil erosion control plan, 863,712 ha of slope farmland can be used to grow crops; 282,895 ha of slope farmland can be used to grow fruits; 4000ha of regional ecological system and water source protection forest can be recovered from 247,781 ha of forests converted from farmland (grazing land); 20000ha of economic forest, 700km of river bank protection forest, and 1300 km of gallery forest along river banks can be planted, with planned afforestation area being 303,385ha in total. In this way, economic benefits of commercial forest and forest carbon-sink benefits can be obtained in due time.

Through overall consideration of the above planned items in aspects of helpfulness in achieving basin plan objectives, cooperation willingness of landowners, community acceptance, basin position, partnership opportunity, attraction to public, traffic convenience of construction site, value of habitat, and community benefits such as recreation & education provided by the project and development of surrounding areas, the items to be implemented in the near future are put forward, as shown in Table 7.3.5 and Fig. 7.3.5.

Table 7.3.5 Items to Be Implemented in Near Future

Item Nature	Whether Economic Benefits can Be Generated	Item Generating Economic Benefits	Venue	Effect	Reasons to Recommend
I. Control of soil erosion and afforestation	√	Demonstration project for management of small river basins	MORALES city of BOLIVAR Department	Forest coverage rate of the area is recovered to the level in 1970s, and ecological environment is significantly improved.	In Magdalena River Basin, different tributaries and river systems are greatly different in economic and social conditions, therefore, difficulty and measure combination for soil erosion treatment are diversified, and thus, treatment should be conducted with small river basin as a unit. Since MORALES city of BOLIVAR Department is suffering serious soil erosion, demonstration treatment should be conducted firstly.
	×	Control and monitoring of soil erosion	Estuary in BARRANQUILL Department, Buena vista city of BOLIVAR Department, HONDA city of TOLIMA Department, and PITALITO city of HUILA Department.	By collecting environmental basic information on the basin and building information zed infrastructures, effective environmental monitoring system is established.	The selected monitoring and control points represent 4 different types of control areas of soil erosion.
	√	Construction of gallery forest along river banks	Main stream of Magdalena River in MAGANGUE city, BOLIVAR Department.	30m-wide gallery forest along both banks of the main stream of Magdalena River in MAGANGUE city and the nearby areas is restored, and erosion on bank zone of main stream is greatly controlled.	BOLIVAR Department has the longest shoreline of Magdalena River. Shoreline in MAGANGUE city has poor scouring resistance capacity, river regime is unstable and investment in regulation of river course is low, therefore, development conditions of riparian zone can basically represent the whole riparian zone conditions of Magdalena River.

Table 7.3.5(continue)

Item Nature	Whether Economic Benefits can Be Generated	Item Generating Economic Benefits	Venue	Effect	Reasons to Recommend
I. Control of soil erosion and afforestation	√	Recovery of mangrove forest	Riparian zone in ATLÁNTICO Department and MAGDALENA Department.	By carrying out study on impact of river-ocean system connection and salinity change of wetland on mangrove forest, and rationally connecting water systems, a certain area of mangrove forest can be recovered.	On the right bank of marine outfall in Barranquilla, there is a large mangrove wetland with relatively obvious habitat change due to refresh water inflow through river system; besides, the Ciénaga Grande is the key wetland under protection of international convention, and thus it belongs to key protection region.
	√	Commercial plantation	AIPE city of HUILA Department	By planting eucalyptus globules, nagkassar, ceiba and other economic trees, commercial forest reaches an area being about 50000ha.	The area is located in key soil erosion treatment area at the upper reaches of the Magdalena River, with main soil types being upland soil and hilly soil, which are suitable for developing commercial plantation.
	√	Penned livestock	PURIFICACION city of HUILA Department	The production mode, in which land is intensively used for penned livestock, is promoted, to reduce grazing land occupation and dependency on land, and increase vegetation coverage.	In Colombia, HUILA Department is the main agricultural production area and grazing area, which is facing with serious deforestation for animal husbandry currently.
II. Replacement with or transformation of clean energy	√	Replacement with or transformation of clean energy	AMBALEMA city of TOLIMA Department	The mode of using firewood as major energy of daily life is improved, to reduce deforestation and forest destruction, and control ecological environmental destruction and soil erosion.	In AMBALEMA city of TOLIMA Department, soil erosion is serious. Currently, residents in the area use firewood as main energy of daily life.
III. Flood control and bank protection works	√	Flood control works	17 cities and towns, including Pinillos and Magangu	Structural measures, such as artificial curve cutoff, widening of waterway bottleneck, building of embankment works and bank protection works, are taken to improve flood control system in the area, enhance scouring resistance capacity of river bank, prevent bank slump and reduce sediment into the river.	Some of the 17 cites and towns including Pinillos and Magangu, are provided with dikes and flood walls for local protection. However, there is no unified standard and the works are simple, thus closed protection ring is not shaped and flood control capacity is limited.

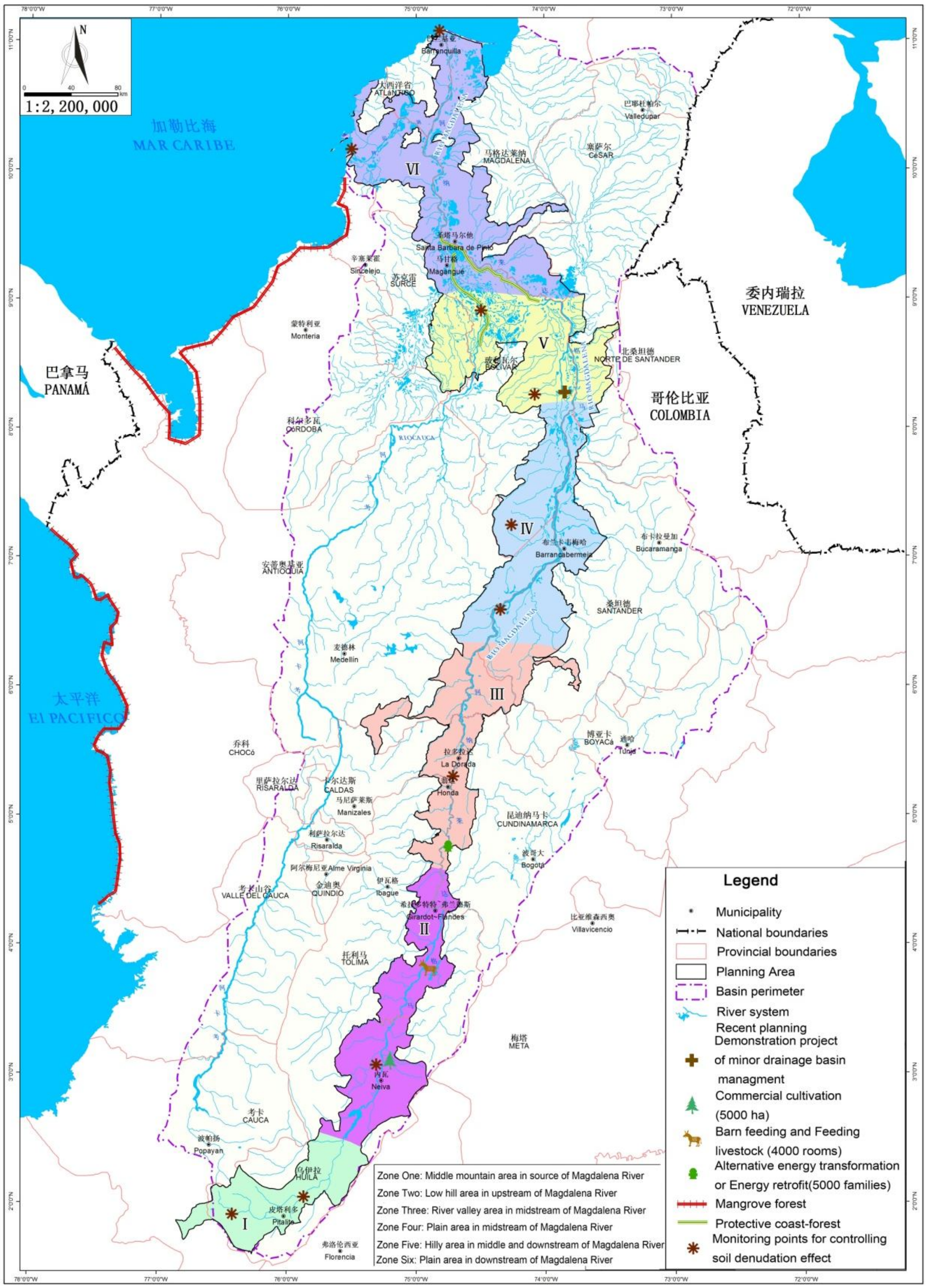


Fig.7.3.5 Layout of Items to Be Implemented in Near Future in Soil Erosion Control and Afforestation Plans

7.4 Environmental Monitoring Planning

Monitoring network should be established to collect and monitor information on water environment, water ecology and soil erosion control in real time regularly or irregularly. Construction of existing monitoring stations should be strengthened and modernized testing equipment should be provided to constantly improve monitoring capacity.

7.4.1 Water Quality Monitoring

Environmental monitoring system should be improved as soon as possible, involving positioning function, structural system, personnel, quality guarantee and update of equipment, operation mechanism and funds guarantee, and the monitoring sections that must be monitored to ensure water quality of Magdalena River should be identified. Industrialization development of environmental monitoring should be promoted, capacity of automatic environmental monitoring should be strengthened, and online automatic monitoring should be adopted for major water area.

According to influx of water system & pollution source distribution, current situation and control objectives of water quality of the river, and boundary between provincial administrative regions, 13 water quality control and monitoring sections are preliminarily identified in the plan, as shown in Fig. 7.4.1. It is recommended to intensify monitoring sections in the next step according to water environment quality of the basin.

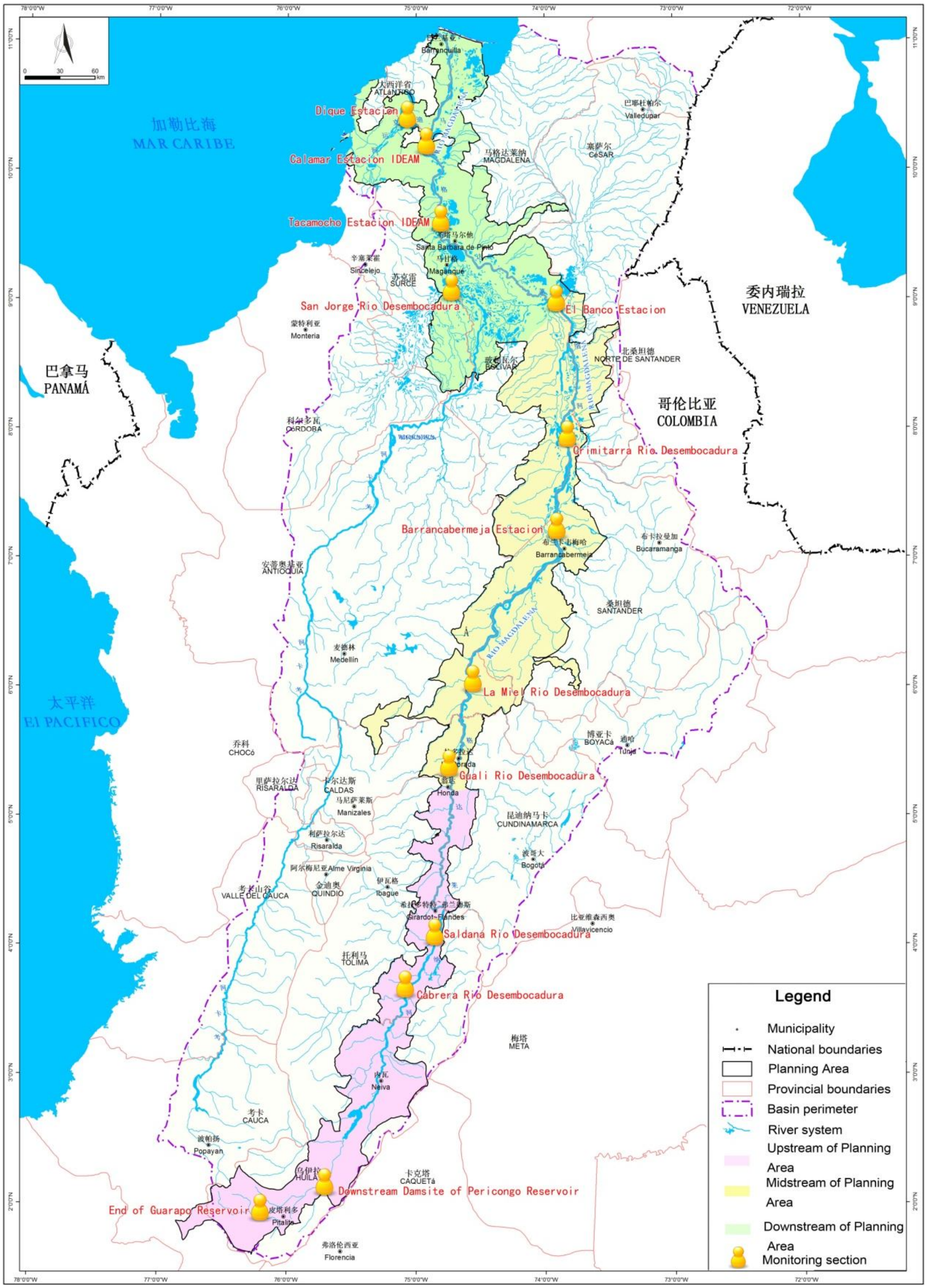


Fig. 7.4.1 Distribution of Surface Water Quality Control and Monitoring Sections in Planned Area

7.4.2 Aquatic Ecology Monitoring

In order to correctly assess the impact of the plan and project implementation on water ecology, it's planned to take following measures:

a) Carry Out Aquatic Ecological Investigation & Monitoring and Establish Study System in Due Time

CORMAGDALENA should establish a water ecology monitoring and study center and a long-term dynamic monitoring system for the whole river basin and formulate a systematic water ecology study plan. In the planned area, aquatic organism monitoring sections should be set in line with the same the water quality control sections, as shown in Fig. 7.4.1. Monitoring should be carried out four times each year, and a monitoring assessment report should be submitted at the end of each year.

b) Establish Aquatic Ecological Protection and Supervision System

Sort out national laws and regulations related to aquatic ecological protection systematically, prepare corresponding implementation rules specific to the actual demands of water ecology protection for the river basin, and perfect the law and regulation system.

Law enforcement agencies and teams for protection and supervision of fishery resources should be established and improved to enhance law enforcement capacity. A master station for aquatic ecological protection and supervision should be set in the headquarter of CORMAGDALENA, and one substation be set in Neiva, Girardot, Honda, El Banco, Magangue, Calamar and Barranquilla, respectively. Each substation should be provided with sufficient law enforcement administrators and some law enforcement facilities including vehicles, ship & boats and police equipment. During fish catching period, strict inspection should be conducted for fishing, supplemented by severe punitive measures and publicity & education. A rapid response system for rescue should be established to timely cure, feed and release important fishes wrongly caught, injured, stranded and confiscated.

c) Implement Follow-up Assessment

Follow-up assessment should be conducted for impact of implementation of cascade hydropower development plan on important fishery resources and artificial breeding & releasing result, besides, protection of and study on important fishery resources should be strengthened.

7.4.3 Soil Erosion Monitoring

Soil erosion monitoring mainly involves surface soil erosion intensity, vegetation coverage & type change, soil improvement and economic benefits of crops, sediment load at typical sections of the Magdalena River. 10 monitoring points are set, and their distribution is shown in Fig.7.4.3.

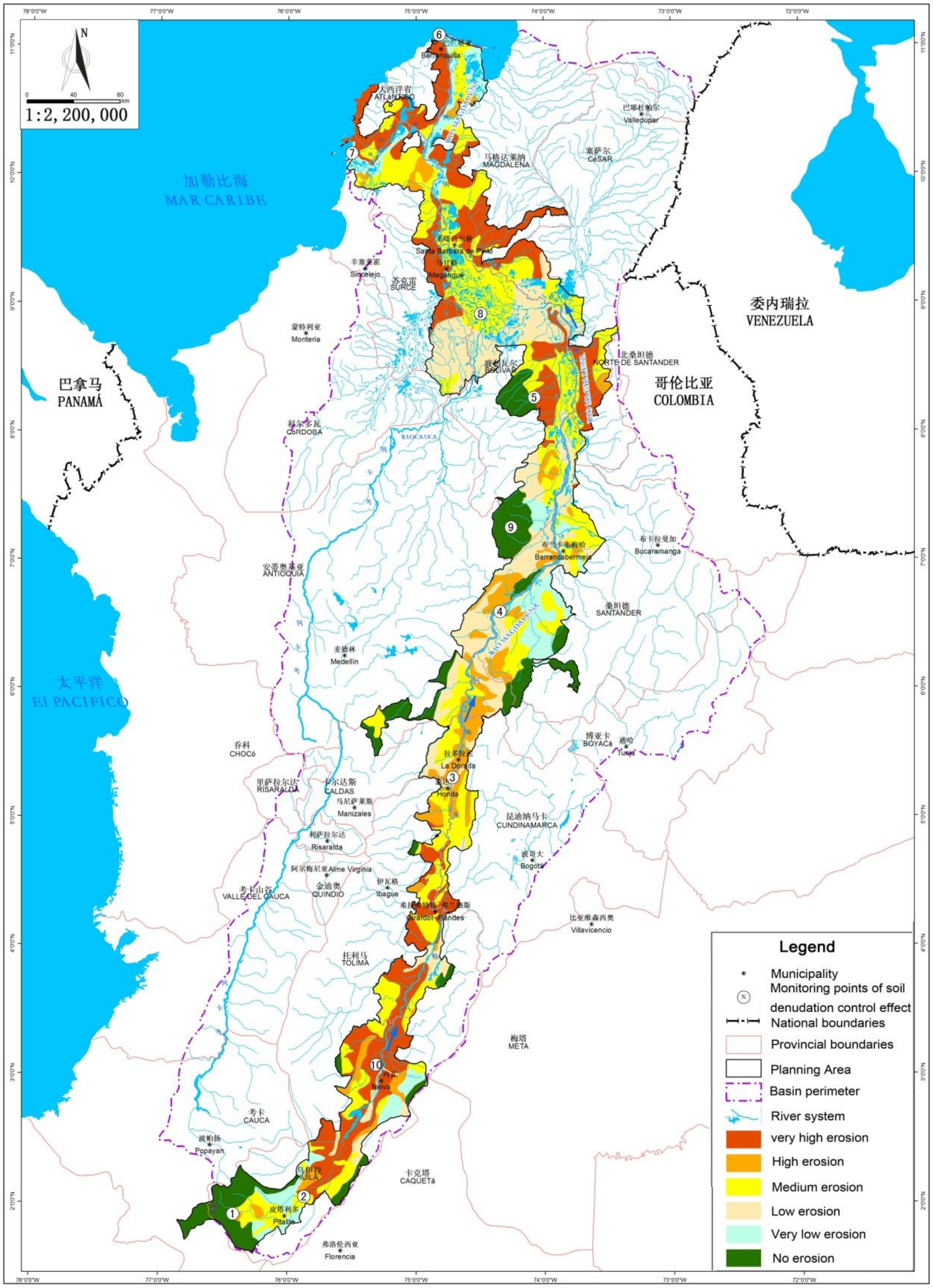


Fig.7.4.3 Current Situation of Soil Erosion in Planned Area and Layout of Control Effect Monitoring Points

8 Other Plannings

8.1 Flood Control Planning

8.1.1 Current Situation and Existing Problems

8.1.1.1 Floods and Flood Disasters

a) Floods and Food Compositions

Floods of the main stream of the Magdalena River mainly occur between April and June and between October and December. The floods occurring at the middle and lower reaches of the Magdalena River between October to December are generally stronger than that occurring between April and June. The peak discharge and the increment of flood volumes at certain time interval at the reaches close to Honda as well as the middle reaches from La Dorada to Berrio are relatively high and the duration of floods is longer, which causes relatively serious impact on the disastrous floods in the area along the middle and lower reaches of the river. The average maximum annual flood peak discharge over years of the river reach upstream of Betania Reservoir is smaller, with short duration and larger water yield per unit area, but it has just a slight influence on the downstream floods. The peak discharge and flood volume of the CAUCA River generally account for 34.6% and 31.4% of that in the lower reaches respectively and the duration of flood is usually between 20 to 40 days, which causes a considerable adverse impact to the lower reaches. Floods occurring at the lower reaches are not strong and the main sources of flood disasters are floods at the middle reaches, from the CAUCA River and floods hitting simultaneously. The longer duration of floods, disasters would bring about severe flood disasters to the lower reaches.

1) Spatial Compositions of Floods

The maximum average annual flood peak discharge of the upper reaches is 3,579 m^3/s (taking the Arrancaplumas Station as an example), which accounts for some 30.4% of that at the lower reaches (Calamar Station); the year-to-year maximum average monthly flood volume is 4.45 billion m^3 in May (4.11 billion m^3 November respectively), which is about 16.5% of that at the Calamar Station. The maximum average annual flood peak discharge of middle reaches is 6,340m ^{3}/s (taking the Penoncito Station as an example), which is about 53.8% of that in Calamar Station; the maximum year-to-year average monthly flood volume is 14.95 billion m^3 (November), which is about 55.4% of that at the Calamar Station. The maximum average annual flood peak discharge of the Cauca River is 4,076m^3/s (taking the Las Varas Station as an example), which accounts for about 34.6% of that at the Calamar Station; the maximum year-to-year average monthly flood volume is 8.49 billion m^3 (November), which is about 31.4% of that at the Calamar Station. The maximum average annual flood peak discharge of the lower reaches is 11,780m^3/s (taking the Calamar Station as an example) and the maximum mean monthly average flood volume is 27 billion m^3 (November). Refer to Table 8.1.1-1 for flood percentages at the upper, middle and lower reaches.

As shown from the table, the controlling staion of Cauca River accounts for 22.9% of the total catchment area but contributes 31.4% of the total flood volume. The interval catchment area between controlling stations on the middle reaches accounts for 33.1% of the total catchment area but gathers about 38.9% of the total flood volume, and the interval catchment area (Excluding the Cauca River Basin) between controlling stations on the lower reaches accounts for 22.8% of the total catchment area but contributes 13.6% of the total flood volume. Among them, floods from the middle reaches and the Cauca River have considerable influence on the floods in the lowe reaches.

Table 8.1.1-1 Statistics of Flood Characteristic Values Measured at Controlling Stations of Different Reaches

Reaches	Catchment Area of Controlling Station		Year-to-Year Average Annual Flood Peak Discharge		Maximum Year-to-Year Average Monthly Flood Volume	
	km^2	%	Discharge (m^3/s)	Percentage (%)	Flood volume (billion m^3)	Percentage (%)
Upper reaches	54,359	21.1	3,579	30.4	4.45	16.5
Middle reaches	139,657	54.2	6,340	53.8	14.95	55.4
Lower reaches	257,438	100	11,780	100	27.0	100
Cauca River	59,013	22.9	4,076	34.6	8.49	31.4

2) Typical Year Flood Compositions

Different reaches of the main stream had big floods in different years including 1975, 1984, 1996, 2010 and 2011.

The 2011 flood had the largest flooded area in recent years. The flood at El Banco Station lasted for 86 days with a discharge over 6500 m^3/s, and a peak discharge of 7900m^3/s , which was equivalent to a five-year flood; and the peak discharge at Calamar Station was less than that of a 20-year flood

The 2010 flood was also a larger flood in recent years. Its peak discharge was 7,900m^3/s at EL BANCO Station (equivalent to a 5-year flood), and 16,500m^3/s at Calamar Station (equivalent to a 20-year flood).

The 1996 flood was the measured largest flood in the Cauca River Basin, and its peak discharge at Las Varas Station was 4800 m^3/s, equivalent to a 25-year flood.

The 1984 flood was the largest flood measured at El Banco Station with a peak discharge of 9700 m^3/s, equivalent to a 30-year flood.

The 1975 flood was the largest flood measured at Calamar Station with a peak discharge of 16,900 m^3/s, equivalent to a 40-year flood.

The 1984 and 1996 floods had a peak discharge of 13,700 m^3/s and 11,800 m^3/s respectively at Calamar Station, identical to or slightly higher than the mean annual peak flood discharge .

Refer to Table 8.1.1-2 for the max. 30d and 60d flood volumes measured at the representative stations of the upper reaches, middle reaches, lower reaches of Magdalena River and the Cauca River in 1975, 1984, 1996, 2010 and 2011. Refer to Figures 8.1.1-1 and 8.1.1-2 for the flood hydrographs at the representative stations.

Table 8.1.1-2 Statistics of Max. 30d and 60d Flood Volumes at Representative Stations of Different Reaches

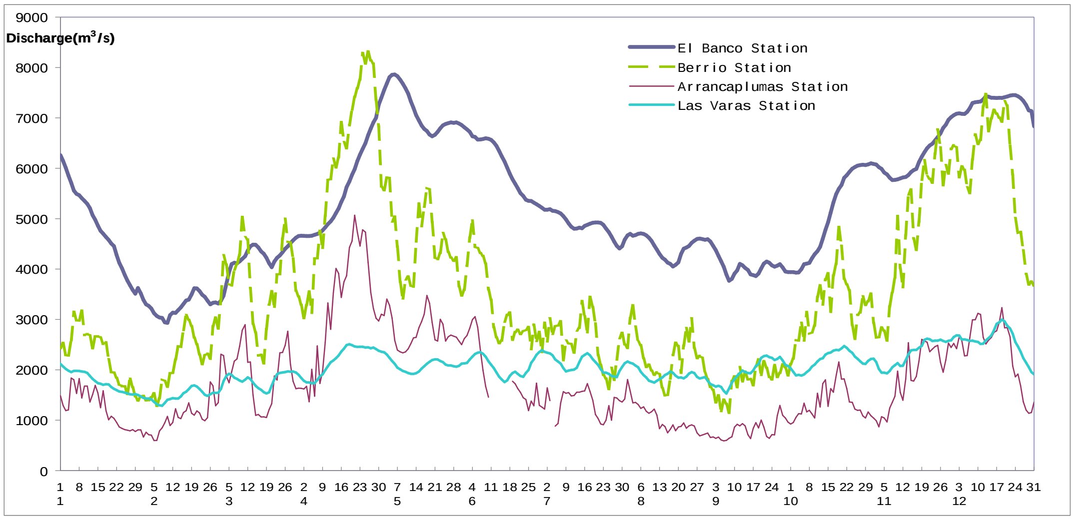
Reaches		Upper reaches	Middle reaches	Cauca River	Lower Reaches
Catchment area at controlling station	km^2	54,359	139,657	59,013	257,438
	%	21.1	54.2	22.9	100
Year 2011	30d	6.5 (8.4)	18.9 (18.6)	6.9 (6.0)	
	60d	11.1(16.3)	35.0(35.5)	12.8 (11.5)	

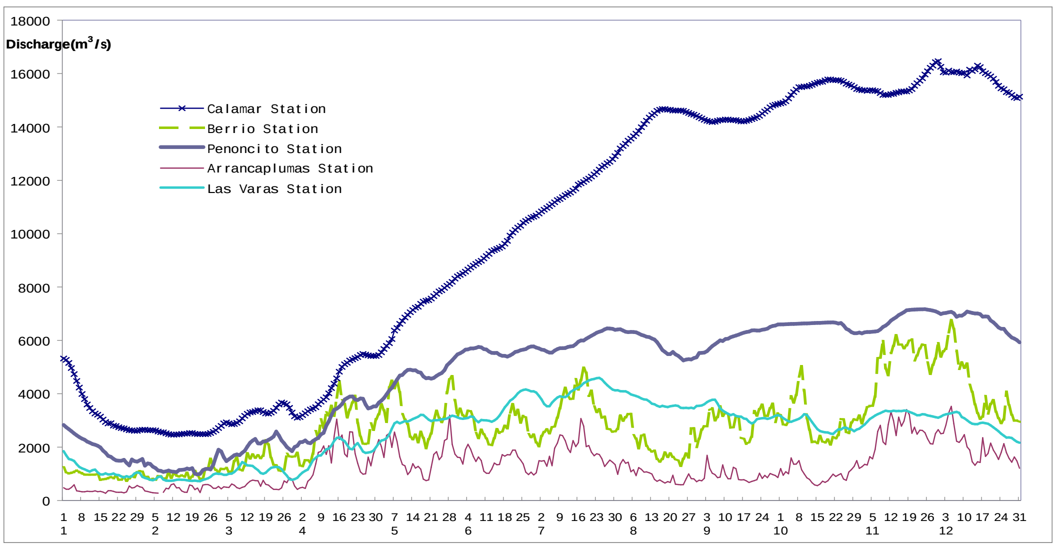
Table 8.1.1-2(continue)

Reaches		Upper reaches	Middle reaches	Cauca River	Lower Reaches
Year 2010	30d	4.8	16.2	10.9	41.6
	60d	9.0	30.9	20.8	81.6
Year 1996	30d	5.9	15.6	11.1	29.9
	60d	9.9	30.9	21.0	57.6
Year1984	30d	6.3	18.3	10.1	34.4
	60d	11.2	35.2	19.4	65.9
Year 1975	30d	6.3	28.2	11.5	42.3
	60d	13.4	53.8	22.3	79.9

Notes: 1) Unit of flood volume: billion m^3.

2) The figures out of the brackets in Year 2011 are for the second wet period (from October to December), and those in the brackets are for the first wet period (from April to June),





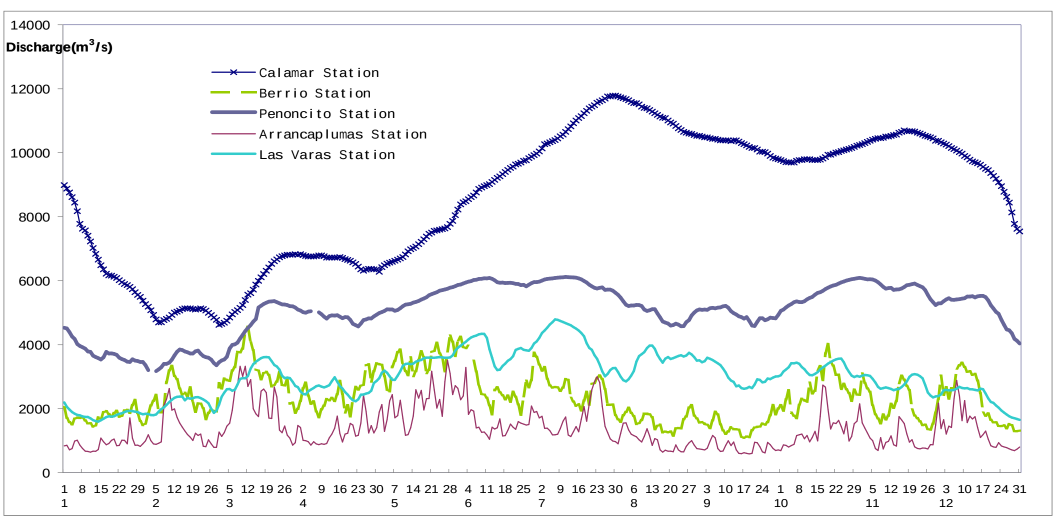
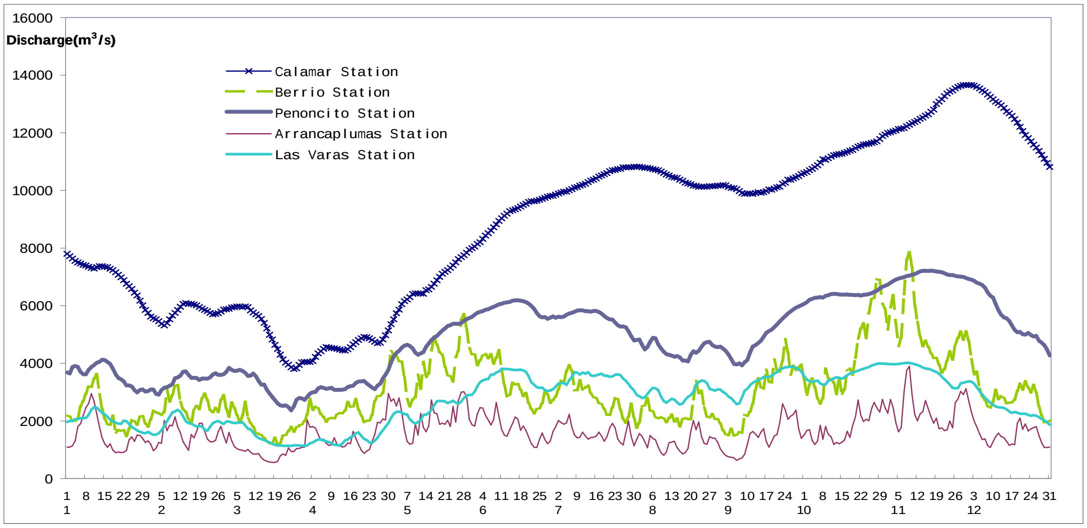


Fig 8.1.1-1 Flood Hydrographs at Gaging Stations of Different Reaches in 2011 (Upper Reaches), 2010 (Middle Reaches) and 1996 (Lower Reaches)



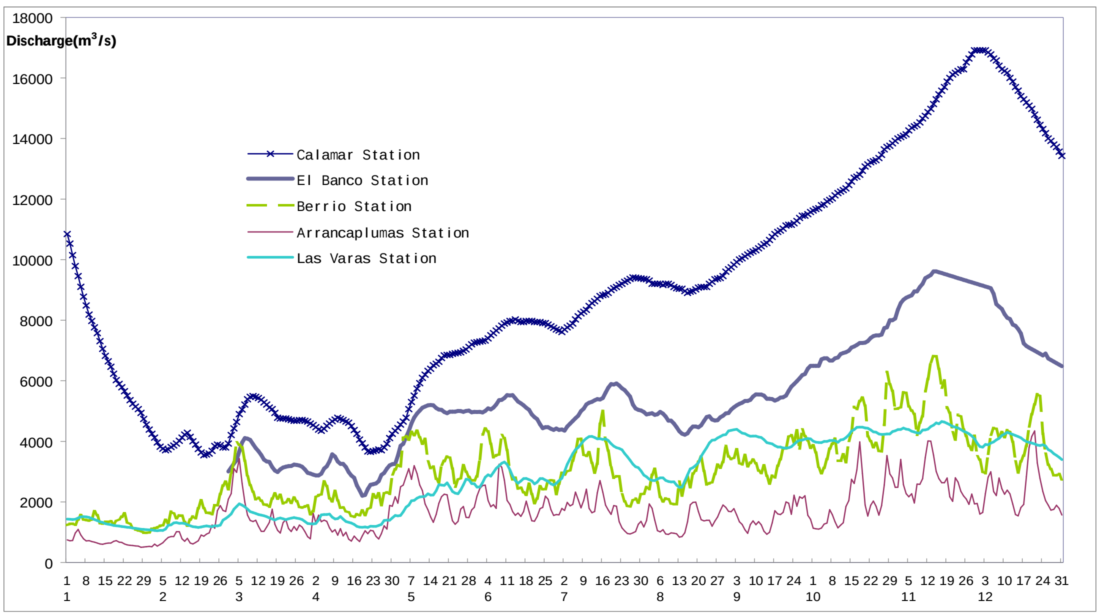


Figure 8.1.1-2 Flood Hydrographs at Gaging Stations of Different Reaches in 1984 (Upper Reaches) and1975 (Lower Reaches)

b) Flood disasters

1) Types and affected areas of flood disasters

The Magdalena River is a typical rain-fed river with abundant rainfall and there are two rainy seasons in the riverbasin downstream of the Betania Reservoir. Floods in the basin are attributable to rainstorm, resulting in a vast area affected by flood disaster. flood disasters may occur where rainstorms and floods passes. According to statistics, the area threatened by floods in the Magdalena Basin is about 14,700 km^2, including 99% in the area along middle and lower reaches which is the key area for flood protection. The IDEAM has classified floods in the Magdalena River Basin into high & low-speed floods by using the Froude number 0.5 as the demarcation line. The flood frequency zoning in the river basin is drawn and shown in Fig. 8.1.1-3 and sketches of range and extent of influence of low & high-speed floods are shown in Fig. 8.1.1-4 and Fig.8.1.1-5 respectively. According to the IDEAM research result and site reconnaissance, the high-speed floods, characterized by high peaks, heavy attack, short duration and scattering areas, mainly occur at the upper reaches and its tributaries. Besides, the high-speed floods may also bring about disasters such as bank caving, debris flow, and landslide that can cause casualties for human being and livestock. The low-speed floods mainly occur in the areas along middle and lower reaches. They flow over the river channel and spread to the broad valleys along the banks. Although the water level on the riverbed increases slowly, the flooding duration is long.

Table 8.1.1-3 Areas prone to flood disasters in the Magdalena River Basin (IDEAM)

Unit: ha

S/N	Department	City/Town	Affected Area	S/N	Department	City/Town	Affected Area
8001	Atlántico	Barranquilla	2,272	13473	Bolívar	Morales	54776
8137	Atlántico	Campo de la Cruz	9,945	13549	Bolívar	Pinillos	77390
8436	Atlántico	Manatí	12,126	13600	Bolívar	Ríoviejo	49869
8520	Atlántico	Palmar de Varela	4,319	13647	Bolívar	San Estanislao	8,677
8560	Atlántico	Ponedera	19,895	13657	Bolívar	San Juan Nepomuceno	4,656
8675	Atlántico	Santa Lucía	5,762	13670	Bolívar	San Pablo	29864
8758	Atlántico	Soledad	2,412	13744	Bolívar	Simití	46,724
47245	Magdalena	El Banco	47,866	13760	Bolívar	Soplaviento	6,592
47555	Magdalena	Plato	47,012	70265	Sucre	Guaranda	34,683
47745	Magdalena	Sitionuevo	25,212	70429	Sucre	Majagual	87,858
13006	Bolívar	Achí	90,065	70771	Sucre	Sucre	110,069
13042	Bolívar	Arenal	8,208	17380	Caldas	La Dorada	25,251
13074	Bolívar	Barranco de Loba	32,135	20011	Cesar	Aguachica	8,807
13140	Bolívar	Calamar	12,628	20295	Cesar	Gamarra	6,364
13160	Bolívar	Cantagallo	23,872	20383	Cesar	La Gloria	23,626
13001	Bolívar	Cartagena de Indias	1,957	20787	Cesar	Tamalameque	48,964
13188	Bolívar	Cicuco	12,417	68081	Santander	Barrancabermeja	62,326
13248	Bolívar	El Guamo	9,828	68190	Santander	Scimitar	97,157
13430	Bolívar	Magangué	74,471	68573	Santander	Puerto parra	28,420
13433	Bolívar	Mahates	12,683	68575	Santander	Puerto Wilches	95,508
13442	Bolívar	María La Baja	35,839	41001	Huila	Neiva	7,028
13468	Bolívar	Mompos	65,302	25307	Cundinamarca	Girardot	5,952

2) Flood disasters in recent years

Influenced by the El Nino and La Nina phenomena, the Magdalena River Basin has been hit by rainstorms in recent consecutive years. According to statistics, the flood occurred in September 2010 hit 28 of 32 departments across the country. In 2011, Colombia experienced the longest rainy season since 1974 with the Port Nare in the Antioquia Department being flooded by the continuous heavy rain starting from April. After that, the second rainy season of the year started in September and most cities and towns along the middle and lower reaches of the Magdalena River were affected. According to statistics, in 2011, the flood-stricken area under the Plan was 1,818 km^2 with a flood plain area of 1,353km^2 (accounting for 75.1% of the total). Refer to Figure 8.1.1-6 and Table 8.1.1-4 for the flooded area and refer to Figure 8.1.1-7 for flood-stricken sites. Floods occurred between 2010 and 2011 in the Magdalena River Basin made 3 million people homeless, 570,000 houses damaged, 813 schools and 15 health service centers affected. The economical loss exceeded 8.6 billion USD (cut to February 2011, IDB and ECLAC). In order to provide humanitarian aid to the flood-hit area and rehabilitate the damaged public facilities, the total budget from 2011~2014 accounts for about 3% of the GDP in 2011.

3) Causes for floods occurring in the areas along the middle and lower reaches

The direct cause for floods in the areas is the abundant rainfall attributed to the abnormal weather system, and the impact of natural geographical conditions in the riverbasin is another cause. From the aspect of watershed system of the Magdalena River, there are four tributaries of Sogamoso, Cesar, Cauca and San Jorge each with a drainage area of over 10,000 km^2 running into the middle and lower reaches. What's more, the 143 km-long reaches between El Banco and Magangue covers 3 tributaries (Cesar, Cauca and San Jorge) of the four and the 262.5 km-long reaches between Barrancabermeja and El Banco also covers some large tributaries such as Sogamoso, Cimitarra and Lebrija. As a result, the flood control situation becomes serious in rainy season in case of simultaneous occurrence of floods in the main stream and tributaries. From the aspect of terrain, the watercourse downstream of Salgar is getting wider and the land along the banks is already very flat at Barrancabermeja. Below El Banco is the alluvial plain of the Caribbean region with relatively gentle terrain, which is not good for flood discharge. The existing flood control system in the Magdalena River Basin is poor and incapable of storing and discharging flood. In addition, the flood storage and detention capacity in the basin has also been weakened by encroachment of lakes, marshes and wetlands due to human activity. It is predicted that with the social and economic development in the flood plain area, floods of the same magnitude would be more and more disastrous.

4) Characteristics for flood disasters occurring along the middle and lower reaches

The two banks and plain area along the middle and lower reaches of Magdalena River are key areas for flood control. There are 24 cities and towns along the middle reaches with a population of 830,000 and a farmland area of 1,364 km^2, accounting for 13.7% and 20.2% of the total population and total farmland under the Plan respectively; whereas there are 57 cities and towns along the lower reaches with a population of 3.92 million and a farmland area of 2,033 km^2, accounting for 64.6% and 30.1% of the total population and total farmland under the Plan respectively. There is dense river network below Barrancabermeja at middle reaches, and most of the area belongs to flood plains with no flood control facilities. Only partial protection is provided through construction of embankments and flood walls in urban and rural areas which are seriously threatened by flood. According to the analysis of the data of past several floods, the area along the middle and lower reaches affected by floods is large, mostly of flood plains. On the other hand, the floods along middle and lower reaches of Magdalena River are characterized by high volume, and the flood lasts for a long time with gentle fluctuating water levels along the banks. Due to very low height of embankments (within 2m in general), floods could not result in catastraphic losses. Although regional flooding and water logging occur every now and then, direct casualties are not serious. For example, the 2011 flood in the Magdalena River basin was very serious, but most of the casulties were caused by secondary disasters such as bank caving, debris flow and landslides. triggered by floods, and almost no casualties occurred due to direct flood disasters.

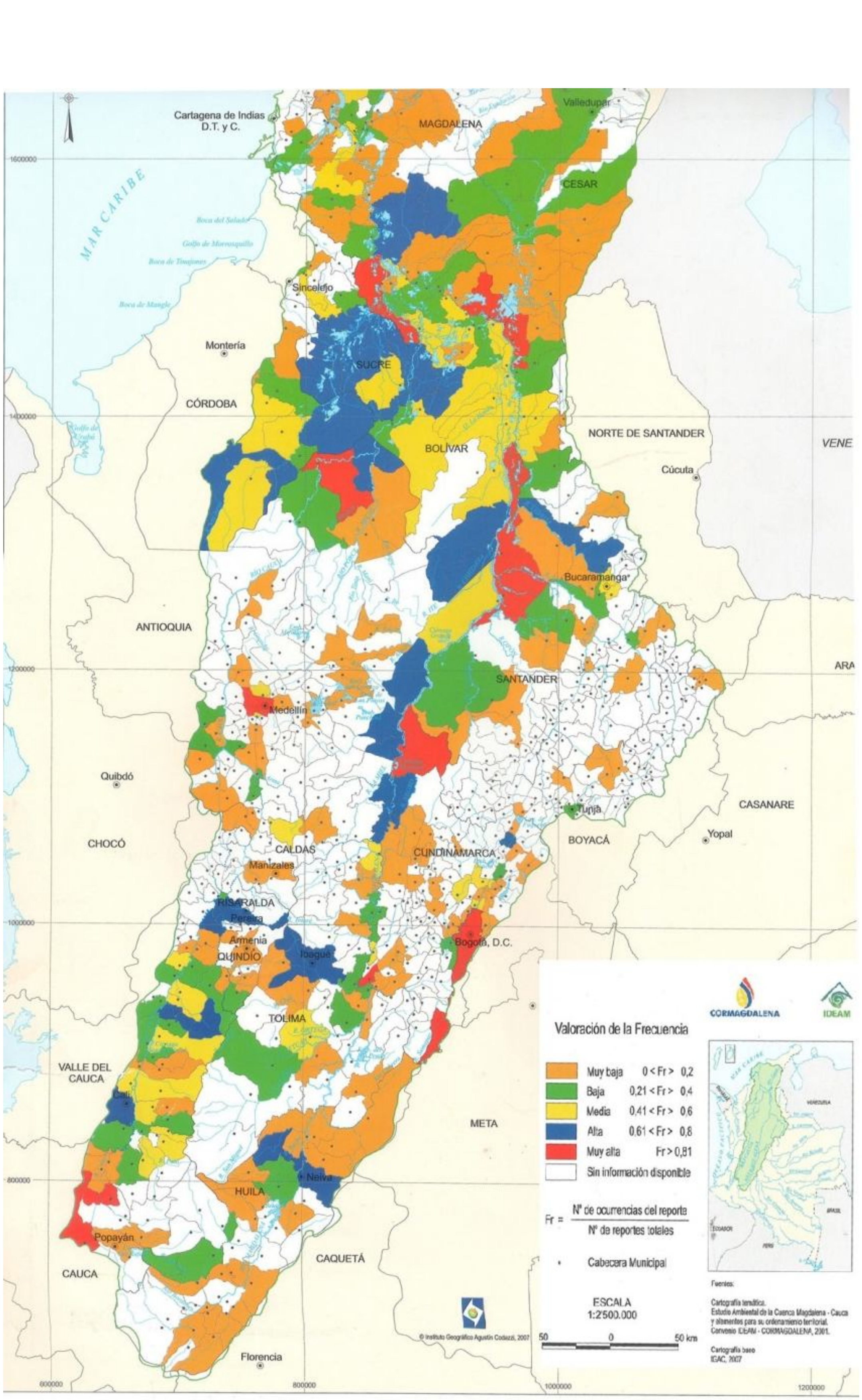


Fig 8.1.1-3 Flood Frequency Zoning in the Magdalena River Basin

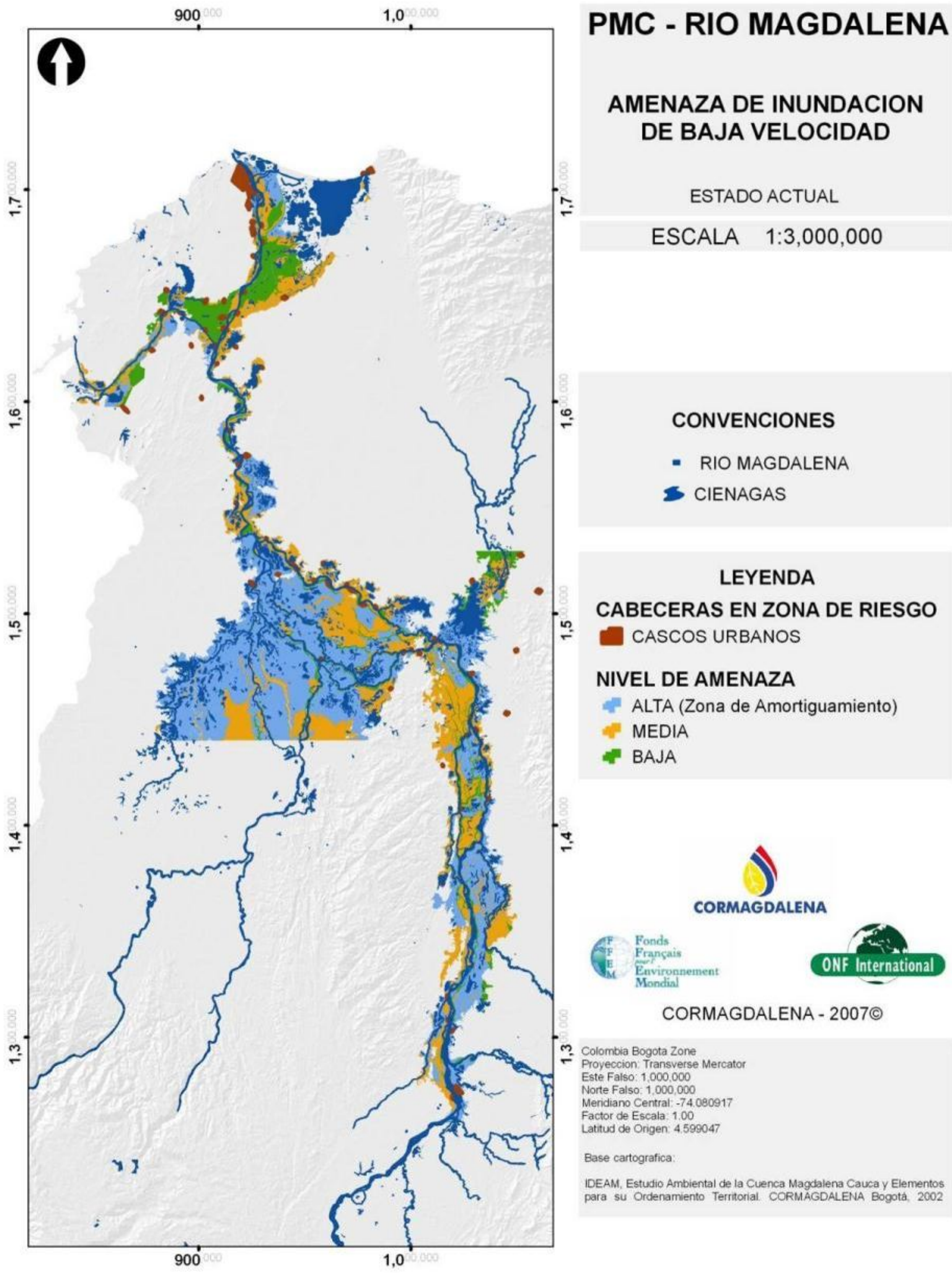


Fig 8.1.1-4 Range and Extent of Influence of Low-Speed Floods

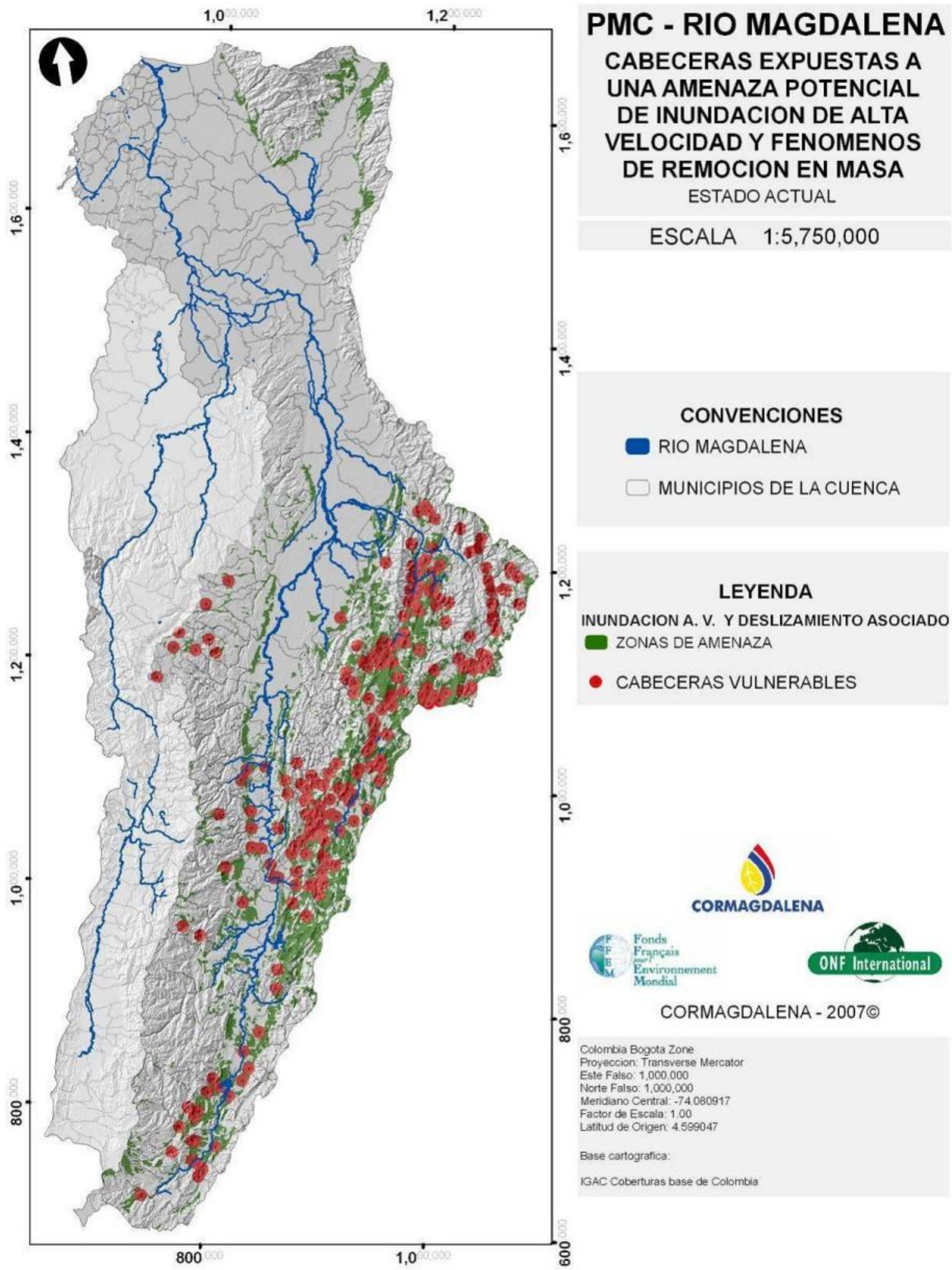
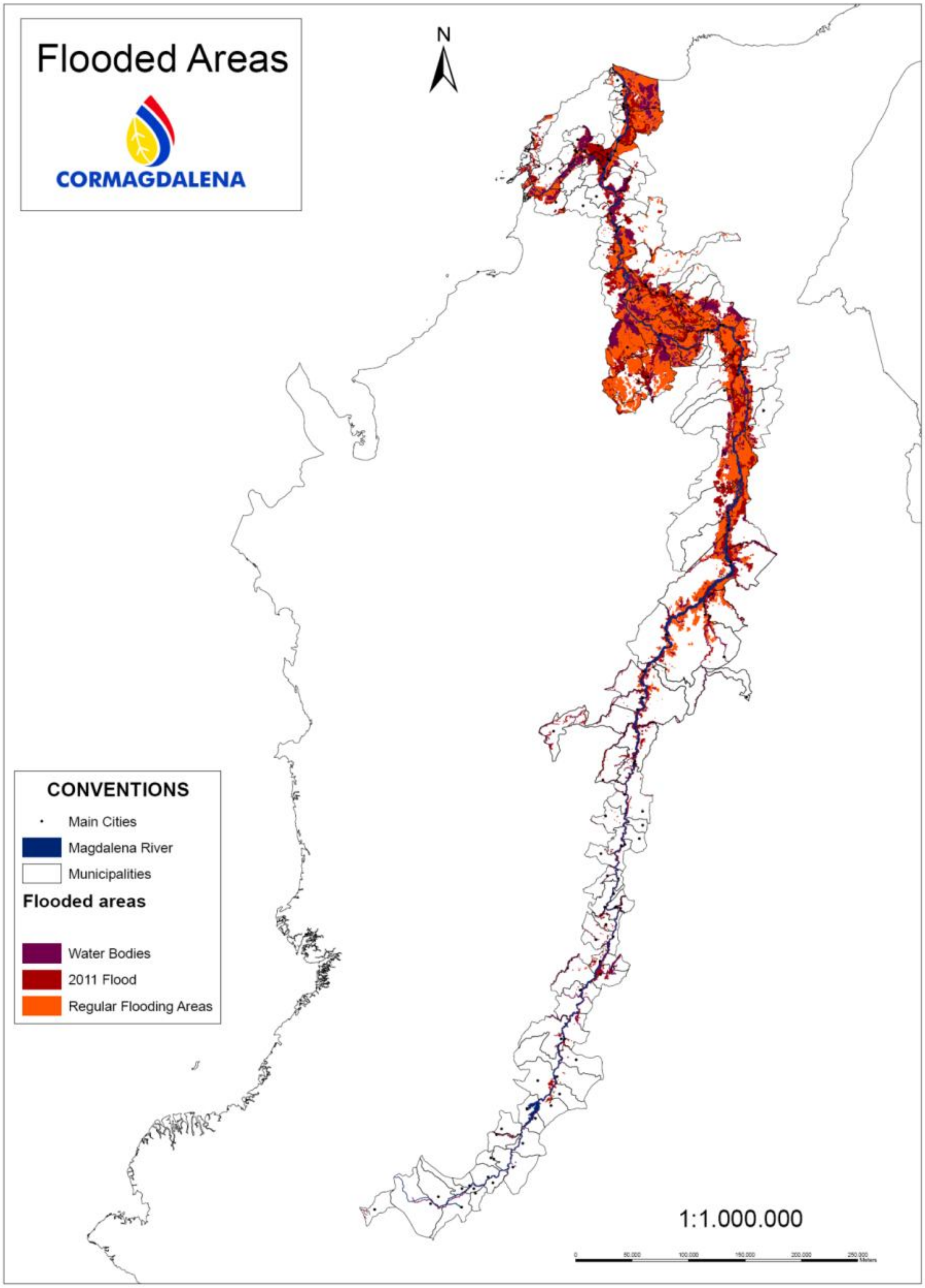


Fig 8.1.1-5 Range and Extent of influence of High-Speed Floods



Information Sources. Flooded areas May 2011- IDEAM

Fig 8.1.1-6 Flooded Areas under Cormagnalena due to 2011 Flood

Table 8.1.1-4 Floodes Areas under the Plan due to 2011 Flood (IDEAM) within Area in

Unit: ha

Department	S/N	City/Town	Affected Area			
			Natural flooded area	Agricultural area	Living area	Total
Antioquia	1	Puerto Berrio	786			786
	2	Puerto Nare	894			894
	3	Yondo	4064			4064
Atlántico	4	Barranquilla	597			597
	5	Campo de la Cruz		1559		1559
	6	Manatí			143	143
	7	Ponedera		2004	210	2214
	8	Repelón			101	101
Bolívar	9	Achí	6987		8909	15896
	10	Altos del Rosario	2513		9333	11846
	11	Arenal	81			81
	12	Arjona	10020	4		10024
	13	Barranco de Loba	81		1	82
	14	Cantagallo	2957			2957
	15	Cartagena de Indias	3054		81	3136
	16	El Peñón	3280			3280
	17	Hatillo de Loba	155			155
	18	Magangué			476	476
	19	Margarita	572			572
	20	María La Baja	4835			4835
	21	Mompos	186			186
	22	Morales	4360			4360
	23	Pinillos	4139		12954	17094
	24	Regidor	2041			2041
	25	Ríoviejo	2003			2003
	26	San Cristóbal	103			103

Table 8.1.1-4(continue)

Department	S/N	City/Town	Affected Area			
			Natural flooded area	Agricultural area	Living area	Total
Bolívar	27	San Estanislao			154	154
	28	San Fernando	74			74
	29	San Martín de Loba	996			996
	30	San Pablo	3093		158	3250
	31	Simití	15651			15651
	32	Soplaviento	7		188	195
	33	Talaigua Nuevo			55	55
	34	Turbana	218			218
Boyaca	35	Puerto Boyaca	358			358
	36	Tamalameque	95			95
Magdalena	37	Cerro de San Antonio		2419	37	2456
	38	El Piñon		2375		2375
	39	Guamal	44			44
	40	Pedraza		129		129
	41	Remolino	11604		41	11645
	42	Salamina	37	567		604
	43	Santa Ana	129			129
	44	Sitionuevo	10927	810	2408	14145
Santander	45	Barrancabermeja	2041	146		2187
	46	Scimitar	13192			13192
	47	Puerto parra	3053	3		3056
	48	Puerto Wilches	15227			15227
Sucre	49	Guaranda	3933			3933
	50	Majagual	549			549
	51	Sucre	1568			1568
Total			136504	10016	35249	181770

Fig. 8.1.1-7 2011 Flood-Stricken Sites

8.1.1.2 Current Situation of Structural Measures against Floods

A variety of structural measures against floods have been taken for many cities and towns along the Magdalena River. However, most of the flood control facilities were not well designed or constructed, thus having a very limited effect in flood protection. At present, the structural measures against floods along the Magdalena River mainly consist of the following:

a) Earth dikes and retaining walls. These structures are commonly seen in the areas along the middle and lower reaches.

b) Cement dikes. Very few cities/towns have cement dikes at a large scale, such as the dike at Boyaca Port.

c) An overall heightening of cities/towns. For instance, Armenia Village of Pinillos City often suffered from severe floods over the past. The foundations of major residential areas in the village were raised by 1.5 m with the help of the CORMAGDALENA in 2010 by laying sediment from desilting the Magdalena River. What was done made the village free from flooding in 2011.

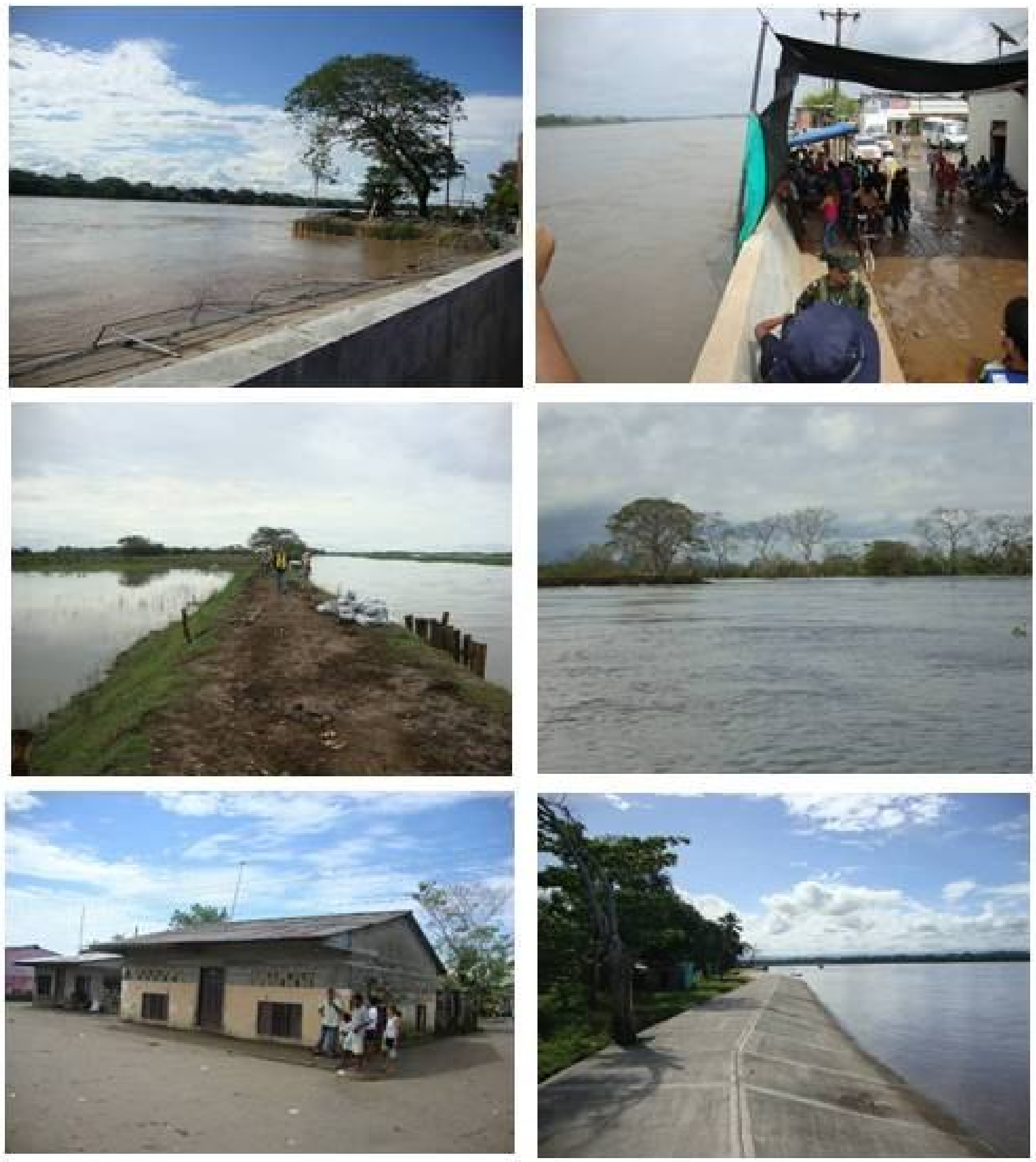


Fig. 8.1.1-8 Existing Flood Protection Works along the Magdalena River

At present, there are mainly two ways to decide the places for flood control projects in cities and towns along the river:

a) According to geographical locations of important areas that are closely related to the nation's development and people's livelihood or areas that were badly hit by floods in the previous year, implementation of flood control projects will start step by step by prioritizing from upstream to downstream;

b) The government will determine places for implementation of the flood control projects by thoroughly considering the reports of all affected regions of the year.

8.1.1.3 Major Existing Problems for Flood Control

a) High-speed floods and frequent mountain torrents take place in areas along the upper reaches and tributaries of the Magdalena River, which could easily cause casualties and property losses. However, flood control in these areas is just beginning with backward non-structural measures.

b) In rainy seasons, the volume of flood rushing to the middle and lower reaches of the Magdalena River often exceeds the volume for safe discharge. And during flood period, the water level rises greatly, overbanks, lasts for a long time and affect a large scope of areas. At present, there are no effective measures against such kind of low-speed flood.

c) Flood control safety has not been guaranteed in cities along the river banks. At present, there are no flood standards being practiced in Colombia and the flood control capability of these cities is generally fragile. Dikes and retaining walls are scattered, but most of them were designed or built with semi experience, and the flood control capacity is generally on the low side. As guard circles against flood have not been formed in most of the cities, flood threats are posed in case of big floods.

In general, an effective flood control system has not been established in the Magdalena River Basin. A lack of key flood control reservoirs on the mainstream and tributaries as well as regulation means result in poor capacity in flood control. At present, dikes and flood walls are the main structural measures along the banks of the Magdalena River, so their capability in flood control is very limited. And the non-structural measures against flood are only at its initial stage, so no depebdable countermeasures are available in case of big floods. In addition, neglect on scientific Plan and management as well as flood control safety in the flood plains would also indirectly increase the flood losses within the river basin.

8.1.1..4 Main Experience and Common Understanding

a) The rationale for development of key reservoirs should be further studied.

In the 1970s, a study on construction of flood control reservoir projects on the mainstream and tributaries for controlling floods occurring along the middle and lower reaches of the Magdalena River was conducted by a company in Holland. The reservoirs of Betania, Honda, Palmalarga, Sogamoso and Cauca Medio that were proposed to be built as that time were studied. These reservoirs controlled 45% of the catchment area of the whole basin and the proposed capacity of the reservoirs was 48 billion m³ in total. The main development tasks of all the reservoirs were for power generation. The study showed that when the reservoirs were also developed for flood cont4rol for the middle and lower reachess in addition to power generation, the flood control capacity was 19 billion m³ which could store 4% of the flood volume and reduce about 5% of the peak discharge of the flood coming from the middle and lower reaches with a flood frequency between 5% and 25%. In this way, the flooding time for the flooded areas along the lower reaches would be reduced from about 15 days to 7 days, the water level would be lowered by 0.2m, and the flooded area would be reduced by some 80,000 ha. If the capacity of all reservoirs were used for flood control without considering power generation, a volume of about 8% of floods with the corresponding frequency would be stored and some 9% of the peak discharge would be reduced. In this way, the flooding time for flood plains along lower reaches would be reduced from about 30 to 45 days to 15 to 30 days, the water level would be lowered by 0.3m to 0.4m and the flooded area would be reduced by some 120,000 to 85,000 ha. So, it can be seen that construction of key reservoirs on the mainstream and tributaries could reduce the flooding time and flooded area along the lower reaches due to their enormous flood control capacity.

However, there are two rainy seasons in areas along the middle and lower reaches of the Magdalena River every year, which can bring abundant rainfall and a flood duration over 45 days. By analyzing the data from gauging stations, the maximum average annual flood volumes at the middle and lower reaches from January to December are 14.95 billion m³ (El Banco Station) and 27 m³ (Calamar Station) respectively. The flood duration and high flood volume in the Magdalena River

Basin make it necessary for reservoirs to spare enough capacity in advance for flood storage and detention when the rainy season approches. According to analysis on landforms and site survey, Honda, a dividing point between the upper reaches and the middle reaches of the main stream of the Magdalena River, is probably the place for building a key reservoir complex. The maximum average annual flood volume at Honda dam site from January to December is 4.45 billion m^3. On the premise of not affecting the upstream cascade Girardot, Honda project may be designed to have a reservoir capacity of 13 billion m^3 and a regulation capacity of 8.9 billion m^3. After completion, it will effectively control the floods along the the upper reaches. However, from the aspect of flood composition, the maximum 30day flood volume at Hongda dam site only accounts for 27.5 % and 15.2% of the maximum 30d flood volume at the middle and lower reaches respectively, so the flood volumes at the middle and lower reaches are mainly caused by reach interval rainfall converging into the river. With water in tributaries below Honda converging into the river and an increase in the reach interval area, the role the Honda high dam plays in controlling and regulating floods at the middle and lower reaches will gradually become smaller. According to experience, the Honda high dam could, to some extent, reduce the flooded area and depth for cities and towns along the middle reaches. However, with the increase in distance from the Honda dam to the lower reaches, the flood control benefit for the lower reaches would not be obvious. Therefore, the rationale for developing a high Honda dam should be further studied in accordance with the social and economical development within the riverbasin.

b) Lakes, marshes and wetlands could play an important role in flood storage and detention.

There are a large number of lakes, marshes and wetlands at the middle reaches of the Magdalena River below Barrancabermeja. Especially in the Caribbean alluvial plain along the lower reaches, a large area of seasonal flood plain with shoals, water channels, lakes, marshes and wetlands systems are formed due to the low terrain. In rainy season, water flows over banks to filling the marshes and wetlands along the banks, which makes the water level in natural lakes connected to the marshes rise. In dry season, the water level in the Magdalena River goes down, and some water in the marshes and lakes returns to the Magdalena River. Like reservoirs, all lakes, marshes and wetlands along the Magdalena River could store and detain floods, flatten the hydrographs, weaken the flood damages and delay the floods from flowing to the lower reaches.

About 68% of all the natural wetlands in Colombia is within the Magdalena River Basin. The marshes, reeds and lakes are the natural media between land and water resources. The wetland has a strong capability of flood storage and its area also changes greatly. According to statistics, the average area of the natural wetlands along the Magdalena River is about 1,981 km^2 with a gap of more than ten times between rainy season and dry season. The water level in rainy season could exceeds that in dry season by some 5m in La Dorada, and 3m to 4m in Barrancabermeja.. On the long run, mashes, lakes and wetlands in the Magdalena River Basin could play a much more important role than artificial reservoirs in flood storage and detention, so restoring and reserving them in a natural way is one of the economically-feasible ways in the flood control system of the Magdalena River.

c) Dikes are effective ways for flood control

The dike projects are the most direct structural measures in flood control system by blocking floods out of protected objects. The flood control experience in many countries shows that dikes are regarded as a convenient and feasible way to protect their key flood control areas. At the middle reaches of the Magdalena River below Salgar, the river channel is getting wider and wider, with decreasing gradient and slower flow rate, so flood walls and dikes have been built along the river. According to statistics, by the end of 2004, 125 dikes have been built in areas along the middle and lower reaches of the Magdalena River, which have relieved flood threat for over 900,000 people living along the banks.

There are no key reservoirs for flood control on the main stream and tributaries of the Magdalena River, so the river channels, lakes, marshes and wetlands along the banks are the only means for flood storage and detention. Due to lack of flood control means, any extradinalry flood would flow over banks, threatening the cities and towns along the banks. It is somewhat difficult to implement such flood control measures as construction of reservoirs and flood storage and detention areas along the Magdalena River according to the natural geographical features and land attribute. In order to reduce flood damages, it is unavoidable to take flood protection measures and dike project is the most widely used measure for flood protection. Due to flat terrain, wide water surface, numerous lakes, marshes and wetlands, and low water level fluctuation (the difference in water level between a 2-year flood and a 100-year flood in cities and towns along the banks is in the range of 1.0 ~ 2.6m) along the middle and lower reaches, relatively low dikes can be effective jn retaining floods. It is economical and effective to build dikes in important cities and towns and protection areas along the banks.

d) Potential management benefits are considerable in the flood plains

In recent years, with the development of flood control,concept,higher and higher attention has been paid to the harmony between human and water in terms of flood control. Flood protection concept has been changed from initially controlling floods to adating to floods. Land is being developed scientifically and overall social and economical development framework is also being adjusted by a variety of managing measures taken in the flood plains in order to adapt to the law of floods and reduce flood damages. Due to low population density and rich land resources along middle and lower reaches of Magdalena River, the price paid for human actively avoiding floods would be low, Therefore, it is an important measure for flood control and disaster mitigation to strengthen the management of flood plains.

8.1.2 Flood Control Standards and Objectives

8.1.2.1 Development of flood control standards

a) Experiences of some countries in flood control standards

The flood control standard is directly related to the importance of protected objects and the severity and influence of floods, and the development level of the national economy. Most of countries have stipulated their flood control standards with Codes according to the necessities and possibilities. The current flood control standards stipulated by some countries are as follows:

1) China: The urban flood control standards are classified into four levels according to the social and economic significance and the population of cities. Extremely important cities are to resist a 200-year flood and above, and ordinary cities and towns are to resist a 50 to 20-year flood. The flood control areas in countryside are classified into four levels according to the population size and farmland area, the highest and lowest standards of flood control are a 100 to 50 year flood and a 20 to 10-year flood respectively. .
2) The USA: The flood control standard for big cities is a 100 to 500-year flood.
3) Japan: the flood control standard is a 200-year flood for extremely important cities, a 100-year flood for important cities, a 50-year flood for ordinary cities, and a 10 to 20-year flood for farmland.
4) India: The flood control standard is a 25-year flood for farming areas, and a 50 year flood for important cities and their suburbs.
5) Turkey: The flood control standard is a 10 to 20-year flood for farming areas, and a 100-year flood for industrial areas.

In view of the development of flood control standards of the countries above-mentioned, most of them have made their flood control standards according to local conditions and the social and economic development level. And these countries don’t settle the matter of flood control measures at one-go after the development of flood control standards. Instead, they make a relatively stable investment every year according to the nation’s financial capability and reach the objective step by step by putting the most important flood control area in priority.

b) Analysis on flood control standards for cities and towns along the Magdalena River

The flood control standards are the prerequisite and basis for formulating the flood control plan, choosing flood control measures and determining the scale of flood control projects. A flood control standard for the Magdalena River Basin is studied and developed on the basis of analysis and investigations since Colombia has not made its national flood control standard yet. The following factors should be taken into consideration when selecting the flood control standard for the Magdalena River: the position and role of the flood control areas in the national economy (the imporatance of cities and towns, the economic value and social influence, the population of cities and towns), the national economic development level and the available investment in flood control, the range and damage degrees of flooded areas, the natural conditions for flood prevention, the technical and economical conditions of flood control projects and the economic benefit of flood control projects.

According to the analysis on Colombia's demographic statistics, there are a total of 1,097 cities/towns in Colombia, including four cities of Bogotá D.C., Medellín, Cali and Barranquilla, each with a population over 1,000,000; 33 cities, each with a population ranging from 100,000 to 1,000,000; 263 cities, each with a population ranging from 10,000 to 100,000; and 797 cities/towns, each with a population below 10,000 (including 423 cities/towns, each with a population below 3,000). It is clear that the population distribution in Colombia is extremely uneven with a relatively larger amount of medium-sized and small-sized cities/towns. It is suggested that cities/towns in Colombia be divided into five categories of megacities, metropolis, medium-sized cities, small cities and towns according to the population criteria of one million, one hundred thousand, thirty thousand and ten thousand under the plan. And the cities/towns classified above account for 0.36%, 3.01%, 7.11%, 16.86% and 72.65% of the total cities/towns across the country. The flood control standards for cities/towns are developed in the plan in reference to the flood control standards of other countries and in consideration of the economic development stage of Colombia (refer to Table 8.1.2-1). In a similar way, the flood control standards for farming areas are developed in reference to the characteristics of scattered distribution of agricultural areas on medium and small scales in cities/towns in Colombia and the similar experience all over the world (refer to Table 8.1.2-2).

Table 8.1.2-1 Classes of Cities and Towns & Flood Control Standards

Classes of cities	Population size (person)	Flood Control Standard [recurrence interval (year)]
Megacities	≥1,000,000	≥100
Metropolises	1,000,000~100,000	100~50
Medium-sized cities	100,000~30,000	50~20
Small cities	30,000~10,000	20~10
Towns	＜10,000	10~5

Table 8.1.2-2 Flood Control Standards for Agricultural Areas

Classes of agricultural areas	Protected Farmland Area (ha)	Flood Control Standards [recurrence interval (year)]
□	≥30,000	50~20
□	30,000~10,000	20~10
□	10,000~3000	10~5
□	＜3000	＜5

There are 128 cities/towns under the plan. Statistics of population (as of 2010) and agricultural area of cities/towns is shown in Table 8.1.2-3. Percentages of all kinds of cities/towns and agricultural areas are shown in Fig.8.1.2-1. The flood control standards for all the cities/towns and agricultural areas are shown in Tables 8.1.2-1 and 8.1.2-2. It is pointed out that the flood control standards for all protected areas should be determined as per Table 8.1.2-1 in accordance with their importance, flood damage degrees, population size when a city/town is divided into several protected areas, or several cities/towns are combined into one protected area. For cities/towns locating in the hilly regions along the upper reaches of the Magdalena River, areas to be possibly flooded by floods of different magnitudes should be analyzed when there is a relatively big gap on elevations of the urban distribution. In this situation, the flood control standards should be determined as per Table 8.1.2-1 in accordance with the urban popu;ation in flooded areas and magnitude of flood damages. For cities locating on the plains and low-lying and lake districts along the middle and lower reaches of the Magdalena River, the flood control standards should be determined as the higher ones in Table 8.1.2-1.The flood control standards may be properly raised for countrysides with a dense population, developed economy and agricultural areas with high yields. The flood control standards may be properly lowered for agricultural areas with a sparse population and relatively smaller flooded areas and losses.. The flood control standards for the numerous pastures along the Magdalena River are proposed as a 2 to 5-year flood.

Table 8.1.2-3 Statistics of Populations and Agricultural Areas of 128 Cities/Towns under the Plan

S/N	Name of City/Town	Population	Urban Population	Non-urban Population	Area of Agricultural Area	River Reach
		Nr.	Nr.	Nr.	ha	
1	San Sebastián	13330	1148	12182	1321	Upper reaches
2	Villa Vieja	7338	2452	4886	5198	Upper reaches
3	Tello	13835	6152	7683	12550	Upper reaches
4	Aipe	22854	14255	8599	3779	Upper reaches
5	Neiva	330487	310902	19585	12953	Upper reaches
6	Rivera	17761	9874	7887	5663	Upper reaches
7	Campo Alegre	33361	25107	8254	15570	Upper reaches
8	Hobo	6762	5166	1596	1829	Upper reaches
9	Gigante	30664	16153	14511	10658	Upper reaches
10	Garzón	78642	37726	40916	18896	Upper reaches
11	Altamira	3934	2653	1281	758	Upper reaches
12	Elías	3610	1165	2445	1245	Upper reaches
13	Timaná	20155	7025	13130	7881	Upper reaches
14	Pitalito	113980	67568	46412	24636	Upper reaches
15	Palermo	29828	14179	15649	11739	Upper reaches
16	Yaguará	8364	7075	1289	1782	Upper reaches
17	Tesalia	9073	5173	3900	3323	Upper reaches
18	Paicol	5375	2228	3147	2659	Upper reaches
19	Agrado	8766	4980	3786	3147	Upper reaches
20	Pital	13249	4698	8551	7060	Upper reaches
21	Tarqui	16778	4697	12081	5754	Upper reaches
22	Oporapa	12104	3386	8718	3759	Upper reaches
23	Saladoblanco	10868	2495	8373	4572	Upper reaches
24	Isnos	25401	5325	20076	10327	Upper reaches
25	San Agustín	31299	10668	20631	9603	Upper reaches
26	Suárez	4534	2075	2459	1980	Upper reaches
27	Armero-Guayabal	12509	8689	3820	10752	Upper reaches
28	Ambalema	7249	5523	1726	13247	Upper reaches

Table 8.1.2-3(continue)

S/N	Name of City/Town	Population	Urban Population	Non-urban Population	Area of Agricultural Area	River Reach
		Nr.	Nr.	Nr.	ha	
29	Venadillo	19192	13846	5346	6962	Upper reaches
30	Piedras	5526	1693	3833	6520	Upper reaches
31	Coello	9370	1715	7655	3849	Upper reaches
32	Flandes	28592	24457	4135	7307	Upper reaches
33	Espinal	76405	57514	18891	21539	Upper reaches
34	Guamo	33628	16570	17058	21652	Upper reaches
35	Purificación	28601	16804	11797	16874	Upper reaches
36	Prado	8267	3397	4870	5927	Upper reaches
37	Coyaima	28120	4511	23609	4955	Upper reaches
38	Natagaima	22889	14543	8346	4731	Upper reaches
39	Guaduas	35018	17241	17777	5682	Upper reaches
40	Chaguaní	4021	771	3250	3331	Upper reaches
41	San Juan de Río Seco	9708	2893	6815	6805	Upper reaches
42	Beltrán	2065	393	1672	1392	Upper reaches
43	Guataquí	2549	1320	1229	1191	Upper reaches
44	Nariño	2140	1404	736	1046	Upper reaches
45	Girardot	101792	98318	3474	456	Upper reaches
46	Ricaurte	8771	3953	4818	2639	Upper reaches
47	Honda	26010	25190	820	136	Middle reaches
48	Puerto Salgar	17082	12662	4420	823	Middle reaches
49	La Dorada	75011	67581	7430	765	Middle reaches
50	Victoria	8832	3690	5142	1776	Middle reaches
51	Puerto Boyacá	52992	35959	17033	1491	Middle reaches
52	Puerto Wilches	31498	16429	15069	39843	Middle reaches
53	Barrancabermeja	191498	172778	18720	4405	Middle reaches
54	Puerto Parra	7007	3296	3711	2210	Middle reaches
55	Cimitarra	39249	15266	23983	6692	Middle reaches
56	Bolívar	13138	1368	11770	958	Middle reaches
57	Yondó	16788	8285	8503	2449	Middle reaches

Table 8.1.2-3(continue)

S/N	Name of City/Town	Population	Urban Population	Non-urban Population	Area of Agricultural Area	River Reach
		Nr.	Nr.	Nr.	ha	
58	Puerto Berrío	42829	38057	4772	797	Middle reaches
59	Sonsón	37116	15367	21749	8361	Middle reaches
60	Puerto Nare	17729	7296	10433	933	Middle reaches
61	Puerto Triunfo	18114	5453	12661	280	Middle reaches
62	Aguachica	87821	75383	12438	8678	Middle reaches
63	La Gloria	13760	6104	7656	10942	Middle reaches
64	Gamarra	15551	8656	6895	3160	Middle reaches
65	Morales	19718	5350	14368	6773	Middle reaches
66	Regidor	9592	3705	5887	5465	Middle reaches
67	Río Viejo	16708	7736	8972	5420	Middle reaches
68	Arenal	16994	4529	12465	1204	Middle reaches
69	Simití	19073	8163	10910	10769	Middle reaches
70	San Pablo	29893	25216	4677	8589	Middle reaches
71	Cantagallo	8477	3771	4706	3559	Middle reaches
72	Tamalameque	13988	5410	8578	5027	Lower reaches
73	Guaranda	16396	6122	10274	11390	Lower reaches
74	Majagual	32392	10110	22282	15293	Lower reaches
75	Sucre	22369	6966	15403	4529	Lower reaches
76	Sitio Nuevo	29515	14365	15150	3417	Lower reaches
77	Remolino	8434	5515	2919	1451	Lower reaches
78	Salamina	7690	4707	2983	2885	Lower reaches
79	El Piñón	16834	6022	10812	3723	Lower reaches
80	Cerro de San Antonio	8053	4295	3758	1337	Lower reaches
81	Pedraza	8016	2382	5634	1502	Lower reaches
82	Zapayán	8699	3466	5233	977	Lower reaches
83	Tenerife	12358	5890	6468	950	Lower reaches
84	Plato	53271	39651	13620	718	Lower reaches
85	Santa Barbara de Pinto	11828	6733	5095	1912	Lower reaches
86	Santa Ana	24468	12342	12126	3842	Lower reaches

Table 8.1.2-3(continue)

S/N	Name of City/Town	Population	Urban Population	Non-urban Population	Area of Agricultural Area	River Reach
		Nr.	Nr.	Nr.	ha	
87	San Zenón	8998	1540	7458	1816	Lower reaches
88	San Sebastián de Buena Vista	17362	5501	11861	1940	Lower reaches
89	Guamal	26206	7583	18623	3150	Lower reaches
90	El Banco	55012	34397	20615	3013	Lower reaches
91	Barranquilla	1186640	1182493	4147	0	Lower reaches
92	Soledad	535417	534735	682	220	Lower reaches
93	Malambo	111257	104758	6499	2595	Lower reaches
94	Sabanagrande	28421	27391	1030	491	Lower reaches
95	Santo Tomás	24636	23644	992	2978	Lower reaches
96	Palmar de Varela	24544	23829	715	1872	Lower reaches
97	Ponedera	20591	10536	10055	1280	Lower reaches
98	Campo de la Cruz	17512	15255	2257	1601	Lower reaches
99	Suán	9240	8865	375	1563	Lower reaches
100	Repelón	24427	16492	7935	4652	Lower reaches
101	Manatí	14751	13289	1462	1182	Lower reaches
102	Santa Lucía	12052	11035	1017	1250	Lower reaches
103	Cartagena	944250	899200	45050	1343	Lower reaches
104	Turbaná	14141	12915	1226	3457	Lower reaches
105	Arjona	66089	51937	14152	5394	Lower reaches
106	María La Baja	46477	19420	27057	12756	Lower reaches
107	Mahates	24231	9198	15033	11711	Lower reaches
108	Soplaviento	8342	8095	247	1430	Lower reaches
109	San Estanislao	15721	11399	4322	4668	Lower reaches
110	Calamar	21888	12143	9745	6089	Lower reaches
111	El Guamo	7758	4256	3502	3720	Lower reaches
112	Zambrano	11259	10171	1088	334	Lower reaches
113	Córdoba	12678	3245	9433	4747	Lower reaches
114	San Cristóbal	6598	5263	1335	841	Lower reaches
115	San Juan de Nepomuceno	32921	25135	7786	20594	Lower reaches

Table 8.1.2-3(continue)

S/N	Name of City/Town	Population	Urban Population	Non-urban Population	Area of Agricultural Area	River Reach
		Nr.	Nr.	Nr.	ha	
116	Magangué	122913	83504	39409	6423	Lower reaches
117	Achí	21211	3694	17517	9962	Lower reaches
118	Pinillos	23721	2532	21189	4142	Lower reaches
119	Altos del Rosario	12425	6686	5739	4568	Lower reaches
120	Barranco de Loba	16327	5498	10829	1980	Lower reaches
121	San Martín de Loba	15546	6552	8994	1271	Lower reaches
122	Hatillo de Loba	11681	3147	8534	2128	Lower reaches
123	Talaigua Nuevo	11190	5115	6075	1662	Lower reaches
124	Cicuco	11077	7189	3888	276	Lower reaches
125	Mompos	42618	24070	18548	1180	Lower reaches
126	San Fernando	13305	2828	10477	781	Lower reaches
127	Margarita	9535	1677	7858	897	Lower reaches
128	El Peñón	8552	3298	5254	2393	Lower reaches

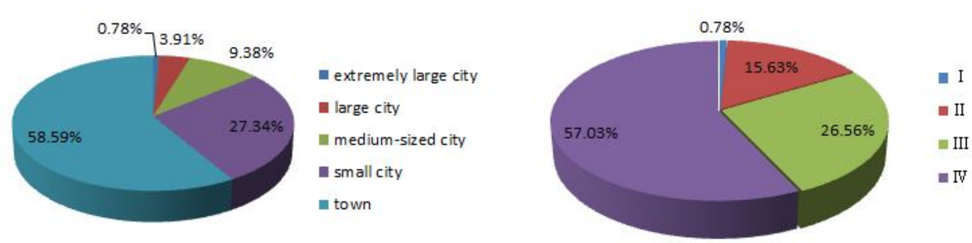


Fig. 8.1.2-1 Percentages of Cities/Towns and Agricultural Areas under the Plan

c) Characteristic values of floods of flood control standards

According to the analysis on the flood characteristics in Magdalena River Basin, the characteristic flood value for the flood control standard of cities and towns along upper reaches of Magdalena River can be expressed by peak discharge, whereas for areas along the middle and lower reaches, it is suggested to adopt the flood level. In the flood control plan, the design flood discharges and design flood levels of important hydrological stations along the Magdalena River are analyzed through the statistics from a long series of hydrological data from the important hydrological stations. Based on this, the design flood discharges and design flood levels of some cities and towns along the banks are speculated. For the results, see Tables 8.1.2-4 and 8.1.2-5.The final goal of flood control for the 128 cities/towns along the Magdalena River is to enable the cities/towns and agricultural areas to reach the corresponding flood control standards by taking a variety of flood control and disaster relief measures. That is, the safety of cities/towns can be guaranteed by correctly taking flood control measures when the actual flood frequency is not higher than the flood control standard.

It is a time-consuming process to build the cities/towns to achieve their respective flood control standards. And the flood control standards should be achieved gradually by the order of priority in accordance with the country's financial capability. The flood control standards should also be raised when the social and economic development of cities/towns have reached a certain level.

Table 8.1.2-4 Design Peak Discharges of Some Cities/Towns along the Upper Reaches of the Magdalena River Unit: m^3/s

City/Town	P=2%	P=5%	P=10%	P=20%
Neiva	3330	2900	2560	2210
Girardot	5900	5230	4700	4130
Honda	5990	5310	4770	4190

Table 8.1.2-5 Design Flood Levels of Some Cities/Towns along the Middle and Lower Reaches of the Magdalena River Unit: m.s.n.m

City/Town	P=1%	P=2%	P=5%	P=10%	P=20%	P=50%
La Dorada	172.8	172.63	172.38	172.17	171.93	171.51
Yondó	78.67	78.52	78.33	78.15	77.96	77.61
Barrancabermeja	76.15	76.01	75.82	75.65	75.46	75.12
Puerto Wilches	66.34	66.17	65.92	65.7	65.46	65.03
Aguachica	42.9	42.57	42.07	41.65	41.16	40.28
La Gloria	37.15	36.85	36.42	36.05	35.62	34.85
Regidor	35.93	35.73	35.43	35.13	34.83	34.23

Table 8.1.2-5(continue)

City/Town	P=1%	P=2%	P=5%	P=10%	P=20%	P=50%
Tamalameque	33.43	33.17	32.82	32.47	32.07	31.34
Peñón	30.38	30.14	29.78	29.44	29.03	28.29
El Banco	29.71	29.53	29.21	28.93	28.59	27.98
Guamal	23.95	23.7	23.34	23.03	22.67	22
Pinillos	22.45	22.19	21.92	21.65	21.33	20.74
Magangué	19.94	19.64	19.15	18.75	18.27	17.41
Plato	15.75	15.25	14.45	13.85	13.05	11.65
Calamar	9.75	9.48	9.04	8.66	8.21	7.4
El Piñon (Todosnovan)	8.4	8.16	7.77	7.44	7.04	6.34
Ponedera	6.11	5.92	5.62	5.36	5.06	4.53
Remolino	5.58	5.41	5.12	4.88	4.61	4.11
Malambo	4.4	4.25	4.01	3.81	3.58	3.18
Soledad	3.52	3.39	3.18	3	2.82	2.48
Barranquilla	3.07	2.95	2.76	2.6	2.43	2.13

8.1.2.2 Objectives of Flood Control Plan

This flood control plan has been made based on the relevant laws and regulations of Colombia by taking a combination of structural and none-structural measures and taking the non-structural measures as the principal thing in flood control. It follows the principles of overall plan, taking all factors into consideration, combining regulation with management in flood control. Besides, advice for flood control in the Magdalena River basin has also been put forward so as to improve the flood control system and to meet the needs of social and economic development. Following the human-nature harmony concept, relations between human beings and the nature should be correctly dealt with, such as giving way to floods and moderately undertaking risks brought by floods. Plan and coordinate the relations between flood control and the utilization of water resources, the relations between construction of flood control facilities and flood management. Regulating water according to the law and in a scientific way should be enhanced to improve the capabilities of flood control and disaster mitigation along the Magdalena River Basin. In order to provide safety guarantees and maintain a healthy river, major principles for flood control are given as follows:

a) Protecting the biodiversity of the Magdalena River and its natural environment while guaranteeing the safety of flood control..Minimizing the the negative effects of flood control projects.

b) According to the characteristics of floods and flood disasters of the Magdalena River, an overall arrangement addressing flood control at the upper, middle and lower reaches should be made and the areas along the middle and lower reaches should be treated as the key places.The proper flood control standards should be determined according to the social and economic development levels of cities/towns along the river by guaranteeing the key places and considering the ordinary ones. An overall arrangement of flood prevention should be made according to the analysis on the characteristics of floods and flood disasters in the upper, middle and lower reaches.

c) Combining the structural and non-structural measures together, adopting a variety of measures for integrated treatment and highlighting the overall function of the flood control system. Building and reinforcing dikes; improving the capabilities of flood and waterlog control of key cities/towns along the banks; removing sediments, enlarging bottlenecks and dredging channels to improve the flood discharge capability of river channels. Studying the operation mode of reservoirs built and to be built on the mainstream and tributaries and enhancing the reservoirs' capabilities of regulating and storing floods. Restoring and protecting the natural flood plains, improving the connectivity between rivers and lakes, and plan the flood storage and detention areas according to local conditions to improve the capability of flood storage and retention. Enhancing the establishment of flood forecasting and early warning systems, improving the ability in flood control management, scientifically plan the utilization and management of land and reducing flood losses as far as possible.

According to the principles set above, the flood control objectives are made as follows:

It is planned that a framework of flood control and disaster mitigation systems with the combination of structural and non-structural measures in which the latter being regarded as the principal thing should be preliminarily built by the year 2020. Efforts should be made that, in case of big floods, the economic activities and social life would not be damaged, the ecological environment would not be severly deteriorated, the sustainable development process would not be considerably disrupted, and casualties and property loss would be reduced.

It is planned that, by the year 2030, a flood control and disaster mitigation system compatible with the social and economic development in the basin should be preliminarily built, properly dealing with severe floods, enhancing the capabilities of flood control and alleviation, effectively controling high and low-speed floods and minimizing the human casualties and property losses.

8.1.3 Layout of Flood Control System

The framework of flood control and disaster mitigation systems for the Magdalena River Basin: the flood management guidelines of “reservoir regulation, lake storage, dike retaining and river drainage” should be be applied according to the natural conditions and the characteristics of floods and flood disasters. That is to say, for the upper reaches and the tributary areas, flood regulation capacity of existing reservoirs should be fully exploited, an appropriate number of new reservoirs should be constructed and flood regulation and storage capabilities should be increased to regulate floods and reduce the flood pressure of the middle and lower reaches. For areas along the middle and lower reaches, the connectivity between rivers and lakes should be improved, natural flood storage and detention areas should be restored and expanded, an appropriate number of new flood storage and detention areas should be constructed in the low-lying areas and flood diversion volumes should also be increased. In addition, in consideration of zoned flood protection and waterlog control in key areas, pump stations should be constructed and dikes should be heightened, strengthened and lengthened to form a enclosed circle for flood protection and improve the flood control capability. The river network areas along the middle and lower reaches should be properly regulated in order to lead more floods into the sea. And the flood control and disaster mitigation system should be improved by the non-structural measures of flood forecasting and early warning system and the management of flood plains etc.

The Magdalena River is divided into the upper reaches, middle reaches and lower reaches with Honda and El Banco as the boundaries. Due different locations of the upper, middle and lower reaches, they have relatively big differences in landforms, characteristics and causes of floods, and emphasizes on the study of flood control and disaster mitigation. Therefore, specific treatment should be adopted and reasonable plan should be made while dealing with flood problems.

a) Upper reaches

The upper reaches of the Magdalena River is relatively steep, with an average gradient of 5.4‰ and considerable fall change. So, runoff yield and flow concentration are rapid, making cities/towns along the banks frequently hit by high-speed floods. Regulating reservoirs have been built and planned to be built along the upper reaches of the Magdalena River, and their flood regulation function should be fully played. The catchment area of the upper reaches is 55,440 km^2, accounting for about 20.8% of the entire basin. The flood control and disaster mitigation measures for the upper reaches should solve the its own flood control problems on one hand and play some roles in the flood control of the middle and lower reaches on the other hand. Therefore, the framework of flood control of the upper reaches is developed as follows: Firstly, based on non-structural measures like the mountain torrent early warning system, the flood regulation capability of the reservoirs existing and under construction should be fully exploited, and reservoir groups should be planned on tributaries in combination with conservation to increase the flood regulation capability, retain and store floods and weaken the peak discharge. Secondly, the river channels on the main stream and tributaries should be regulated. Thirdly, dikes should be constructed, slopes should be protected, and soil erosion control projects should be implemented for cities/towns and important areas that need to be protected.

b) Middle and lower reaches

The terrain is gentle along the middle and lower reaches of the Magdalena River. Below the Cimitarra river mouth at the middle reaches, the water area is getting wider and wider and the river channel is winding, bifurcated and braided.. Especially along the reaches between Elbanco and Magange, a intricate water channel network is formed. There is abundant rainfall in this area. The runoff becomes larger and lasts for a long time when the rainy season comes, which makes the river channel incapable of discharging the floods. Therefore, floods often flow over banks and hit farmland and cities/towns along the banks.

According to the characteristics of flood control and requirements of the sustainable development of the society and economy along the middle and lower reaches of the Magdalena River, the framework of flood control has been developed as follows: existing dikes should be rationally heightened and reinforced, and new dikes and pump stations should be built in accordance with the requirements of zoned protection and water log control for key areas; the river channels should be regulated to increase the flood discharge capacity; the natural flood plains should be gradually restored, and the connectivity between rivers and lakes should be improved to increase flood diversion volume; a flood control commanding system should be established and the flood forecasting and monitoring system should be improved so as to improve the prevention and rescue capacity against disasters; the relationship between human beings and the nature should be coordinated, the management of flood plains should be strengthened, flood insurances should be developed to increase the bearing capability of the whole society in case of flood disasters.

8.1.4 Flood Control Planning Scheme and Implementation Opinions

8.1.4.1 Flood Control Plan Scheme and the Implementation Opinions for the Upper Reaches

A combination of structural and non-structural measures should be adopted for flood control along the upper reaches of the Magdalena River. This should be performed based on non-structural measures such as integrated defense, establishing monitoring and early warning systems, strengthening management in risk-prone areas, preparing and implementing defense plans, and strengthening publicity and education, and structural measures such as building revetments, drainage ditches and reservoirs, to gradually form a sound flood prevention and control system.

In areas affected by mountain torrents, in addition to the above non-structural measures, active disaster prevention and self-rescue should also be important measures, so as to gradually form a mass monitoring and prevention system.

The main structural measures are as follows:

a) Reservoirs

According to the mountain torrents control experience in China, medium- and small-sized reservoirs on tributaries and subtributaries can help reduce the peak discharge, reduce sectional area of flood discharge channels in the lower reaches, which can save project investments and land for construction, and avoid damages caused by floods. At present, some reservoirs have already been built along the mainstream and tributaries of the upper reaches of the Magdalena River. In order to strengthen the flood control capability in areas downstream of the reservoirs, the potential flood control capability of the existing reservoirs should be fully developed and new reservoirs with flood control functions should also be built to retain and store floods and reduce peak discharge.

b) River channel regulation

Regulating the river channels of the main stream and tributaries in the upper reaches mainly includes strengthening channel management, prohibiting unauthorized occupation of and dumping in flood flowing areas to keep the river course unblocked to allow smooth flood discharge, adopting necessary measures such as dredging and bottleneck expansion for reaches in cities/towns, and strengthening treatment of banks subject to serious caving and those in cities/towns.

c) Dikes

In consideration of the reservoir plan, an appropriate number of dikes should be built at places where protected areas are centralized and in important cities/towns along banks. Dikes should be built in such a manner that allows smooth flood discharge without encroaching river channels and enclosing shoals and alluvions.

At present, the implementation of non-structural measures for flood control in the Magdalena River Basin just begins. The areas threatened by floods in the upper reaches are divided into key flood control areas and general flood control areas based on the severity of flood disasters. Further work needs to be done to improve the monitoring, early warning and communication systems, strengthen management in risk-prone areas, prepare and implement defense plans, and strengthen publicity and education.

8.1.4.2 Flood Control Plan and Implementation Opinions for the Middle and Lower Reaches

a) Dikes and flood walls

Dikes are an economical and feasible way for flood control and disaster mitigation along the Magdalena River. Up to now, the CORMAGDALENA has planned the flood control works for 17 cities/towns including Barrancabermeja, Magangue, El Banco and Pinillos based on the requirements for key flood control areas (Refer to Table 8.1.4-1). The characteristics of floods and the flood control scenarios in the Magdalena River Basin should be fully considered during dikes construction and management:

1) Existing dikes or flood walls along the main stream and tributaries under the Plan should be fully repaired, heightened and strengthened. For key areas and reaches, the flood control standard for relevant areas should be strictly followed in dike heightening.

2) For important protected areas under the plan, their dikes should, in accordance with the size and landform features of cities, and the principle of zoned protection, be heightened, strengthened and extended to form an enclosed flood control circle so that these important protected areas can gradually meet the flood control standard specified in the plan.

3) Because of the low-lying land in the plain river network area, the water level in the rivers outside of dikes is high, liable to cause waterlog disasters. Therefore, the drainage channels and pump station system should be further improved to raise the pumping and drainage capacities. In addition, flood storage and detention areas should also be set in low-lying areas.

4) The dike works mainly aim at flood control and disaster mitigation for cities/towns along the river. New dikes should be built in such a manner that the natural conditions of river channels are maintained and their winding or braiding conditions retained or restored, so that dike directions are basically consistent with ecology of the river channels. In addition, wetlands, river bends, riffles and shoals should be reserved or restored to guarantee enough flood discharge section on one hand and protect the natural shapes of bank slopes and natural vegetation on the other hand.

5) Leisure, recreation, tourism and communications should be taken into consideration in dike construction. In dike design, retaining walls of different types and shapes should be adopted depending on the landform and their combination with riparian landscape to form a satisfactory waterscape. A waterfront landscape of the garden style that combines wetlands, waters, green plants, relevant facilities and roads should be shaped by lowering the height of retaining walls and building waterside platforms according to the local customs and regional characteristics.

6) Flood control water levels such as flood warning level and design flood level should be set in key areas protected by dikes. Flood control countermeasures should be developed according to different water levels.

Table 8.1.4-1 Plan for Dikes, Flood walls and Drainage Channels

S/N	City/Town	Project Overview	Investment (billion Peso)
1	Pinillos	1. Build a new 1281m-long dike with local materials, 2. Build 7 spur dikes with local materials so as to control the deposition situation along the banks.	0.723
2	Magangue	1. Barrio Samarkanda District: Build a new1435m-long dike with imported materials and protect the slopes with cobbles; build two pumping stations; build a 80m-long plain concrete flood wall and a 70m-long reinforced concrete wall for revetment. 2. Flood dyke in the southern part: Build a 620m-long reinforced concrete flood wall and use imported materials to reinforce the existing slopes from K1+360 to K1+980. Use soft cobbles to pave a 620m-long slope protection zone.. 3. Chorro District: Use 300 m³ of gravel to pave a slope protection zone.	8.458
3	Puerto Wilches	1. Guayabo Town: Build a 300m-long concrete slope protection works along the river bank and build a 3600m-long flood control dike between Guayabo Town and the drainage channel. Build cofferdams for the existing drainage channel to enable geotextile to be used to build a new 300m-long dike for the overflow channel. 2. Carpintero Town: Build a new 3,323m-long flood control dike with local materials, 3. Downtown of Puerto Wilches: Add reinforced concrete wallboards to the existing flood walls and heighten some parts of the walls along the reaches. Build a 595m-long ordinary concrete flood wall. 4. Bucarelia: Use imported materials to reinforce the 8640m-long flood control dike at the south side between the quarry and the causeway; build a new 122m-long flood control dike.	7.740

Table 8.1.4-1(continue)

S/N	City/Town	Project Overview	Investment (billion Peso)
4	Calamar	1. Barranca Vieja: Reinforce and rebuild the existing dikes and heighten them to 10.25 m, totally 1800 m long. Build new pumping stations. 2. Downtown of Sleep: Build a new 280m-long flood wall with a height of 1.5 m to 1.8 m. Reinforce and rebuild the existing dikes and heighten them to 9.55 m , totally 240 m long. 3. Brisas District: Build a 700m-long ordinary concrete flood wall with a height of 1.5 m to 1.8 m. Reinforce and rebuild the existing dikes and heighten them to 9.8 m , totally 380 m long.	2.540
5	Rio Viejo	1. Victoria drainage channel: build a 130m-long flood dike for the drainage channel with imported materials. This dike will be connected with the existing flood dike. Reinforce the existing facilities and lay short-stalk straw on the surface. The length of reinforcement works is 270 m. 2. Flood dike for the ferry dock from Victoria to Rio Viejo: Build a 4,400m-long flood dike with imported materials.	7.055
6	La Gloria	1. River banks in downtown: Build a 915m –long ordinary concrete flood wall as per the designed elevation. Reinforce the 72m-long flood walls and heighten the existing facilities to the new design elevation. 2. Palomar river banks: Extend the existing drainage channels with imported materials, totally 1750 m long. Heighten them to the new design elevation and lay short-stalk straw on their surfaces. 3. Marquetalia river banks: Extend the existing discharge channels with local materials, totally 726.9 m long. Heighten them to the new design elevation and lay short-stalk straw on the their surfacess.	3.132
7	Regidor	1. Downtown of Regidor: Build a 220m-long erosion control structure,build a new 700m-long flood dike with imported materials and build a 200m-long approach dike at the electric gate. 2. Flood dikes in areas between Regidor and Victoria: Build flood dikes with imported materials, totally 2,300 m long.	3.602
8	Guamal	1. Puerto Rangel: Reinforce the existing flood dikes, totally 2,800 m long. 2. Flood control works in the residential area of Puerto Rangel：Set timber piles and pave gravel on the 428 m-long channel slopes.	2.850
9	El Banco	1. Cerrito Town: Reinforce the 75 m-long shear wall and the existing 760 m-long reinforced concrete wall. Use local materials to build a 460m-long new flood dike. 2. Mata de Cana: Reinforce the 800m-long flood dike with screened imported materials and build a new 1,100m-long flood dike with local materials.	2.291

Table 8.1.4-1(continue)

S/N	City/Town	Project Overview	Investment (billion Peso)
10	Plato	1. Waterway between the sluice and Camargo: Build a new 107.7m-long ordinary concrete flood wall and reinforce the flood walls on the slopes. Chalupas Port: Build a new 130m-long flood dike with imported materials. Reinforce the flood dike of the Chalupas Port to achieve a crest width of 7 m and a length of 118 m. In addition, build rigid pavement, platforms and stairs on the reinforced flood dikes and build pumping trenches and electric pump stations in the reinforced structures. 2. River channel from Camargo to the police station: Build a new 100m-long flood dike with imported materials and build a 94m-long protective belt with timber piles. 3. The river channel between the police station and the original ECP station: Reinforce the 1316.44m-long flood dike with imported materials. Reinforce the flood dike near the police station that is vulnerable to floods by installing 10m-high timber piles and reinforcing the 67m-long protective belt. 4. Pekin: Build a new 120m-long drainage channel. 5. Iguanera: Build a new 140m-long drainage channel. 6. San Rafael：Reinforce the 260 m-long flood dike with imported materials and build a new 110m-long concrete pipeline and a rain water pumping system.	4.605
11	El Pinon	1. Build a new 2,140m-long flood dike with imported materials along the river channel in the north east part of the downtown. 2. Build a new 500m-long flood dike with imported materials along the river channel in the northern part of the downtown to connect Salamina. 3. Build a new 2,440 m-long flood dike in the southern part of the downtown.	3.244
12	Remolino	1. Downtown: Reinforce the flood dike along the river channel in the south which stretches to the Salamina City and the length for reinforcement is 1,450 m. 2. Build a new 900m-long flood dike with imported materials. 3. Build a 9km-long flood dike from the downtown to Renegado with imported materials.	4.590
13	Tamalameque	Reinforce the flood dike from the suburb of Alegre to Jobo District, totally 5,600 m long.	3.030

Table 8.1.4-1(continue)

S/N	City/Town	Project Overview	Investment (billion Peso)
14	Yondo	1. Casabe Port and Tomas Port areas: Build a new 860m-long flood dike with imported materials. Install gates to control discharge volume and build drainage channels. 2. San Luis: Protect the river banks with gabions. Build a flood dike on the top the slope protection structure. Build drainage ditches in the surrounding area to control the drainage of rain water. Build concrete docks at the portals of the communities along the banks. 3. Casabe Port and Mangos Port areas: Build a 1,060 m-long flood dike with imported materials. Reinforce the existing flood dikes with local materials , totally 315 m long. Build an approach dike with local materials, totally 377m long. Build sluices to control the discharge volume.	3.610
15	Ponedera	The Plazitas- Uvero river channel 1. Reinforce the flood control works of the river channel between k2+800 and k4+268 with imported materials. 2. Build two new box culverts and provide gates for them.	2.435
16	Penon	1. Build a new flood dike between Humareda and Totumos and reinforce the existing flood dikes . 2. Último Caso: Build a 320 m-long flood dike with local materials and reinforce the flood dike between Peñón and Humareda, totally 1,500 m long.	2.913
17	Barrancabermeja	San Rafae Town: Build a new 150m-long slope protection structure. Set timber piles along the 150 m-long river bank and pave a 120 m-long gravel layer to reinforce the slope protection structure. Pave a 150 m-long gravel layer to strengthen the river dike. Install a gabion structure of 855 m³ along the slopes and pave 1183 m³ of cobble stone to protect the slopes. Build a 110 m-long ordinary concrete flood wall.	0.782

b) Lakes, marshes and wetlands (natural flood storage and retention areas

In 2001, IDEAM investigated and made statistics on the major wetlands in the Magdalena River Basin. The results are shown in Table 8.1.4-2. Based on the natural geographical features along the middle and lower reaches of the Magdalena River and requirements for the overall plan, the opinions on plan of existing natural flood storage and retention areas such as lakes, marshes and wetlands are as follows:

1) For areas discharging floods all the year round, that is, the river channels and shoals under the Plan., it is suggested that the river channels should be desilted in combination with river improvement works, and the exploitation of of shoals by

residents living along the banks should also be regulated and reduced to enhance the discharge capabilities of the river channels.

2) For seasonal flooded areas, which mainly refer to the flooded areas between El Banco and Magangue, permanent residents there should be gradually displaced in principle. For places with dense population or with difficulty in resettement, proper protective measures should be taken, management in the flooded areas enhanced and forecasting and early warning information system improved. Small flood storage and retention areas should be set up based on local conditions and the overall flood control plan. Implementation of the above measures would increase the flood storage capacity and reduce flood losses.

3) For lakes, marshes and wetlands along the banks, it is suggested that their natural conditions be reserved or restored, and the connectivity between rivers and lakes be improved to exert the functions of the lakes serving as “connectors”, “converters” and “water containers” in the water system. The mouths of all tributaries of the lakes along the banks of the Magdalena River and all channels connecting the lakes and the Magdalena River should be dredged in the near future to keep a smooth connection between river water system and lake water system as well as the mobility and continuity of the river water bodies and exert the flood storage and regulation functions and ecological benefits of the lakes, marshes and wetlands. The lakes and rivers should be scientifically and effectively connected by natural or artificial means based on their characteristics so as to form a water network system that features effective diversion and discharge, proper storage and retention, regulation in wet and dry seasons, mutual complementation with multi-sources, easy regulation and control, and favorable internal connection.

Table 8.1.4-2 Distribution of Wetlands of Departments in the Magdalena River Basin

Unit: km^2

Name of Wetland	Atlantico	Bolivar	Cesar	Cordoba	Magdalena	Santander	Sucre	Total
Tesca o La Virgen		10.79						10.79
Canaletal		10.09						10.09
Capote		49.61						49.61
Cerro de San Antonio					35.43			35.43
Ayapel				79.2			0.3	79.55
La Auyama					32.65			32.65
La Piedra					22.08			22.08
Machado							50.22	50.22
Malibu					49.72			49.72
Maria La Baja		23.34						23.34
Mendegua					17.05			17.05
Pajaral					155.59			155.59
Parades						12.62		12.62
Pijino					19.06			19.06
Plato					79.27			79.27
Simiti		22.25						22.25
Zapatosa			210.4		77.45			287.86
El Medio		37.8						37.8
El Morro					18.24			18.24
El Pinalito		14.79						14.79
El Rubio			23.25					23.25
Florida							29.46	29.46
Grande	5.05	42.57					7.26	54.88
Grande de Santa Marta					436.03			436.03
Mantequera		89.45						89.45
Sapayan					48.3			48.25
Cienagas de Tumarado	15.14							15.14
ComplejoAstilleros							126.36	126.36
Complejo Castillo		0.9					20.93	21.83
Complejo Las Islas		62.31					46	108.31
Total area deldepartament	20.19	363.9	233.65	79.2	990.87	12.62	280.53	1980.96

Note: IDEAM, Year 2001.

c) Reservoirs

In 2001, IDEAM performed statistics on the major reservoirs originally planned to be built on the Magdalena River. The total regulating capacity of the planned reservoirs on the main stream and tributaries of the Basin is about 33.2 billion m³. However, with the development of social economy in the Magdalena River basin and environmental protection concept, some high dams and large reservoirs originally planned have been postponed or adjusted due to the social and environemntal impacts as well as economic benefits etc. For example, the Guajaro Hydropower Station originally planned on the middle reaches of the main stream has been suspended because of the poor topographical conditions and high investment. And Bucaramanga Hydropower Station (the former Sogamoso Hydropower Station) on the Sogamoso River has been changed from a dam-toe powerhouse to a conduit type. according to the latest design report, the capacity of the reservoir is only 17.6 million m³. Up to now, there are very few key reservoirs completed on the main stream and tributaries of the Magdalena River and the current regulating capacity is much lower than the originally planned regulating capacity. According to the analysis on the terrain and social economy conditions along the Magdalena River, it would very difficult to control the investment if a large-scale reservoir for flood control is built on the main stream. In addition, the flood control effect would be limited and the adverse environment impact would be obvious. So, it is suggested to perform further study on the feasibility and economic benefit for constructing key flood control reservoirs by considering the flood control benefit and other factors.

According to relevant data, the hydropower stations Betania (completed) and El Quimbo (under construction) on the upper reaches of the main stream of the Magdalena River as well as the hydropower stations Farallones, Canafisto, Ituango (under construction) and Apavi that are being built or to be built have relative larger regulating capacities. However, their tasks are all power generation and their ability for flood control can not be functioned since detaining and storing floods for the lower reaches was not considered in the plan. So, it is necessary to study the functional orientation for these large reservoirs on the mainstream and the tributaries, adjust the reservoir operation mode with the help of the hydrological telemetry system, reserve a certain storage capacity for flood control to enable the reservoirs to detain floods and weaken the peak discharge.

Since most of the owners of the reservoirs in Magdalena River Basin are private enterprises, to inspire them to actively participate in flood control, it is suggested that relevant policies be enacted by the government to give subsidy or lower the taxes to compensate their losses caused by the reserved capacity for flood control.

d) Management of flood plains

Increase of population and wealth in the flood plains makes it more difficult for flood control and also causes heavy losses when floods occur. Management of the flood plains is from the aspect of sustainable development to solve the problems between human beings and floods, which can coordinate the relationship between human beings and the nature and is also a long-term measure for flood alleviation.

1) Division of flood plains

At present, there are no unified standards for division of flood plains around the world. And the flood plains are usually divided according to land forms, flood frequency, flooding depth, flow rate and possible degrees of damages. The commonly adopted standard is the three-zone division method: The flood plains below a 5-year flood level should not be exploited; the flood plains between a 5-year flood level and a 20-year flood level should be exploited with some limitations; the flood plains above a 50-year flood level should be allowed to exploit. It is difficult in a certain degree to draw the flooded areas by flood frequencies due to a lack of basic information on Magdalena River Basin as well as the complexity of flood compositions. A preliminary division has been carried out in flood control plan according to IDEAM flooded area map .

(1) Areas threatened by floods at a very high frequency or high degree. Where the social economy is relative developed, economically and technically feasible, structural measures are proposed for the protection. For the rest places, gradual displacement and no further exploitation are proposed.

(2) Areas threatened by floods at a moderate degree. Only necessary development should be conducted, and irrational development should be limited.

(3) Areas threatened by floods at a low degree. Development should be allowed, and

flood control measures should be taken.

2) Management scope of flood plains

Management on the utilization of land and construction of structuress within the areas should be implemented by enacting laws, rules and regulations or by other ways based on the division of the flood plains. The management of flood plains generally covers taking measures against flood to reduce flood losses in the developing areas, limiting the social and economic development at high flood risks, arranging the flood damage reduction and land utilization in an overall manner as well as keeping the flood discharge and detention functions of the flood plains.

3) Advices on management of flood plains

(1) Improve the existing forcecasting and early warning system such as the flood risk map.

(2) Enhance the development of the water regime early alarm system and the flood control commanding system.

(3) Accelerate the plan and construction of flood control and disaster mitigation projects within the flood plains.

(4) Enact relative laws and regulations on management of flood plains and try to improve the public participation.

(5) Improve the emergency response mechanism for flood disasters

e) River regulation

The key areas for water channel regulation are the areas along the middle and lower reaches of the main stream. The river channel regulation is not only a measure for navigation development and rational exploitation of riparizn zones but also an important part of the flood control system of the middle and lower reaches. The structural measures for flood control projects mainly consist of river cutoff and expansion of river channel bottlenecks. Refer to 8.5 “River Regulation Plan” for details.

f) Soil erosion control and forestation

Gradually implement the soil erosion control and forestation measures according to the plan by establishing an ecological environment monitoring and protection system. Refer to 7.3 for “Soil Erosion Control and Forestation Plan” for details.

g) Flood insurance

The flood insurance is regarded as an important means for risk management of floods because it transfers indefinite risks of huge damages into definite, fixed and small expenditures. The combination of flood insurance and flood plain management can effectively control blind economic development in flood plains and reduce resulting damages. At present, the Magdalena River Basin is facing huge flood risks and the post-disaster relief mainly relies on the government and there is no sound flood insurance of "transferring risks by individuals” and “risks being shared by the society”.

There are two major insurance modes for shielding against flood risks all over the world: The first one is that risks are shouldered by private insurance companies voluntarily or according to relevant laws and regulations rather than the government; the second one is that the government bears risks brought by floods with private insurance companies only responsible for selling insurance policy and providing services. According to the analysis of the current social and economy environment in the Magdalena River Basin, flood losses may exceed the bearing capability of private insurance companies and it is also almost impossible for the low-income people who are facing the greatest risk from floods to pay for the high premium, so, it is suggested gradually implementing the insurance mode of “government shouldering flood risks”.

At present, river regulation and flood control construction is being carried out in the Magdalena River Basin. In particular, after the great flood disasters in recent years, importance is attached to arrange the flood control construction under the frame of reconstruction of the ecological system in the basin. With the application of system theories and risk management approaches, flood control is changing to flood managment. Many effective efforts have been put into flood control and disaster mitigation, laying a solid foundation for the establishment of flood insurance system.

h) Plan on flood control commanding system

According to the flood control situation in the Magdalena River Basin, the key priority of this plan on flood control commanding system is the construction of a flood control commanding center – build a functionally complete, technological advanced, efficient and reliable flood control commanding system following the principle of "unified standard and information sharing" and build sub-systems of data collection and transmission, computer network (communication), flood control database, decision support, remote consultation and flood control information service with the flood forecasting and monitoring system as a platform.

8.1.4.3 Urban Flood Control Plan and its Implementation Opinions

La Dorada, Barrancabermeja, Puerto Wilches, La Gloria, Tamalameque, Pinillos, El Banco, Magangué, Plato, Calamar, Ponedera, Soledad and Barranquilla along the middle and lower reaches of Magdalen River are the key priorities in the flood control, for these cities are either prone to flood threats or have large population. Refer to Table 8.1.4-3 for design flood levels corresponding to different flood control standards of different cities.

Table 8.1.4-3 Design Flood Levels under Different Flood Control Standards of Key Cities

nit: m

City	Flood Control Standards				
	P=2%	P=5%	P=10%	P=20%	P=50%
La Dorada	172.63	172.38	172.17	171.93	171.51
Barrancabermeja	76.01	75.82	75.65	75.46	75.12
Puerto Wilches	66.17	65.92	65.7	65.46	65.03
La Gloria	36.85	36.42	36.05	35.62	34.85
Tamalameque	33.17	32.82	32.47	32.07	31.34
El Banco	29.53	29.21	28.93	28.59	27.98
Pinillos	22.19	21.92	21.65	21.33	20.74
Magangué	19.64	19.15	18.75	18.27	17.41
Plato	15.25	14.45	13.85	13.05	11.65
Calamar	9.48	9.04	8.66	8.21	7.4
Ponedera	5.92	5.62	5.36	5.06	4.53
Soledad	3.39	3.18	3	2.82	2.48
Barranquilla	2.95	2.76	2.6	2.43	2.13

For flood control of key cities and protected areas, importance should be attached to protection of banks and dikes and management of flood plains, the banks and dikes should be heightened and reinforced according to relevant standards to form enclosed flood protection zone. Wherever necessary, flood storage and detention areas should be set upstream of these cities according to local conditions to ensure safety.

According to the practical situation, cities in Colombia are facing severe problems in flood control because there are no complete urban flood control systems. The following suggestions are proposed according to the characteristics of cities along the Magdalena River and with reference to flood control practices in China and other countries:

a) The urban layout should abide by the principle of "priority-oriented land utilization". Downtowns, residential communities, important industrial storages as well as other important facilities should be arranged in areas with a relatively high safety guarantee for flood control while open space such as ecological wetlands, parks and green belts, squares, sport grounds etc should be arranged in the wet low-lying areas and shoals.

b) Relevant safety measures against flood should be taken according to the property of the land when the urban construction can not avoid the low-lying areas.

c) The layout of land usage in cities should guarantee the flood control safety of important public facilities.

d) The shoal land for the passing floods, land for flood discharge channels and land for river regulation that are defined in the urban plan should be delimited as the construction restricted area, in which facilities that may deteriorate the safety for flood control should not be built. An impact assessment on flood control safety should be conducted for land and facilities that are really needed to be developed and built.

8.2 Waterlog Control Planning

8.2.1 Current Situation and Existing Problems

According to the analysis on site survey and investigation, it is found that the infrastructures for waterlog control in cities/towns along the banks of the Magdalena River is characterized by backward construction, low capability in regulation and storage of rain flood and emergency management. Since there is no planning of river channels for water drainage included in the development of cities and towns, there is a lack of a complete channel system for waterlog control. Besides, most of the current flood control dikes are not equipped with sluices and culverts for flood drainage and there are water pump stations in only a few places along the banks with very low capabilities of water pumping and draining. When there is abundant rainfall in the rainy season, waterlog will be formed in the low-lying areas in cities/towns along the banks due to a lack of waterlog control and water draining facilities. And for a complete flood control and disaster relief system has not been established in the Magdalena River Basin, the standards for flood control of most of the cities/towns are relatively low and cities/towns along the shoreline frequently suffer from flood and waterlog disasters due to unsmooth flood discharge.

8.2.2 Waterlog Control Planning Framework

Flood and waterlog disasters occur frequently along the Magdalena River, but it is quite difficult to provide a detailed project for the planning of waterlog control due to a lack of basic materials. Therefore, only guidelines and some advice can be given on the planning of waterlog control:

a) Guidelines on the planning of waterlog control

1) Make an overall general investigation so as to get the whole picture of the current situation

Make an overall general investigation on the surface runoff, water drainage facilities and receiving water bodies etc in the local areas and build a geographical information system of water drainage facilities such as the pipe network. Make a statistical survey on scopes, causes and losses of all past floods and comprehensively evaluate the capabilities of water drainage and waterlog control and risks of cities with the basis of meteorologic and hydrologic data.

2) Make standards for waterlog control

There is no conception of waterlog control standard for the design of waterlog control facilities in the Magdalena River Basin. For different regions, standards on facilities construction for water drainage and waterlog control for cities and farmland should be rationally determined according to the importance degree of cities, the level of economic development and risks of waterlog occurrence due to rainstorms, etc. in order to be taken as the basis for the plan waterlog control.

3) Make the plan of waterlog control

Waterlog control is to drain away a large area of impounded surface water and rainwater gathering in the rainwater pipe networks. As part of the plan of the flood control and disaster relief system, the waterlog control plan should be coordinated and linked with the flood control plan of the whole basin and facilities contruction for water drainage and waterlog control should be included in the flood control and disaster relief system. The waterlog control plan mainly includes structural and none-structural measures such as: determining the discharge outlets and the divisions, scientifically preparing the layout of the drainage network, plan the draining pipelines, pump stations, facilities for rainwater detention, permeation, regulation and storage, facilities for rainwater and flood discharge, dredging and improvement works for rivers and lakes systems.

b) Recommendations on the plan of waterlog control

Due to the flat terrain of plain areas at the middle and lower reaches of the Magdalena River, it is easy for waterlog to form in rainy season and the flood would overflow the river embankment and flow to the plain areas at the middle and lower reaches in flood season, which further increases the pressure of waterlog control. Measures for waterlog control should be taken properly and reasonably according to the conditions of landform and terrain, the distribution of rivers and confluence.

1) Channels, ditches, culverts, sluices and supporting facilities for waterlog control

(1) An overall improvement on the current water drainage channels in the basin should be conducted through measures including dredging, desilting, clearing reeds, clearing and cleaning the banks, adjusting and improving the channels, etc. mainly in combination with the heightening and strengthening works of the revetment to realize the objective of making channels almost straight and draining water freely. Great importance should be especially attached to the reconstruction and improvement of drainage channels in the plain areas at the lower reaches and channels should be widened when it is necessary.

(2) In order to determine the design standard of waterlog control, areas division for waterlog control should be conducted in the plain areas at the lower reaches according to the conditions of landform, terrain, distribution of rivers, the confluence conditions

and the waterlogs over the past years. According to the design standard, water drainage channels system should be expanded or built newly; bridges, culverts, suices, pump stations, etc. should be improved and newly built; supporting works for the farmland should be completed; discharging conditions should be improved to guarantee a free water discharge from inside to outside in all areas.

(3) The channels system in the waterlog control areas should be expanded and rebuilt according to the plan layout scheme of projects such as the municipal sewage blocking and discharging projects and the sewage treatment and discharging projects in urban areas as well as the practical conditions in all of the waterlog control areas.

(4) Level-to-level management for water drainage channels in all of the areas should be implemented and a main channel for water drainage should be built. And water will be discharged into river channels by means of a combination of self-draining and pumped draining after the waterlog of all the areas converges into the main channel throuth the water drainage channel system .

(5) Flood storage areas with a certain scale should be built by taking advantage of low-lying land when it is possible to gather and regulate floods.

2) Pump stations for waterlog control

(1) The water drainage facilities such as pump stations, sluices which have been damaged during the flood periods over the years should be repaired and rebuilt. Aged pumps or pumps with a high failure rate and low efficiency due to a long operating period should be replaced according to the unified standard. Besides, the capacity of pumps should be expanded and increased when it is possible.

(2) Water pumping stations should be expanded or newly built at suitable places newly selected according to the distribution of waterlogs and the operation conditions of pump stations during the flood periods in recent years in order to further improve their pumping and discharging capabilities.

(3) A certain amount of mobile water pumping stations should be equipped according to the practical conditions of all the areas as emergency measures in case of rainstorms, structures failures or floods overflowing the dikes, etc.

3) Make the laws, regulations and standards sound

The plan, construction and operation management of facilities for water drainage and waterlog control in cities should be standardized; the drainage standard for cities, drainage standard for farmland and relevant standards for the construction and development of cities as well as land plan should be formulated and completed. Supervision on the construction and operation of the facilities for water drainage and waterlog control should be strengthened. Make sure that the requirements on plan formulation, facility construction and operation maintenance, etc. should be put into practice. The licensing system of accessing to drainage pipe networks should be strictly followed to avoid the interconnecting between rainwater pipeline and and sewage pipeline. Dredging and management of the river and lake systems should be enhanced and an overall inspection, maintenance and clearance for water drainage facilities in cities should be conducted by strictly following the requirements of flood control before the flood period.

4) Complete the emergency mechanism and strengthen the scientific support

A waterlog monitoring and alarming system should be established based on the flood control command system to comprehensively improve the digital level of water drainage and waterlog control. Technical systems such as the geographical information system, the global positioning system and telemetering system should be actively used. A comprehensive information management platform should be built with functions of disaster monitoring, forecast and early warning, risk evaluation, etc. in combination with the flood control command system. The support function of digital information technology in water drainage and waterlog control should be strengthened. The interconnection mechanism of information co-sharing and coordination linkage should be made sound. Before rainy season, the emergency plan for waterlog control should be formulated and improved; the warning levels, the content, corresponding measures and handling procedures should be determined; emergency measures for prevention by technology, structures and people should be made sound. Precaution should be strengthened especially for traffic arteries in cities, low-lying areas, dilapidated houses and construction sites, etc.; and necessary warning marks should also be set at the same time. Education on emergency response capability and the publicity of warning information as well as launching emergency drills should be conducted.

8.3 Irrigation Planning

8.3.1 Analysis on Land and Water Resources

The Magdalena River Basin is located near the equator, due to which the sunlight is abundant, the annual time variation of sunrise and sunset is very small, and the sunlight duration is stable. Within the planning area, the sunlight time of the areas upstream Neiva is about 1,300-1,700 h/year; the sunlight near the Neiva~El Banco is much more sufficient, being about 1,700 h/year~2,100 h/year; the annual sunlight time of the areas downstream El Banco is the longest, reaching 2,100 h/year~2,500 h/year. Similarly, the annual temperature change in Colombia is not big, and the change of temperature is only related to the altitude. The planning area is river valley. Most areas are characterized by tropical climate, with annual average temperature of more than 28℃, and temperature of small part of the areas is 24℃~28℃. On the whole, the solar-thermal resources in the planning area are relatively adequate.

According to *Atlas Cuenca del Rio Grande de la Magdalena*, the dry grade is used for the Magdalena River Basin to measure the sufficient degree of rainfall for meeting the requirements of plants. Based on the sufficient degree of rainfall with the order from much to less, five grades of excess, abundance, normal, close to water shortage, water shortage are classified in total. The areas at middle reaches within the plan area take the normal grade, while the areas at upper and lower reaches are at the edge of being close to water shortage.

Different geological, landform and climate characteristics of the Magdalena River Basin make the land possess rich diversities. According to the classification of IGAC, the soil of the Magdalena River Basin can be divided into four categories as per the geological environment, dynamic form, climatic environment and other factors:

The first category is the land influenced by volcanic material. It is developed mainly after the weathering of cinerite sediments, located in most parts of mountain area. Most of the soil in the Valle del Cauca is formed by volcanic material.

The second category is mainly formed through sedimentation near the volcano slope area, essentially being volcanic metamorphic rock or sedimentary rock, which is mainly distributed in Garzon, Quetame and Santander, etc. Since the cold moist climate and dry hot climate appear alternately in these areas, the soil there are sensitive, leading to landslide always.

The third category mainly appears in the areas at the lower reaches of the Magdalena River Basin, which is formed by bed load and suspended load carried by the river flow in the dry hot climate. The kind of soil also appears on desertification areas with rainfall capacity of less than 500 mm and no flood influence.

The fourth category exists in the areas with water and soil not fully developed. Affected by the water flow movement, the surface configuration keeps changing. The kind of soil exists in the Magdalena alluvial plain, mainly in Momosina. Since the surface mineral and organic nutrition are rich, the soil is suitable for the growth of crops. Besides, the kind of soil can also form in high and cold areas such as Fuquene and Bogota Plain etc.

According to the actual situation of jurisdictional scope of CORMAGDALENA, the soil type can also be divided into eight categories:

a) The land of Huila Piedmont mainly comes from cinerite, forming relatively fertile soil. The area extends to Garzon from the Magdalena River, covering different altitudes.
b) Many terraces are distributed in Huila and Tolima area, which are formed by alluviation of sediments on the eastern and western mountain chains.
c) Tolima area, which is dry-hot valley area represented by Espinal City and Honda City, is provided with fertile soil and dense population.
d) Between the Girardot City and Salgar City of northern Tolima, most land is under semiarid status, and soil is slightly poor.
e) The Antioquia area is mainly formed by the igneous rock intruded from Boyaca and Santander.
f) The Perija Piedmont is mainly formed by the sedimentary rock within the mountain area, and Cesar is the mainly affected area by flood, therefore, the land between Auguachica and Tamalameque is formed by deposition of mud and clay, and the soil is relatively fertile.
g) The district between San Pablo and Magangue is basically located in dry and hot area. With relatively less rainfall, the river migrates throughout the year, and the deposit

sediment in the river forms fertile soil.

h) The reaches from Magangue to the estuary are under water shortage in most of the time, and the fertile degree of the soil depends on the quantity of sediment carried by the river flow.

8.3.2 Current Situation and Existing Problems of Irrigation

8.3.2.1 Overview on Agriculture in Colombia

In the mid 20^{th} century, agriculture was the foundation of national economy of Colombia, wherein agricultural population accounted for about half of the Colombia population, and the total value of agricultural output accounted for about 30% of the GDP. With the rapid development of manufacturing industry, service industry and mining industry, the total value of agricultural output drops to less than 5% of the GDP. The principal crops in Colombia include coffee, cotton, sugarcane, banana, tobacco, cocoa, rice, corn and soybean etc., mainly distributed in plains and mountain valleys, wherein the most important areas are: sugarcane region in Valle del Cauca Department, cotton planting regions in departments along the Caribbean Sea, tobacco planting region in Santander, Uraba banana planting region in the northwest of Antioquia Department and flower planting region in Bogota Plain.

The exported farm products in Colombia are dominated by coffee, accounting for more than 50% of gross export of all products. The animal husbandry is relatively developed, of which the production value ranks the fourth in Latin America second to Brazil, Argentina and Mexico, accounting for about 1/3 of total value of agricultural output in Colombia. The main pasturing areas are distributed in plains and tropical zone, including Bolivar, Sucre, Cordoba and other departments and LlanosPlain in the east. The animal husbandry in Colombia mainly focuses on cattle rearing, and the production value of cattle husbandry accounts for about 40% of the total production value of animal husbandry. Colombia is the important fresh milk producing country in South America. In recent years, the production of fresh milk continues to increase. The major production areas comprise Atlantic coastal region (including Cesar Department, Magdalena Department, Cordoba Department and Atlantico Department, etc.) and central region (including Cundinamarca Department, Boyaca Department, etc.).

8.3.2.2 Current Situation of Land Utilization in the River Basin

The total land area of Colombia is 1,142,000 km^2. According to the national information survey of agriculture and animal husbandry in 2000 (DANE-SISAC), the area of arable land is 46,100 km^2, accounting for 4.04%; the grassland area is 362,200 km^2, accounting for 31.73%; the forest land area is 553,200 km^2, accounting for 54.76%. What is worth describing is that: the land suitable for farming in Colombia is about 193,800 km^2, accounting for 17%, mainly located in the Magdalena River Basin; but due to unreasonable utilization of land resources, most arable land is occupied as grassland and urban land, and the actual land available for farming only accounts for 23.8% of the arable area. 32.7% of land in Colombia is under overexploitation, of which 61% is located in the mountain areas at upper reaches of the Magdalena River and 10% is in the Caribbean coastal areas at lower reaches of the Magdalena River; areas with insufficient utilization ratio takes up 29.7%; and land of other areas is under rational exploitation.

Seeing from agricultural development distribution of the Magdalena River, the soil and planting conditions at middle reaches are poor, and compact district for agricultural development is the Dique Canal area at upper and lower reaches, especially the upper reaches. 17% of the land at upper reaches of the Magdalena River is used for agricultural development, and most irrigation areas are located between Neiva~Honda. In 1950s, planting pattern of crop rotation of rice and cotton appeared in Huila and Tolima Department, and the gross product of the two departments occupied about 40% of the national production; what was more, companies specialized in agriculture came into being in areas of Pitalito, Garzon, Neiva, Espinal, Guamo, Girardot, Saldana, Purificacion etc. At present, besides conventional agriculture, there are commercialized agriculture and industrial agriculture with high technical content in the river basin.

According to the analysis on GIS map of land utilization provided by CORMAGDALENA in February 2013, the basic information of current land use by classification within the plan area is as follows:

The land area in the plan area is 69,400 km^2. Wherein: arable land and grassland (Territorios AgrÍColas) are 39,228 km^2, accounting for 56.5%; land of forest (Bosques y Áreas Seminaturale) is 18,007 km^2, accounting for 25.9%; wet land (Áreas Húmedas) is 5,128 km^2, accounting for 7.4%; land of water area (Superficies de Agua) is 4,592 km^2, accounting for 6.6%; urban (Territorios Artificializados) use is 554 km^2, accounting for 0.8%; other land is 1,891 km^2, accounting for 2.7%. Refer to Fig. 8.4.2-1 for the current situation of land use structure within the plan area. According to the ownership situation, the state-owned or department-controlled area is 28,600 km^2, and the private land area is 40,800 km^2, respectively accounting for 41.2% and 58.8%. The private ownership and centralization of land in Colombia is the inheritance and continuance of regional land system history, causing decentralized land management, having no perfect and uniform management system.

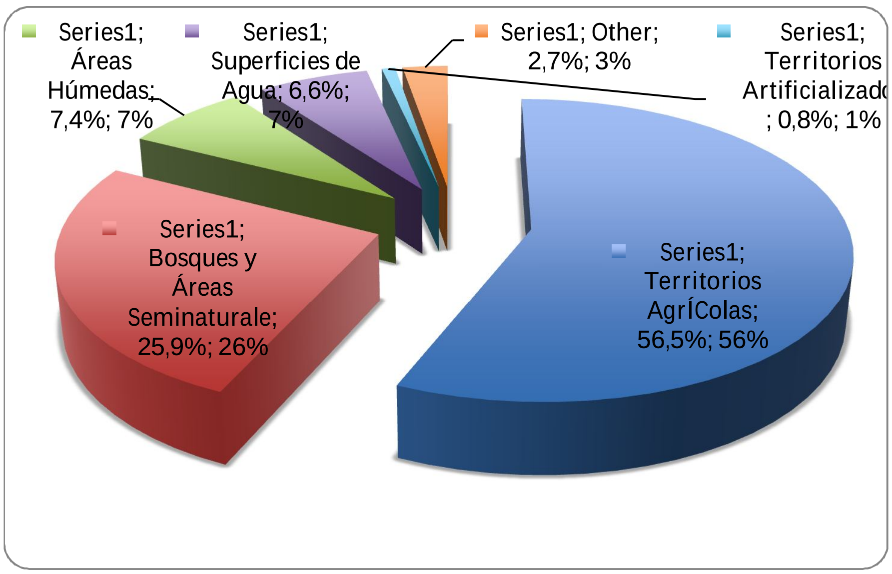


Fig. 8.3.2-1 Current Land Use

8.3.2.3 Conditions of Existing Irrigation Areas

a) Distribution and scale of irrigation areas

According to the terrain of river basin, distribution of arable land and statistical data of Ministry of Agriculture and Rural Development of Colombia, the regions with relatively developed agriculture of Colombia are mainly distributed in ATLANTICO Department, BOLIVAR Department at lower reaches of the Magdalena River and HUILA Department and TOLIMA Department at upper reaches. At present, the total irrigation area of large-scale and small-scale irrigation areas reaches 153,896 ha, wherein there are 12 large and medium-scale irrigation areas, with the irrigation area

Gof 145,893 ha; there are 75 small-scale irrigation areas, with the total irrigation area of 8003 ha. 5 of the large and medium-scale irrigation areas are provided with water lifting facilities such as pump stations, wherein irrigation areas in ATLANTICO Department are all provided with pump station systems.

Expect the irrigation areas completed, there are 2 irrigation areas under construction currently, with a design irrigation area of 24,225 ha. One is the Natagaima in TOLIMA Department, of which the construction period is from 2005 to 2015, and the design irrigation area is 20,402 ha; the other is the Tesalia in HUILA Department, of which the design irrigation area is 3,823 ha. There are 2 irrigation areas planned, wherein one is located on right bank of Betania Reservoir, in Hobo City, HUILA Department, and its planned irrigation area is 15,000 ha; the other is located near the entrance of Dique Canal, in the cities of Pivijay, el Piñon, Salamina, Cerro de San Antonio of MADALENA Department, and its planned irrigation area is 29,500 ha.

Refer to Table 8.3.2-1 for the existing major large and medium-scale irrigation areas. Refer to Fig. 8.3.2-2 for the distribution map of irrigation areas completed or under construction within the plan area of the Magdalena River Basin.

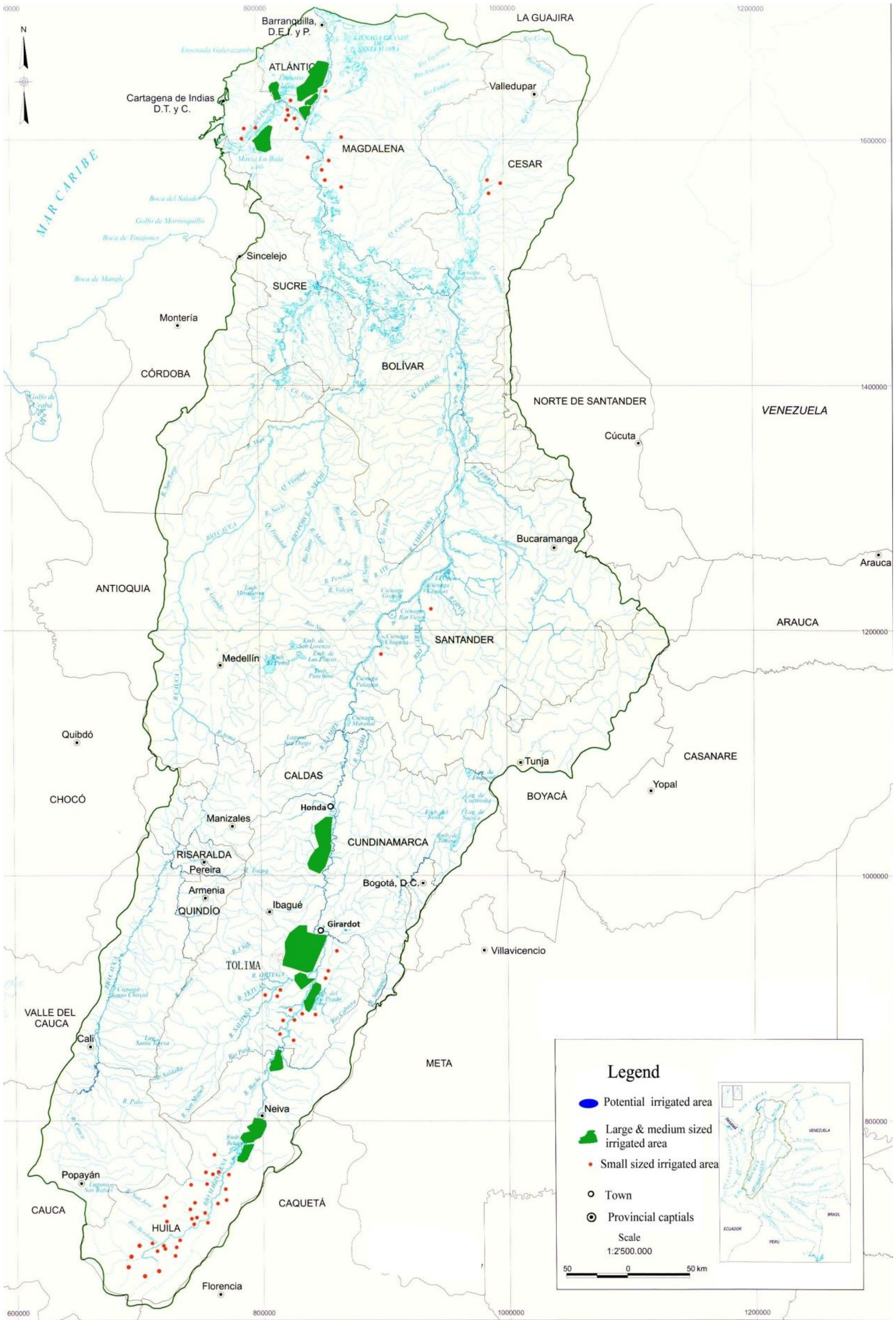


Fig. 8.3.2-2 Distribution Map of Large and Medium-Scale Irrigation Areas Completed or under Construction within the Plan Area

b) Current situation of facilities in irrigation areas

In the mid 20th century, most canal system irrigation facilities were constructed with the government as the leading investor, and the ratio of investments between the government and individual was 7:3, and the leasehold mode was adopted for individual use. But since the income of this mode is too low, with expansion of privatization of land, most agricultural lands are concentratedly owned by a small number of farmers. The government has stopped the construction of new irrigation projects. At present, the irrigation projects are mainly constructed with the investment from individuals who have such demand, and the government provides a little subsidy. Generally, the ratio of investment from the government to that from individuals is 3:7. Since the individual capital is limited, and the input and output of agricultural products are low, the post-maintenance for the completed irrigation facilities are lacking, and use ratio of water is low. According to the field survey , parts of the canal systems are overgrown with weeds and out of service for long due to being out of repair for long years.

Fig. 8.3.2-3 Channels and Water Pumps for Irrigation in Irrigation Areas Upstream Neiva

Fig. 8.3.2-4 Aqueduct, Irrigation Pump Station, Channel and other Irrigation Facilities of Irrigation Areas near Villavieja

Fig. 8.3.2-5 One of the Gates of Guajaro Irrigation Reservoir at Entrance of Dique Canal

Table 8.3.2-1 Statistics of Existing Large and Medium-Scale Irrigation Areas within the Plan Area of the Magdalena River Basin

No.	Department	Municipality	Irrigation and drainage districts				Total area
			District name	Pump system	Design flow	Channels Lengjt	
				Yes or no	m³/s	km	ha
1	HUILA	CAMPO ALEGRE	EL TUNEL	No	1.1		1060
2		PALERMO	EL JUNCAL	Yes	6	9.93 km de canales principales de riego 27.53 km de canales secundarios 17.07 km de canales terciarios 11.31 km de canales de drenaje 47.26 km de vias y carreteables	3500
3		VILLA VIEJA	SAN ALFONSO	No	2.3		1800
4	ATLANTICO	CAMPO DE LA CRUZ	CAMPO DE LA CRUZ	Yes	1.3	4 km Canales principales 3 Km Canales secundarios	1200
5		SANTA LUCIA	SANTA LUCIA	Yes	4.8	17,5 kms de canales de riego 236.4 km de vias y carreteables 138,7 kms de canales de drenaje	3000
6		PONEDERA	MANATI	Yes		137.9 Kms de canales de drenaje 105.1 km de vias carreteables	29000
7		SUAN					
8		CAMPO DE LA CRUZ					
9		REPELON	REPELON	Yes	5	26,0 kms de canales de riego 19,9 kms de canales de drenaje	3800
10	BOLIVAR	MARIA LA BAJA	MARIA LA BAJA		8		9688
11	TOLIMA	ESPINAL	COELLO Y CUCUANA	No	25	128.24 km de canales principales de riego 140.53km de canales secundarios 49.09km de canales terciarios 125.83km de canales de drenaje 411.35 km de vias y carreteables	65000
12		GUAMO	GUAMO	No	1.8		1526
13		PRADO	PRADO	No	3.66		2719
14		AMBALEMA Y LERIDA	RIO RECIO	No	11		23600

8.3.2.4 Existing Problems

a) In recent years, especially after signing FTA(Free Trade Agreement) with America, the agricultural exports of Colombia descends year by year. Colombia has become a net food importer.

b) Because of limited irrigation facilities, lack of logistics, difficult loans, abnormal climate and other reasons, the cost of agricultural products gets high, and the agriculture risk is big.

c) Since the land of Colombia is of private ownership, and most lands belong to private persons (61.2% of agricultural land of the nation belongs to 0.4% of farmers), in terms of the pattern of land utilization, the individual opinion predominates, while the government at each level mainly exercises the rights of guidance and suggestion. Therefore, lacking integrated plan of land use goes against the rational utilization and allocation of land resources.

d) The land resources are not reasonably and fully used, and the cultivation method is extensive; many suitable farmlands are occupied by grassland and urban land or for other purposes.

e) The construction standard of the existing irrigation facilities (including channels and pump stations) is low, and most were constructed ages ago, with little maintenance.

8.3.3 Analysis on Potential Irrigation Areas

Although the consumption of grains accounts for a relatively low proportion in the daily consumption of Colombia, the current grain output cannot satisfy the demand of the nation any more and requires import from other countries. On the other hand, since Colombia is located near the equator, provided with rich solar-thermal resources and fertile soil, and enjoys exceptional advantage on grains planting, it has been praised as one of 8 countries with biggest grain yield-increasing potential by the FAO. Therefore, it is necessary and advantageous to develop agricultural irrigation in Colombia.

8.3.3.1 Distribution of Potential Irrigation Areas

The planning area is one of the areas with developed agriculture in Colombia, and the irrigation areas are mainly concentrated in the Neiva~Honda section at upper reaches of the Magdalena River and surrounding areas of Dique Canal, of which the irrigation area accounts for more than 90% of the total irrigation area in planning area.

Mainly based on the suitable cultivated land resources and distribution of irrigation areas completed, under construction and planned, combining with the filed survey and planning of hydroelectric cascade, 5 potential irrigation areas at Neiva ~ Honda section at the upper reaches are preliminarily selected for this master plan, of which the serial numbers are respectively 1 to 5, distributed in HUILA, TOLIMA and CUNDINAMARCA Departments. The total irrigation area is preliminarily estimated to be 16,400ha. The potential irrigation area in HUILA Department is characterized by flat terrain, wherein the rice, corn and coffee are mainly planted, and the total irrigation area is about 7133 ha; rice is mainly planted in potential irrigation areas of TOLIMA and CUNDINAMARCA Departments, with total irrigation area of about 9267 ha. Refer to Fig. 8.3.3-1 for the distribution of the potential irrigation areas. See Table 8.3.3-1 for the basic conditions of irrigation areas.

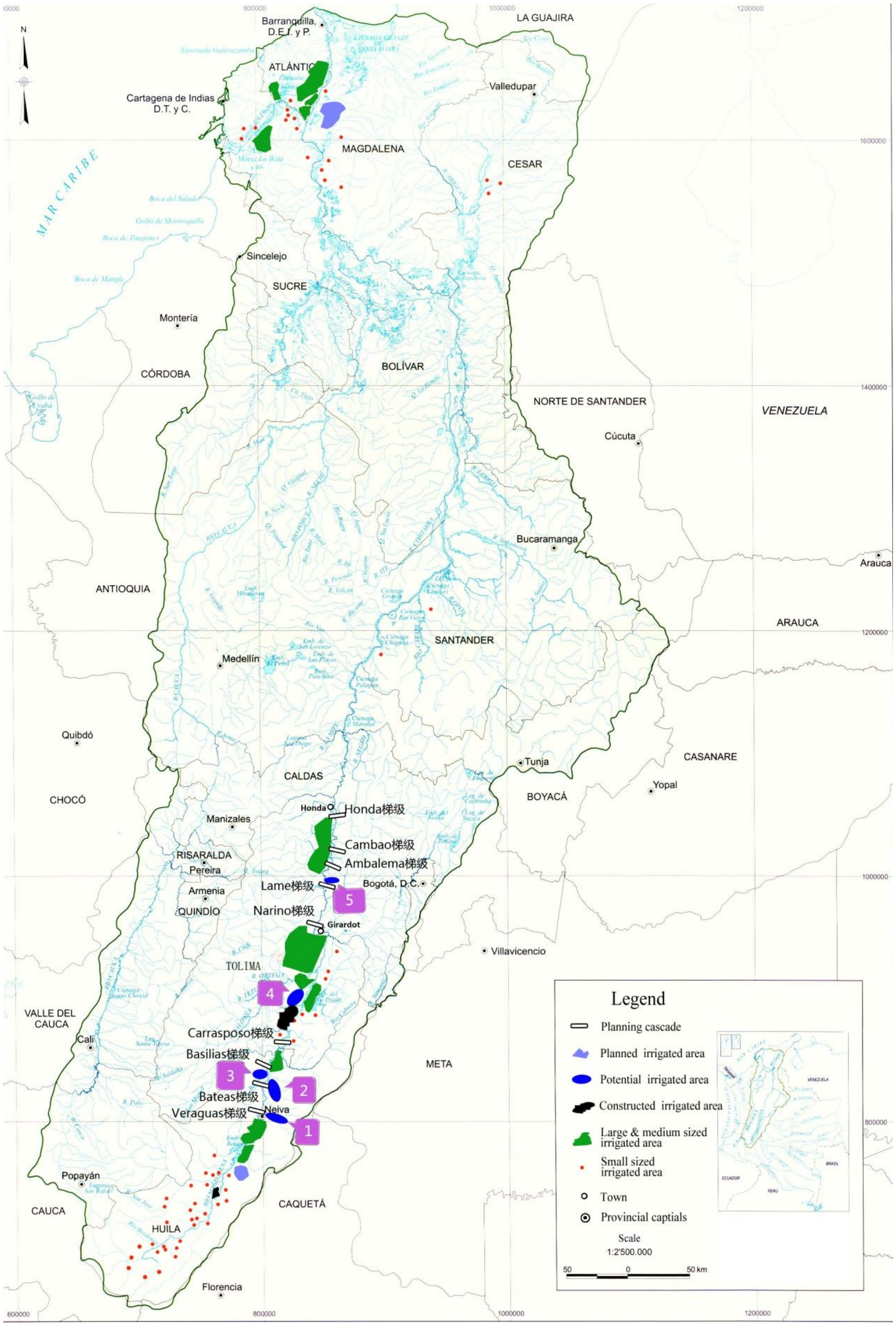


Fig. 8.3.3-1 Distribution Map of Potential Irrigation Areas

Table 8.3.3-1 Basic Conditions of Potential Irrigation Areas

S/N	Department	Name	Irrigation Area	Design Discharge	Elevation of Irrigation Surface
			ha	m^3/s	M
1	HUILA	Cucharito	3733	6.0	450~520
2	HUILA	Polonia	933	1.5	370~390
3	HUILA	La Victoria	2467	4.1	355~364
4	TOLIMA	Saldaña	7867	10	290 ~ 310
5	CUNDINAM ARCA	Paquilo	1400	1.9	230 ~ 245

8.3.3.2 Analysis on Water Sources Conditions

Considering that the planned irrigation areas are all located in areas close to water shortage at upper reaches of the Magdalena River, water shortage problem may be faced with after the completion of irrigation areas. Therefore, combining with the position, elevation of irrigation surface, scale of water intake, river system of main streams and tributaries and planned cascades layout of five irrigation areas, the water source option and possibility of conducting agricultural irrigation with cascade reservoirs as water sources are preliminarily analyzed. The potential irrigation areas are mainly distributed in the Neiva ~ Honda reaches, therefore, contrastive analysis have been conducted between the planned cascades and elevations of potential irrigation areas. Refer to Fig. 8.3.3-1 for the distribution of irrigation areas and cascade reservoirs.

Potential Irrigation Area 1: located at a distance of about 15 km ~ 20 km in east of Neiva, of which the ground elevation is 450 m ~ 520 m; the normal water level at dam site of upstream Veraguas Cascade is 398.27 m, and the full supply level is 420 m. This region basically has no conditions for conducting irrigation by combining with the gravity flow of cascades, so it is recommended to apply method of water diversion from tributaries.

Potential Irrigation Area 2: located at a distance of about 25 km in north of Neiva, near the Villaieja Village, and the regional elevation is about 370 m~390 m. The

Bateas Cascade is planned upstream the region, wherein the normal water level of the cascade dam site is 376.9 m, and the full supply level is 399 m. More than half of this irrigation area is located in the Beteas Reservoir area, and the elevation is lower than the full supply level of Beteas Reservoir. If constructing the reservoir, the irrigation area will be affected to a certain degree, therefore, it can be considered as water source for agricultural development or the plan of irrigation area in the next stage with deep research.

Potential Irrigation Area 3: this region is located on the left bank of the main stream of the Magdalena River, with an elevation of about 355 m~364 m. The Basilias Hydropower Cascade nearby is located downstream the region. This region is about 17.5 km away from the Bateas Cascade upstream. In the next stage, depending on the scale of the irrigation area, option of irrigation by pumping water from the main stream or option of gravity diversion irrigation from upstream Bateas Cascade can be selected after comparison for water source.

Potential Irrigation Area 4: it is located in Neiva~Girardot reaches, at a distance of about 100 km downstream Neiva, on the left bank of main stream of the Magdalena River. The irrigation area is located among the Saldaña, Santa Inés, Purificacion, of which the elevation is 290 m~310 m, with no planned cascade reservoirs nearby, and the method of tributary diversion can be used for irrigation.

Potential Irrigation Area 5: this area is located about 30 km downstream Girardot, on the right bank of main stream of the Magdalena River, with the elevation of 230 m~245 m. And the elevation of most of the area is below the full supply level of Lame Cascade at a distance of 3 km upstream the area. In the next stage, combining with the design of irrigation area and cascades, further research and demonstration on the gravity diversion of reservoir area can be conducted.

8.3.4 Implementation Opinions

8.3.4.1 Continued Construction of Supporting Facilities of Existing Irrigation Areas

At present, there are some irrigation areas with a certain scale along the bank of the Magdalena River. But due to being out of repair for long years with little maintenance, the use ratio of water in the irrigation area is low. Therefore, the existing conditions of the irrigation areas should be improved at first; the continued construction of supporting facilities of existing irrigation areas should be completed and the use ratio of water for irrigation should be improved for the existing irrigation areas.

The main tasks for continued construction of supporting facilities of irrigation areas are headworks, main canals and branch canals as well as other relevant structures. The main objective is to improve the use ratio of irrigation water and water productivity, to improve and moderately enlarge the effective irrigation area, and to promote the structural adjustment of agriculture, increase of agricultural output and increase of farmers' income.

8.3.4.2 Expansion and New Construction of Irrigation Areas

According to the topographical and landform conditions along the bank of the Magdalena River, areas which can be developed into irrigation areas are mainly located at the upper reaches, distributed in three departments of Huila, Tolima and CUNDINAMARCA. There are 5 resource points in total. The expansion and new construction of irrigation areas can proceed from the resource points of potential irrigation areas, and the construction feasibility of irrigation areas should be further analyzed with more sufficient data provided.

8.3.4.3 Construction of Irrigation Water Sources

The principle of proximity can be adopted for selection of irrigation water sources based on the location of irrigation areas, with water lifting and diversion from main stream or tributaries. Besides, water can be obtained from the planned cascades for some potential irrigation areas, and the development of these cascades should consider the irrigation need, Near the planned large-sized irrigation areas, when large-scale water consumption is required, water source points can be newly built at the main stream and tributaries to meet the irrigation need.

8.3.4.4 Water-saving Irrigation

Water-saving irrigation is an irrigation mode that the least water is used to gain the most crop output as far as possible, of which the objective is to improve the use ratio of water and the water productivity. The content of water-saving irrigation comprises the rational development and utilization of water resources, water saving of water transport and distribution systems, water saving during field irrigation process, water saving of water consumption management and agricultural techniques and measures of production increasing and water saving, etc.

Although the water in the Magdalena River Basin is plentiful, water shortage of different degrees still exists in local regions. Developing agricultural modes with high efficiency, high yield and energy saving is the challenge faced by all the countries in the world, and is also the development direction of modern agriculture. The development and application of water-saving irrigation techniques has also become the inevitable trend of agricultural development.

8.3.4.5 Suggestions on Management Mode of Irrigation Areas

At present, within the jurisdictional scope of CORMAGDALENA, the completed irrigation areas lack comprehensive and effective water management mode, leading to low use ratio of irrigation water.

Following relevant national laws and regulations, jurisdictional scopes should be divided based on territory. Strengthening the management of irrigation areas, guaranteeing the agricultural irrigation and urban & rural water supply, improving the utilization efficiency of water resources, enhancing the capacity of withstanding natural disasters, improving the agricultural production conditions and rural ecological environment, and promoting agricultural and rural economic development should be realized.

The management system by combining professional management with water users management should be carried out.

Reasonable dispatching water resources, making strict plan of water consumption, saving water and promoting the advanced technologies for water saving should be conducted; protecting the water quality against from pollution, enhancing the protection of land and water resources within the engineering management scope of irrigation areas should beimplemented, so as to provide water supply services of high grade. Diversified operations should be carried out by taking advantage of the land and water resources in irrigation areas and the capacity for sound operation of the irrigation areas should be improved.

8.4 Riparian Zone Utilization Planning

8.4.1 Current situation and Existing Problems

Riparian resources of Magdalena River refer to the overall natural resources provided by water and land areas within a certain scope on both river banks. These resources are the important basis for the economic development at the middle and lower reaches of Magdalena River; they are also considered as the important support to the industrial deployment, urban construction, port development, water works, river-crossing facilities, ecological protection and tourism development; they are the superior resources to accelerate the economic rise in riverside areas as well as the basis for the life of residents along all riverside cities and towns.

The Magdalena River is 1613 km in total length and it connects several wetlands and lakes at its middle and lower reaches of Cauca River, Dique Canal and Cesar River. Therefore, it is rich in riparian resources and has wide influence. For a long time, people have been relying on the Magdalena River for urban construction, industrial, agricultural and tourism development. However, the records about riparian resources have not been fully made. As the bank slope at part of the Magdalena river reaches is unstable, the scope of the riparian zone along the river course is unclear and the definition on the functions of the riparian zones is unidentified, the conditions for the riparian zone utilization becomes deteriorated and flood flowing and water ecological protection has been affected, leading to the failure in the full utilization of the riparian resources in a scientific way.

With the economical development and improvement in people's living standards, demands for riparian zone utilization are on the rise. As riparian zone utilization is necessary in such aspects as port construction, tourism development, urban recreation, ecological protection, urban construction, riverside industrial parks, conflicts emerge gradually. The country and CORMAGDALENA have already realized this problem and begun to conduct some basic works in riparian zone utilization. Currently, the major problems are as follows:

a) The absence of the basis for riparian zoning. Due to the disparity in regional economic development and the variation in riparian forms along the Magdalena River as well as the existence of a number of lakes and wetlands, the defining of the scope of riparian zones concerns with the interests of various parties. This makes it difficult to determine the standard for zoning and a simple and rough zoning method without sufficient demonstrations will cause even stronger conflicts.

b) The absence of the basis for riparian resources development, utilization and management. Therefore, it is unlikely to carry out effective supervision and control over the unreasonable utilization and orderless development.

c) The absence of related plans for riparian resourced development and utilization leads to the simplification in utilization function, repeated construction and damage to the ecological and natural conservation areas.

d) The river banks of the Magdalena River is poor in scour resistance and unstable in river regime, which, together with the comparatively low investment in river course improvement, leads to the deterioration in the development conditions of riparian zone.

In this comprehensive plan, the principles for the division of the functional riparian zones, the defining of the control line as well as the comments on the plan of riparian zone utilization and management are primarily proposed according to the actual situations of Magdalena River and the management mechanism in combination of experiences in riparian zone management of Chinese river channels, lakes and reservoirs.

8.4.2 Purposes and Tasks

a) Purposes and Significance

Riparian zone refers to the belt zones in certain scope of water and land boundaries in the surrounding of both sides of the rivers, lakes and reservoirs. It has such natural, ecological and environmental functions as flood passing, flow regulation and river/lake maintenance. Meanwhile, it also has the land resource property of having the value for development and utilization under certain circumstances. The development and utilization as well as protection of riparian resources play such an important role in the sustainable economic and social development, guaranteeing flood flowing of rivers and flood adjustment and storage of lakes, keeping positive cycling in ecological system and keeping rivers healthy.

With the continuous economic and social development and the acceleration of urbanization along the riverside, the requirements for utilization of riparian zone of river (lake) are even higher. The increasing development activities along rivers (lakes) and the growing number of riverside buildings, together with the orderless management and development of some riparian zone, negatively impact the flood flowing and the water ecological protection. Especially in urban reaches of the big cities, both riversides and surrounding riparian zones are developed and utilized to a high extent due to flourishing economy, dense population and land shortage. Riparian zone utilization Planshall define the functional areas of riparian zone, formulate management regulations, so as to provide technical basis for riparian zone utilization and protection for administrative permits and approvals of water engineering.

Governmental departments shall make scientific and reasonable utilization and protection of riparian zone resources to guarantee safe flood flowing and retaining of rivers and lakes and to keep healthy ecological environment of rivers and wetlands. They shall make summary about the current situation of the riparian zone development and utilization, management experiences and existing problems, define the riparian zones of rivers and lakes, classify functions, and realize scientific management, reasonable utilization and effective protection of riparian zone resources.

b) Tasks of Plan

The main tasks in the plan of riparian zone utilization are to analyze the rules of channel changing, investigate the riparian resources and the current situation of riparian zone development and utilization, summarize the existing problems in riparian zone development, utilization and protection; divide the functional riparian zone scientifically and reasonably in accordance with the main functional characteristics of riparian zones at different river reaches in combination with comprehensive consideration of flood flowing in the river course, waterway improvement, urban construction, hydropower generation, water intaking for agricultural irrigation, ecological and environmental protection as well as the requirements for the development of national economy and society along the rivers and the lakes; define the scopes of riparian zones and the two lines (riverside control line and periphery control line) for both river banks based on the further analysis on various impacts of utilization and protection of riparian zone; define the overall layout of riparian zone utilization and protection based on the above division; put forward management instructions for riparian zone layout adjustment as well as control and utilization, and make suggestions on policies and systems for utilization, protection and management of riparian zone. Due to the limited data and information, this planonly involves the methods for functional area division and control line defining and management suggestions.

8.4.3 Division of Riparian Functional Zones

According to the natural and eco-social attributes and functional characteristics of the riparian resources along the Magdalena River, those resources are divided into four different types for management: riparian protection area, riparian reserved area, riparian control and utilization area, and riparian development and utilization area. The scale of these functional areas are determined by giving full consideration to such limit factors as planning reaches, length of each functional area ranging from a few kilometers to tens of kilometers. For the urban reaches and developed areas at middle and lower reaches with higher degree and requirements of riparian zone utilization and development, the length of each functional area should be no longer than 10 km due to the shortage in riparian resources and diversified utilization methods. For the river reaches of underdeveloped rural area with lower requirements on development and utilization or underpopulated hilly river channels along upper reaches or river channels limited by some strong restraints (like natural conservation area), the length of each functional area may be longer.

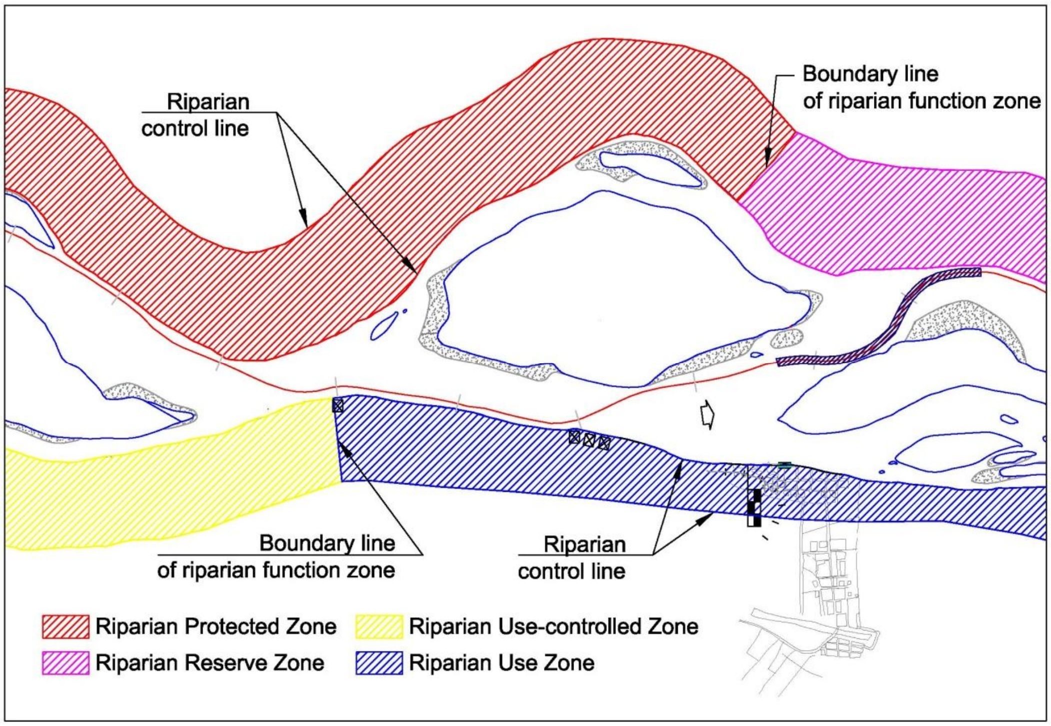


Fig. 8.4.3-1 Division of Functional Riparian Zone

a) Riparian protection area

Riparian protection area refers to the riparian zones where development and utilization are prohibited due to its importance to water resource protection, water ecological protection, rare and endangered species protection, flood control safety, unobstructed navigation, etc., or protection areas with higher levels (like natural conservation areas, water ecological protection areas, wetland reserved areas, important water sources, forest parks, geological parks, reaches with natural and cultural heritages), or the riparian zones where the development and the utilization have great influence on flood control and navigation.

For those riparian protection areas established for water ecological protection, rare and endangered species protection and unique natural and cultural landscape protection, engineering constructions except for flood control, river regime control and water resource development and utilization are basically not allowed. However, in case of the construction of important river-crossing facilities necessary for national economic and social development and infrastructures necessary for ecological environmental protection, these works can be constructed only after further demonstration about their impacts on the protected objects in those areas.

For the reaches already classified as the protection areas in functional zoning of surface water function division or the riparian protection area where important water sources exist, water intakes and shoal reservoirs for water resource development and utilization can be constructed within the area. However, construction of dangerous cargo ports, sewage outlets, outlets of power station, tideland reclamation, etc. that are against water resource protection are not allowed. Ports and piers and river-crossing (river-through) facilities can be constructed only after the demonstration has proved that water resource protection will not be affected.

b) Riparian reserved area

Riparian reserved area refers to the riparian zones that will not be developed or utilized temporarily during the period of plan or has no qualified conditions for development or utilization. Those areas include: the reaches under evolution, the reaches with unstable river regimes, the reaches with obvious changes in channel erosion and deposition, the reaches with main river migration, or the areas that have special requirements on certain ecological protection or with specific functions, such as flood control reserved area, water resource protection area, water source for water supply and estuary reclamation area.

For those reserved areas with unstable regimes and incapable of development and utilization due to undefined schemes of flood control or river regime control, except for such engineering works as flood control, river regime control and dangerous section treatment, other engineering works of development and utilization are basically not allowed. After the completion of flood control and river regime control works, however, when the conditions for riparian zone development and utilization are remarkably improved, these areas can be managed with reference to the way of riparian utilization area management after the approval of related authorities.

For the reserved area of flood control plan, construction of the projects irrelevant to flood control is not allowed. In case of the occupation of the reserved area due to the infrastructure project of the nation, it can only be started after the approval by water administrative department is obtained.

For the reserved areas with poor conditions for development and utilization and its development and utilization will possibly influence river regime, safety of flood control and ecological environmental protection, the construction of any development and utilization projects in these area is not allowed except for about the works of flood control, river regime control, dangerous section administration and water intaking.

For the bottomland riparian zones that have been classified as reserved areas, engineering works of flood control, river regime control and dangerous section treatment, as well as river-crossing (river-spanning) facilities and other infrastructures concerning traffic, cables, water transmission pipes necessary for the production and living of the public can be constructed in accordance with different flood control situations and flood control plan at different reaches. Engineering construction standards shall be strictly controlled. Basically, the construction of ports and piers and other commercial engineering projects is not allowed. In case of the necessity of the construction of major engineering project of the nation, it should not be commenced until in-depth analysis and demonstration have been made about the impacts on flood control, river regime, water resource protection and water ecological protection.

For those reserved areas required by economic and social development, expect for the engineering works of flood control, river regime control, dangerous section treatment and water intaking, the construction of other engineering projects is not allowed during plan period.

c) Riparian control and utilization area

Riparian control and utilization area refers to the riparian zones where development and utilization may threaten flood control safety and river ecological protection, or the already developed and utilized riparian zones where further development and utilization may affect the safety of flood control, water supply and river ecological protection. of the control and utilization areas are generally qualified for moderate development and shall be further divided into river regime control and utilization area, special control and utilization area, etc. , according to which different projects are allowed to be constructed.

For those highly developed and utilized control and utilization areas, further development and utilization may affect flood control, river regime stability and water resource protection. Therefore, new projects shall be controlled strictly in these areas to minimize the accumulative effect of riparian zone development and utilization on flood control.

For the riparian control and utilization areas whose development and utilization may have certain influence on the safety of flood control, river regime stability and river ecological protection, control and guidance shall be provided accordingly. For those areas potentially affecting the flood control, riparian zone development and utilization projects shall accord with the overall flood control layout and different flood control situations at upper, middle and lower reaches of the river; accumulative effect caused by those projects shall be strictly controlled; the Constructors shall be responsible for the compensation of flood control impact. For the areas affecting river regime stability, development and utilization shall only be started after the implementation of the schemes for river regime control. For the areas affecting the water resource and water ecological protection, the development and utilization patterns shall be strictly controlled and the construction of dangerous cargo ports, sewage outlets, outlets of power stations, ash yards of power stations and other projects having adverse influence on the water resource and water ecological protection is not allowed.

For some island riparian zones divided as control and utilization area, development shall be conducted strictly according to flood control standards and implementation schemes formulated as per flood control plan. Construction of those projects shall not beyond the standards and affect the dynamic conditions of the tributary flow.

d) Riparian development and utilization zone

The riparian development and utilization zones refer to the riparian zones with basically stable river regime and no special requirements on ecological protection or function and its development and utilization will have only small influence on the stability of the river regime, the safety of flood control, the unimpediment of waterway, the safety of water supply and the soundness of the river course

Riparian development and utilization zone has the lowest level of restriction on development and utilization. Based on the comprehensive consideration of flood control, navigation, river regime, water supply, water resource, ecological environment, etc., development and utilization will somehow cause negative effects. Therefore, emphasis shall be laid on the riparian development and utilization areas in the plan. Urban reaches with higher degree and requirements of development and utilization shall be subdivided into several functional areas like port riparian zone, industrial riparian zone, river-crossing facilities, water intakes and outlets, living facilities and reservoirs.

For the management of riparian development and utilization area, the need for the economic and social development along the riverside shall be fully considered, in combination with the various related local plan, relevant administrative approval systems should be implemented in a strict manner, including those for flood control impact assessment, water resource demonstration and environmental impact assessment shall be strictly carried out. Ports and piers, river-crossing (river-through) structures, water intakes and outlets and other development and utilization projects can be constructed in accordance with laws and regulations.

8.4.4 Demarcation of Riparian Zone

A riparian control line is the management control line stipulated along the river flow direction or the periphery of rivers or lakes for the purpose of strengthening the reasonable protection and development of the riparian zone resources. Riverside control line is along the river flow or surrounding the lakes to stabilized river regime and guarantee flood flow safety and river health. Periphery control line is the outer boundary within the management area of river (lake) embankment backwater side or boundary between design flood level and river side for river channel without embankment for resource protection and management. Riparian zone is the belt zone between the periphery control line and the riverside control line. The riparian zone has not only the natural and ecological property of flood passing, flow regulation and maintaining the healthy ecological conditions of rivers and lakes but also has the value for development and utilization. Any development and utilization activities in the riparian zone within the periphery control line shall accord with the functional zoning of riparian zone and the management regulations, and shall not exceed the riverside control line in principle.

Generally, riparian control lines are stipulated based on the functional riparian zones. Riverside and periphery control lines shall be stipulated within riparian development and utilization areas and riparian control and utilization areas. For the reserved areas and protection areas however, periphery control lines shall be specified. During the defining of the riparian control line, requirements in such aspects as water resource utilization and protection, ecological environmental protection, flood control and navigation shall be fully considered and the defining of these lines shall be made in accordance with the principles combining reasonable utilization with regulation and protection.

The riverside control lines are the restrictions made in regard to the distance and the way of how the riparian utilization projects enters into the river course. Except for water retaining (gate) dams, flood and river regime control works, bridges, pipelines, water intakes and outlets and other river-crossing and river-spanning projects, any substantial water blocking structures shall not go beyond the riverside control line in principle. The projects shall meet the technical requirements in the project examination and approval within the management scope of the river course and shall obtain the approval from the water administrative department with approving authority. For projects like bridges, piers, pipelines, etc. which need to go beyond the riverside control line, sections beyond the line shall be overhead, lower to the ground or submerged. Occupation of cross-section of river shall be reduced as far as possible.

8.4.5 Implementation Opinions

a) Compile special plan of riparian zone utilization and define scope of riparian zone

In order to realize scientific management and full utilization of riparian zone resources, the scope of management shall be defined via special plan of riparian zone utilization. The scope of riparian zone management is defined based on the complete investigation on utilizations and loads of river channel, lakes and reservoirs, in combination with hydrological and geological conditions as well as the interests of all parties. Investigation and statistics about the current situation and the requirements of riparian zone should be made to compile special plan of utilization.

Generally, the overall plan period for the development and utilization of riparian zone resource is 20 years, and the implementation period is 5 years. These periods can be prolonged for some reaches with lower extent of utilization.

b) River course improvement works shall be actively promoted, and utilization conditions of the riparian zones shall be optimized by both engineering and non-structural measures so as to promote the development of riverside economy and industry.

c) Stipulate the responsible body for riparian zone management and improve the coordination and management mechanism

The responsible body for riparian zone management shall be determined to realize unified management and to coordinate and settle the major issues relevant to riparian zone resource development and utilization.

d) Improve laws and regulations system for riparian zone utilization management

Management regulations are an important component in the system of water management laws and regulations. In order to strengthen the management of the riparian zone utilization, supporting laws and regulations system shall be completed.

8.5 River Channel Regulation Planning

8.5.1 Current situation and Existing Problems

8.5.1.1 Current situation

The mainstream of Magdalena River runs through mountains, hills and alluvial plainsand varies in hydrologic conditions and riverbed boundary conditions at different reaches with a variety of river types. The middle and upper reaches are in north-south direction, and lower reaches are in east-west direction from about 100 km downstream of El Banco before it goes in north-south direction finally running to the sea.

The upper reaches of Magdalena River refer to the river reaches upstream of Honda (K930), where the 400km-long river section upstream of Girardot (K1092) is mountainous river with rapid flow and shoals; the landform from Honda to Girardot is of hilly feature, with both banks dominated by low mountains and hills as well as terraces; the river bank is strong in souring resistance and the river channel is relatively straight with stable riverbed.

The middle reaches of Magdalena River refer to the reaches from El Banco (K379) to

Honda. The river section from Honda to Barrancabermeja (K631) is featured by open river valley with terrace areas on both banks expanding rapidly. The terraces are mostly piled up with sand cobbles and therefore, are poor in souring resistance. The river channel twists and bends and is distributed with several islands at bends. River bifurcations are quite developed, with the bifurcated stream and branches appearing in an alternated pattern. Concave banks at bends are badly scoured, almost all of which have collapsed. However, situation that terraces are submerged by water rarely occurs. The reaches from Barrancabermeja to El Banco are lower part of the middle reaches, having similar river channel characteristics with the upper part. However, with river valleys being more open, river turns into plain and wetland type. The river surface is as wide as 2 km in some reaches. The river types are dominated by straight type, minor bending type or bifurcated type. Terraces of banks consist of silty soil, having poor scouring resistance. With large transversal migration scope of river channel, the talweg is very unstable. River channel evolution is mainly shown in main river migration at straight reaches, as well as numerous sand bars and shoals. With three bottlenecks, San Pablo, Regido and El Banco within the reaches, the river valley forms into three independent wetland flooded areas. The main riverbed is located at the middle of wetland, and becomes wider and shallower every year due to multi-year floods, having adverse influence on navigation and flood flow ability of main river, resulting in more frequent floods and vicious circles.

The reaches from El Banco to Barranquilla estuary refer to the lower reaches of Magdalena River, typical plain wetland river with wide surface. Within such reaches, the section from El Banco to Plato (K163) is the main flooded area of Magdalena River. Two tributaries are formed from El Banco, with the left one being the main tributary mixed with several little tributaries. The right main tributary is the north boundary of the wetland, running through some important historic cities like Mompos. The left main tributary runs through wetland, Pinillos and Magangue and converges with Cauca River. The maximum distance between the two main tributaries is 33 km, the two converging at Buenos Aires. Generally, left tributary is a river of straight and minor bending type, a large bend existing at Pinillos reaches but trending to natural cut-off. Right tributary is typically meandering type. The riverbed of silty soil has bad scouring resistance. With slow flow at wetland, river regime of the main river is basically stable. Reaches from Buenos Aires to Plato is basically stable, with one sharp bend and several tributaries, minimum width of this reaches being about 350 m. Channels are deep, narrow but stable, functioning as jacking and increasing pressure of flood control for upper reaches. Lower reaches of Plato are relatively stable, with several islands. The river channel between Barranquilla port to estuary is 22 km long, capable of navigation of 30,000 t seagoing vessel. Through maintenance and regulation for a long time, the river way is stable and with good developing tendency.

For Dique Canal, it was systematically regulated in 1985; after that, most of bank slopes have been regulated by artificial works to form straight channel and stable river regime, making the development of riverside wetlands and lakes under control. The estuary reaches is of a trumpet type, divided into three tributaries before connecting to the sea. Cartagena Port is the main tributary, maintaining one estuary, but brings silts leading to bad sedimentation at Cartagena Port and threatens the natural port. Other two left tributaries are smaller, with several estuaries, accelerating the sedimentation and influencing the discharge of the tributaries.

8.5.1.2 Functions of River Reaches and Regulation Requirements

The Magdalena River has such functions as flood control, navigation, drainage, irrigation, recreation and tourism. Therefore, it is of great significance in socio-economic development, urban development and living standard improvement. In the river channel regulation, requirements of all parties shall be considered, combining with the socio-economic development levels, the characteristics of the river reaches and rational plan by section so as to realize comprehensive utilization and harmonious development.

a) Upper reaches of Salgar

The area where this reaches is located is densely distributed with small towns and cities such as Neiva, Girardot, Honda, etc. Agriculture and tourism are relatively developed. Main functions of the reaches are power generation; flood flowing, irrigation, water intaking, navigation, recreation and tourism, etc. With abundant hydropower resource, this reaches is a hydropower development area. Development of hydropower shall be combined with flood control, navigation, irrigation and other functions. Currently, due to the steep river slopes and solid bank soil, demand for flood control for riverside is relatively small. Only a few banks suffering from scouring may threaten the riverside residents. In addition, this river section has a water depth lower than 1.35 m throughout the year and thus has low requirements on navigation, with no large ships but about 20 speedboats shipping through this reaches. Therefore, regulation requirements on this reaches during the plan are not high.

b) Reaches from Salgar to Barrancabermeja

This river section is distributed with cities like Puerto Berrio, Boyaca, Nare, Salgar and has such main functions as flood flowing, navigation, irrigation, water intaking, etc. Navigation regulations have been started from 2013 by CORMAGDALENA. This project aims at stabilizing the bank slopes and riverbed, converging flow into main channel and ensuring allowable water depth for navigation. Main structural measures include slope protection, spur dikes, longitudinal dikes, submerged dikes, etc. Upon the completion of the project, it will provide protection for the riverbed and the bank slopes in an all-rounded way and stabilize the channel completely. For the project has been started, this reaches shall not be included in this river channel regulation plan.

c) Lower reaches of Barrancabermeja

These reaches are at the midstream and downstream Magdalena River with such functions as flood control, navigation, wetland ecological protection, recreation and tourism.

Numerous cities and towns are distributed along the channel. Medium and small cities and towns from Barrancabermeja to Calamar are faced with big pressures of flood control. The main purpose in the regulation of this river channel is to improve the flood flowing performance and shorten the flood hydrograph, as these areas are wetlands with lower terrains where flood flowing is blocked, making the water level normally higher than the urban ground. In addition, due to the underdevelopment of medium and small cities, the engineering standard for the revetment is low, leading to higher risks.

Navigation is the main function of the reaches. The water depth of 2.1 m basically meets the navigation requirements of thousand tons pusher fleet. However, due to riverbed unstability, shoals appear during dry season and hinder navigation. Therefore, navigation requirements shall be considered in river channel regulation so as to ensure the sound development of the navigable channels.

Wetland ecological environment is of crucial importance and the wetland lakes are the major spots for local fishery, recreation and tourism, and also an important flood plain to cut down flood peaks. Meanwhile, wetlands are capable of flow purification and sedimentation, mitigating the river channel sedimentation at lower reaches. Therefore, river channel regulation shall give consideration to wetland ecological protection as well so as to postpone the disappearance of wetlands as far as possible and maintain the inundation scope and area of the flood plain.

8.5.1.3 Existing Problems in River Channel

The main stream of Magdalena River is the major support of riverside socio-economic development; its middle and lower reaches are the major freight channel connecting inland of Colombia with Atlantic coast. In the past, the river channel regulation focused mostly on partial reaches regulations such as maintaining water depth of channel shoals and protecting urban riparian zones and roads; large-scale regulation works aiming at river regime control, flood control security or channel regulations are rarely carried out. However, researches on the above items have been started. In recent years, major regulations for midstream and downstream river channel include: digital-analog research on winding reaches of Pinillos, research on the physical modeling tests of Calamar reaches, maintenance dredging downstream of Barrancabermeja, as well as partial revetment, short spur revetment (Barrancabermeja reaches, Mompos, etc.), flood embankment, etc. Numerous valuable experience has been accumulated during the implementation and researches of regulation works of Magdalena River and experience in both research and construction will be further accumulated during the regulation for the Salgar to Barrancabermeja reaches, so as to accelerate the regulation process of Magdalena River.

Although large-scale river regulation works similar to that has been done for the Salgar to Barrancabermeja reach at the middle and lower reaches of Barrancabermeja, the navigable channel here is basically capable of meeting the requirement. However, for some of the unstable reaches, they are extremely unstable and vary considerably in river regime,

bringing big pressure of flood control for the cities and towns at middle and lower reaches, worsening the living environment of residents and threatening agricultural production. The following problems exist currently:

a) The middle and lower reaches of Magdalena River are alluvial plains, the river banks are mostly consisted of silty soil and thus are poor in scouring resistance and serious in bank caving problem. The riverbed suffers from frequent variation in erosion and deposition as well as unstable mainstream, making the riverbed become wider and shallower gradually. In addition, the serious river bifurcation at the river reaches with bifurcated stream and branches appear in an alternated pattern together with the frequently moving shoals lead to the unstability and insufficient depth of the navigable channel in dry season.

b) Most of the previous river channel regulation works were carried out partially instead of comprehensively systematical regulations, especially for most bifurcated reaches and wandering reaches. Some of the river reaches vary remarkably in river regime and some have their river regime keep on deteriorating, which causes unstableness in most riparian zones and threatens the safety of riverside residents and lands.

c) The serious sedimentation at some river channel and indistinct boundaries between wetlands and river channel increase the roughness of channel, reduce its ability in flood flowing, raise the upstream urban flood level, increase the flood control pressure and expand the flooded areas. Especially in recent years, continuous floods bring great losses in middle and lower reaches.

d) Salt tides at the estuary of Dique Canal become serious, which brings greater sedimentation and threaten the natural deepwater port of Cartagena Port.

8.5.2 Objectives

According to the evolvement rules of the Magdalena River, aiming at improving and adjusting the form of the river channel and stabilizing the river regime to meet such requirements as flood control, navigation, water withdrawal and environmental protection, the river channel regulation plan for Magdalena River is preliminarily proposed as follows:

a) Comprehensive consideration shall be given to the requirements of flood control, navigation, water withdrawal, environmental protection, riparian zone utilization and urban development, relations between upper and lower reaches, left and right banks as well as among different industries shall be properly handled and key requirements shall be satisfied with due consideration given to general requirements so as to comprehensively utilize water resource and promote socio-economic development.

b) Specific analysis shall be made about the characteristics and evolvement rules of all reaches to predict the development trend of the river channel and accumulate the experience and learn from the lessons of river regulation of similar types before rational layout scheme for the plan is proposed.

c) Taking into consideration of the requirements from various aspects, both the short-term and long-term objectives for river channel regulation should be identified to decide on the order of priorities and make suggestions on the implementation of plan.

The objectives for river channel regulation include: river regime control and improvement, riparian zone stabilization, embankment safety guarantee, flood flowing performance improvement, navigation condition enhancement, and creation of beneficial conditions for the economic and social development along the riverside. By 2020, reaches directly threatening urban safety will be dredged to reduce flood control pressure; existing embankment will be comprehensively consolidated and guarded to control the river regime; reaches impeding navigation will be under maintenance dredging and systematical regulation with satisfactory conditions to ensure smooth navigation. By 2030, comprehensive regulation scheme for middle and lower reaches shall be further studied, comprehensive regulations for middle and lower reaches of Magdalena River will be conducted to enable stable river regime, riparian zone and embankment, and good channel and port regions, so as to support further development and riverside economy and society.

8.5.3 General Arrangement

8.5.3.1 Division of Reaches

This plan is divided into the key reaches and the common reaches according to the current situation, and existing problems of the river course. It aims to identify the focus and the regulated reaches within the planning period and to provide reference for the systematic regulation of the river channel.

Large-scale regulation works for the 256km-long waterway from Salgar to Barrancabermeja has been put into implementation and is defined as the key reaches.

The middle and lower reaches of Barrancabermeja (including Dique Canal) are divided into several key sections, including: the estuary of Dique Canal (dk114-dk100), the estuary of Barranquilla (-k22-k0), Calamar reaches (k91-k103), Tacamocho (k207-k220), Magangue (k251-k259), Pinillos (k309-k322), El Banco (k391-k403), Regido-La Gloria (k451-485), Bodega-Wilches (545-640), Barrancabermeja (k654-k674) (stake marks taken from RIO MAGDALENA V1.Older.dwg, provided by CORMAGDALENA). Among those, the estuary of Dique Canal (dk114-dk100) is the urban water intakes as well as an important channel for Cartagena, having great social impact; however, with salt tides flowing backward and sedimentation, it is defined as key reaches. Estuary of Barranquilla (-k22-k0) is the entrance for seagoing vessels in Barranquilla port, of which the riparian zone is the major support for the port and the city development. Calamar reaches is the entrance of Dique Canal, bifurcated type with two tributaries, relatively stable. The river channel of this reaches is of great significance to the sand volume entering the Canal and the embankment and the port of Calamar. Tacamocho is the bottleneck for lower reaches of wetland between El Banco and Tacamocho, winding type but naturally cutting off, influential to the flood level and the flood process of wetland. Magangue reaches is of winding type, stableness of which is in relation to the urban flood control and the port. Pinillos reaches is of winding type, tending to be naturally cut off, also the estuary of Cauca River; severe sedimentation and winding threaten the navigation. El Banco is also a bottleneck and the estuary of Cesar River, in relation to the urban flood control and the flood level of lakes at estuary of Cesar River. Regido-La Gloria is the convergence of several tributaries at upstream wetland; with complicated river regime and numerous shoals, it has insufficient water depth in dry season for navigation. Bodega-Wilches reaches is of typical wandering type; with wavering talweg and numerous sand bars and shoals, it has insufficient navigation depth. Barrancabermeja reaches has wavering talweg from side to side, and with developed tributaries and shoals, navigation in dry seasons being influenced.

The upper reaches of Salgar are in good condition except for partial bank caving. With smaller flood control pressure and lower navigation requirement, it is defined as common reaches.

8.5.3.2 Layout of River Channel Regulation Plan

The river channel control line will be determined with the mainstream route as the basis and according to different evolutional characteristics and existing problems so as to control the positions of riparian zones on both banks and those of the islands.

a) Key reaches

The estuary of Dique Canal (dk114-dk100) is stable in river regime but its estuary is advancing forward in a rapid way that the harbor is threatened. Researches shall be further conducted to reduce sand volume entering the Canal or expand the discharge capacities of two tributaries, so as to delay sedimentation in Cartagena Bay.

The estuary of Barranquilla (-k22-k0) is generally in good condition with stable river regime and normal estuary development. Continuous observation and study on the characteristics and countermeasures of riverbed drifting sand bar shall be made in the short term.

Up to now, the Calamar reaches (k91-k103) has had two tributaries and stable river regime. Further bank protection shall be conducted to prevent bank caving and drifting of islands, so as to reduce sand content in flow and relieve sedimentation in Dique Canal.

Tacamocho (k207-k220) has had natural cut-off recently and therefore, research on the optimum cut-off position and the stabilization and control of river regime is of urgent needs. Impact of discharge capability on the upstream wetland shall be studied, as the cut-off works certainly increase the flood flow in river channel and will influence the sedimentation of upstream wetland and the flood level as well as duration. It is a preferential solution for flood control in upstream area.

Magangue(k251-k259) is generally stable in river regime and therefore, focus shall be placed on further consolidation of embankment to prevent concave bank from deteriorating Manual cut-off may be considered under allowable conditions.

Pinillos(k309-k322) has already had natural cut-off having and therefore, study on the river channel control lines is of urgent need and cut-off works shall be started as soon as possible.

Downstream of El Banco (k391-k403), three river bifurcations are seen. The flow of the left bifurcated branch should be guaranteed and either one of the left or middle bifurcated branch is considered to be developed into the main bifurcation. Meanwhile, the protection of concave bank should be strengthened to avoid further development of curve. Estuary of El Banco is a bottleneck, enlarging cross section of flood flowing may be considered to relieve the submerging of upper reaches and estuary wetland of Cesar River.

Regido-La Gloria (k451-485) is the river reach where a number of bifurcated branched converge into one. Due to the failure in main channel stability, emphasis shall be put on the stabilization of the right bifurcated stream with other bifurcated branches properly blocked and the downstream revetment of La Gloria consolidated. Meanwhile, the revetment upstream of Regido city should be consolidated to avoid continuous deterioration caused by riverbank scouring.

Bodega-Wilches (545-640) and Barrancabermeja (k654-k674) are the most unstable reaches. In general, it is caused by long-term evolution of straight river channel, therefore regulations of middle water and low water shall be strengthened, converging flow into main channel to realize the sediment transport balance in medium flow period and low flow period, stabilize the river regime and the talweg, and improve the navigation conditions. Meanwhile the flood discharge capability should be increased to reduce the expansion of flood plain.

Salgar-Barrancabermeja (256 km) reaches will be with better navigation condition after implementation of channel regulation. In plan period, impact on flood river channel shall be closely focused on, necessary restoring measures being taken in time.

b) Common reaches

In addition to the key reaches, the common reaches have the major issue of indistinct bifurcated stream for the river reaches of bifurcation type. In case of the frequent occurrence of bifurcated stream and branches in an alternated pattern, regulation works should be relied upon in due time according to the functions of river reaches and the utilization of riparian zones so as to avoid further deterioration of the river course and improve the navigation conditions by consolidating the bifurcated stream. Another commonly seen problem is that due to the poor souring resistance ability of the river bank, bank caving exists at most banks. Bank prevention works shall be conducted to prevent soil erosion and to stabilize the banks.

8.5.4 Structural Measures

The river channel regulation is divided into flood regulation, medium flow regulation and low flow regulation. Flood regulation aims at preventing flooding and guaranteeing people's lives and properties as well as agriculture, traffic and other infrastructures. Medium flow regulation aims at controlling the river channel evolvement towards beneficial direction, which has decisive impact on evolvement and regulation of flood riverbed and low riverbed. Low-river regulation aims at ensuring navigation as well as normal water intaking and irrigation in the city and the agricultural zones, also maintaining the wetlands. The three types of regulations may have mutual impact. For unstable riverbed, one flood may totally change the medium flow riverbed and the low flow riverbed, so medium flow and low flow riverbeds may also have influence on the hazard of flood.

a) Flood regulation

Structural measures for flood regulation mainly include manual cut-off, wide expansion in bottleneck, embankment construction and bank protection. Manual cut-off can change the winding river channel or over-bending curve into curve with medium bending. Cut-off can increase the discharge capability and stabilize the river regime. For river reaches, it has obvious benefit in flood control. However, impact of manual cut-off on downstream flood control shall be also considered.

Commonly, water flow in bottleneck of river channel runs rapidly with large slope, having impact on upstream navigation of ships. With rapid flow and strong scouring, deep grooves are formed in riverbed, which will threaten the stabilization of riverbank in the future. Expansion of bottleneck can increase the discharge capability, lower the upstream flood level and reduce the flood control pressure.

Bank protection is a major engineering measure in river channel regulation as well as embankment protection, directly preventing bank caving, improving and controlling river regime. Meanwhile, some manual bank protection can change the roughness of river channel, indirectly increase the discharge capability.

Flood regulation is designed as per the standard of flood control for the certain reaches. Design flood level of main control station and design discharge of the reaches is determined as per the situation of the reaches.

b) Medium flow regulation

Measures for medium flow regulation are similar to measures for flood and low flow regulations. Building types for riverbed regulation mainly include spur dike, short bank protection structure, longitudinal dike, bank protection, etc.

In medium flow regulation, channel forming discharge is taken as design standard. For reaches with the tasks of waterlog control, gravity drainage of both sides shall be considered in medium flow regulation. The standard for waterlog control shall be selected according to the natural conditions of water logging area, severity of flood disasters and the impacts. Return period shall be determined by technical economy and is considered as per 3 years to 10 years.

c) Low flow regulation

Low flow regulation mainly focuses on constructing buildings on shoals impending navigation, ports, important irrigation water intakes, etc. in order to improve navigation conditions, ensure normal water intaking and water level of wetland in dry seasons. Spur dike, longitudinal dike, closure dike and diversion structure are often constructed, and jamming tributaries and strengthening main stream, flushing sediment with converging flow, sediment flushing by diversion, dredging, etc. to achieve the goal of regulation.

Low flow regulation design of Magdalena River is mainly based on navigation, water supply, irrigation, ecological environment water demand, etc. of the reaches. Navigation is mainly considered in midstream and downstream low flow regulations, water delivery discharge, diversion discharge and diversion elevation shall be considered in reaches with irrigation and water supply tasks.

8.5.5 Implementation Opinions

After years of regulations of the Magdalena River, certain effects have been achieved, especially in ensuring the normal navigation of thousand tons fleet in midstream and downstream river channel. However, some obvious conflicts exist. For these, following comments on planning and implementation are suggested:

a) Implementing manual cut-off works in Tacamocho reaches and Pinillos reaches as soon as possible

   As natural cut-offs having occurred in bending river channels of Tacamocho reaches and Pinillos reaches, river channel control lines shall be urgently studied and cut-off works shall be started as soon as possible so as to prevent new sedimentation and river migration caused by natural cut-off and to provide a beneficial development of river regime.

b) Strengthening sediment monitoring and soil erosion prevention works

   Sediment monitoring for Magdalena River shall be improved to collect data for sediment transport research. Bank protection, ditch prevention and control, vegetation recovery and other engineering construction shall be strengthened.

c) Further studying on regulation of key river reaches

   Recent emphasis shall be put on the regulations of estuary of Dique Canal, impact of Calamar river channel on sediment in Dique Canal, impact of bottleneck river channels (Tacamocho reaches, El Banco reaches and Regido-La Gloria reaches) on upstream wetland, necessity and feasibility of bottleneck expansion works. Bodega-Wilches reaches and Barrancabermeja reaches are the reaches with most unstable river regime, and for the necessity and feasibility of regulations for these two reaches, implementation of Salgar-Barrancabermeja channel regulation can be combined to consider, together with flood control and navigation factors.

d) Establishing and improving river channel management mechanism

   River channel management mechanism shall be established and improved with the management organization clearly defined to coordinate the relations between various parties in aspects of navigation, flood control, irrigation, water withdrawal and environmental protection, and give response to and dispose with dangerous cases and problems occurred in the river channels.

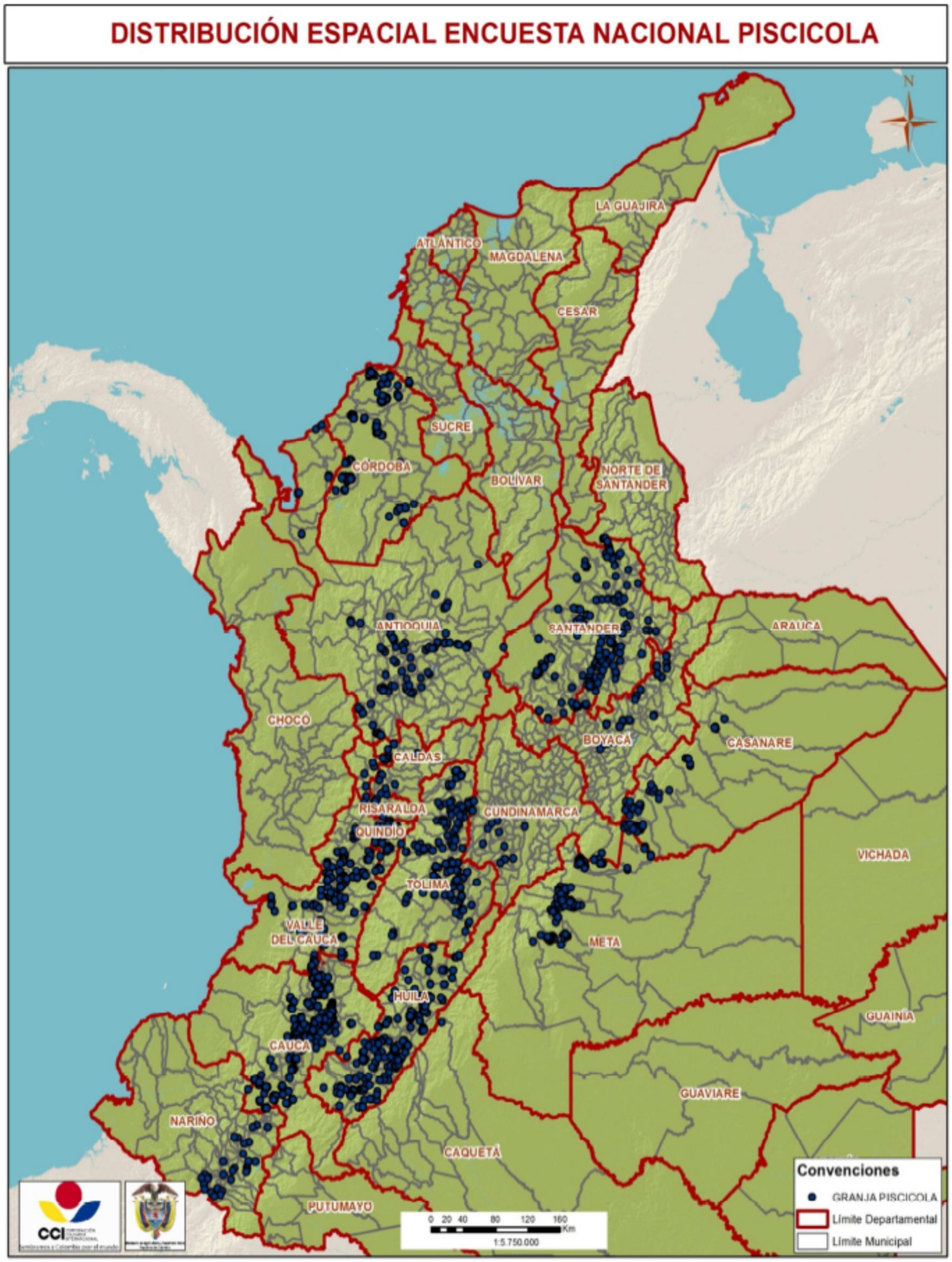
8.6 Fishery Resources Utilization Planning

8.6.1 Current Situation

According to the Total Fishery Production of Colombia in 2002 (Table 8.6.1-1) provided by INCODER (Institute of Colombia for Rural Development), the Magdalena River Basin provided 62% of freshwater fish and 18% of total yield (including marine fishery). In recent years, artificial aquaculture of the inland freshwater fishes has developed rapidly, with near 2,000 ha of pond culture and 1,050,000 m^2 of cage culture including 1,770 cages. Most aquaculture farms are distributed in the Magdalena River Basin (Table 8.6.1-1), making itself more outstanding in fishery production.

Table 8.6.1-1 Fish Production of Colombia in 2002

	Traditional	Industrial	Total	%
Marine				
Atlantic Ocean	3.400	19.500	22.900	28,4
Pacific Ocean	7.400	50.314	57.714	71,6
Sub-total marine	10.800	69.814	80.614	100
Continental				
Magdalena basin	17.600	0	17.600	62,6
Orinoco basin	3.300	0	3.300	11,7
Amazon basin*	7.200	0	7.200	25,6
Sub total continental	28.100	0	28.100	100
Total	38.900	69.814	108.714	



Informe ENP 2012A
MADR - CCI

Fig. 8.6.1-1 Distribution of Aquaculture Farms in Magdalena River Basin

a) Fishery Resources

According to the BD_CuencaMagdalena.mdb of TNC, there are 202 species of fishes of 11 orders, 39 families and 102 genera in Magdalena River Basin, including 51 endemic species, of which 23 are included in the Red Book of Endangered Freshwater Fishes in Colombia published by Mojica et al. (2002). 26 species among the fishes in the basin are of high commercial value (Source: Lasso et al., 2011), with *Prochilodus magdalenae, and Plagioscion magdalenae taking a predominance in the market.* According to the data of CCI-MARD 2011, 11 major species were caught from the lower Magdalena in May 2011, and the *Bocachico (Prochilodus magdalenae)* accounted for 56% of the total capture.

The major aquaculture species in Colombia are the imported *Tilapia mossambica, T. nilotica and T . rendalli* and other Tilapia species and Tilapia's hybrid specie, Tilapia roja. The production of Tilapia species, according to the statistics of the first half of 2012, surpassed 70% of the total aquaculture production, with cachama and trucha accounting for 16% and 11% respectively. Besides, aquaculture experiments of native fish, such as *Prochilodus magdalenae, Petenia kraussii, Brycon moorei and Colossoma bidens* are also carried out. *According to the experiments, Colossoma bidens* is the most promising local fish with best production performance, but local fish is not competitive in yield.

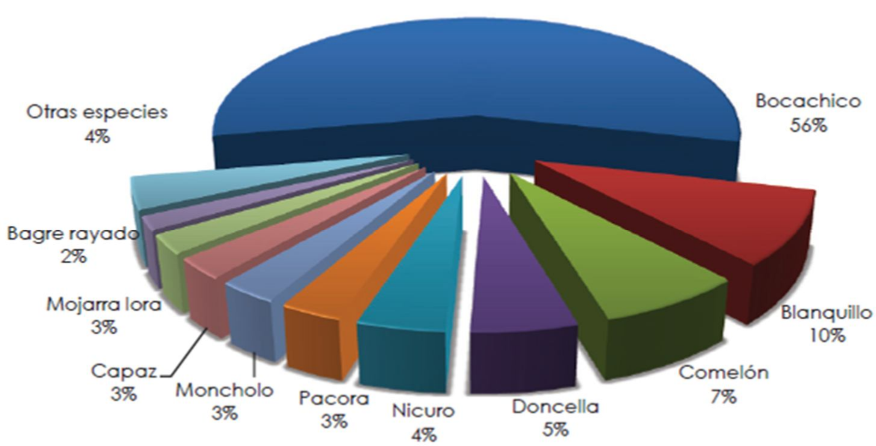


Fig. 8.6.1-2 Species and Distribution Percentage of the Fish Catches in Lower Magdalena Region in May 2011. (CCI-MARD 2011)

b) Development of capture fishery

1) Fishing gears, fishing methods and fishermen

The capture fishery has a long history in Magdalena River, and the traditional capture still dominates. The major fishing gears and fishing methods include: hook, dredge, casting net, encircling gear, gill net, trammel net and small trawl etc. In recent years, the purse seine, trammel net and other fishing gears and fishing methods have been introduced to improve the catching effeciency; in general, the fishery is traditional, without deep processing, with pickling or drying at most; most fisherman families along the banks mainly live on fishing. Now, there are about 46,000 professional fishermen (Table 8.6.1-2), and there are more than 200,000 people with fish as their main source of income and these people have a low livelihood. The seasonality for catching is strong; the production is high from December to next March because it is the high water period in which fish migrates; the production is relatively low in the another catching period from July to August. There is certain yield in September. However, with the increasing living pressure, catching is stilled proceeded in low water period, and the production of single boat is limited.

Table 8.6.1-2 Number of Fishermen on Magdalena River

Sector and landings ports	No. fishermen
Magangué	21,150
El Banco-Zapatosa	15,780
Gamarra	2,350
Barrancabermeja	1,600
Plato	950
San Pablo- Puerto Wilches-Cantagallo	900
Canal del Dique	450
Betania	490
Puerto Berrío-Puerto Nare	400
Caucasia-Nechí	340
Guájaro	300
Zambrano	300
Puerto Boyacá-Puerto Servíez	250
Sector Neiva	230
La Dorada-Guarinocito	220
Prado	180
Honda-Puerto Bogotá	40
Total approximate	45,930

2) Changes in fish production

According to the historical statistics, the fish production decreased from 60,000 t ~ 80,000 t before 1980 to about 30,000 t in 1990 and to the minimum (< 10,000 t) in1998. In the 21st century, the production further decreases to 10,000 t ~ 20,000 t. Given the production decrease of commercial fish and the constantly increasing demand, fishermen begin to catch species with low quality and small size, such as *Cyphocharax magdalenae, Centrochir crocodilii, Trachycorystes insignis, Hoplosternum magdalenae* (Mojica, 2002) to meet the market demand. Due to the intense capturing of low-quality fish, the production has a moderate recovery, but it cannot stop the sharp production decline caused by the decreasing resources. In order to recover the fishery resources, the government, governmental organizations and international organizations have made certain efforts, such as, two closed fishing seasons from 15 May to 15 June and from October to November, provisions on the screen size (not be less than 8cm), no use of trammel net, explosives and poisons and other methods that might destroy the fish resources, no capturing in waters connected to rivers and lakes; rehabilitation of destroyed wetlands ecosystem of lakes and marshes, and delimiting of the protection zone. At present, the trend of sharp drop of fish resources is under control to some extent, and the fish production rises again.

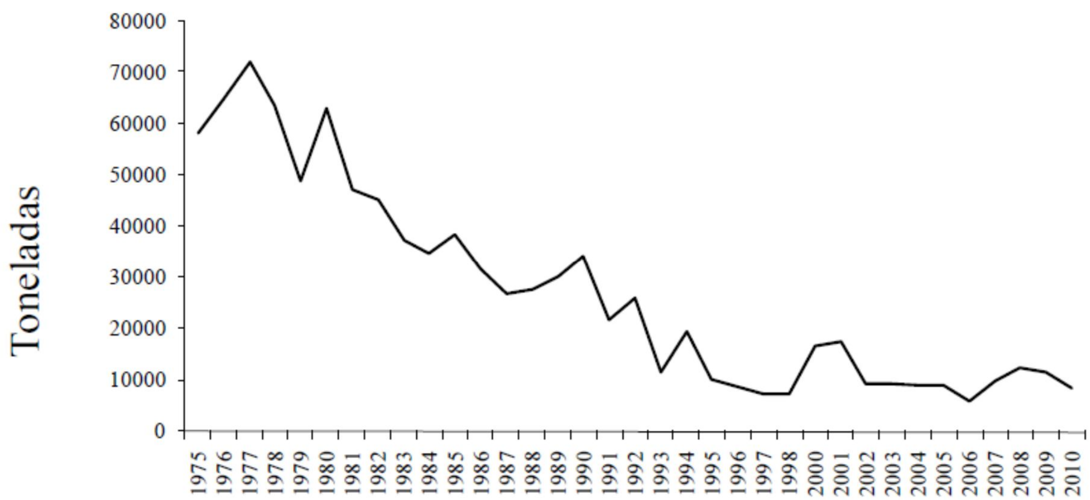


Fig. 8.6.1-3 Fish Productions in Magdalena River over Years

3) Marketing of fishery products

Aquatic products distribution and trading centers include La Dorada-Honda, Puerto Boyacá, Puerto Berrío, Puerto Wilches and Barrancabermeja at middle reaches, and Gamarra, El Banco, Magangué, Plato, San Cristobal- Canal, Magangué and Barranquilla at lower reaches. There are 5 middlemen engaged in aquatic products wholesale in Barrancabermeja.

c) Development of aquaculture

1) Development history of aquaculture

The earliest fish culture is the culture of the introduced rainbow trout in 1938. At the late 1960s, *Tilapia mossambica, T. nilotica and T. rendalli. were introduced and* aquaculture experiments of local fish such as *Prochilodus magdalenae, Petenia kraussii, Brycon moorei and Colossoma bidens* were carried out. According to the experiments,. *Colossoma bidens* is the most promising local fish with the best production performance. According to INPA's 2001 statistics, the annual production of aquaculture is about 42,000t, exceeding the total sum of the freshwater catching production.

2) Scale and production of aquaculture

According to the survey data about fish culture in some areas in the first half of 2012, the fish culture in Colombia was mainly represented by cage culture and pond culture. There were 6,663 pond culture farms, including 17,836 aquaculture ponds of 1,983.4 ha, and 7,546 idle ponds of 446.9 ha, and they accounted for 50% of the total number of pond culture farms all over the country. There were 107 cage culture farms, including 1,770 aquaculture cages of 105.0 ha, and 84 idle cages of 0.9 ha. The Tilapia is the dominating specie, with *Tilapia roja* accounting for 48% of the total aquaculture production, and tilapia plateada, cachama and trucha accounting for 23%, 16% and 11% respectively. Besides, there are other culture species such as Yamú, Bocachico, Carpa and Otros, but their production is small (Table 8.6.1-3, Fig. 8.6.1-4).

Table 8.6.1-3 Aquaculture Production and Composition in Different Departments

Tabla 6. Cantidad de granjas, estanques, jaulas o jaulones y superficie de espejo de agua (m²) , utilizados y no utilizados, para la producción piscícola para el período enero - junio de 2012

Departamento	Estanques					Jaulas o jaulones				
	Cantidad granjas	Estanques usados	Espejo de agua usado (m²)	Estanques no usados	Espejo de agua no usado (m²)	Cantidad granjas	Jaulas o jaulones usados	Espejo de agua usado (m²)	Jaulas o jaulones no usados	Espejo de agua no usado (m²)
Huila	864	2.292	2.740.184,3	999	633.861,6	88	1.301	590.602,8	26	7.600,1
Tolima	1.214	2.180	1.445.206,7	613	206.923,0	4	228	450.002,0	-	-
Meta	888	3.150	5.572.909,9	1.441	1.498.777,6		3	36,0	3	36,0
Antioquia	419	2.053	705.851,9	663	78.515,8	4	35	584,0	25	376,0
Cundinamarca	602	1.076	462.305,4	695	243.656,9					
Valle del Cauca	427	1.081	884.116,0	614	631.727,1					
Córdoba	290	735	6.194.689,8	257	530.708,7					
Boyacá	257	1.199	130.044,8	581	30.876,8	11	203	8.609,9	29	1.181,1
Casanare	256	872	856.749,6	520	305.116,0					
Cauca	343	1.571	228.744,6	162	46.371,9					
Santander	529	1.135	491.426,0	617	177.729,6					
Risaralda	232	252	97.915,6	210	74.425,2					
Caldas	64	76	11.427,1	12	411,6					
Quindío	278	164	12.389,7	164	10.391,9					
Total	**6.663**	**17.836**	**19.833.961,3**	**7.546**	**4.469.493,7**	**107**	**1.770**	**1.049.834,7**	**84**	**9.193,2**

Fuente: Encuesta Nacional Piscícola 2012 A. CCI – MADR

Departamento	Especie								Total (t)
	Tilapia roja	Tilapia plateada	Cachama	Trucha	Yamú	Bocachico	Carpa	Otros*	
Huila	8.878,9	6.363,2	608,4	52,4	177,3	59,6	16,7	1,2	**16.157,6**
Tolima	1.228,3	15,7	794,2	26,9	21,8	60,0	2,6		**2.149,5**
Meta	1.040,6	7,3	1.044,3		25,4	2,1	0,6		**2.120,4**
Antioquia	701,0		350,4	954,2	5,4	3,0	1,0		**2.014,9**
Cundinamarca	135,9	0,0	163,1	1.093,0	2,1		9,5		**1.403,6**
Valle del Cauca	536,1		396,8	160,2	6,6		6,8	0,3	**1.106,7**
Córdoba	61,0	2,5	847,2			81,9			**992,7**
Boyacá	265,5	20,0	8,8	632,8			0,4		**927,5**
Casanare	596,9		107,2		9,5		0,0		713,6
Cauca	117,9	20,3	16,8	312,4	11,9				479,2
Santander	74,3	0,5	179,7	5,1	1,5	3,5	0,1	6,9	271,5
Risaralda	68,0	8,8	7,8	4,2			1,4		90,2
Caldas	13,8	2,1	0,3			0,5			**16,7**
Quindío	7,4	1,2	0,5		0,4	0,0	0,5		**10,1**
Total general	**13.725,6**	**6.441,5**	**4.525,5**	**3.241,2**	**261,9**	**210,7**	**39,5**	**8,4**	**28.454,2**

* Sardinata, bagre y Salmón rosado
Fuente: Encuesta Nacional Piscícola 2012 A. CCI – MADR

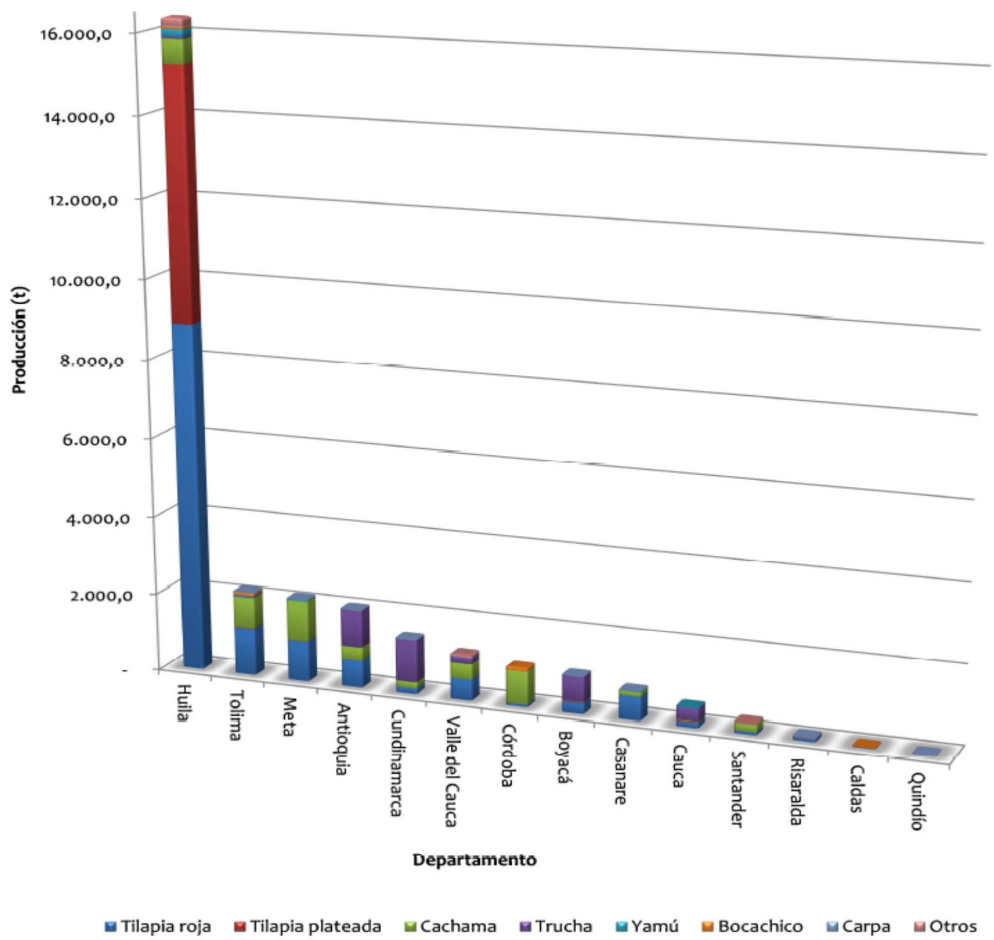


Fig. 8.6.1-4 Aquaculture Production of Different Fish within Magdalena River Basin

3) Sales of aquaculture products

According to the statistics in the first half of 2012, 53% of the aquaculture products were sold in urban market, 15% were sold in markets near the aquaculture farms, 18% were exported, and only 3% were processed.

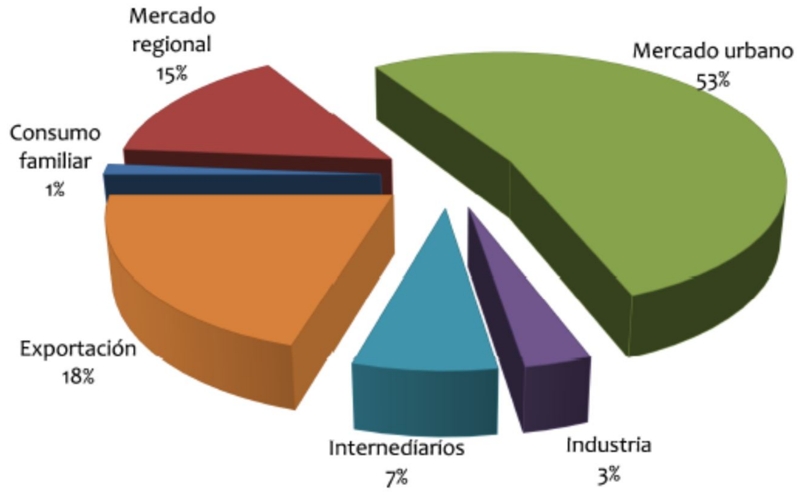


Figura 5. Destinos en la comercialización de la producción piscícola para el período enero - junio de 2012
Fuente: Encuesta Nacional Piscícola 2012 A. CCI – MADR

Fig. 8.6.1-5 Sales Ratio of Aquaculture Products

d) Construction of support system for fishery development

1) Culture of native and improved species

In order to improve the aquaculture production performance, a series of researches and practices on specie improvement were carried out, obtaining the hybrid specie Tilapia roja through hybridization. At the same time, in order to develop the culture of native species, taming and breeding technical researches and experiments on aquaculture production of *Prochilodus magdalenae, Petenia kraussii, Brycon moorei and Colossoma bidensj were carried out,* but the native species were not competitive in yield. In order to meet the fish fry supply to fish culture, farms of improved species were established in main producing areas of aquaculture for the culture of fish fry and heredity study.

GIGANTE farm of improved species: located in Gigante City. The total area is 29 ha, and the water area is 5.5 ha. It has two small reservoirs of 11,000m^2 and 66 cultivating pools of 5100 m^2. There is also a special separated area of 3ha, which is equipped with laboratories, regional fishery processing management laboratories, water quality monitors, and facilities for feed R&D and production and is used for the breeding fries of bocachico, bagre, guabina, cachama, mojarra criolla o anzuelera, capaz y peje and Tilapia mossambica. During the period from January to May of 2008, 1,290,000 red Tilapias fries were cultured, 100,000 Nile tilapias fries and 850,000 other fries.

REPELÓN farm of improved species: located in Repelón, covering an area of 16 ha, wherein the water area is 9.2 ha, divided into many zones with unequal areas from $18m^2$ to $5000m^2$. There are 101 ponds. Besides, there are also the library, water quality labs, biological assay rooms, hatching houses etc. In addition to Tilapias fry, there are also fish fries of Bocachico, Cachama, Coroncoro, Lisa and lebranche (Mugílidos) in the farm of improved species (Table 8.6.1-4).

Table 8.6.1-4 Fry Culture in REPELÓN Farm of Improved Species

	2004	2005	2006	2007	TOTALES
TILAPIAS	714.000	1’635.000	680.000	1’044.000	4’073.000
BOCACHICOS	3’560.000	3’278.362	4’600.000	6’210.000	17’648.362
CACHAMAS	50.000	1’270.000		150.000	1’470.000
MUGILIDOS	5’970.000		10’080.000	10’000.000	26’050.000
TOTALES	10´294.000	6.183.362	15´360.000	17’254.150	49’241.362

2) Processing and transport of fishery products

Most fishing aquatic products are sold in nearby markets without deep processing. In order to retain freshness, transport with ice is adopted. For the products not sold out, simple processing methods of killing, pickling or drying up are used, for the convenience of storage and transport. The export processing and manufactured goods occupy a lower ratio, 18% and 3% respectively. Slicing and refrigerated shipment are the main processing methods for exported products.

8.6.2 Existing Problems

a) Recession of fishery germplasm resources and dramatic decline of fish production

Due to overfishing, shrinkage of wetland habitat in water area, water pollution and invasion of alien species, the fish resources in Magdalena River Basin suffer from a dramatic recession.

b) Lack of diversity

According to a survey report of fishery culture in the first half of 2012, the species of fish culture in Colombia amounts to less than 10. The aquaculture production is mainly from Tilapias, wherein only Tilapia roja accounts for 48% and trucha with relatively high quality only accounts for 11%. Although native species such as *Prochilodus magdalenae, Petenia kraussii, Brycon moorei and Colossoma bidens* are cultured, the production is low, accounting for less than 2%.

c) Underdevelopment of fishery production potential

According to the statistical data of fish culture in the first half of 2012, there were 7,546 idle ponds of 4,469,493.7m^2, with idle ponds and water area accounting for 29.7% and 18.4% respectively, and 84 idle cages of 9,193.2m^2. The analysis of aquaculture area and aquaculture production shows: whether it is pond culture or cage culture, the per unit area yield is still in a low level, still belonging to extensive fish culture.

d) Imperfect support system of fishery production

Most fishery products are sold in nearby markets, without refrigeration, processing and marketing system. The catching products in fishing seasons are under oversupply, thus large amount of aquatic products are discarded after decaying and deterioration. The waste is serious and the utilization ratio of fishery is low.

The leading enterprises of fishery production are weak, and fish culture enterprises are small and disperse. Although some associations of fisheries are set up, they are small and lack of effective communication mechanism. In addition, a high-efficient operation mode integrating the production, fishery supplies, processing and marketing has not been established.

Besides, the weak aquaculture techniques and imperfect fry and feed systems seriously restrict the development of fishery culture.

8.6.3 Fishery Resources Utilization Planning Scheme

8.6.3.1 Guidelines and Objectives

a) Guidelines

To established an integrated production – service – processing – marketing mode by integrating advanced domestic and foreign technology and experience in fishery production based on the fishery resources and ecological environment characteristics and the socio-economic development status in the river basin and the ever increasing consumer demand for aquatic products, so as to realize the effective protection and proper utilization of fishery resources and promote the efficient and sustainable development of fishery production.

b) Plan objectives

Effective protection and sustainable utilization of fishery resources, recovery of fishery resources and increase in fishing production and efficiency by protect and increase the fishery resources by protecting and recovering the aquatic habitats, and regulating the fishing order in natural water area, protecting the breeding fishes resources and establishing the processing and sales service system; perfection of existing fishery culture facilities; establishment and perfection of supporting fishery culture mode and business model; promotion of high-quality and high-efficient species and advanced culture technology; development of fishery culture in a high-quality and high-efficient and healthy manner; more jobs, income increase; people's demand for aquatic products satisfied.

8.6.3.2 Plan Layout

For the utilization of fishery resources, priority should be given to aquaculture, concurrently supplemented by capture fishery. Aquaculture should be developed with increase in production and scale to satisfy the market demand for aquatic products and release the catching pressure of natural fish resources, and combined with protection of fish resources, to effectively recover the natural fish resources, and gradually improve the production and efficiency of capture fishery.

For capture fishery, with consideration of the aquatic ecological protection plan, the aquatic habitats and fish species for priority protection should be identified, capture activities regulated, fish resources protected and recovered so as to gradually improve the fish production; relatively independent lakes and reservoirs should be selected for natural breeding fishery bases, where native commercial fish fries would be input and natural fish food resources and other biological resources could be used, to increase fish production from large water areas; the refrigeration, processing and marketing system of capture fishery should be established, and bases for fish refrigeration and processing should be built in El Banco, Magangue and Calamar in the short term.

For the aquaculture, on the basis of the existing culture bases, the standardized renovation should be done to the existing ponds; with the local native fishes as the predominant species, high quality and high-efficient species and advanced culture technology should be studied and promoted. The introduction and domestication of foreign cultured species should be controlled; the service systems concerning fish fry breeding, supply of fish food resources and necessary fishing resources, and processing and sales of aquatic resources should be improved to promote development of aquaculture fishery with high quality and high efficiency.

8.6.3.3 PlanFishery Resources Utilization Plan

a) Capture fishery

1) Protection and recovery of fishery resources

In combination of the water ecology protection plan, priority should be given to protection of ecologically important water areas and endangered rare species to achieve effective protection of fish germplasm resources; laws and regulations on fishery resources protection should be established and refined, the enforcement of laws and regulations should be refined, the catching activities in natural water areas should be regulated; construction and rehabilitation of five fish multiplication stations, i.e. CORMAGDALENA, REPELÓN, Neiva, Girardot and Magangue, should be done to recover fish resources.

2) Improvement of capture fishery and standard operation

Proper catching devices, catching mode, catching water area and catching timing should be studied and recommended according to the composition of species and community structure characteristics of the catches in the river basin so as to improve the efficiency and correctness;

In water areas with slow flow such as lakes and reservoirs, the fixed net catching method should be introduced and promoted; where possible, a multiple-way-united catching method, which is effective and popular in China should be introduced, which would be helpful for the freshness of the catch products and the flexibility of the supply to the market as demanded.

The catching license system should be implemented; the catch limit, minimum catchable size of major catches, and the allowable proportion of juvenile fish in the catch mix should be studied and formulated; the closed fishing area, closed fishing season and major catching areas and catching seasons etc. should be determined.

3) Improvement of construciton of fishing ports and wharfs and regulation of the market of the fish products

The construction of the infrastructures of the fishing ports and wharfs should be improved and the sales market of the fish products should be regulated based on the existing ones. The focus should be put on to La Dorada-Honda, Puerto Boyacá, Puerto Berrío, Puerto Wilches and Barrancabermeja on the middle Magdalena River, and Gamarra, El Banco, Magangué, Plato, San Cristobal- Canal, Magangué, Barranquilla on the lower Magdalena River.

4) Establishment and improvement of the refrigeration, processing and marketing system

Leading enterprises of aquatic product processing should be forstered. Cooperatives between leading enterprises and fishermen should be established, where the leading enterprises should give the purchaseorders and quality requirements, and the fishermen should conduct fishing based on the requirements of the orders. This is a mutual-benefit mode by not only providing guarantees for the sales of fishermen's catchings as well as raw materials for processing and sales enterprises, and is helpful for development, expansion and healthy operation of the cooperatives. Refrigeration and processing bases are planned at El Banco, Magangue and Calamar in the short term, and each base should comprise refrigeration and processing workshops, packing workshops, improving the additional values of fish.

b) Aquaculture

1) Cage culture

The cage culture should be carried out mainly in reservoirs and appropriately in deepwater lakes. A cage culture model base is planned to be constructed in Betania Reservoir in the short term.

(1) Scale and layout

The ecological environment investigation of reservoir should be systematically carried out. Based on the ecological environment status of the reservoir and high production technical parameters of the reservoir, the research on cage culture water carrying theory should be conducted, along with the plan layout of cage culture. In accordance with the techniques and experiences in setting-up of cage culture in China, the area of cage culture should be controlled to be 0.78‰ of the reservoir water surface. Since different reservoirs have different ecological environments, the recommended area of cage culture varies largely. The area generally planned is 0.5‰~1.5‰ of the reservoir area. Considering the requirements on ecological environmental protection in the Magdalena River Basin, the area of cage culture should not be more than 0.5‰. As cage culture will cause water quality pollution at a certain degree, dispersed culture should be appropriate. But for convenience of management, the cages should be combined. Each combination of cages should not have an area more than 1000m^2, and the combination mode of cages should be beneficial for the water exchange as far as possible. It's easy to deposit residual feeds and feces on the water bottom below the cage culture areas, which will lead to water quality deterioration after long time of culture. Therefore, the culture areas should be changed after 2 to 3 years of culture.

(2) Selection and development of cage culture species

Aimed at the status that the cage culture species are single with the foreign species dominated, cage culture techniques of local native high-quality fish should be researched and developed. Studies and practices on taming and breeding and culture should be conducted mainly for 26 fish species of relatively high commercial value.

(3) Enhancement of studies and promotion of cage culture techniques

Puffed feeds of complete formula should be promoted. The feeding of the feeds should be based on the "three-fixed principle", i.e. fixed time, fixed location and fixed quantity and in the slow-quick-slow operation mode so as to improve the conversion efficiency of feeds, reduce water pollution, and the feed coefficient is recommended to be not more than 1.2.

The fish growth should be controlled by the cage culture density, to form a gradient of different sizes, for the convenience of sales; the nesting combined cage culture technique, in which several small fed cages are put in one large non-fed cage, should be introduced and promoted. The residual feeds of small cage culture and rich zooplankter in the water area near the feeding type cage would be utilized for the fish of large cage culture. By means of cyclic utilization, the use efficiency of feeds would be improved and the pollution on water environment be minimized.

2) Pond culture

The pond culture should be based on the existing culture base. Through the standardized renovation of the ponds, the idle rate of ponds could be reduced. Through strengthening of culture and development of famous and high-quality fish strengthened, promotion of techniques such as three-dimensional culture and catching and stocking in rotation for species, digging the potential for efficiency, the production and benefit of pond culture would be improved.

(1) Standardized renovation of ponds

High-yield aquaculture ponds usually requires a water depth of 2 m ~ 3 m, an area of 1000 m^2 ~ 1500 m^2, easy water inlet and drainage without leakage, relatively stable water level, and support equipment such as aerators wherever necessary. Therefore, standardized renovation of ponds should be performed on the basis of systematic investigation on general information of aquaculture facilities.

(2) Development and promotion of culture of valuable and high-quality native species

At present, the fish culture specie predominant in pond culture is the introduced Tilapia, which is not favorable for three-dimensional aquaculture with multiple species and of which the quality of the product is not high. Studies concerning the multiplication, breeding and pond culture techniques of valuable and high-quality native species should be strengthened.

(3) Test and promotion of advanced pond aquaculture techniques

Three-dimensional pond aquaculture of multiple species: According to the eco-environmental conditions as well as feeding and activity habitus of fish, species with different feeding and living habits should be scientifically selected and combined, so as to enhance the utilization efficiency of the pond area and fish baits and to further increase the output.

Catching and stocking in rotation: According to living habits and growing features of different fish species and sizes, fish species should be scientifically matched, adult fish reaching the sizes should be regularly caught for the market, fish fingerlings should be timely supplemented for recycling culture, so as to increase the output.

3) Large-area natural breeding (with artificial fingerling input) in lakes and reservoirs

It is a breeding method that by artificial input of fish fingerlings, utilizes the biological base of the natural food in lakes and reservoirs, so as to increase the production of large water areas. It is popular in China. In case of a good condition, input of 1 kg fish fingerlings may result in a catch of 5 kg ~ 7 kg adult fish.

Implementation of natural breeding needs water bodies relatively independent with less escaping chance for fish, which is beneficial to increase the output; so some fish pounding facilities should be built if necessary.

(1) Evaluation of fishery production potential

Morphological characteristics of the lakes and reservoirs, physicochemical property of the water body and food organism basis should be investigated in an overall way to evaluate the production of the aquatic organisms and the fishery production potential of different biological types.

(2) Breeding plan

On basis of evaluating results of fishery production potential, in combination of feeding habits, living natures and re-catching situations of different fish species, reasonable breeding plan should be made.

(3) Management of catching and re-catching

Reasonable catching sizes should be stipulated as per growing situations of the breeding fish; reasonable re-catching methods should be made as per behaviors and habits of the breeding fish.

c) Recreational fishery

Reasonable layout and step-by-step promotion should be made for recreational fishery based on overall recreational plan with characteristics of recreational fishery within the basin. Recently, natural and hydraulic engineering landscape of Betania reservoir should be utilized and angling resources in reservoir should be fully used for establishing demonstration base of recreational fishery.

Considering fish resources, natural landscape, cultural landscape and catering and recreational facilities, it is divided into angling area, sight-seeing area and recreational area, equipped with catering, recreational and angling facilities and equipment; the development should focus on angling fishery, so as to promote comprehensive benefits.

d) Support system

1) Grading system of native elite breeds

Studies and practices of domestication and culture as well as specie breeding technique for native famous and high-quality should be strengthened and promoted.

As required by fishery culture, it is needed to improve construction and layout for native elite fish species, introduce and transform facilities and equipment for fish culture, and strengthen the market ability of the fish fingerlings.

Joint research in combination of production, knowledge and research should be made on domestication and culture technique for native fish species, technical support for fingerling production being increased significantly.

2) Service system

Production processes for different fish species and feed sizes should be developed on basis of native feed supply characteristics and local resources.

2-3 feed production enterprises should be guided and cultivated, complete assorted feed processing and sale system should be established as required by fish culture.

Fishery production technique service team should be formed on the basis of enterprise R&D technique team jointed by universities and colleges as well as research organizations.

3) Processing and marketing system of fish product

Fishery product processing is very weak. Cage culture and pond culture are flexible for the market, but caught products are difficult for flexible marketing as well as keeping fresh. Therefore, the construction of fish products refrigeration and processing bases should preferentially consider catching fishery. It is recently planned to construct fish refrigeration and processing bases in El Banco, Magangue and Calamar, and cultivate local fishery product brands.

8.6.4 Implementation Opinions

Magdalena River Basin enjoys an outstanding fishery status for 62% freshwater fish output and 18% total yield (including marine fishery) in Colombia. Fishery resource utilization plan focuses on fish culture, supplemented by catching fishery and properly developing recreational fishery. Fish culture that based on the existing culturing bases and standardization transformation for existing ponds, should select the relatively independent lakes and reservoirs as breeding fishery bases. Native fish species are mainly bred by manual work. High-quality and high-efficient breeding species and advanced breeding techniques should be researched and promoted. Introduction and domestication of exotic fish should be controlled. Support systems such as fingerling production, feed and fishery material supplies and aquatic product processing and sale should be completed, so as to promote the development of fish culture with high quality and high efficiency.

For catching fishery, aquatic ecological protection plan should be combined, protection and restoring of genetic resources should be developed, catching activities and fishery product market should be standardized, fishing ports and wharfs should be improved, and fishery product refrigeration and processing & sale system should be established and completed.

Following items are recommended in plan as items for recent implementation: improvement and standardization of catching fishery production method; construction of cage culture demonstration base in Betania Reservoir; construction of recreational fishery demonstration base in combination of natural and hydraulic engineering landscape as well as angling resources in Betania Reservoir; construction of fish refrigeration and processing bases in El Banco, Magangue and Calamar, together with cultivation of local fishery product brands, and each base should include refrigeration house, processing workshop and packing workshop.

8.7 Leisure and Recreation Planning

8.7.1 Current Situation and Existing Problems

8.7.1.1 Recreation Status

Recreation activities have always been focused by Colombia government. Legislations guaranteeing rights and interest of people’s recreation and traveling has been established since 1996, and has been gradually improved by several modifications. With the development of social economy and people’s living standard, requirements for recreation and travel have been gradually increased. As “mother river” of Colombia and with rich resources of mountains, water, culture and historical sites within its basin, Magdalena River has become a hot spot for international and domestic tourism, enjoying great developing potential.

At present, cities have a few water and river recreational facilities, only in some big cities like Neiva being provided with public recreation facilities such as riverside quirements on recreation and amusement, no large scale and luxury being pursued. Information of part recreational scenic spots are as follows:

Fig. 8.7.1-1 Site Conditions of La Holgazana Recreational Wharf

La Holgazana recreational wharf (located at 25 km of upstream Girardot) shown in the pictures is constructed as a celebrating place for local festivals and holidays. The traffic is convenient, but the construction is simple, mainly consisting of a gallery and a thatched shack. It is known that people gather here in festivals and holidays for drinking, singing and dancing, and it has less visitors beyond festivals and holidays.

Fig. 8.7.1-2 Site Conditions of Prado Reservoir Recreational Spot

Fig. 8.7.1-2 shows a recreational spot constructed in combination of finished reservoir, 5 km away from the nearest town, providing a place of drinking and chatting for local residents. With beautiful scenery, the reservoir enjoys large visitor flow rate; but the attraction is limited due to simple recreational infrastructure.

Fig. 8.7.1-3 Charca de Guarinocito Lake Recreational Spot

The spot is located at 17 km of the lower reaches of Honda City, which belongs to original riverway of Magdalena River and now forms a little lake after rechanneling of Magdalena River. In view of field survey, shade-sheds and small-type sightseeing boats are the major facilities which have been half-abandoned due to limited attraction and being distant from towns.

At present, major tourism resources and scenic spots of main stream of Magdalena River are centralized at the upstream riverhead and downstream estuary. Tourism in these two places has been developed to some extent: San Agustin Archaeological Park at the upper reaches together with Cartagena Ancient City and Old Castle at the lower reaches are listed as world cultural heritages. Part photos of the two spots are as follows:

Fig. 8.7.1-4 General View of San Agustin Ancient City

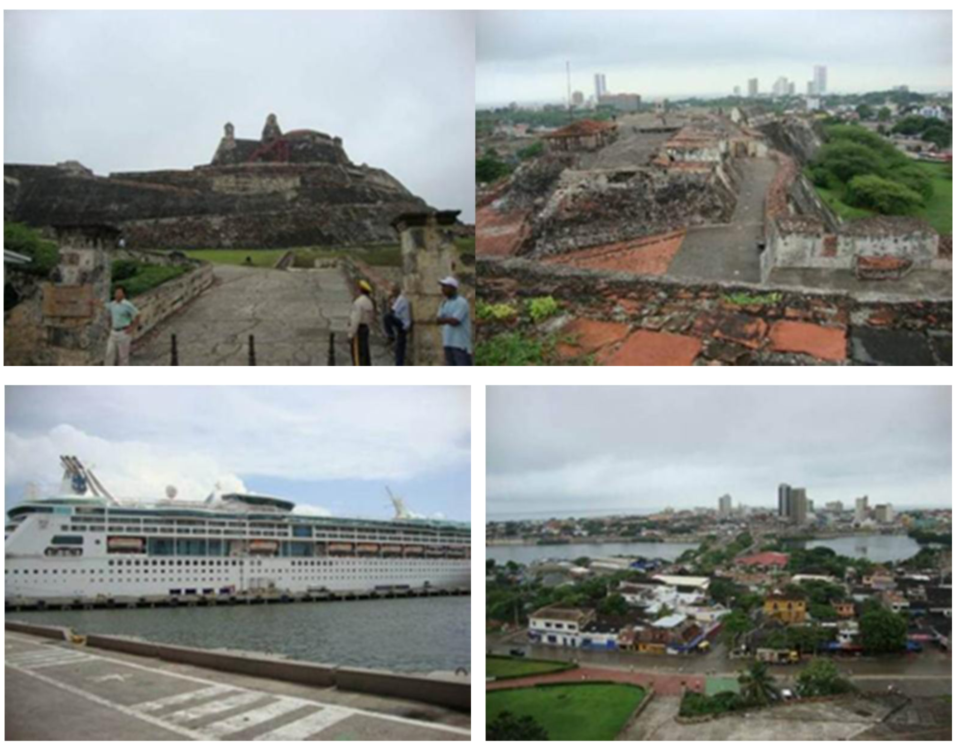


Fig. 8.7.1-5 General View of Cartagena Ancient City

8.7.1.2 Existing Problems

The plan area enjoys rich natural and cultural resources, possessing great developing potential in agricultural recreation, village recreation, natural tourism and ecological tourism. It is said by Estudio de competitividad del sector turistico: "Diversity in species, climates and sceneries, as well as archaeological zones, natural prairies and parks in tropical rainforest are the special resources in Colombia, which provide Colombia a very important status in world tourism system." In recent years, however, recreation and tourism in Colombia has not been developed well. Generally, following problems exist:

a) Economic downturn and safety issues in towns result in drops of recreation and tourism demands.

b) Insufficient or poor assorted infrastructures in tourist spots weaken the advantages of recreation and tourism resources within plan area. Recreational and tourist potentials of many famous towns, although with long histories, abundant buildings and cultures within the plan area, have not been completely developed due to incomplete assorted infrastructures (public service facilities, traffic, restaurants, commercial centers, etc.).

c) Urban plan does not keep pace with the development of recreation and tourism. Excessive tourists may influence the daily life of local people, such as traffic, accommodation, food supply, etc. Increasement of floating population may result in rising of local living cost and land price.

d) Overspeed development in hotels and tourist resorts in suburbs to attract the recreational demands of big cities like Girardot, Melga and Bogota, together with insufficient necessary public facilities, provisions for resources utilization and waste handling, bring many local problems and meanwhile put pressures on local natural and social resources.

e) Simple recreational site construction cannot meet the local diversified recreational demands; some facilities are half-abandoned due to being distant and poor traffic.

Therefore, sustainable development plan should be made for recreation and tourism on the premise of regarding development and protection as equal importance. It will benefit to sustainable utilization of social, cultural, biological and ecological natural resources, and the tourism resource potential will change the local development.

8.7.2 Recreational Resources Analysis

Magdalena River Basin enjoys abundant natural and cultural resources, possessing great developing potential in agricultural tourism, natural recreation and ecological recreation. Ancient City beside Caribbean Sea area as well as many other potential recreational and tourist spots exist within Magdalena River Basin. Those spots include: commercial centers in Bogota, Cartagena, Medellin and Cali; some coffee plantations recently opened; Tayrona Park in Santa Marta; Nevados National Park; San Agustin Ecotourism Area; Mompos, Santa Fe de Antioquia and other historical and cultural heritage areas.

Recreational and tourist resources are classified into 10 grades as per grading in Magdalena River Atlas, Grade 10 being the highest level and smaller number indicating lower level. Refer to Fig. 8.7.2 for resources grading.

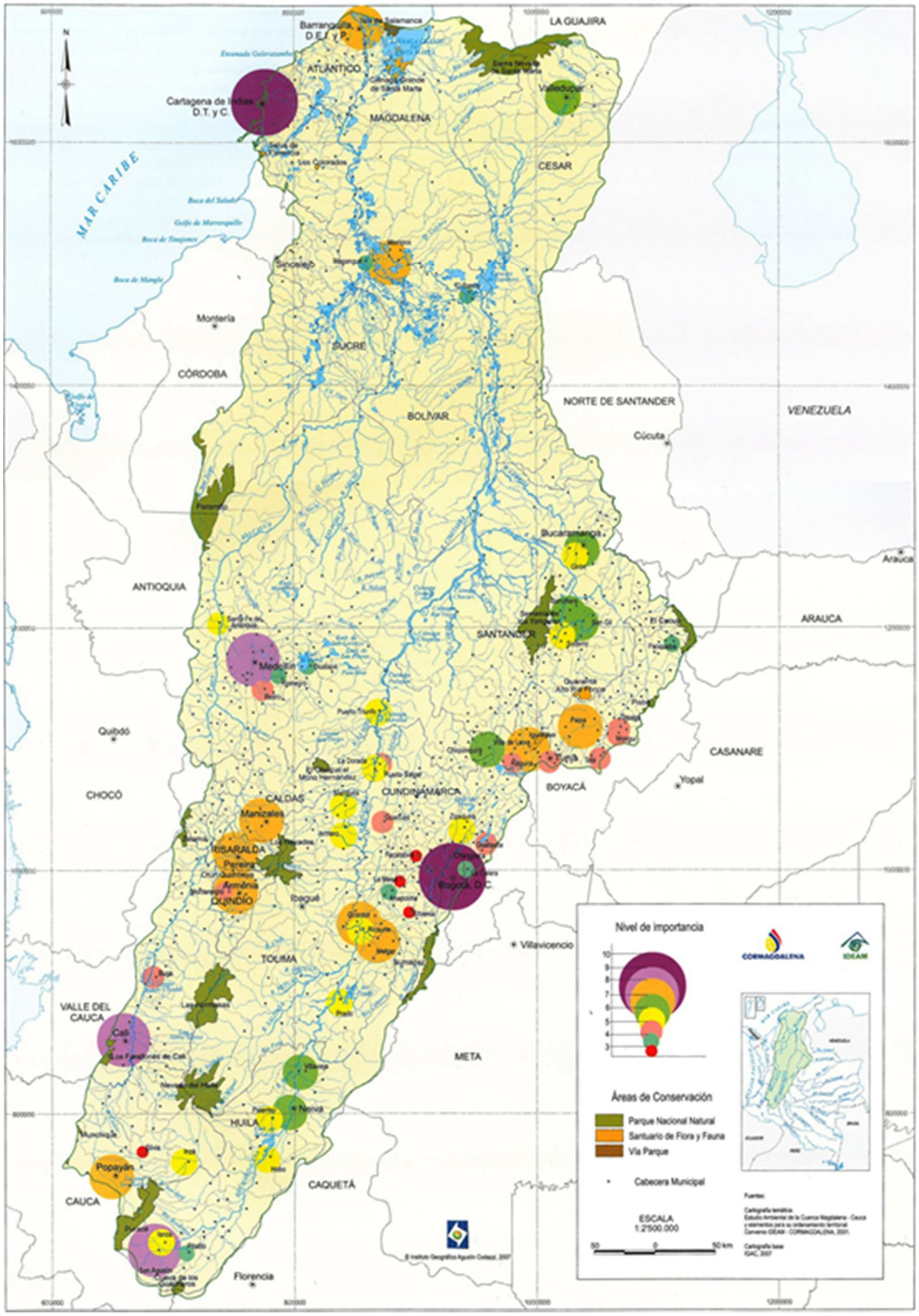


Fig. 8.7.2 Grading of Recreational and Tourist Resources in Magdalena River Basin

Refer to Table 8.7.2 for tourism grades of major cities and towns within plan area collected as per Fig. 8.7.2. It is shown in view of tourism resource conditions along Magdalena River: 1 Grade-10 city (2 within the whole basin, the other one being the Capital Bogota), 1 Grade-9 city, 2 Grade-8 cities, 2 Grade-7 cities, 9 Grade-6 cities, 2 Grade-5 cities and 3 Grade-4 cities. 4 places in Colombia are collected in World Heritage List, 3 of them located along the main stream of Magdalena River: the port, the fortresses and the group of monuments of Cartagena (1984); Historic Center of Mompos (1995); San Agustín Archaeological Park (1995). In view of existing conditions, tourism resources along Magdalena River are abundant.

Table 8.7.2 Tourism Grades of Major Cities and Towns Within Plan Area

S/N	Department	City/Town	Population ($\times 10^4$)	Tourism Grade Made by Colombia
1	HUILA	Villa Vieja	0.73	6
2		Neiva	33.05	7
3		Hobo	0.68	6
4		Pitalito	11.40	4
5		Palermo	2.98	6
6		Isnos	2.54	6
7		San Agustín	3.13	9
8	TOLIMA	Armero-Guayabal	1.25	6
9		Prado	0.83	6
10	CUNDINAMARCA	Puerto Salgar	1.71	5
11		Guaduas	3.50	5
12		Girardot	10.18	8
13		Ricaurte	0.88	6
14	CALDAS	La Dorada	7.50	6
15	ANTIOQUIA	Puerto Triunfo	1.81	6
16	BOLIVAR	Cartagena	94.43	10
17		Magangué	12.29	4
18		Mompos	4.26	8
19	MAGDALENA	El Banco	5.50	4
20	ATLÁNTICO	Barranquilla	118.66	7

By analyzing the recreational and tourist spots in above 20 cities and towns and the celebrations, religious and local traditional festivals are mostly celebrated in those cities and towns along the river, while besides common festivals, carnivals, music festivals, various exhibitions and other modern festivals are celebrated in some modern metropolis, such as Barranquilla, Cartagena, etc.

Recreational sites mainly include: a) sites in relation to water body: ports, rivers, streams, etc.; b) urban recreational infrastructures: parks, museums, libraries, etc.; c) ancient buildings, monuments, etc. from colonial period; d) squares, churches, etc. in relation to religious activities.

According to the list of recreational sites and festival celebrations within plan area provided by CORMAGDALENA, besides of those sites defined with tourism grades, some areas without grades actually possess the potential developing into larger recreational and tourist sites. Those areas include: downstream Santa Ana with many recreational tourist spots such as art galleries, wall paintings, museums and other artistical places; Magdalena River Museum downstream Honda, recording history of the river, and the only one place in Colombia presenting thousands people catching fishes at Honda torrent.

Generally, the plan area enjoys abundant recreational and tourist resources and obvious advantages, possessing greater development potential.8.7.3 General Arrangement

In view of concepts of recreation and travel as well as socio-economic development tendency, recreation and travel go closer and closer and begin to mix with each other. It is said that recreation is a daily relaxation, and travel is a high-level recreation. Based on this, in combination of overall development object in recreation and tourism plan of CORMAGDALENA, as well as grading and distribution of Colombian recreational and tourist spots, layout of the plan is divided into three levels.

8.7.3.1 Level I

Level I: Grade 8 ~ Grade 10, areas collected in World Heritage List, mainly located near the head and estuary of Magdalena River. The recreational and tourist resources here have been developed to some extent, and future plan will focus on integration and upgrade of tourist resources as well as update of assorted infrastructure to highlight the local scenic characteristics, create more comfortable recreational environment and attract more visitors (from home and abroad), so as to promote recreational industry by tourism.

a) Headwater reaches

Theme: Pursuing footprints of ancient times, paradise of adventurers. San Agustín Archaeological Park is taken as major selling point for its mysterious atmosphere of paleo-indians. Besides, upper reaches are steep canyon sections rarely seen within Magdalena River, which can be transformed into paradises for adventurers; as slopes in canyon sections are relatively steep, conditions of transforming some reaches into adrift areas will be discussed in the future.

Distribution center: Pitalito is a Grade-4 tourist city, the only big city with a population above 100,000 in Neiva, with convenient accessibility, including airport and national roads connecting upstream and downstream areas. Therefore, Pitalito can be selected as distribution center for upper reaches. It connects San Agustin upstream (about 1 hour by car) and Betania Reservoir and even Neiva downstream (about 3 hours by car).

Analysis on visitor sources: San Agustín Archaeological Park, a Grade-9 tourist spot in Colombia and collected in World Heritage List, receives visitors from home and abroad. However, as it is located at relatively remote inland, major sources are from home and American area.

b) Estuary reaches

Theme: Reviewing memorable years. Cartagena-Barranquilla-Mompos could form a tourist golden triangle. Cartagena and Mompos respectively stand for famous historical cities in colonial period and independent revolution period, taking historical and cultural landscapes and ancient cultural cities as selling points; Barranquilla stands for a modern city, taking carnivals, modern art festivals and music festivals as selling points. The golden triangle is connected by Magdalena River and Dique Canal. If those scenic spots are combined together, cruise items can be provided for sightseeing along Magdalena River. Besides, Barranquilla-Salamanca National Mangrove Park (about 50 km in the east) can be chosen as a tourist branch. The upper reaches are distributed with river network and wetlands, which enjoys abundant organisms, landscapes and cultural resources, but with lower development and utilization. Recreation and tourism in Cartagena and Barranquilla have been developed into relatively mature extent. Major object is to promote the development of recreation and tourism in the whole lower reaches under the guidance of the two key cities.

Distribution center: As a mature city of recreation and tourism with complete infrastructures and convenient accessibility, Cartagena could be selected as the distribution center for lower reaches.

Analysis on visitor sources: As a beautiful costal city and collected in World Heritage List, Cartagena has natural attraction to tourists around the world. Currently, Cartagena is a famous tourist city in Colombia as well as the whole world. Therefore, visitors from home and abroad may be paid equal attention.

8.7.3.2 Level II

Level II: Grade 4~ Grade 7 cities and towns, mainly located at upper and middle reaches of Magdalena River. With certain characteristics but limited popularities, these places may pay attention to provide water and river recreational facilities, to enhance the quality of natural riverside landscape and to attract groups from nearby big cities to come here for holidays and vacations.

Theme: Home garden of Bogota. Middle reaches are mostly distributed with sceneries of Grade 5 and 6, less attractive in cultural and natural landscapes compared with other sceneries of higher grades. However, the main advantage of the middle reaches is that it is close to the capital Bogota and has convenient accessibility. Therefore it is possible to make this area as a recreational and traveling place in weekends or minor vacations for residents from Bogota and the surrounding big cities. Existing data shows that the area has realized its advantage currently by constructing holiday centers in Girardot, Melgar, etc. Based on existing facilities, it is suggested to enrich the recreational types and add water entertainment items such as angling centers, water parks, etc. According to the hydropower plan of the Master Plan, Girardot-Honda reaches are planned into several cascades, which can be combined with the recreational and tourist products, so as to enrich the recreational types and strengthen the attraction.

Distribution center: As Girardot is a big city with a population above 100,000 within the area, the recreational infrastructures and assorted hotels have been developed to some extent, this city can be selected as the distribution center.

Analysis on visitor sources: As the attraction of the sceneries is relatively weak, it is supposed to receive domestic visitors, especially visitors from surrounding big cities.

8.7.3.3 Level III

Level III: Cities without tourism resources are mainly located at the middle and lower reaches. Recreation should be combined with the local situation or other plan projects, such as riverside scenic belts, wetland, lakes, etc. to meet daily recreational demands of local residents. Based on this, it will attract visitors from surrounding cities if conditional.

Areas of level III mainly refer to Puerto Triunfo-El Banco district where no national tourist spot is located. Recreational infrastructures mainly meet the daily demands and demands of festival and holiday celebrations by local residents. For big cities like Barrancabermeja with a population nearly 200,000, scenic belts or commercial recreational centers may be constructed to meet the daily demand of local residents as well as attract residents from surrounding cities and towns. For smaller cities, simple scenic belts in combination of the flood control facilities may be designed to meet the demands of local residents.

8.7.4 Implementation Opinions

As above said, recreational products of level I have been developed to some extent and will focus on upgrading and transformation in future; products of level II and III have been slowly developed or have not been developed, therefore, areas with developing potentials in level II and III are preferentially recommended in short term to meet the recreational demands of residents from more areas.

a) Short-term plan projects

1) Riverside scenic belts may be constructed in combination of embankment, and with a certain foundation, it can be considered as short-term project for some cities and

towns. As Girardot can be selected as a recreational and tourist distribution center within the area, riverside scenic belts should be preferentially designed for this place to enrich the types of recreational and tourist products and enhance attraction.

2) According to flood control plan, riverside embankments will be built or optimized in Pinillos, Magangue, Puerto Wilches, Calamar, Rio Viejo, La Gloria, Regidor, Guamal, El Banco, Plato, El Pinon, Remolino, Tamalameque, Yondo, Ponedera, Penon, Barrancabermeja, etc. Scenic belts may be considered in construction of embankments in these cities to meet the daily recreational demands of local residents. For some big cities like Barrancabermeja and Magangue, standards of assorted scenic belts construction may be improved to form local scenic spots so as to attract residents from surrounding cities and towns.

b) Long-term plan projects

1) As one of the World Cultural Heritage, ancient city of Mompos enjoys abundant tourism resources; however, for the traffic difficulties (mainly by waterway), recreational tourism develops very slowly. Combined with areal recreational plan, cruise items within Cartagena-Mompos-Barranquilla area may be developed with allowable navigation depth of riverway, guided by Cartagena and Barranquilla and in combination of the superior navigation conditions along lower reaches.

2) Adrift projects could be planned at proper location of canyon reaches near San Agustin with beautiful scenery and medium slope to enrich local entertaining and tourist items and to enhance the areal attraction.

The short-term and long-term projects proposed in the Master Plan are preliminary opinions which need to be specially demonstrated in implementation of specific projects. Besides, as public welfare projects serving local residents, the recreational facilities need large investment but receive limited incomes. Therefore, development of recreational function may be combined with other planned projects (cascade plan, riparian zone utilization, etc.).

9 Integrated River Basin Management

Governance and exploitation of Magdalena River are a complicated systematic project, in which water problems with prominent contradictions are required to be comprehensively solved, and management relation between the basin and the region should be overall planned and coordinated, as well as interest distribution relationship among stakeholders within the basin should also be coordinated. For this reason, a complete governance system and operation mechanism combining basin governance and regional management should be established, water conservancy policy & law & regulation should be made sound, and law enforcement for the basin and supervision & information release capacities should be strengthened, to actively promote the unified plan , management and scheduling of the basin.

9.1 Current Situation and Existing Problems

9.1.1 Current Situation

The territorial scope of the comprehensive plan is the area under jurisdiction of CORMAGDALENA. Being affected by unique water resource management framework and system of Colombia, although CORMAGDALENA is found in accordance with the Constitution of Colombia and jointly composed by the Ministry of Environmental, Housing and Territory Development, the Ministry of Transport, the Ministry of Commerce, Industry & Tourism, the Ministry of Agriculture, the Ministry of Mines & Energy and ECOPETROL, its administrative management of water-related affairs is conflicted in a certain degree with competent environmental department and agencies taking charge of public utilities for water and electricity supply. CORMAGDALENA is entitled to plan, develop, utilize and protect the natural resources in the river in an overall manner, but the current management still involves both basin management and industrial management.

CORMAGDALENA has organized and formulated the basin governance plan (el Plan de Manejo de la Cuenca, PMC), with the purpose to plan the utilization and sustainable management of natural resources in the river, so as to maintain the balance between economic benefits and natural ecological system protection. In PMC, areas required for ecological system protection, land utilization change and infrastructure construction are delimited, so as to realize sustainable utilization of natural resources. Environmental objectives and budgets are also involved, and responsibilities of mechanisms implementing the said activities are clarified.

As for system framework of water resource management, Colombia has established governance systems involving water withdrawal permit and water use charge, etc. As for water resource protection, systems involving effluent discharge permit, environmental permit, and effluent discharge charge are established. Aquatic ecological & environmental protection and management for the river are carried out forward in order. In the planned area, water for energy development, city, living, environmental health and agricultural irrigation is under the charge of different departments. Environmental management functions are not fully deregulated. For example, 1) management of domestic water and municipal water: The operation franchise is authorized to special private person, public-private entity or public entity and public utility corporation. To access or increase intake of drinking water, water withdrawal permit issued by local competent environmental department (CAR) should be necessary, and water use fees should be paid to CAR. 2) Management of water for power generation: Power company is under supervision of energy regulatory commission, which is responsible for formulating the scheduling and operating procedures of electric power system. If a company is intended to build a power station, the company must prepare all study data based on scale of the power station and submit the data to the Ministry of Environment or relevant CAR to apply for environmental permit. The water use permit is contained in environmental permit. For a power station with an installed capacity over 10 MW, either hydropower station or thermal power station, royalty payment should be given to CAR and municipality in which the reservoir or power station is located. Royalty paid to CAR is 3% of total income from electricity sales and such royalty must be used to construct environmental projects within the basin. 3) Management of water for agricultural irrigation: Agricultural irrigation system is established with funds of special agency (INCODER) under the Ministry of Agriculture Relevant management fees and maintenance fees should be recovered by charging against water users. For large irrigation system, management unit responsible for the operation and maintenance has been set up. Since no competent organization is set up for small irrigation system, its basic facilities are aging as time goes by. In some areas, CAR and municipality are responsible for maintenance fees of irrigation canals. Before a new irrigation system is built, INCODER must apply to relevant CAR for water use permit.

9.1.2 Existing Problems

In recent years, although some achievements have been made in integrated management of Magdalena River, the following difficulties and problems still exist: 1) the unified management of the river should be strengthened, the feasible and high-efficient trans-department and trans-region coordination mechanism should be established, and the function division and combination of the river management and administrative regional management need further confirmation and implementation. 2) water resource governance system should be put into practice, and unified scheduling governance system of reservoirs should be established. 3) the river plan system should be refined and the guidance & restraint of river planplan on the regulation, development and protectionmanagement, exploitation and protection of Magdalena River should be intensified in the future. 4) protection and governance system for water resources and aquatic ecological environment should be improved, and supervision and management of aquatic functional areas and pollution discharge outlets to the river should be further strengthened. 5) flood control and disaster alleviation system should be established, and flood governance system should be improved. 6) law and regulation system for integrated management of the river should be refined. 7) supervision on law enforcement should be strengthened.

9.2 Management Institutions

The governance system combining basin management and regional management should be adopted for Magdalena River Basin, including sound organization, clear authority, coordinated relation, normative operation, just, transparency, authoritativeness and high efficiency. According to actual needs, organizations of all levels for basin management and regional management should be set up and improved. Based on the principle that right is corresponding to responsibility, right and obligation relations between basin management and regional management should be refined in accordance with laws, and authorization clarification should be clear. Basin governance agency should strengthen capacity of management of water-related affairs and public service. By observing open, fair and just principle, and carrying out administration by law and management by law, water-related administration duties should be performed. Sound open platform of water-related administration affairs & public service information platform should be established, so as to effectively guarantee that the public can participate in the basin governance in order.

Integrated basin governance mainly involves unified management & scheduling of water resources in Magdalena River, protection & supervision & management of water resources, management of flood control & disaster alleviation, management of river course & water works, enforcement of water-related administrative law, etc.

9.3 Operation Mechanism

Effective trans-department & trans-region negotiation and cooperation mechanism should be established. The negotiation and cooperation mechanism should be established, which is headed by basin governance agency and participated by agencies involving water conservancy, environment, transport, agriculture and land. Cooperative procedure charters should be developed, and basic negotiation principle & method & procedure, decision-making mechanism, implementation & feedback mechanism, and punishment mechanism should be determined, to solve management problem of public affair whose management mode cannot be determined due to unclear specification in current laws or can not be determined by laws & regulations in short term. This is to make the decision-making of water-related administration more scientific and democratic, so as to lay a practical foundation for establishing democratic, collaborative, authoritative and efficient basin governance committee.

A sound operation and management mechanism of Magdalena River Basin involves establishment of a sound negotiation mechanism for basin governance, enhancement of unified management and scheduling mechanism of water resources, establishment of important management and scheduling mechanism of hydroprojects on the main stream and tributaries, improvement of management mechanism of construction projects within scope of river course management, improvement of responsibility supervision mechanism for water quantity and quality of control section, refinement of early warning and emergency management mechanism of water-related emergencies, etc.

9.4 Policies and Regulations

Existing laws & regulations should be amended, and administrative laws & regulations and departmental rules for key areas and fields should be formulated, to gradually establish a relatively sound integrated management law and regulation system of river basin which regards water law, environment law and flood control law as the core and is supported by administrative law & regulation, departmental rule and local water-related law & regulation.

In combination with actual conditions of Magdalena River, rules and regulations involving unified scheduling of Bogota River, Cauca River, Dique Canal, estuary, Mompos wetland and reservoir should be worked out in a short term. Based on implementation experience of water-related affair management laws and regulations of Magdalena River Basin, law and regulation on basin management, exploitation and protection should be formulated in a long term, and development, utilization, protection and management rules for water resources in Magdalena River Basin should also be formulated. In addition, local regulations, systems and rules about management of water-related affairs in Magdalena River should also be formulated for each administrative region along the basin, so as to establish a sound water law and regulation system of Magdalena River.

9.5 Capacity Building

Enhancement of basin governance capacity is an important guarantee for improving basin governance level. In combination with the actual management conditions and based on full use of existing management capacity, construction of water-related administrative law enforcement capacity, supervision capacity and information release capacity should be further strengthened.

Construction of law enforcement capacity of water-related administration agencies at each level should be strengthened, scientific law enforcement concept and supervision

& management awareness should be enhanced, and synchronization management and advance management should be given equal emphasis. Focus should be placed on construction of law enforcement team, law enforcement security and law enforcement informatization, so as to ensure that water law and regulation system can be fully carried out and implemented in Magdalena River Basin, and that good order of water-related affairs and harmonious relation between water-related affairs can be maintained.

Supervision capacity construction mainly covers the supervision on enhancement of plan implementation, flood control & disaster alleviation, water resource management & scheduling, water resource protection, soil erosion control, construction & management of water conservancy works.

Lots of information on regulation, development and management of river basin is attained. According to relevant provisions of laws and regulations, releasing, publicizing or notifying the information to the society and related agencies in a proper method is an important means to reflect regulation condition of the river basin, safeguard the public's rights to know facts, and strengthen supervision. During plan period, release capacity of information on government affairs, water regimen, water quality and soil erosion should be further strengthened, and a sound release management method of basin information should be prepared.

9.6 Technical Support

Science and technical support system of Magdalena River should be based on application and R&D of modern science & technology. By hydrological and sediment observation, informatization construction and other methods, the science and technology support system can promote scientific research to provide scientific basis and decision support for regulation, development, protection and management of Magdalena River. The system includes three aspects, i.e., Magdalena River hydrological and sediment monitoring & forecasting system, "digital Magdalena River" works, and scientific research.

9.6.1 Hydrological and Sediment Monitoring & Forecasting

Based on improved hydrological network and depending on modernized facility & equipment and science & technology, Magdalena River hydrological and sediment monitoring & forecasting system is to monitor and forecast the hydrological and sediment in Magdalena River timely and accurately, and to analyze variation laws of hydrological and sediment in the river, so as to provide decision support for Magdalena River regulation, development, protection and management. The hydrological and sediment monitoring & forecasting system involves layout & monitoring of hydrological network, construction of hydrological monitoring infrastructure and monitoring & foresting capacities, monitoring and testing for hydrology and sediment in reservoirs, river courses and estuary, communication network of water regime and flood, forecasting of hydrology & water resources, information management, etc.

In the hydrological and sediment monitoring & forecasting system, technologies involving modern communication, automatic control, telemetry and computer are integrated and used in monitoring of hydrology, water resources and sediment. Such system has been established and used in many countries and regions. The system is provided some functions, such as real-time information collection & transmission of hydrological and sediment in the river, collection & transmission of basin rainfall data, monitoring & warning, forecast & forecast, data management and information query.

Hydrological and sediment monitoring & forecasting system can quickly and accurately collect, transmit and process hydrological and sediment information, also can make corresponding forecast and forecast based on information obtained in real time. Such system is characterized by short response time, strong real-time and high reliability. According to characteristics of Magdalena River Basin, establishment of hydrological and sediment monitoring and forecasting system should be carried out step by step in different areas, so as to master information on hydrological and sediment, flood control & disaster alleviation and safe operation of projects. Currently, many hydrometrical stations have been built in Magdalena River Basin. Manual monitoring system has been formed, but automatic monitoring system is still faced with such problems as insufficient monitoring stations, small control scope and low degree of automation. Plan and construction of hydrological and sediment monitoring & forecasting system in the river basin can be carried out based on existing hydrological network.

9.6.2 Magdalena River Digitalization Program

Magdalena River Digitalization Program is to digitalize the basin information and all information related to the basin, and makes the information an organic integrity with the form of space information, so as to effectively reflect the complete and real situations of the whole basin from all aspects. By integrated use of modern high and new technologies involving remote sensing, geographic information system, global positioning system, network technology, media and virtual reality to collect and digitally manage various information about geographical & geological environments of the basin, natural resources, ecological environment, human landscape, social and economic statuses, etc., the integrated information platform and three-dimensional image model for the basin should be structured, so as to provide supporting decision-making basis and means for government departments of all levels to plan, design, construct, manage and serve for the basin, also to provide basin information for the public.

System of “digital Magdalena River” works mainly includes data acquisition & updating, data processing & storage, information extraction & analysis, data management, data application, etc.

9.6.3 Scientific Research

Research on major strategic issues of river regulation should be strengthened. Major scientific & technological researches should be carried out on Magdalena River health indicator system, relation evolution between river and lake & counter measures, flood risk management & floodwater utilization, unified scheduling of water resources, basic theory and techniques of soil erosion prevention & control, simulation & control technologies of non-point source pollution, ecological restoration and water quality improvement technology, etc. Soft scientific & technological researches involving integrated management regime, mechanism and system for the river basin should be strengthened. Research on impact of global climate change and human activity on water resources, flood regime and river regime in the basin (area) and on their change laws should be strengthened, so as to put forward corresponding strategies and measures.

a) Strengthen Research on Major Strategic Issues of River Regulation

Key multi-purpose hydroproject, as a strategic measure to affect the whole basin, should be determined according to needs of basin regulation and development, especially the demand of water resource utilization, navigation and flood control & regulation, in combination with topographical conditions, geological conditions and reservoir inundation conditions.

As Honda reaches is the only one whose good topographical and geological conditions are suitable for constructing a large-scale regulation reservoir on the mainstream of Magdalena River, the in-depth study on the necessity and feasibility of the construction of key multi-purpose reservoir in Honda reaches should be conducted in the next stage based on demand of social economy, energy and navigation and development of flood control situation. Besides, since key multipurpose project generally involves high inundation, research should be carried out in due time for the mechanism in which land is acquired and people are resettled to construct reservoir.

b) Strengthen the Construction of Scientific Research Support System

Information technology and other high-tech means should be adopted to improve modernization level of scientific research support system. Computer, information, network, material, remote sensing, telemetry and remote control technologies should be fully used to improve information processing capacity and realize information sharing, so as to provide better software & hardware supports for scientific research. Two applications are mainly included, one is the application of automatic high-precision all-weather collection technology system of water resource information and water environment information, and the other one is the application of water resource & water environment information management technology and data sharing technology.

c) Carry Out Research on Science & technology and System Related to Integrated management of the Basin

Research on basic theories including flood risk management theory and river ecology management theory should be strengthened. Research on flood and drought warning & forecasting technology, impact of climate change on flood control & water resource and coping technology, comprehensive treatment technology of soil erosion, and water resource protection technology & aquatic ecological system restoration technology should be strengthened. Besides, prototype observation for topography, hydrology and sediment should be performed. Corresponding coping measures should also be put forward.

Research on various systems related to integrated management of the basin and scheme design should be strengthened. Besides, institutional innovation should be conducted in combination with actual conditions in Colombia and in Magdalena River Basin, to provide practical and operable management means for the basin.

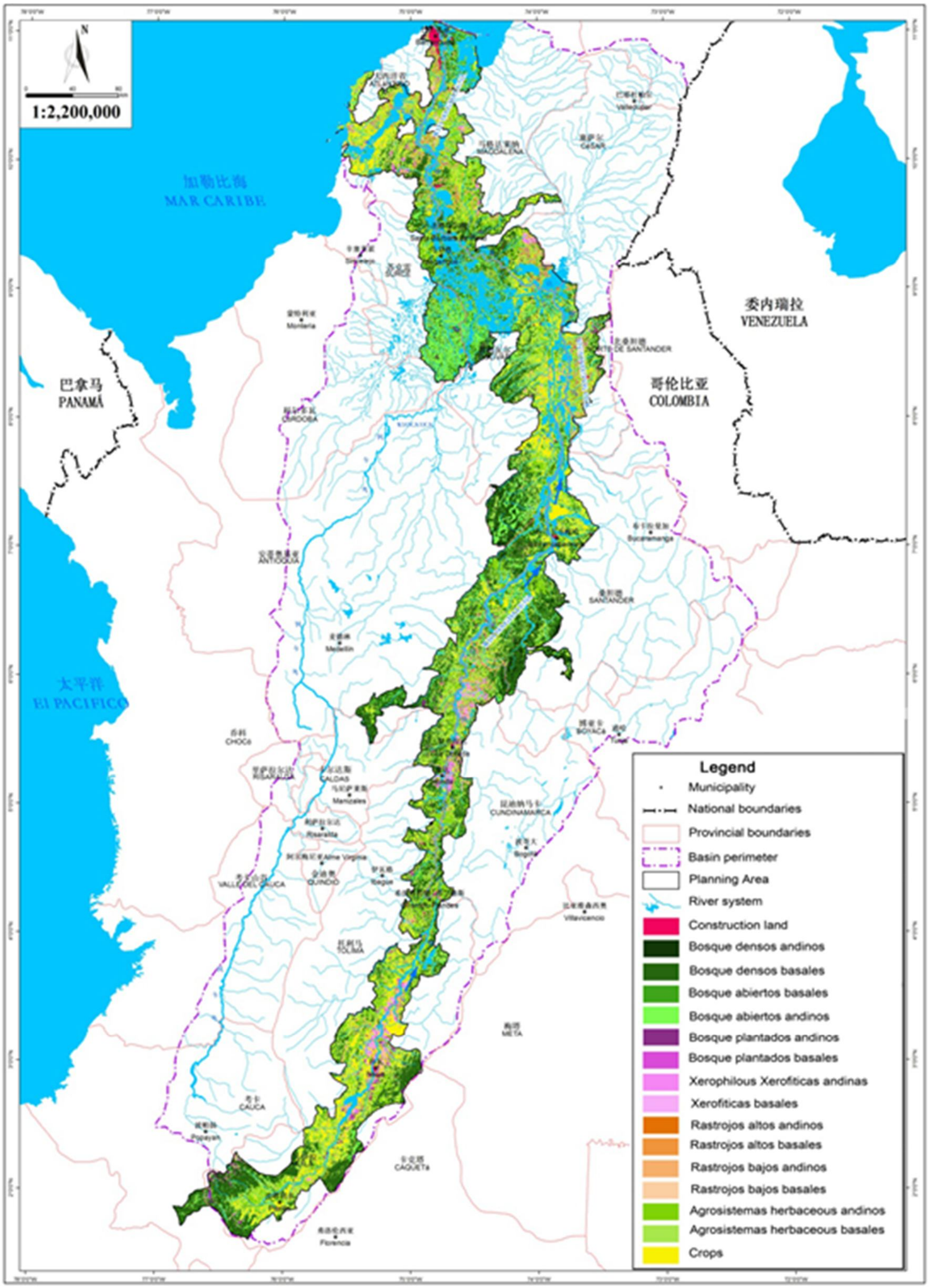
10 Environmental Impact Assessment (EIA)

10.1 Current Situation and Existing Problems

a) Current Environmental Situation in the Basin

The basin is in a tropical climate region. The zone below El.1000m has diversified climate environment, covering some very arid areas including el Desierto de la Tatacoa and some very moist areas dominated by humid tropical rainforest. The middle reaches enjoy the highest rainfall, followed by the upper reaches and the lower reaches. Because the upper reaches have relatively large gradient and rainfall, with extensive land utilization method and agricultural practice, soil erosion here is relatively serious.

The basin has a forest coverage of 26.36%, mainly of natural secondary forest. Forests here are mostly distributed in Basales forest region (below El.1000m) and the Andes Mountains (above El.1000m) forest region. In Caribbean coast, especially the large swamp area in Santa Marta, a large area of mangrove forest is distributed. In river valley and plain, forage grasses and brushes are mainly distributed. In Bolivar alluvial plain area, a large area of swamp and aquatic vegetation are distributed. In valleys of the Andes Mountains, arid tropical forest is distributed. In alpine region above El.3500m, alpine barren land-type vegetation is distributed. In the upper reaches of the basin, arid tropical forest adapted to dry and hot climate is mainly distributed. Distribution of vegetation type in the plan area is shown in Fig.10.1-1.



Fuente: Atlas Cuenca del Rio Grande de la Maggdlena

Fig. 10.1-1 Types of Vegetation in Plan Area

The basin has various species of animals, about 2735 kinds, among which the bird species account for 20% of the total bird species in the world, the amphibian species rank second in total amphibian species in the world, and the reptile and mammalian species rank sixth in the world. Besides, a large number of unique species is distributed in Colombia.

In the basin, there are 202 kinds of fishes, including 42 kinds of wetland and swamp fishes, 26 kinds of fishes with important commercial value, 35 kinds of migrating fishes, and 23 kinds of important endangered fishes in Magdalena River. In upper reaches, some fishes in valley habitat with fast-flowing current are distributed. Spawning ground and migration passage of fishes are mainly distributed in the reaches from Berriro to Garmarra on the middle and lower reaches of the river.

In the basin, water environment quality is generally poor, which is mainly polluted by COD and $BOD_{5.}$ Local water area at confluence of Cauca River is polluted by heavy metals mercury and cyanide. Comparatively, the water quality of upper reaches in the basin is relatively good with COD being 0~20mg/L; the water quality of upper middle reaches is slightly poor with COD being 21mg/L~41mg/L; the water quality of lower middle reaches is the poorest with COD reaching 42mg/L~62mg/L; and the water quality of lower reaches has improved slightly with COD being 21mg/L~41mg/L. Pollution sources leading to poor water quality of Magdalena River are mainly from three aspects: 1) domestic pollution source including urban domestic wastewater and solid waste; 2) industrial pollution source such as industry belts and mining areas; 3) agricultural non-point pollution source due to extensive application of fertilizer and pesticide in farmland.

In the plan area of Magdalena River, there are wetlands under international protection, national natural parks, flora and fauna protection areas and some local reserves, as shown in Fig.10.1-2.

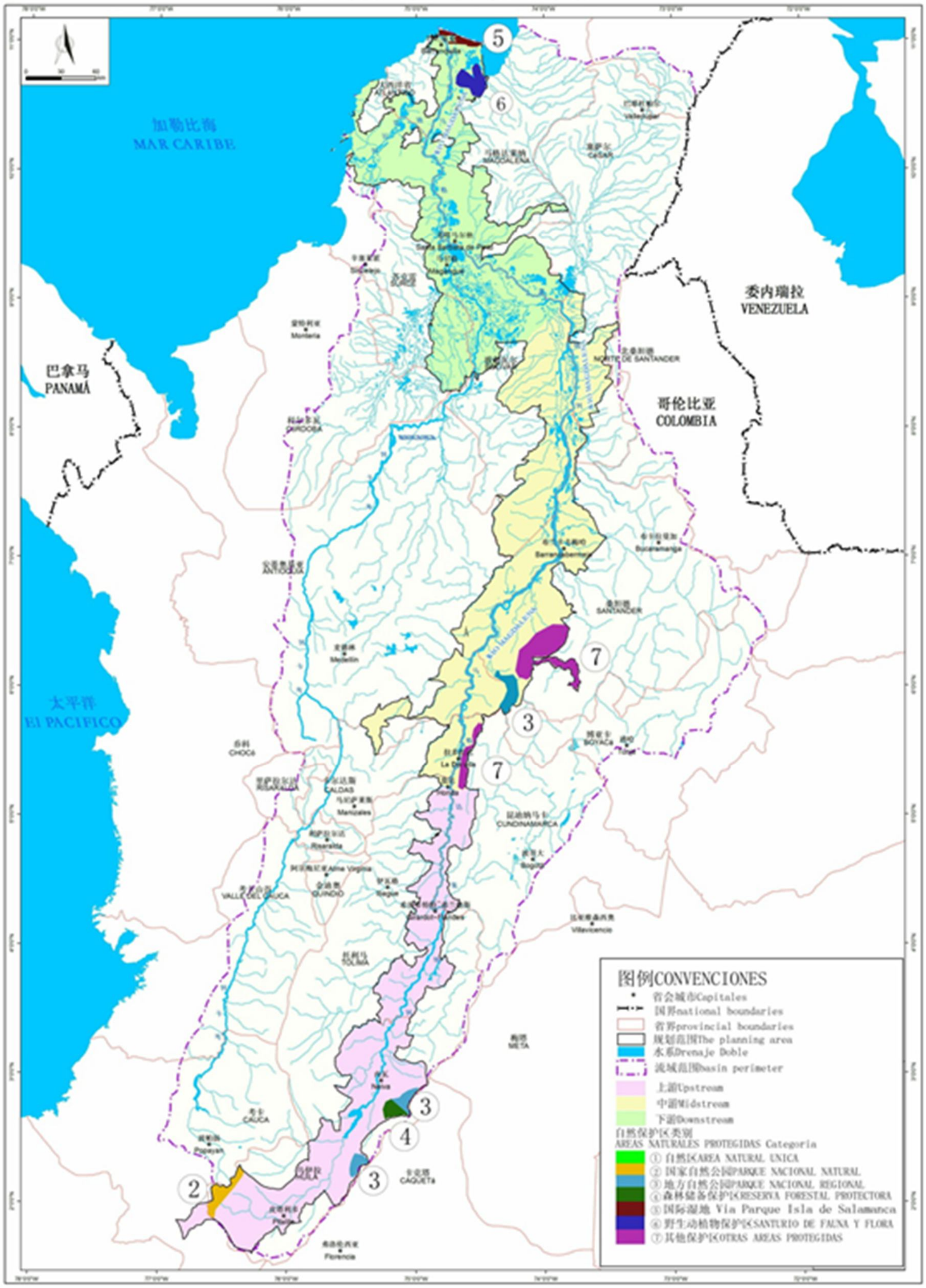


Fig. 10.1-2 Distribution of Environmental Sensitive Areas

b) Major Environmental Problems

1) Vulnerable natural ecology, widely-distributed loose deposits, week lithology of some deposits, irrational development by human and other interferences result in relatively serious soil erosion;

2) Excessive deforestation, global warming and increase of extreme climate lead to the decrease of forest area;

3) Relatively serious domestic pollution and non-point source pollution lead to poor water quality in the river;

4) Irrational utilization of such aquatic organisms including fishes and habitat change lead to decrease of aquatic organism biodiversity and decline of resource quantity.

5) Lakes, swamps and wetlands are occupied to develop agriculture, leading to shrinkage, sedimentation and drought of the lakes, swamps and wetlands.

c) Analysis on Development Trend

Increase of population and irrational utilization of land will further exacerbate soil erosion in the plan area.

Since aquatic ecology is relatively vulnerable in the basin, coupled with natural conditions and interferences by human activities, aquatic habitat will be further shrunk.

Based on existing development mode, quantity of main pollutants (COD and BOD5) entering the river in the basin will greatly exceed the pollution bearing capacity of the river, which will exacerbate pollution on the river and make water quality deteriorated.

10.2 Identification of Environmental Impact Factors

In the comprehensive plan of Magdalena River, sectoral plan is made respectively for navigation, hydropower, irrigation, fishery, recreation, riparian exploitation, river course regulation, flood control, environmental protection, etc. According to environmental impact behavior, identification of environmental impact factors is conducted for each sectoral plan, as shown in Table 10.2.1.

Table 10.2.1 Identification of Main Environmental Impact Factors of Magdalena River

Environmental Elements	Main Environmental Factors	Major Environmental Impact Behaviors									Cumulativity	Persistence	Importance
		Navigation Plan	Hydropower Plan	Irrigation Plan	Fishery Plan	Recreation Plan	Riparian Exploitation Plan	River Course Regulation Plan	Flood Control Plan	Environmental Protection Plan			
Ecological Environment	Ecological integrity	-	-2	-	-	-	-	-	-	+2	T	T	II
	Terrestrial plants	-	-3	±1	-	-	-1	-1	-	+3	T	T	III
	Terrestrial animals	-	-2	-	-	-	-	-	-	+1	F	T	II
	Aquatic organisms	-1	-3	±1	±1	-	±1	±1	-	+2	T	T	III
	Soil erosion	±2	-2	-	-	-	±2	+2	+2	+2	F	F	II
	Natural reserve	-	-2	-	±1	-	-1	-1	-	±1	F	F	II
Water environment	Hydrological regime	±1	±3	-	-	-	-	±1	±1	-	T	T	III
	Water resource utilization	-	±2	+2	±1	-	±1	+1	-	±1	T	T	II
	Water temperature	-	-2	±1	-	-	-	-	-	+1	T	T	II
	Water quality	±1	±1	±2	-2	-	±2	±1	±1	+2	T	T	II
Social environment	Economy	+2	+2	+2	+1	+1	+2	+2	+2	+1	T	T	III
	Society	+2	+2	+2	+1	+1	+2	+2	+2	+1	T	T	III
	Tourism	+1	+1	-	+1	+3	+1	-	-	-	F	F	II
	Cultural relics and historic sites	-	-1	-	-	±1	-	-	+2	±1	F	T	I
	Traffic and infrastructure	+1	±2	-	-	-	+2	+1	+2	+1	F	T	II
	Population health	±1	±2	±1	±1	±1	±1	±1	±2	+2	F	F	I

Note: In the above table, figures "1", "2" and "3" represent "slight", "medium" and "significant" impacts respectively;
"+" and "-" represent positive impact and adverse impact respectively;
"I", "II" and "III" represent "less important", "relatively important" and "very important" of environmental factors on environmental impact assessment of the plan.
In "cumulativity" and "persistence" columns, "F" indicates that the factor has no cumulativity or persistence, while "T" indicates that the factor has cumulativity and persistence.

10.3 Environmental Impact Analysis

10.3.1 Impact on Water Regime

Reaches upstream of Honda are the upper reaches of Magdalena River with concentrated drop and good water power resources. The reaches are mainly planned to develope hydropower, environmental protection, irrigation, navigation, leisure and recreation, etc. 17-cascade hydropower development scheme is planned for the reaches, including Quimbo HPP (cascade 5) under construction, and the existing Betania HPP (cascade 6), and the remaining planned 15-cascade hydropower stations. Development of cascade hydropower stations would raise water level of some reservoir areas, slow down flow velocity and change the discharge volume in a certain degree. However, the spatial and temporal changes are slight. Water level changes from gradual slope dropping of original water surface to stepped surface combining gradual sloping and sharp drop. Longitudinal consistency and horizontal connection of river morphology and runoff are significantly changed. In the planned 15-cascade hydropower stations, Guarapo (cascade 1), Chillurco (cascade 2) and Oporapa (cascade 3) reservoirs will be capable of seasonal regulation, while Honda (cascade 16) (high dam scheme) reservoir will be generally capable of over-year regulation. Reservoirs capable of seasonal regulation will change the water regime among different seasons. Reservoirs capable of over-year regulation will decrease discharge volume in high-flow period and increase discharge volume in low-flow period, making runoff volume even. The reservoirs of other cascades will have no regulation performance, which would have slight impact on water regime of river. The navigation plan for the upper reaches of Magdalena River mainly focuses on canalized arrangement of navigation structures based on hydroelectric development plan, which would have relatively minor impact on water regime. The irrigation plan for upper reaches mainly focuses on new and expanded irrigation areas. The reservoirs planned to be constructed will be used as the source of water for irrigation. Since the diversion amount is low, little impact will be caused on the water regime of Magdalena River. Neither the implementation of the plan of environmental protection nor leisure and entertainment would cause impact on the water regime.

Reaches downstream of Honda are the middle and lower reaches of Magdalena River, of which the main improvement and development purposes are navigation, flood and waterlog control, regulation of river course, riparian exploitation, irrigation, fishery, environmental protection, leisure and entertainment, etc. In the navigation plan, the reaches will be subject to river course regulation and dredging and port and wharf rehabilitation and expansion, which would improve the traffic conditions and result in slight impact on water regime. In the flood control plan, dikes in 17 cities and towns, flood wall works and supporting non-structural measures will be conducted to improve the standard of flood control and protect the residents and residential environment along both banks. Implementation of the flood control plan would prevent flood disaster and have slight impact on perennial water regime. River course regulation and riparian exploitation would change the river regime locally, which would have some impact on flow pattern but liitle impact on river flow and flow velocity. In environmental protection plan, measures should be taken including control of pollution sources, development of ecological agriculture, comprehensive treatment against soil erosion, growth of protective forest & commercial forest against soil erosion, connection among lakes, swamps and wetlands, standardization of fish catching mode, reconstruction & new construction of fish breeding station, enhancement of supervision, etc., to restore and improve the environment quality and maintain the sustainable utilization of fishery recourses. Implementation of the environmental protection plan would basically have no adverse impact on the water regime. The implementation of the plans of irrigation, fishery, leisure and entertainment, etc. would have no adverse impact on the water regime.

Therefore, in comprehensive plan implementation, impact on water regime is mainly attributable to hydropower cascade development. Water storage of upstream reservoir group would have cumulative impact on the water regime of middle and lower reaches.

10.3.2 Impact on Water Environment

10.3.2.1 Impact on Water Temperature

In the plan projects, it is the implementation of the hydroelectric cascade plan that may cause impact on water temperature. In comprehensive plan, the three planned cascade reservoirs of Guarapo (cascade 1) and Chillurco (cascade 2) and Oporapa (cascade 3) are capable of seasonal regulation. Honda (cascade 16, high dam scheme) reservoir has over-year regulation performance. Other planned reservoirs of cascade hydropower stations have no regulation performance (including low and middle dam schemes of Honda). Impact of reservoirs on water temperature is determined by ratio of year-to-year mean runoff to total storage capacity of reservoirs. Determination results of impact of four regulating reservoirs on water temperature are shown in Table 10.3.2-1.

Table 10.3.2-1 Water Temperature Structures of Planned Reservoirs of Cascade Hydropower Stations

Cascade Scheme	Name of Cascade	Full supply level (m)	Regulation Property	Dam Height (m)	Annual Runoff (billion m^3)	Total Storage (billion m^3)	Value of α	Water Temperature Structure
Cascade 1	Guarapo	1220	Seasonal regulation	108	3.343	0.152	21.99	Mixed type
Cascade 2	Chillurco	1125	Seasonal regulation	140	4.257	0.360	11.83	Transition type
Cascade 3	Oporapa	1015	Seasonal regulation	92	4.573	0.300	15.24	Transition type
Cascade 16	Honda 260 (High dam scheme)	260	Over-year regulation	96	29.991	13.160	2.28	Stable stratified type

Among cascade reservoirs, only Honda high dam scheme is of stratified type reservoir, and other planned reservoirs are of mixed type or transition type. In reservoir areas, stratified water temperature structure and discharged water temperature would change water temperature process of downstream river course. During temperature rising period, discharged low water temperature would have some adverse impact on breeding of fish in the river. Stratification of reservoir water temperature would also lead to stratification of water quality. Therefore, multi-level intake measures should be considered for Honda cascade high dam scheme.

10.3.2.2 Impact on Water Quality

Hydropower cascade development on upper reaches of Magdalena River would result in changes on such hydraulic characteristics as flow velocity, flow volume, water depth and water surface width of the river course, influencing water quality of the river. Cascade reservoirs with good regulation performance would have high storage capacity. This may increase environmental capacity of water in corresponding reaches, but the water quality would be degraded when flow velocity slows down and pollutants enter. Reservoirs with water quality being improved generally and with weak regulation performance and low storage capacity, would have relatively slight impact on water quality. During initial reservoir filling, reservoir-inundated organic substances and pollutants in the reservoir area would have some adverse impacts on water quality of the reservoirs. Therefore, reservoir clearance should be strengthened before impoundment.

The implementation of the navigation plan of middle and lower reaches of Magdalena River would promote the development of navigation. With the increase of loading capacity of ships, the wastewater from shipping would cause some adverse impact on water quality

Since most cities have no or very few wastewater treatment plants with low capacity, a vast majority of urban domestic wastewater is directly discharged into rivers without treatment. Implementation of environmental protection plan would radically reduce discharge volume of domestic wastewater entering rivers, relieve pollution load and improve water quality of the river.

The implementation of other sectoral plan has relatively minor impact on water quality.

10.3.3 Impact on Terrestrial Ecological Environment

10.3.3.1 Analysis of Impact of Hydropower Cascade Development on Sensitive Factors

Colombia Tremarctos early warning information system (www.tremarctoscolombia.org) is adapted to check the environmental sensitive factors (including forest reserves specified by laws & regulations, national natural parks, other sensitive areas of RUNAP system, natural reserves of non-governmental organizations, distribution area of sensitive species, archaeological parks, reserved area for Indians, land of black community, archaeological sites, compensation index, etc.) within the impact area of cascade hydropower stations, with results shown in Table 10.3.3-1.

The table shows that, among 15 planned cascades, red light warning is presented by Tremarctos early warning information system for Perícongo (cascade 4), Bateas (cascade 9), Basilias (cascade 10) and Piedras Negras (cascade 17). Within impact area of the four cascades, important endangered protected animals (extremely endangered or vulnerable) are included. Among them, Bateas, Basilias and Piedras Negras cascades have impact on locally unique ecological system with high compensating factor (8-9). Hydropower station development involves relatively large area of ecological compensation. Basilias cascade may also involve a local natural park (La Tatacoa), what's more, local archaeological sites may be distributed around impact area of Bateas, Basilias and Piedras Negras cascades. Therefore, the four cascades would have significant impact on ecology, it is thus recommended to develop them in relatively later time.

For Veraguas (cascade 8) and Carrasposo (cascade 11) with yellow light warning, protected birds are involved in impact area of hydropower stations, and locally unique ecological system with high compensating factor (8-9) is also affected. Hydropower station development would involve relatively large area of ecological compensation. In addition, around impact area of the two cascades, historical sites and aboriginal residential area may be distributed. Therefore, the two cascades would have relatively significant impact on ecological environment.

The remaining planned nine-cascade hydropower stations are with green light warning, which means hydropower station development would have relatively slight impact on surrounding ecological environment, and important endangered protected animals involved are less. However, the four cascades including Lame (high dam scheme), Ambalema, Cambao and Honda (high dam scheme) would have impact on many special types of ecological systems, with relatively large area of ecological compensation. This indicates that current situation of biodiversity is good in the project area, thus, protection of the biodiversity should be strengthened during development as much as possible, so as to reduce vegetation destruction. In addition, historical sites and aboriginal residential area may also be distributed in most impact areas of cascade hydropower stations. Special attention should be paid to this.

Table 10.3.3-1 Check of Terrestrial Ecological Sensitive Factors in Impact Area of Planned Cascade Hydropower Stations

Cascade	Name of Cascade	Full supply level (m)	Regulation Performance	Sensitive Factor Identification by Tremarctos Early Warning Information System						
				Early Warning and Indicating	Protected Animals Affected	Reserve and Park	Particular Ecological System			Other Sensitive Factors
							Quantity	Compensation Area (ha)	Compensation Factor	
Cascade 1	Guarapo	1220	Seasonal regulation	Green light	-	-	-	-	-	YANACONA aboriginal residential area
Cascade 2	Chillurco	1125		Green light	-	-	-	-	-	YANACONA aboriginal residential area and 7 archaeological sites of ISNOS
Cascade 3	Oporapa	1015		Green light	-	-	-	-	-	1 archaeological site of TARQUI
Cascade 4	Perícongo	870	Incapable of regulation	Red light	1 kind of mammal, Saguinus leucopus (CR)	-	-	-	-	-
Cascade 7	El Manso	485		Green light	-	-	-	-	-	-
Cascade 8	Veraguas	420		Yellow light	3 kinds of birds (2 kinds of migration birds and 1 locally unique species)	-	5	95.21	8~9	1 archaeological site of NEIVA
Cascade 9	Bateas	399		Red light	1 kinds of bird (immigration) and 1 kind of reptiles, Crocodylus acutus (CR)	La Tatacoa natural park	11	7321.81	8~9	2 archaeological sites of NEIVA and 3 archaeological sites of VILLAVIEJA
Cascade 10	Basilias	378		Red light	20 kinds of birds (18 kinds of migration birds and 2 kinds of locally unique birds) and 1 kind of reptile, Crocodylus acutus (CR)	-	11	9107.09	8~9	3 archaeological sites of VILLAVIEJA
Cascade 11	Carrasposo	357		Yellow light	3 kinds of birds (1 kind of migration bird and 2 locally unique species)	-	4	358.90	8~9	PIJAO aboriginal residential area and 3 archaeological sites of VILLAVIEJA
Cascade 12	Nariño	260		Green light	-	-	4	306.04	7.5	-
Cascade 13	Lame (High dam scheme)	260		Green light	-	-	24	10710.80	6.5~9	-
Cascade 14	Ambalema	232		Green light	1 kind of bird (migration)	-	13	9422.56	6.5~7.5	-
Cascade 15	Cambao	221		Green light	2 kinds of birds (migration)	-	9	5842.56	6.5~7.5	-
Cascade 16	Honda (High dam scheme)	260	Over-year regulation	Green light	-	-	10	9157.86	6.5~7.5	6 archaeological sites of HONDA, 3 archaeological sites of ARMERO and 1 archaeological site of GUADUAS
Cascade 17	Piedras Negras	192	Incapable of regulation	Red light	20 kinds of birds (17 kinds of migration birds and 3 kinds of locally unique birds; Crax Alberti (CR) and Dendroica cerulean(VU))	-	6	1589.81	7~7.5	6 archaeological sites of HONDA and 1 archaeological site of GUADUAS

10.3.3.2 Analysis of Impact on Other Sensitive Factors

Navigation plan mainly focuses on canalization of river course along upper reaches, regulation of river course along middle reaches and dredging of river course along lower reaches as well as upgrading and reconstruction of existing ports along the river. The regulation plan of river course mainly focuses on implementation of bank reinforcement and protection projects and river course cut-off projects. The impact caused by such plan is within the range of both banks of the river course basically without important environmentally sensitive areas involved. Nevertheless, there may be protected animals distributed. Therefore, early warning system should be adopted during the implementation stage of plan to inspect whether there are any objectives sensitive to project environment. The irrigation plan mainly refers to implementation continued construction of supporting projects, and new and expanded construction of irrigation areas in Huila and Tolima Departments at upper reaches. The scope of impact caused by new and expanded construction of irrigation areas may involve environmentally sensitive areas, so inspection work should be done in the implementation stage of plan. Fishery plan mainly refers to establishment of fishery production base in lakes and reservoirs and provision of refrigeration and processing bases. The leisure and entertainment plan mainly refers to construction of supporting infrastructure for tourism along the river and integration of tourist resources. Although the scope of impact for the implementation of plan is relatively small and would not involve important environmentally sensitive areas, early warning system should still be adopted in the implementation stage for overall identification of such areas.

10.3.3.3 Impact on Terrestrial Ecology

Ecological system is complex and diversified in the basin, with various functions of habitat support, biodiversity maintenance, water source conservation, and purification & beautifying of environment. After implementation of the plan, such ecological landscape systems in the basin as forest, farmland & grassland, wetland and water area would not change obviously in structure and function. Implementation of soil erosion control and afforestation plan would increase forest coverage in the plan area, promote development of forestry economy, effectively control soil erosion, and improve the ecological environment in the basin. In addition, construction of ecological forest would be conducive to strengthening such service functions as improving soil erosion control of the basin, water source conservation, climate regulation and pollution reduction. Besides, it can also inhibit ecological environment destruction, increase soil & water & fertilizer holding capacity, and improve biological productivity of the ecological system.

Hydropower plan involves inundation and land occupation, which would damage the original wetland ecology along both banks of valleys, have adverse impact on terrestrial vegetation, decrease & change wildlife habitat in forests, and may generate impact on some particular ecological systems in Magdalena River Basin. According to "resolution on adopting guidelines for biodiversity loss compensation" issued by the Ministry of Environment and Sustainable Development in Colombia in August 2012, it is recommended that ecological compensation must be given for reservoirs with a storage capacity over 0.2 billion m^3, and ecological compensation area should be calculated based on affected area and ecological compensation factors. Ecological compensation area for the planned 15 cascades is shown in Table 10.3.3-1.

After implementation of planned reservoir works, area of water surface will increase. This would provide a broader inhabiting and reproducing place for wading birds and swimming birds. Besides, new habitats for amphibians and reptiles will be formed along both banks of valley. Implementation of irrigation plan can change the original extensive agriculture & animal husbandry method, improve irrigation efficiency, improve & expand properly irrigation area, improvet the agricultural ecological system & land utilization method, and increase agricultural output and farmers' income.

10.3.4 Impact on Aquatic Ecological Environment

10.3.4.1 Impact on Fish Resources

n hydropower plan, construction of cascade hydropower stations would generate a certain adverse impact, in which the main impact is that of cascade dam blocking and water regime change on fish resources in the basin. Due to construction of cascade hydropower stations, the upper reaches of Magdalena River will be separated into many relatively independent reservoir water bodies. Original running water habitat will shrink, original spawning grounds of migrating fishes and fishes adapted to rapid current environment will disappear. Fishes will change to be adapted to slow flow, even still water, resulting in change of structures of fish species in local water area.

Blocked by dam, fishes in middle and lower reaches of Magdalena River cannot swim upward to the reaches above Honda to find food and lay egg, which would shrink space for finding food and laying egg, and lead to reduction of fish supplementation in middle and lower reaches. Consequently, loss of fishes in middle and lower reaches is caused. In Magdalena River, important fishes are mainly distributed in middle & upper reaches below Honda. Most of the fishes migrating among rivers and lakes and part of the fishes migrating among rivers and the ocean can swim upward to the valley reach with fast-flowing current near Honda. But a few individual fishes can swim upward to the reach near Neiva. Hydropower plan area is the upper reaches above Honda, and the plan would have little impact on migrating fishes. However, cascade construction in the reaches below Neiva will block swimming of fishes; therefore, fish-passing facilities should be set to ensure that fishes can swim upward and pass through the dams.

In reaches with fast-flowing current of Honda, there are abundant fish resources. Such reaches are important place to catch migrating fishes in a traditional way. During fisgh catching season, a large number of population catch fishes along the reaches. Therefore, construction of Piedras Negras cascade below Honda would have significant impact on local fish resources. Since there mainly is sediment and sludge at bottom of middle and lower reaches of Magdalena River, with very few batholith riverbeds and pebble riverbeds, consequently, reservoir inundation will lead to inundation of such batholith riverbeds and pebble riverbeds. In addition, the dam will block fishes to swim upward to traditional catching river reaches, and therefore fishermen cannot catch fishes during catching season.

High, medium and low dam schemes are provided for Honda cascade plan. Honda reservoir with high dam scheme is capable of over-year regulation and has relatively high influence on water regime. Moreover, water discharge from the dam will generate a series of impacts including gas oversaturation and water temperature change. The cascade is not provided with re-regulation hydropower station, control section has large water volume, and tributaries have limited relief effect. This would directly affect water level rise for fish breeding in reproducing reaches below the cascade, and have obvious impact on breeding of fishes. The reaches downstream of Honda are important fishery resource reaches, therefore, cancellation of high dam scheme for Honda cascade is recommended. Honda low dam scheme is not provided with regulation performance, has relatively small impact on water regime and will not lead to stratifying of water temperature. After effective mitigation measures are taken, the low dam scheme may be adopted.

In aquatic ecological protection plan, Magdalena River Basin will be divided into 9 key protection areas in upper, middle and lower reaches in the short term. Thereinto, running water habitat both in mainstream and tributaries will be protected in hydropower development reaches above Honda. Fish-passing facilities are planned to be set in reaches below Veraguas (cascade 8), and fish breeding stations are planned to be built in upper and middle reaches to breed and release fishes. In concentrated distribution reaches of fish spawning grounds between Honda and Sogamoso, relevant researches should be conducted on hydrological and hydraulic conditions for breeding of fishes and conditions of habitat of spawning grounds; and research should also be conducted on ecological scheduling method of upstream cascade hydropower stations. Research on technical measures including release of ecological flow and ecological scheduling should be conducted in Tributary Sogamoso. Research should be conducted on protection and restoration of diversified habitats of rivers and lakes in downstream lakes, swamps and wetlands, to protect connectivity between river and lake systems, maintain stable areas of rivers and lakes, standardize activities in fishery, and promote sustainable utilization of fishery resources.

In aquatic ecological protection plan, implementation of a series of fish protection measures would play an important role in mitigating adverse impact of hydropower development on breeding of fishes, promoting protection & restoration of fish resources in the area, and ensuring sustainable utilization of fishery resources. The adverse impact on fishes generated by hydropower plan can be effectively mitigated.

10.3.4.2 Impact on Wetlands in Middle and Lower Reaches of Magdalena River

About 200,000 ha swamps, lakes and wetlands are distributed in the middle and lower reaches of Magdalena River. During low-flow period, swamps, lakes and bottomlands are densely distributed, while during high-flow period, the water surface is wide. Therefore, the wetlands here are important place for feeding of young fishes, growth & development and breeding of some fishes in the basin. In the whole basin, the water area has the highest biological productivity, abundant fish resources and high fish yield, which is the main fishery water area. Maintenance of water system connection between lakes & marshes and rivers, and of wide living water area of aquatic organisms, is the basic condition to maintain fish resources.

Currently, with development of agriculture & animal husbandry and urbanization, a large area of lakes, swamps and wetlands is occupied. Soil erosion on ground surface around the wetlands exacerbates sedimentation and drought of the lakes, swamps and wetlands, leading to loss of extensive lakes, swamps and wetlands. In addition, in the navigation plan and river course regulation plan, implementation of dredging works may block connection between lakes, swamps and wetlands and rivers, and affect habitats of lakes, swamps and wetlands. In hydropower plan, cumulative effects of cascade development will generate adverse impact on water supplementation in the wetlands of middle and lower reaches. Therefore, mitigation measures should be taken to maintain the structure and function of aquatic ecological system.

In short-term key protection area, there is wetland (Ciénaga Grande) under protection of Ramsar Convention. In aquatic ecological protection plan, research on the impact of river-ocean system connection and salinity change of wetland on mangrove forest will be carried out as key tasks. Besides, reasonable connection of river systems will be carried out to provide guarantees for the restoration of mangrove forest in wetland. For other lakes, swamps and wetlands, research will be conducted on protection and restoration of diversified habitats of rivers and lakes, to protect connectivity between river and lake systems and maintain stable area of river and lake.

In aquatic ecological protection plan, measures to be taken mainly include the following: □ maintain existing water connection between lakes, swamps and wetlands; and strictly control the activities like constructing artificial dikes, building dams, narrowing waterway connecting rivers and lakes; □for marsh wetlands cultivated for agriculture & forestry and animal husbandry, carry out the works in which farmland and grazing land are returned to lakes, so as to restore water area and wetland area; □for water area with river network system connection damaged, carry out proper works like dredging, expansion, even re-excavation to connect waterway; remove unnecessary barrages and restore original water system connection of river network; □delimit some water areas including river course connecting rivers and lakes as perennial closed fishing areas, so as to restore the channels through which fishes migrate to rivers and lakes; □take measures, such as reconstruction of sluices, optimization of scheduling, dredging of connection river course and construction of artificial natural bypasses, to restore the connection of river and lake systems.

Implementation of the above aquatic ecological protection plan would effectively mitigate the adverse impact of implementation of hydropower & navigation plans on wetlands on the lower reaches of Magdalena River, improve connection between Magdalena River and lakes, swamps and wetlands, restore wetland area & aquatic ecological system, and provide a favorable ecological environment for development of fishery resources.

10.3.4.3 Ecological Flow

According to requirements of Colombia on ecological flow control of construction projects, in construction of hydropower stations, ecological flow of reaches below dams should be more than 30% of year-to year mean flow. Currently, ecological flow is calculated by the following four methods:

a) The minimum year-to-year monthly mean flow (minimum monthly mean flow among the mean flows of 12 months)×75%;
b) Daily mean flow corresponding to 97.5% of guarantee rate according to the curve for daily mean flow frequency for more than 5 consecutive years;
c) Daily mean flow corresponding to 90% of guarantee rate according to the curve for daily mean flow frequency (no requirement for 5 consecutive years);
d) Daily mean flow corresponding to 85% of guarantee rate according to the curve for daily mean flow frequency (suitable to rivers with small change in daily flow; for

rivers with big change in daily flow, take the daily mean flow corresponding to 75% of guarantee rate).

Ecological flow below planned cascades is mainly used for ecological water. The first method is adopted to preliminarily calculate the ecological flow of each cascade herein, as shown in Table 10.3.4.

Table 10.3.4 Ecological Flows of Cascade Hydropower Stations

Cascade	Name of Cascade	Limit Value of Ecological Flow (m^3/s)	Year-to-year Mean Flow at Dam Site (m^3/s)	Proportion of Ecological Flow (%)
Cascade 1	Guarapo	51.53	119	43.30
Cascade 2	Chillurco	60	135	44.44
Cascade 3	Oporapa	65.03	145	44.85
Cascade 4	Perícongo	67.65	149	45.40
Cascade 7	El Manso	225	398	56.53
Cascade 8	Veraguas	279.75	495	56.52
Cascade 9	Bateas	297.75	526	56.61
Cascade 10	Basilias	317.25	561	56.55
Cascade 11	Carrasposo	354	625	56.64
Cascade 12	Nariño	633	1140	55.53
Cascade 13	Lame	641.25	1150	55.76
Cascade 14	Ambalema	658.5	1190	55.34
Cascade 15	Cambao	672.75	1210	55.60
Cascade 16	Honda	684.75	1240	55.22
Cascade 17	Piedras Negras	697.5	1260	55.36

In the 15 planned cascade hydropower stations, only 3 cascades are reservoirs capable of seasonal regulation, therefore, rational scheduling and operating methods should be adopted to satisfy the requirement of ecological flow. Other cascades are of runoff type, having little impact on water volume of downstream reaches.

10.3.5 Impact on Land Resources

After implementation of soil erosion control and irrigation plan, soil conservation, water conservation and fertilizer conservation can be effectively realized to improve land use types, helpful for adjusting agricultural structure and facilitating rational development and utilization of land resources and integrated development of agricultural, forestry and animal husbandry production as well as promoting ecological construction and integrated development of agriculture, forestry and animal husbandry in mountainous areas. After implementation of flood and waterlog control plan, land area impacted by flood and waterlogging within basin will be reduced. Some land will be submerged and occupied due to construction of hydro projects, having certain negative impact on land resources.

10.3.6 Impact on Environment of Dique Canal

Dique Canal is both an important shipping waterway and crucial fishing waters. Meanwhile the wetlands on its both banks are also biodiversity conservation area. After investigation and analysis, the following major environmental problems exist at present: the surface water quality is polluted by surrounding town life. Seawater encroachment impacts the quality of water at intake of Town Cartagena on the right bank of upper section of Dique Canal. Fishery resources drop because of overfishing. Reclaiming land from marshes leads to reduction of wetland biodiversity. The gate built at the place where wetland and the canal are connected impacts lakes, swamps and wetlands connectivity and flood disasters are serious at lowland.

Regarding integrated improvement of Dique Canal, over the years, Cormagdalena has organized and carried out several studies and achieved some results, such as Fonds d'Etudes et d'Aide au Secteur Privé– FASEP-Etudes –RESTAURACIÓN DEL CANAL DEL DIQUE(2006), CANAL DEL DIQUE PLAN DE RESTAURACION AMBIENTAL (CORMAGDALENA IDEHA - UNIVERSIDAD DEL NORTE, May, 2003) and so on. By desilting and dredging the river course, gravel and sludge in the river course can be dug out, navigational obstacles in the river course can be cleared to increase flood carrying capacity of flood discharge section, and meanwhile shipping is unobstructed, advantages are drawn on and disadvantages are avoided, and sediment load at estuary can be reduced. But the desilting and dredging works in river regulation plan will unavoidably disturb and change the river course and alter river regime, and the change of deposition and erosion in riverbed will take place. The large amount of sediment and sludge produced in desilting and dredging works is prone to erosion if not properly disposed of, and will damage the ecological environment of spoil area, and may affect the water quality safety of intakes of towns along Dique Canal. The large amount of sediment and sludge produced in desilting and dredging works should be properly disposed of, cofferdam should be set for mud lump, and settling time should be increased, ensuring the water quality safety of intakes.

The implementation of soil erosion control and afforestation plan would help to control sediment load into river. The implementation of cascade hydropower plan and the sediment retention and storage regulation of cascade reservoirs would help to reduce sediment load in downstream river course. The implementation of river regulation plan would help to reduce river sediment concentration. Therefore, the implementation of this plan is helpful for solving the problem of sediment accumulation for Dique Canal, reducing volume of dredging works, improving navigation conditions of the canal, and increasing connectivity of lakes, swamps and wetlands along the canal.

The sediment problem of Dique Canal is a complex and systematic issue and needs in-depth studies in several aspects. Dredging and guiding is one of the relatively direct measures. It is recommended that intensive studies should be continued and meanwhile hydrological sediment observation and study should be strengthened, and the management scheme should be implemented as soon as possible, so as to realize the sustainable development of Magdalena River.

10.3.7 Impact on Social Environment

a) Boosting Economic Development

The sectoral plan in master plan such as navigation, riparian exploitation, river regulation and irrigation has significant economic and social benefits. The navigation plan would help to improve the navigation conditions of Magdalena River, increase freight volume, reduce transport costs, and promote the social and economic development of the basin. Meanwhile, the irrigation plan would increase the potential irrigation area, ensure the agricultural irrigation water, enhance the agriculture against natural disasters, improve the agricultural production conditions and rural ecological environment, increase the agricultural output, and promote the agricultural and rural economic development. The riparian exploitation plan has identified the functional zones along Magdalena River, which would achieve the sustainable utilization and effective conservation of riparian resources, meet the requirements of riparian exploitation along mainstream of Magdalena River, boos the rapid regional economic and social development. The river regulation plan would effectively stabilize the river regime, improve the disadvantageous river regime, consolidate the control of existing revetment works over the river regime, and improve the navigation conditions.

b) Ensuring Flood Protection Security and Social Stability

The flood protection plan would play a crucial role in improving flood control capacity of Magdalena River, reducing property loss of urban residents along the river banks, and protecting people's lives and safety. Riparian regulation would also produce an important protection effect on safe life of residents along the river. The leisure and recreation plan would explore the rich leisure and tourism resources along Magdalena River, improve the tourism environment, foster the Magdalena River tourism culture, and enrich people's leisure life, largely facilitating the improvement of leisure service function of Magdalena River.

10.3.8 Impact on Sustainable Development

a) Strengthening Infrastructure Construction, and Promoting Promoting Sustainable Economic and Social Development

The implementation of hydropower plan for upper reaches of Magdalena River would actively promote the rational and orderly development of water resources, effectively improve the power structure in the basin and provide clean energy. The implementation of navigation plan for Magdalena River would accelerate the shipping modernization construction, improve the regional integrated transport capacity, provide smooth, excellent, safe, convenient, and efficient transport services for the economic belt of Magdalena River Basin, and further improve the status of Magdalena River water transport in the integrated transport network. The implementation of flood protection plan for Magdalena River would improve the integrated flood control and disaster reduction system, ensure the flood control safety of important cities, regions and infrastructure as well as large industrial and mining enterprises, enhance the flood control and disaster reduction capacity of the basin, and assure the economic development and social stability. The implementation of river regulation plan for Magdalena River would stabilize the river regime, create favourable conditions for social and economic development of regions along the river. The implementation of fishery resources utilization plan would boost the quality and efficient development of aquaculture.. The implementation of leisure and recreation plan would rationally utilize the unique landscape resources, orderly construct the recreational facilities, expand functions and add products. Therefore, the implementation of master plan for Magdalena River Basin would provide strong support for the sustainable development strategy implemented by Colombia and the infrastructure construction, facilitating the sustainable economic and social development in the basin.

b) Maintaining a Good Sound Ecological Environment, and Promoting the Coordinated Development of Management, exploitationExploitation and Environmental Protection

The implementation of surface water environmental protection plan would strengthen the aquatic environmental protection, control the discharge of pollutants into river, accelerate the control of domestic and industrial pollution sources and agricultural pollution source, and enable a positive circulation of water environment

The implementation of aquatic ecological protection plan would, based on the functional demand of aquatic ecosystem environment, rationally plan the waterway improvement and hydropower development for the basin, protect and restore the aquatic habitat, and connectivity among wetlands, rivers and lakes, and maintain the integrity and biodiversity of aquatic ecosystem.

The implementation of soil erosion control and afforestation plan would ehance the supervision and management, effectively curb the soil erosion due to human activity, and accelerate the pace for ecological construction and afforestation..

Therefore, the concept of “ecology first, sustainable utilization” is observed in the master plan, coordinating and plan the relationship between exploitation and protection as a whole, and promoting the the sustainable development of economy and society and ecological environment in Magdalena River Basin.

10.4 Analysis onEnvironmental Rationality of Planning Schemes

10.4.1 Rationality of Planning Objectives and Scales

a) Navigation Plan

Via implementation of navigation plan, the water transport network, of which the skeleton consists of the reach beyond Salgar Port of Magdalena River and the modernized high-grade waterway of Dique Canal, will be fully completed, increasing the freight volume, reducing transport costs, and promoting the social and economic development in the basin.. Water transport is a transport means with low energy consumption, thus reducing carbon emission and saving energy. The implementation of waterway regulation works would effectively tacke the problems such as sediment accumulation, bank caving, river course change and so on, and improve the navigation conditions of Magdalena River, and play an important role in safe life of residents along the river. The plan scheme is rational from the perspevtive of environmental protection.

b) Hydropower Plan

The implementation of hydropower plan would increase the development and utilization rate of hydropower resources by about 20%. The concept of ecology first is put into practice in hydropower plan scheme. A long natural reaches close to headwater is reserved, and the river reaches downstream of Honda where fish resources is abundant is basically avoided so as to minimize impacts on fish resources. In addition, arrangement of fishways and fish breeding stations are concurrently considered for river reaches where fish migration exists to mitigate the ecological environmental impacts caused by cascade hydropower development as far as possible.

In the recommended hydropower cascade plan scheme, the ultimate upstream 3 hydropower stations have reservoirs of seasonal regulation property, and others do not have performance in seasonal regulation (low dam proposal is adopted for Honda Cascade), so the cumulative adverse environmental impacts of the river reaches are minor. Meanwhile, the principle of moderate development is embodied in the hydropower plan scheme, the cascades with good development conditions and small environmental impacts are selected to develop in short-term, which would have no significant effects on the effective play of river ecosystem functions. Overall, the hydropower plan scheme is of environmental rationality. However, the development of hydropower cascades would contribute to the barrier effect and habitat fragmentation for fishes, so effective mitigation measures should be taken against adverse impacts.

c) Irrigation Plan

Huila Department and Tolima Department at upper reaches are the main agricultural regions of Colombia. The implementation of irrigation district plan would renovate the supporting system of large and medium irrigation districts, and construct a new batch of irrigation districts and canal works, increasing the potential irrigation area by 16,400ha, assuring the agricultural irrigation and urban and rural water use, improve the utilization efficiency of water resources, enhance ability of agriculture against natural disasters, improve agricultural production conditions and rural ecological environment, increasing the agricultural output, and promoting the agricultural and rural economic development. So the plan scheme is rational from the prospective of environmental protection.

d) Riparian Exploitation and River Regulation Plan

The implementation of riparian exploitation plan would achieve the sustainable utilization and effective conservation of riparian resources, and ensure to meet the riparian exploitation requirements of the mainstream of Magdalena River. The implementation of river regulation plan would effectively stabilize the river regime, improve the unfavorable river regime, consolidate the control of existing revetment works over river regime, improve navigation conditions, and assure the safety of flood protection works. River regulation and dredging works would have some adverse impacts on aquatic ecological environment, so effective mitigation measures should be proposed. Generally speaking, riparian exploitation plan and river regulation plan are environmentally rational.

e) Environmental Protection System Plan

The environmental protection system plan mainly includes 1) . wastewater treatment plan, 2) aquatic ecological protection plan, 3) soil erosion control and afforestation plan, and 4) environmental monitoring plan. The implementation of the plan would basically realize the healthy development of aquatic environment and aquatic ecology. The implementation of wastewater treatment plan would reache a urban wastewater treatment rate of 85% and a domestic waste treatment rates of 80%, which would control the basin pollution sources, reduce pollutant discharge, improve the surface water quality in the basin, raise residents' living environment quality and health conditions, and ensure the sustainable utilization of water resources. The aquatic ecological protection plan helps to gradually restore the ecological connection between different types of waters including rivers and wetlands, protect habitats of rare and unique aquatic organisms, mitigate impacts of water resources development process on three important grounds (spawning ground, overwintering ground and feeding ground) for fishes. Soil erosion control and afforestation plan helps to reduce sediment load into Magdalena River, control the basin soil erosion, reduce non-point source pollution, increase forest coverage rate in the basin, and improve the ecological environment. The implementation of environmental monitoring plan scheme would timely monitor the implementation effects of various environmental protection measures regarding pollution source control and basin environmental quality improvement and so on. Therefore, the environmental protection plan is rational.

f) Flood Control Plan

The flood control and disaster reduction system plan covers both structural and non-structural measures. Priority is given to non-structural measures at upper reaches; at middle and lower reaches, priority is given to embankments, flood plain management, flood storage and detention areas, and construction of non-structural measures like flood early warning is strengthened. The plan would play an important role in improving flood control capacity of Magdalena River Basin, reducing property loss of urban residents along the river banks, and protecting people's life safety. So the plan scheme is rational from the prospective of environmental protection.

10.4.2 Rationality of Plan Layout and Development Mode

Centered on the overall objectives of improvement, development and protection of Magdalena River, relatively complete systems for water resources utilization, flood control and disaster reduction and environmental protection are established in the overall plan layout scheme. Mutual ties and constraints exist and economic, social and environmental requirements are planned as a whole in these plan systems. The overall layout for plan is environmentally rational. If analysis is performed for each sectoral plan layout, different characteristics can be seen:

The hydropower plan tries to avoid the river reach downtream of Honda where fish resources are abundant so as to reduce the adverse impacts on fishes. The planned hysropower cascades involves such sensitive areas as municipal natural parks, small amount of indigenous communities, archaeological sites, distribution areas of sensitive species, etc. Impacts of each cascade hydropower plant on sensitive objects are all within acceptable scope. Their adverse impacts are mainly in construction period and could be mitigated as long as construction plan is properly carried out, construction scope is strictly controlled, and environmental awareness of construction personnel is raised.

Specific to single projects in flood control plan, navigation plan, river regulation plan, irrigation plan, and environmental protection plan, protection measures are also proposed such as, construction is prohibited in environmental sensitive areas, important distribution areas of protected species are kept away from, and construction areas are strictly controlled, and the like.

The impacts of plan implementation on biodiversity of terrestrial organisms outside environmental sensitive areas should be mitigated by ecological compensation strictly according to ecological compensation policies of Colombia. Situ conservation should be carried out and further disturbance should prohibited for the concentrated distribution areas of rare and endangered species found in the process of individual item implementation

Generally speaking, ecological sensitive areas should be kept away from to the greatest extent in the master plan of Magdalena River and ecological system structure and functions are maintained. The plan layout is basically rational.

The water resources development mode of Magdalena River in this plan conforms to the sustainable economic, social and environmental development mode. According to the actual situations of the upper, middle and lower reaches, main development modes for each river reach are rationally planned. The upper reach is abundant in hydropower resources and mainly objectives power generation. Reservoirs with certain regulation property will be constructed, and reservoir construction is combined to carry out irrigation development and aquaculture development plan, so as to obtain good integrated development benefits. Priority is given to navigation and flood control at middle and lower reaches. In combination with ecological environmental protection, tourism development is also considered to achieve better economic, social and environmental benefits.

With respect to the adverse impacts of hydropower development plan on ecological environment, with ecological environmental protection as a prerequisite in the plan, excessive utilization of hydropower resources is avoided, diversion conduit type development with large impacts is not adopted as development mode, and ecological health of river is ensured while hydropower resources are developed rationally.

So the master plan development mode is basically rational from the perspective of environmental protection.

10.4.3 Rationality of Time Sequence

The recommended near-term projects in the master plan are rational and practical via considerations given to comprehensive benefits from viewpoints of being helpful for fulfillment of basin plan goals, pollutant load reduction, and costs of each pollutant elimination, cooperative willingness of land owners, acceptability of communities, location of basin, partner opportunity, appeal to the public, transport convenience of construction sites, values of habitats, and recreation, education provided by projects, and the revival of neighboring areas.

The hydropower cascade development sequence is also optimized. The four cascade hydropower plants, Cascade 4 Perícongo, Cascade 9 Bateas, Cascade 10 Basilias, and Cascade 17 Piedras Negras, are characterized by sensitive environments and red early warning signs, so their development are postponed accordingly. The four cascade hydropower plants Cascade 1 Guarapo, Cascade 3 Oporapa, Cascade 7 El Manso and Cascade 12 Nariño, are recommended as near-term projects due to low adverse environmental impacts. The other seven cascades, due to their relatively poor technical and economic indicators, and relatively large area of ecological compensation for most of them, will be developed in a proper time according to the economic and social development requirements and under the premise that further research on environmental impact and mitigation measures is conducted. After optimization, the development sequence in hydropower plan is environmentally rational and practical.

10.4.4 Analysis on Uncertainties

10.4.4.1 Uncertainty of Basic Environmental Information

The comprehensive and detailed basic environmental data and the information platform construction are the bases for fulfilling the work of environmental protection plan. Many difficulties are overcome and large amount of data are collected for this plan, but the data are still not systematic and comprehensive at present. For instance, there is a lack of environmental background data, basic geographic information, digital elevation model and hydrological analysis, and the information and data on climate, geology, soil, land utilization and coverage, social economy, and biology and the like. The data including special plan for basin environmental protection and environmental function zoning, the water pollution of main control sections and the parameter values of total quantity control, and the data on national economic development and plan of Colombia and regions are not available.

The collected data on aquatic ecological environment are relatively plentiful, especially those on variety and annual output of fish and some wetland studies. But the valid data usable for this plan are scarce. For instance, there is a lack of detailed information and data on the important fish spawning grounds and habitats and the obstruction of lakes, swamps and wetlands connection. Besides, most data date back to earlier than 2007, and the data on built wastewater treatment plants mostly describe their running conditions before 2002. Commercial afforestation plan is lacking in the data on market demand and development prospect and those on argumentation of ecological suitability including soil and climate.

Some data on current environmental situation are inconsistent, for example, the total population served by existing wastewater treatment projects of Honda City and corresponding treatment capacities and the predicted total population in 2020 and corresponding treatment capacity of Puerto Berrio and the like.

The numerous uncertainties of basic environmental information for plan would lead to some uncertainties of environmental impacts and protection measures.

10.4.4.2 Uncertainty of Plan Content and Layout

This plan is rich in content and involves many aspects. Because of a lack of the aforementioned basic data and the information on current environmental situation, the content and layout of irrigation plan, drainage plan, leisure plan, riparian exploitation and river regulation plan, and lakes, swamps and wetlands connectivity protection plan are not adequately comprehensive or detailed and are characterized by uncertainties. The sites and reticulation layout of urban domestic wastewater treatment plants and garbage disposal plants are short of topographic maps of urban areas, current situation of land utilization and land use plan, direction and distribution of water system, and perennial predominant wind direction, so the plan content and its environmental impact and environmental protection measures are of uncertainties.

The population to be relocated and the direction and method of their resettlement in this plan are still unclear. Meanwhile, the resettlement involves many aspects such as cultivated land adjustment, housing construction, supporting infrastructure and social culture, and economic development, so their impacts on social environment and ecological environment and the countermeasures have some uncertainties.

10.4.4.3 Uncertainty of Construction Sequence in Plan

The master plan aims at specifying basic task, measure system, stage goals of plan, etc. In spite of the specificity of plan tasks and goals, the specific measures for numerous contents of plan and the construction sequence of each individual item remain to be determined because the plan is basically in the depth of strategic plan.

10.4.4.4 Countermeasures against Uncertainties in Plan

In view of the uncertainties existing in the plan, the environmental impact assessment of plan includes the following: from height of strategic environmental impact assessment, mainly investigate and analyze the the current environmental situation and environmental issues, identify the the environmental goals and the environmentally sensitive and restraining factors, highlight the overall environmental impact trend analysis, and propose the recommendations and requirements for optimized adjustment of plan and environmental protection efforts in the next stage from the viewpoints of coordination, integrity and attainability of objective, so as to provide basis for plan decision and guidance to environmental protection efforts in plan implementation.

With respect to plan schemes with large adverse environmental impacts, based on adequate research and demonstration, environmental sensitive objectives should be kept away from as far as possible, and plan schemes with environmental rationality should be chosen via optimized scheme comparison. Coordinated with the plan, the adjustment and modification of plan schemes should be carried out in time.

10.4.5 Recommendations for Adjustment of Planning Scheme

Planning scheme adjustment is mainly aiming at hydropower plan in the master plan. In the 17 cascade development scheme for hydropower plan, Betania has been built, Quimbo is under construction, and the remaining 15 cascade hydropower plants are planned to be built. On the basis of environmental impact analysis, the four cascade hydropower plants, Cascade 4 Perícongo, Cascade 9 Bateas, Cascade 10 Basilias, and Cascade 17 Piedras Negras, involve sensitive protected species, so their development sequences should be postponed to develop in later stage. In view of maintenance of fish migration channel, further research on environmental impact should be conducted to put forward feasible impact mitigation measures for Honda hydropower plant, so as to protect important fish resources in Honda reach as far as possible. The near-term projects should be chosen among the five cascade hydropower plants with good development conditions and littlel environmental impacts, Cascade 1 Guarapo, Cascade 3 Oporapa, Cascade 7 El Manso, Cascade 12 Nariño, and Cascade 16 Honda.

10.5 Environmental Protection Measures

According to the environmental impact forecast for plan scheme and the conclusion of environmental rationality analysis, plan schemes of irrigation, navigation, flood control, river regulation and so on are favorable for coordinated development of river ecological environment and economic and social environment, plan schemes of soil erosion control, afforestation, riparian exploitation, and wastewater treatment and the like are mainly to improve aquatic environment and ecological environment, and the plan generally plays a certain role in environmental protection. But the implementation of hydropower plan may cause some negative ecological environmental impacts. Specific to the aforesaid environmental impact analysis, the following integrated measures should be taken according to the functional orientation requirements of upper, middle, and lower reaches of Magdalena River to mitigate the adverse environmental impacts from plan implementation.

10.5.1 Surface Water Environmental Protection

a) The unified management of water resources in the basin should be carried out step by step, the organization for water resources and aquatic environment in the basin should be established and refined, the laws and regulations on water resources and aquatic environment should be gradually refined and carefully enforced, the improvement and virtuous cycle of development should be ensured, and the sustainable economic and social development should be supported by the sustainable utilization of water resources.

b) The pollution sources in the basin should be controlled according to the principle of “overall plan, point source treatment, non-point source control and making the focal points stand out”. The main measures should be: 1) renovate and upgrade the existing wastewater treatment facilities and construct new wastewater treatment facilities to accelerate urban wastewater treatment; 2) perform comprehensive treatment for rural wastewater surrounding urban area by suiting to local conditions, advancing in due order and categorized guidance.; 3) take the measures such as adjustment of industrial structure and industrial layout and the development and promotion of water conservation and pollution reduction technologies to process industrial wastewater and achieve up-to-standard discharge .

c) According to the water quality, pollution load and management goal, and social development requirements of river reach in the plan, conduct monographic study to control the pollutant into river; strictly control construction of new high-pollution projects; delimit the water source conservation districts; monitor the water quality, the development of pollution sources and wastewater discharge around reservoirs; and strengthen the protection of water quality.

d) Ensuring Ecological Flow

Scientific reservoir operation scheduling mode should be developed. Via structural measures and management measures, the ecological water demand should be ensured. It is ensured that the control indicators should be reached for the control section of ecological flow arranged in the plan. The flow necessary for river ecological environmental health becomes available. The ecological water demand of important habitats including important wetlands downstream should be met. With respect to the planned construction projects, ecological discharge should be ensured. Sound structural measures and monitoring and other measures should be adopted in order that the negative impacts of cascade hydropower development on the ecological environment downstream of reservoirs and dams are within acceptable scope. Environmental restoration and improvement should be gradually carried out.

e) For reservoir subject to thermal stratification, multi-level water intake facilities should to be set to mitigate the adverse impacts of discharged low-temperature water on inhabitation and breeding of fishes.

f) The aquatic environment monitoring system should be gradually established and refined. The water quality monitoring plan for rivers and lakes in the basin should be made, construction of aquatic environment monitoring capability should be enhanced, and monitoring and management should be conducted for water quality in the basin.

10.5.2 Ecological Environmental Protection

a) Keeping Away from Environmental Sensitive Areas, and Protecting River Reach by District and Category

he principle of early intervention by EIA in plan should be practiced. The areas needing special protection such as important natural reserves, natural parks, reserved areas for aboriginal, archaeological sites, distribution areas of sensitive species of Colombia should be kept away from in construction scheme as far as possible.

The hydropower resources on the upper reaches of mainstream are rich. The hydropower resources development plan should be on the basis of river characteristics, resource environmental situation, and requirements of development and protection. According to the principle of limited and orderly development and sustainable utilization, the upper reaches of mainstream of Magdalena River is divided into three categories, i.e. hydropower resources development prohibited area, planned reserved area, and development and utilization area.

Specific to the riparian exploitation zone at middle and lower reaches of the mainstream, on the basis of the characteristics of middle and lower reaches of the mainstream, the situation of riparian resources, and the requirements of development and protection, the riparian zone of middle and lower reaches of the mainstream is divided into four categories, i.e. riparian protection area, reserved area, control and utilization area, development and utilization area according to the principle of scientific development and effective protection.

b) Terrestrial Ecosystem Protection

In implementation of the plan, the laws, regulations and policies on wildlife protection should be earnestly implemented, ecological protection publicity and education should be strengthened for plan project construction, management organization should be improved and staff should be specified, and ecological environmental monitoring management should be reinforced.

The various environmental sensitive areas where terrestrial organisms are objects of protection should be avoided in the plan scheme as far as possible.

The land, forest, population, etc. inundated due to the implementation of hydropower cascade plan should be reduced as far as possible in order that the lost land resources, vegetation and resettlement are controlled within the allowable environmental capacity.

Cultivated land should be occupied as little as possible or not occupied. The protection of farmland and cultivated land should be intensified, the area of land occupied for plan implementation should be reduced. Structural and plant measures should be taken to control land degradation likely to be caused by the plan such as land gleization and swamping.

c) Aquatic Ecological Protection

1) According to the characteristics of habitat diversity, key protected areas should be studied and established for sensitive areas including important wetlands and natural reserves. Sensitive areas should be avoided in plan scheme as far as possible according to law. Measure should be taken to protect local areas and the areas where objects of protection are affected.

2) Aquatic habitats should be protected and restored. Wetlands should be maintained and restored. Farmland and grazing land should be returned to nature for the wetlands encroached due to development activities so as to restore wetlands and waters. Soil erosion control in the basin should be speeded up and sediment accumulation in river courses and lakes should be reduced. The water system connectivity of rivers and lakes should be protected in the embankments, culverts and sluices, and dredging regulation works of flood control plan, navigation, and river regulation plans. Fish-passing facilities construction should be researched and demonstrated in the hydropower cascade development plan according to ecological habits of fish and project characteristics. The implementation of flood control, navigation, and river regulation plans would change the river regime, hydrological regime and process of scouring and silting, so aquatic habitat diversity maintenance and micro habitat restoration should be carried out. The construction of ecological slope protection should be combined for embankment and revetment works.

3) Aquatic biodiversity and fish resources should be protected. According to the impacts of plan scheme implementation on aquatic organisms and the degree of rarity and

endangerment of fish, objects of protection among fish should be determined. The system of closed fishing season and closure of fishing areas should be implemented. According to relevant provisions, management of fishery should be strengthened and fish resources should be protected. The breeding and releasing measures for fish should be taken to encounter hydropower plan cascade development. The object, quantity and scale of fish breeding and releasing should be determined. The plan layout of enhancement and releasing should be carried out to protect fish resources and conserve aquatic biodiversity.

4) The studies of the impacts of project implementation on wetlands should be strengthened, wetland resources should be practically and properly protected, and the relationship between wetland conservation and wetland development and utilization and between short term benefits and long term benefits should be correctly and properly handled.

10.5.3 Compensatory Measures

Ecological compensatory measures should be taken in plan implementation. Ecological compensation modes should be adopted according to *Guidelines for Biodiversity Loss Compensation* issued by the Ministry of Environment and Sustainable Development of Colombia in August 2012, and compensations should be made for biodiversity loss caused by project construction.

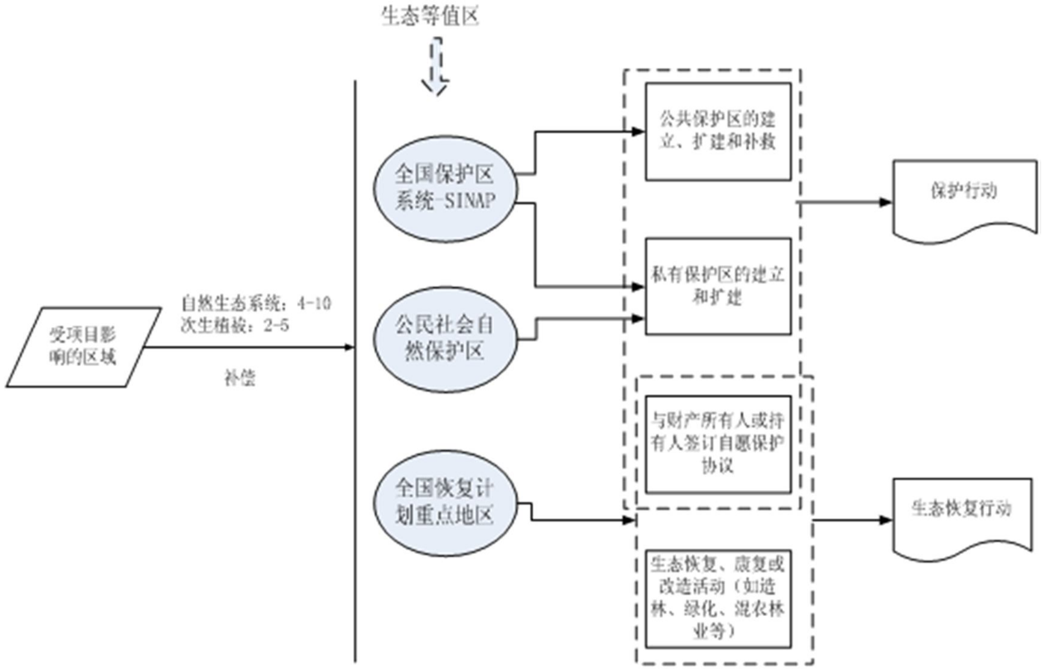


Table 10.5.3 Guidelines for Biodiversity Loss Compensation of Colombia

10.6 Conclusion

From the perspective of environmental protection, the major sectoral plan schemes regarding navigation, hydropower, irrigation, riparian exploitation, river regulation, environmental protection, flood control, fishery, and leisure and recreation. Are all reasonable and feasible,

Since adverse impact caused by the implementation of plans in navigation, irrigation, riparian exploitation, river regulation, flood control, fishery, and leisure and recreation on the environment is relatively minor, positive impact caused by the plan implementation on social environment is considered as the main one. Despite the positive impact caused by hydropower plan on economic and social development, certain adverse impact would also be caused on the ecological environment, i. e. impact of the three seasonal regulation reservoirs at upper reaches on water regime and blocking impact of the newly constructed dams of cascade hydropower stations on fish migrating channels. As a result, research on joint scheduling of reservoirs and impact mitigation measures such as establishment of fish-passing facilities are proposed in the plan. Besides, suggestions for adjusting the development sequence based on the main environmental impact of each cascade hydropower station are put forward. The adverse environmental impact can be reduced in a certain degree through the implementation of measures for mitigation of environmental impact and adjustment of development sequence as suggested in the environmental impact assessment. The environmental protection plan is conducive to mitigating the environmental impact brought about by implementation of each plan, and conducive to restoring and improving the environmental quality of the basin. The implementation of master plan scheme of Magdalena River could facilitate the management and protection of Magdalena River Basin, the optimized allocation, comprehensive conservation, effective protection and integrated utilization of the water resources in the basin, reduce the losses from disasters such as flood, waterlogging, drought and so on, improve the output of local farmland, carry forward the ecological agricultural construction, and increase the income of local farmers.

Overall, the master plan layout of Magdalena River is basically rational and the scheme is practical from the perspective of resource conservation, ecological environmental protection, coordinated development of the basin, etc. The implementation of the plan would vigorously promote the comprehensive, coordinated and sustainable development of economy, society and environment in the basin.

11 Implementation Opinions and Effect Analysis

11.1 Master Plan Framework

Based on the collected usable data and on-site survey data, overall considerations are given to resource potential, ecological environmental elements and sustainable economic and social development, the principle of “overall plan & coordination and comprehensive treatment & utilization” is followed, plan and layout of the system for integrated utilization of water resources, flood control and disaster reduction, and environmental protection, are performed in this master plan.

a) Multipurpose Utilization System of Water Resources

In order to support the coordinated and sustainable development of economy and society, the integrated service function of river water resources must be utilized to coordinate and properly handle the relationship among stakeholders, implement the principle of comprehensive utilization, combine beneficial use with disaster reduction, rationally arrange the layouts of navigation, power generation, water supply, irrigation, fishery, and leisure and recreation, and establish a sustainable comprehensive utilization system of water resources.

Navigation aims at establishing a smooth, efficient and safe water transport system and improving the integrated transport capacity. The long-term goal of navigation development of Magdalena River is that the whole river reaches below Neiva is navigable. Its medium-term (within plan period) goal is, via measures including waterway regulation, dredging and maintenance, to construct the national high-grade waterway including the 887km-long mainstream below Salgar and 114km-long Dique Canal, and to form a modernized land-water and river-sea water transport system with national high-grade waterway as framework and ports as links. The port layout plan is divided into 3 classes: Two coastal ports, Barranquilla and Cartagena, are of Class I; 4 regional central ports including Gamarra, Barrancabermeja (Galan), Berrio, and Salgar, are of Class II; and Calamar, Capulco, El Banco, Mompos, Maganque, Wilches, and Boyaca are of Class III. Inland water transport support system should be established. Ship type standardization within the basin should be actively carried forward and new ship types suitable for water transport on Magdalena River should be studied.

The hydroelectric power generation aims at propelling the rational development of hydropower resources in mainstream, increasing energy supply, and comprehensive utilization. After preliminary on-site survey and project plan and design, in order to reduce the impacts of reservoir inundation as far as possible, it is recommended in this plan that 17 cascade development scheme is adopted for the mainstream reach above Salgar,with a total installed capacity of 3300MW and a total annual energy output of 17,382 GWh. Except for the two hydropower plants existing or under construction, the planned 15 cascade hydropower plants have a total installed capacity of 2340 MW and a total annual energy output of 12980 GWh. Further environmental impact studies should be properly performed for the 4 cascade hydropower plants, i.e., Perícongo, Bateas, Basilias, and Piedras Negras, to coordinate the relationship between development and protection.

The irrigation aims at fully exploring the potential of water and soil resources and increasing grain yield. At present, the irrigation is mainly concentrated on the river valley area from Betania Reservoir at upper reaches to Honda and the plain area around Dique Canal at lower reaches. With fertile land, the upper reaches is the most advanced agricultural region in Colombia and has great potential in irrigation. On the basis of carrying out continued construction, supporting and reconstruction in existing irrigation areas, priority is given to develop new irrigation area in combination of hydropower cascade development in the area along upper reaches.

Fishery resources utilization mainly objectives at fishery economic development. Natural fish resources should be gradually restored, and output and benefits of capture fishery should be improved by standardizing activities in capture fishery and implementing fish resources protection measures. Fishermen should be guided and helped to rationally use natural waters and reservoir resources to develop aquaculture, increase output and scale of aquaculture, and reduce capture pressure of natural fish resources. Besides, a system for refrigeration, processing and marketing should be established for capture fishery, so as to adjust the seasonal supply and demand in market, and improve the added values of fish products.

Leisure and recreation mainly aims at meeting the amateur living needs of local residents and crowd in surrounding metropolises. The local hills, waters, rivers, riparian zones, lakes, swamps and wetlands, reservoirs, and animal and plant resources are rationally used. According to the unique characteristics of resources in each region, tourism resources are combined to gradually construct distinctive leisure and recreation facilities.

Riparian exploitation mainly aims at realizing the sustainable use of riparian resources to ensure flood control safety, stabilize river regime, and protect aquatic ecological environment.

River regulation mainly aims at controlling and improving river regime, stabilizing riparian zone, ensuring embankment safety, increasing flood discharge capacity, improving navigation conditions, and protecting ecological environment.

b) Flood Control and Disaster Reduction System

In order to guarantee the sustainable economic and social development, reduce casualties and property losses as far as possible, and maintain social stability, the flood and waterlog disaster prevention and control in the basin should be strengthened, the relationships between human beings and flood, between river and lake (wetland, swamp), between upper reach and lower reach, between mainstream and tributary, etc. should be coordinated and properly handled, the sound integrated flood control and disaster reduction system combining structural measures with non-structural measures should be established.

Flood control and disaster reduction aims at safeguarding the flood control. The current flood prevention measures in middle and lower reaches mainly rely on embankments and flood walls to carry out local protection for towns and agricultural area where flood threats are serious. The construction criteria are low and most inundated regions are flood plains without protection. The flood control criteria are proposed according to the characteristics of floods and flood disasters in Magdalena River Basin and the economic and social situation of flood-prone area, i.e. establishing an integrated flood control and disaster reduction system based on management of flood plains for middle and lower reach regions, carrying out key protection through embankments or flood walls, and combining flood storage and detention areas, river regulation, soil erosion control and non-structural measures, and tapping the potential of reservoirs built, being built or yet to be built on the mainstream and tributaries. Such measures as construction of embankments and bank protection,regulation of river course, flood regulation of reservoirs, prevention of soil erosion and non-structural measures should be taken for cities and towns, and important areas at upper reaches and hilly areas of tributaries that need protection. Non-structural measures should be adopted as main measures for prevention and control of mountain torrents.

Management of waterlogging area mainly aims at improving waterlogging drainage capacity. The plan concept such as improving the current drainage facilities (culverts and sluices, pump stations) and rennovating waterlogging areas, constructing drainage ditch system, improving irrigation and drainage system in irrigation district, and reserving natural lowlands for flood storage are proposed.

c) Environmental Protection System

In order to promote the coordinated development of human beings and nature, the normal ecological function of river must be maintained, and the relationship among management, exploitation and protection should be properly coordinated, gradually improving the water quality, restoring the damaged aquatic ecosystem, effectively controlling soil erosion, establishing a sound aquatic environment and aquatic ecological protection system, and ensuring the sustainable use of water resources..

Surface water environmental protection objectives the improvement of water quality and the maintenance of virtuous circle of aquatic environment, enhancing urban wastewater treatment and waste disposal, speeding up the pace of industrial wastewater treatment, strengthening the control over agricultural non-point pollution sources, reducing the total discharge of pollutants into river, ensuring the ecological flow, and realizing the sustainable use of water resources.

Aquatic ecological protection objectives the recovery of structural functions of aquatic ecosystem and the maintenance of biodiversity. Key protected areas including lakes, swamps and wetlands and fish spawning grounds should be established. The connectivity of river and lake water system should be recovered, fish way or artificial natural bypass should be constructed, and the operation scheduling mode of hydropower plants should be optimized. Necessary fish breeding and releasing stations should be set up at upper, middle and lower reaches, and the supervision of fishery resources should be strengthened.

The soil erosion control and afforestation aims at rationally utilizing and conserving water and soil resources, reducing soil erosion amount, and improving the coverage rate of forest and vegetation. The method of combining key improvement with prevention and protection should be adopted. The integrated management works against soil erosion including slope surface remediation, ditch prevention and control, closing hillsides to facilitate afforestation, adjusting industrial structure should be implemented in districts to restrain soil erosion. The afforestation plans such as commercial forest, protection forest against soil erosion, water conservation forest, protection forest for mainstream, and gallery forest should be implemented in districts and supervision and management should be strengthened to gradually increase the coverage rate of forest and vegetation.

The environmental monitoring aims at investigating and grasping the basic information of environmental changes in the basin. The monitoring networks for surface water quality, aquatic ecology and soil erosion should be established.

11.2 Opinions on Implementation of Projects in the Short Term

According to the overall plan objective and the master plan layout, specific to the principle contradiction and prominent problems in river management, exploitation and protection, the factors including the importance and urgency of demand should be considered to specify the comments on implementation of projects in the short term (structural and non-structural measures).

11.2.1 Multipurpose Utilization of Water Resources

a) Navigation

The Salgar to Barrancabermeja waterway improvement works should be implemented and the improvement effects should be monitored and evaluated.

The waterway below Barrancabermeja should be dredged and maintained.

Emphasis should be placed on construction of 6 class I and II ports including Barranquilla, Cartagena, Gamarra, Galan, Berrio and Salgar, and. the existing wharf facilities and equipment should be improved.

Part of class III ports with urgent demand of development and good construction conditions such as Calamar, Magangue, and El Banco should be constructed in a proper time. Emphasis should be placed on the improvement of passenger terminals and general cargo terminals.

A smooth, safe and efficient inland water transport support system should be basically established.

The process of ship type standardization within the basin should be actively promoted and the new ship types suitable for water transport in Magdalena River should be studied.

The studies of management of Dique Canal and improvement measures for waterway of Cauca River should be accelerated.

The overall layout plan for main ports should be formulated.

b) Hydropower Generation

According to the results of this preliminary survey and project plan and design, the hydropower plants Oporapa (220MW), Guarapo (140MW) El Manso (140MW) and Nariño (200MW) boast good construction conditions, low reservoir inundation, little adverse impacts on environment, relatively good economic indicators, proper scale, and good reservoir regulation property. So their preparatory work should be actively promoted and efforts should be made their earlier construction.

The river hydropower plan should be carried out as soon as possible to further find out the controlling factors such as reservoir inundation, sensitive ecological environment, and major geological issues and so on and determine the cascade development scheme.

c) Irrigation

Based on the implementation of general investigation of existing irrigation districts and plan for continued construction and supporting facilities, the continued construction, restoration and renovation of existing irrigation works should be promoted, and the two irrigation areas under construction should be accomplished.

The irrigation plan should be formulated as soon as possible. The development of potential irrigation districts with good land resources conditions, great yield-increasing potential, drought and water shortage, and low irrigation level should be prioritized.

d) Fishery Resources

The closed fishing season system should be implemented and the production mode of capture fishery should be regulated. The cage culture and recreational fishery demonstration base should be established at Betania Reservoir. The fish refrigeration and processing bases should be established at El Banco, Magangue, and Calamar.

The general investigation of fishery resources should be carried out as soon as possible and the fishery resources utilization plan should be formulated.

e) Leisure and Recreation

The construction of riverside scenic belt at the cities and towns in need of new construction or renovation of embankments in the short term and with economic strength should be prioritized with consideration of the needs of flood control, riparian protection, riparian exploitation and landscape and so on.

The general investigation of recreational resources should be carried out and the leisure and recreation plan should be formulated as soon as possible.

f) River Regulation and Riparian Exploitation

The river regulation plan should be formulated as soon as possible, establishing and improving the river course management mechanism, and defining the the scope of river course management. The basic research such as river sediment monitoring, river course evolution, river regulation and so on should be strengthened. Priority in the short term should be given to the research and implementation of revetment structural measures for river reaches with major impacts on flood control, navigation, regime control, soil erosion and so on. Research on and implementation of artificial curve cutoff projects for Tacamocho and Pinillos sections should be carried out as soon as possible

The riparian exploitation plan should be formulated as soon as possible, defining the scope of riparian zone. The system of laws and regulations on management and protection of riparian exploitation should be improved.

11.2.2 Flood Control and Disaster Mitigation

a) Structural measures

The new construction and renovation of embankments or flood walls and drainage ditch works in 17 cities and towns should be conducted as soon as possible and the waterlog control facilities should be improved. The occupied flood storage and detention areas should be recovered and the connectivity between rivers and lakes (swamps and wetlands) should be enhanced.

b) Non-structural Measures

The survey of baseline data on existing flood and waterlog control works and facilities, economic and social situation, reservoirs on mainstream and tributaries and flood plains and so on should be carried out as soon as possible. The standards for flood and waterlog control criteria should be studied and specified, the flood control and disaster reduction plan should be formulated, and a sound integrated flood control and disaster reduction system combining structural measures with non-structural measures should be established.

The feasibility of reservoirs undertaking task of flood control via change of operation mode should be studied to explore the flood control potential of reservoirs.

The flood control and disaster reduction system and mechanism should be refined, the flood plain management system should be studied and developed, the construction of hydrological data collection and transmission and early warning system should be strengthened, and an efficient and reliable flood control and disaster reduction command system with complete functions and advanced technologies should be gradually established. The flood risk map should be prepared and the publicity and education about flood control and disaster reduction should be strengthened.

11.2.3 Environmental Protection

a) Surface Water Environmental Protection

It is planned in the short term to newly construct 20 urban domestic wastewater treatment plants and renovate and extend 6 wastewater plants, with total treatment capacity up to 1.886 million m^3/d. It is planned in the short term to newly construct 20 urban domestic garbage disposal facilities, with a treatment capacity of 6003 t/d.

Priority is given to the construction of domestic wastewater and garbage treatment projects of 12 cities, namely, Neiva, Honda, Puerto Salgar, Girardot, La Dorada, Barrancabermeja, Puerto Berrío, Magangue, Mompos, Plato, El Banco, and Barranquilla.

b) Aquatic Ecological Protection

It is planned in the short term to set up 9 key aquatic ecological protected areas. The construction of fish way or artificial natural bypass is recommended when the hydropower cascade development of river reach below Neiva is performed. It is also planned to recover 2 blocked connection channels for rivers, lakes, marshes and wetlands, construct 3 new fish breeding and releasing stations, renovate and extend the projects of Cormagdalena including fish breeding and releasing stations..

c) Soil Erosion Control and Afforestation

In the short term, the integrated management works against soil erosion should be implemented; around 40% of the eroded soil area should be improved; and the construction of commercial forest, protection forest against soil erosion, water conservation forest, protection forest for mainstream and gallery forest should be conducted.

In the short term, priority should be given to the demonstration project for integrated management of small catchments in Morales City of Bolivar Department; the riparian protection forest in Magangue City of Bolivar Department; the coastline mangrove recovery works in Atlántico Department and Magdalena Department; the commercial plantations in Aipe City of Huila Department; and the energy renovation works in Ambalema City of Tolima Department.

d) Environmental Monitoring

The monitoring plan is to establish a water quality monitoring network and aquatic ecology and soil erosion monitoring system. Priority in the short term should be given to the establishment of 13 water quality monitoring sections, 13 aquatic ecology monitoring points, and 10 soil erosion monitoring points.

11.3 Analysis on Implementation Effects

The implementation of the master plan of Magdalena River would bring multipurpose benefits including navigation, hydropower, flood control and disaster reduction, irrigation, fishery resources, leisure and recreation into full play, improve and restore the ecological environment, and generate significant direct and indirect economic, social and ecological benefits.

11.3.1 Multipurpose Utilization of Water Resources

The implementation of navigation plan would substantially improve the capability and quality of waterway transport service, basically realize the effective communication between main inland cities (mineral energy areas) and coastal ports, direct the transport toward low-carbon waterway transport, reduce the transport cost, and boost the inland river transport market. It would play an important role especially in the transport of bulk goods such as coal, petroleum and petroleum products, cement, minerals, building materials, non-metallic ores in the area and in the transport of containers. The scale and economic benefits of waterway transport enterprises would also be significantly increased. The advantages of south-north waterway and water transport of Magdalena River would also promote the exploitation of mineral resources and development of leisure and tourism industries, improve the investment environment, attract the distribution of industries with large freight volume and high water consumption along the river, promote the formation of industrial belt along the river, develop main ports into regional comprehensive logistics center and important traffic junction, increase the local opportunity for taxation and employment, stimulate the development of other relevant industries and cities and towns along the river banks, and meanwhile provide opportunities for the development of poverty-stricken areas along the river banks.

With the implementation of hydropower plan, the total installed capacity of hydropower plants to be developed in the short term, i.e., Guarapo, Oporapa, El Manso, and Nariño, would be 700MW and their annual energy output would be 3,697 GWh, which would increase the energy supply, reduce the annual consumption of fossil fuels (almost 980,000 tons standard coal equivalent), and play a positive role in energy conservation and emission reduction. The access and transport and power supply conditions in areas surrounding hydropower plants would be improved and the local economic and social development would be promoted. In the long term, the development of superior ones selected from the remaining planned cascade hydropower plants would achieve the multipurpose benefits including power generation, navigation and irrigation.

The implementation of irrigation plan would improve the irrigation conditions of farmland in existing irrigation districts, raise the irrigation efficiency and productive force of cultivated land, and increase grain yield. If the 5 planned potential irrigation districts are implemented, the irrigation area would be increased by 16,400 ha.

The implementation of fishery resources plan would gradually recover the fish resources, form a sound production, supply and marketing system, and promote the development of fishery economy.

The implementation of leisure and recreation plan would increase the leisure and recreation places, improve the living environment in cities and towns,enrich the amateur life of local residents and people living in surrounding areas, and promote the local economic development.

The implementation of riparian exploitation and river regulation plan would control the adverse river regime of the river course at middle and lower reaches of mainstream of Magdalena River and Dique Canal, and be favorable for the stabilization of riparian zone and embankments and navigation improvement.

11.3.2 Flood Control and Disaster Mitigation

The implementation of flood control plan would form a relatively sound flood control and disaster reduction system in middle and lower reach regions, remarkably raise the overall capacity of flood control, reduce the disaster frequency, and substantially reduce flood losses including casualties and property loss in case of major floods. The accident of mass death and casualty would be avoided via preventive measures against disasters of mountain torrents.

The implementation of waterlog control plan would enhance the waterlog control capacity, reduce waterlog loss, improve and maintain the normal production and living environment.

11.3.3 Environmental Protection

The implementation of surface water environmental protection plan would effectively control the total discharge of pollutants into river, improve the water quality in the basin and the aquatic environmental quality, realize the sustainable use of water resources, and promote the economic development in the basin.

The implementation of aquatic ecological protection plan would restore the damaged aquatic ecosystem, improve the aquatic ecological environment in the basin, ensure the connectivity between river and lake (wetland), maintain the aquatic biodiversity and integrity of aquatic ecosystem, promote the harmonious development of human beings and nature, propel the virtuous circle of development of aquatic ecological environment, and safeguard the sustainable economic and social development.

The implementation of soil erosion control and afforestation plan would effectively prevent and control soil erosion, reduce the sediment load into rivers, lakes, wetlands and reservoirs, effectively conserve the land resources, and improve the coverage rate of vegetation.

11.4 Supporting Measures

a) Strengthening the Organization and Leadership, and Implementing Assignment of Responsibilities

Coordination mechanism should be established by relevant state departments, the river basin management authority, and local governments at all levels to specify the assignment of responsibilities for plan implementation, make detailed implementation plan according to the overall arrangement of the master plan, and strengthen the guidance, organization, coordination, and supervision of plan implementation, so as to make the master plan actually become the basis of river management, exploitation and protection actions and governance.

b) Refining the Management System, and Enhancing the Management of Plan Implementation

Under the guidance of master plan, the sectoral plans and special plans should be further formulated, the plan system should be gradually refined, the evaluation on plan implementation effects should be performed at proper time, the opinions on revision and adjustment of the plan should be put forward, and the master plan should be updated at proper time.

c) Improving the Public Participation Mechanism

The rights of the public and stakeholders to know, participate and monitor the master plan should be guaranteed.

d) Widely Opening Up Sources of Funds, and Ensuring Capital Investment

The government policies on investment in social welfare projects regarding water conservancy and ecological environment or multipurpose projects should be refined to give full play to the predominant role of government in such projects. Social capital investment should be widely attracted to form a multi-channel, multi-level, and diversified investment guarantee system. The system of paid use of water resources should be improved. Foreign capital should be attracted and utilized.

e) Properly Carry Out the Preliminary Works, and Increase Reserves of Potential Projects

The input in preliminary works of the planned projects should be increased to meet the requirements of plan implementation for reserves of potential projects.

12 Recommendations for Future Work

a) This plan should be timely refined and updated according to the changes in requirements of economic and social development and ecological environmental protection and so on. The management, exploitation and protection of Magdalena River is a long-term, arduous and complicated task. The basic information required by this plan is insufficient, the foundation laid by previous plan is poor, and only conceptual plan advices are put forward for some professional fields in which no previous plan was formulated. Therefore, the survey, collection, observation, monitoring and sorting of basic information should be strengthened in the future and the basic information should be supplemented in time according to the new circumstances and new issues emerging from the implementation of this plan. Besides, the scope of this plan is within the jurisdiction of Cormagdalena and has certain limitations. The master plan for the whole basin is recommended to be carried out at a proper time.

b) The plan system for the basin should be established, the governmental competent department for the plan should be defined, and the capital investment of government in the plan should be ensured. The sectoral plans or special plans regarding flood control and disaster reduction, hydropower, irrigation, river regulation and riparian exploitation, soil erosion control, fishery resources, and leisure and recreation should be gradually formulated. The master plans for important lakes, flood plains and tributaries should be deveoped at a proper time. The overall layout plan for main ports should be formulated in time.

c) Pushing Ahead with the Preliminary Works of Projects in the Short Term, and Propelling the Progress of Construction.

d) Strengthening the Monographic Studies of Major Strategic Issues of Management, Exploitation and Protection of the Basin

The Honda reach is an ideal geographic location with topographic and geological conditions for construction of large controlling reservoirs. This project boasts multipurpose benefits such as flood control, power generation, navigation, irrigation, and leisure and recreation, but also has the disadvantages of large inundation loss and considerable environmental impacts. Given that Honda reservoir project is of great significance for the economic and social development of the region, basin and state, the physical inundation indicators and environmental impact survey should be carried out urgently in the next step to further study and justify the rationale and feasibility of the Honda reservoir.

The basic research including flood risk management, river ecology management, and river course evolution law of Magdalena River should be strengthened. Research on flood and drought warning & forecasting technology, impact of climate change on flood control & water resources and corresponding coping technology, integrated soil erosion control technology, and water resources protection & aquatic ecosystem recovery technology should be strengthened. Besides, prototype observation for topography, hydrology and sediment should be performed, and corresponding coping measures should also be put forward.

Research on various systems related to integrated management of the basin and scheme design should be strengthened. Besides, institutional innovation should be conducted in combination with actual conditions in Colombia and in Magdalena River Basin to provide practical and feasible management means for the basin.

e) The recommended flood control standards for cities and countrysides in Colombia has been put forward in this plan. Due insufficient available data on flood control economy and flood loss in Colombia, some social environmental factors are difficulty to be quantified. Such recommended flood control standards are only for reference. Monographic studies at the next stage are suggested.

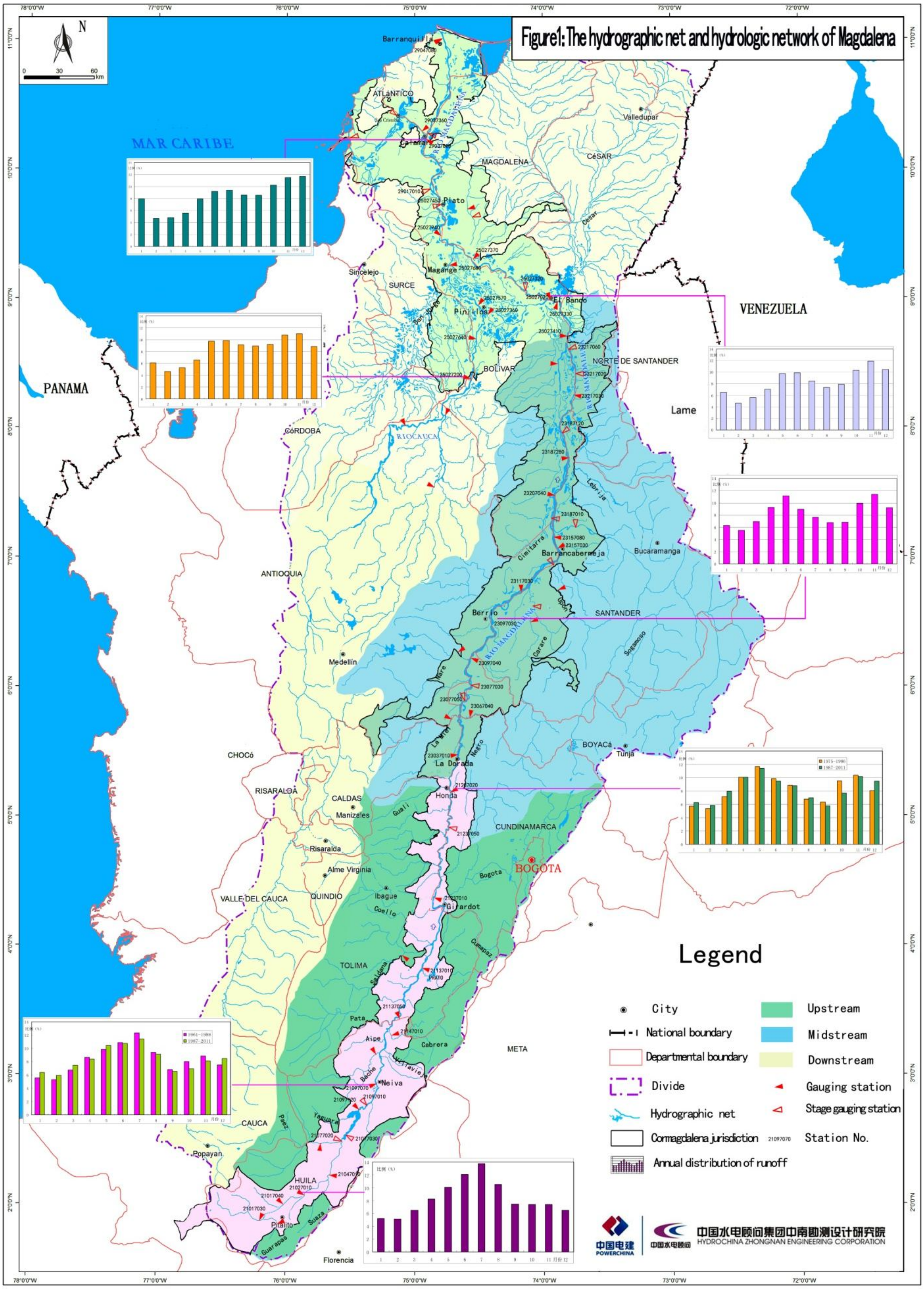
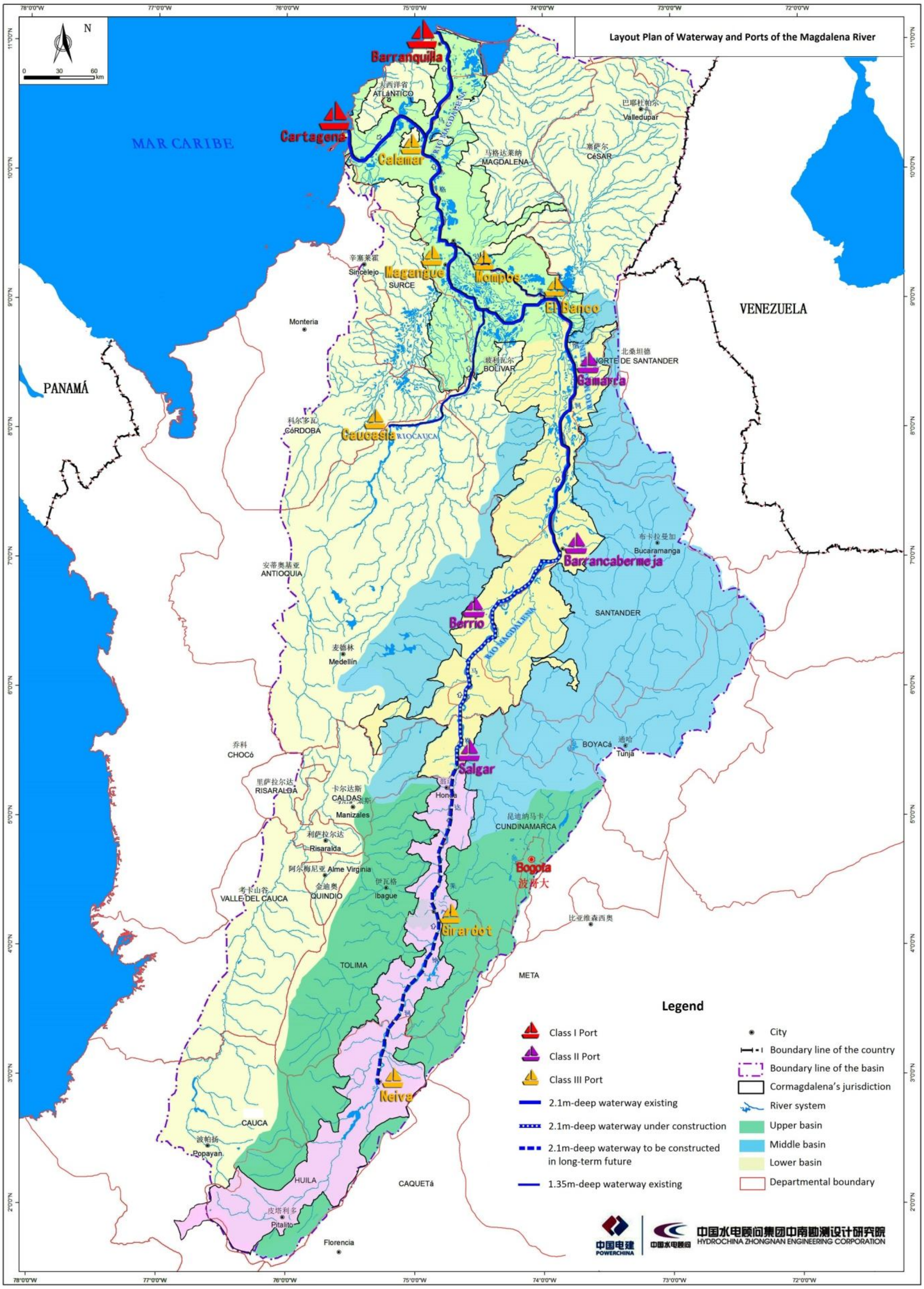
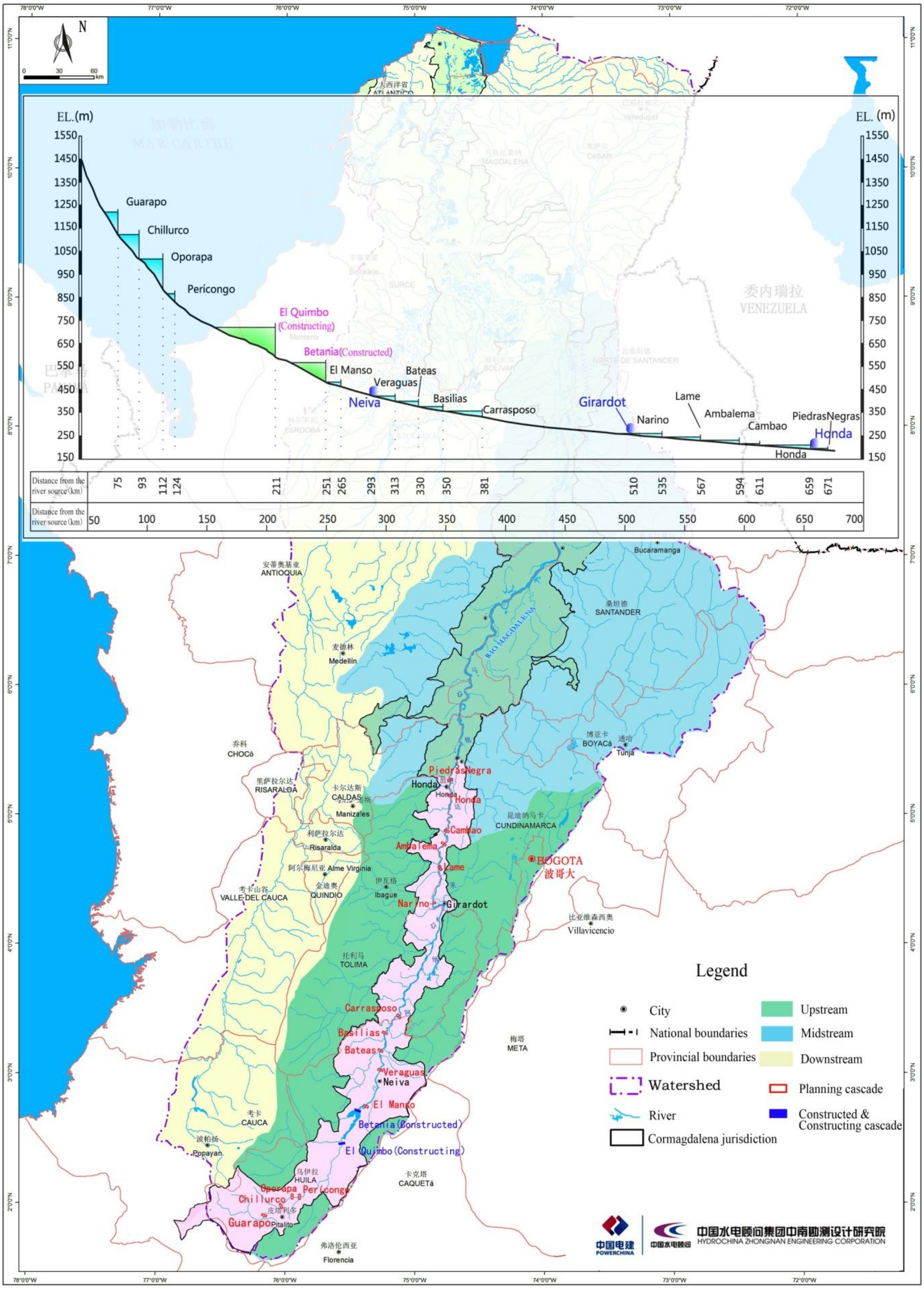


Figure1: The hydrographic net and hydrologic network of Magdalena
MAR CARIBE
PANAMA
VENEZUELA
Barranquilla
ATLANTICO
MAGDALENA
CéSAR
Valledupar
Plato
Magangé
Sincelejo
SURCE
El Banco
Pinillos
BOLIVAR
NORTE DE SANTANDER
Lame
CÓRDOBA
RIOCAUCA
Lebrija
Barrancabermeja
Bucaramanga
ANTIOQUIA
SANTANDER
Berrio
RIO MAGDALENA
Medellin
Sogamoso
BOYACá
Tunja
CHOCó
La Dorada
RISARALDA
CALDAS
Manizales
Honda
CUNDINAMARCA
BOGOTA
Risaralda
Alme Virginia
VALLE DEL CAUCA
QUINDIO
Ibague
Girardot
TOLIMA
META
Neiva
CAUCA
Popayan
HUILA
Pitalito
Florencia
Legend
City
National boundary
Departmental boundary
Divide
Hydrographic net
Cormagdalena jurisdiction
Annual distribution of runoff
Upstream
Midstream
Downstream
Gauging station
Stage gauging station
Station No.
1975-1986
1987-2011
1961-1986
1987-2011
中国电建 POWERCHINA
中国水电顾问集团中南勘测设计研究院
HYDROCHINA ZHONGNAN ENGINEERING CORPORATION


Layout Plan of Waterway and Ports of the Magdalena River
N
0 30 60 km
MAR CARIBE
VENEZUELA
PANAMÁ
Barranquilla
Cartagena
Calamar
Magangue
Mompos
El Banco
Gamarra
Caucasia
Barrancabermeja
Berrio
Salgar
Girardot
Neiva
Bogota
波哥大
Legend
Class I Port
Class II Port
Class III Port
2.1m-deep waterway existing
2.1m-deep waterway under construction
2.1m-deep waterway to be constructed in long-term future
1.35m-deep waterway existing
City
Boundary line of the country
Boundary line of the basin
Cormagdalena's jurisdiction
River system
Upper basin
Middle basin
Lower basin
Departmental boundary
中国电建
POWERCHINA
中国水电顾问集团中南勘测设计研究院
HYDROCHINA ZHONGNAN ENGINEERING CORPORATION

Map 3 The sketch map of planning cascade hydropower stations



Layout of Major Projects for Domestic Pollution Control in Cities