CHAPTER 1 INTRODUCTION

1.1 Outline of the Study

(1) Background to the Study

In Bogotá Plain, with a population of 7 million, the capital city of Columbia, Bogotá D.C., and its neighboring cities are located. The population in the plain is estimated to increase to 9 million in 2015 because of migration from local towns and rural areas as well as natural increase. Public water supply in the metropolitan area depends on surface water sources. Quantity and quality of the public water supply at present reach to sufficient level.

New stable water sources, however, will be necessary to correspond to future population increase and industrial development. Further, alternative water sources for emergency supply have to be urgently developed to avoid social disorder caused by breakdown of water supply facilities at times of natural and social disasters, and to survive during abnormal dry year (or El Niño). Water resources development using surface water will incur higher costs in facility construction as well as in operation and maintenance because the sources will be located in more remote areas due to limited availability of the surface water near the city.

Groundwater development in Bogotá Plain up to the present has been depending on aquifers in comparatively shallow the Quaternary Aquifers. The Groundwater in the Quaternary Aquifers have been fully exploited by now mainly for floriculture and manufacturing industry and further development would be very difficult, on one hand. On the other hand, the promising aquifer in comparatively deep, namely the Cretaceous Aquifer, has yet to be developed. Large interests in the potential of this aquifer are paid as long term and stable water sources.

Bogotá D.C though EAAB formulated a “Groundwater Investigation Plan” and started a study on the Assessment of hidrogeologic potential of deep aquifers in Bogota city in 1999. The results obtained so far are still limited due to insufficient data/information and technical capability. A groundwater development plan should be formulated after confirmation of the potential of deep aquifers for stable water supply.

Against the background described above, the Government of the Republic of Colombia requested to the Government of Japan to conduct a “Study on Sustainable Groundwater Development in Bogotá Plain” (herein after referred to as the “Study”). In response to the request, Japan International Cooperation Agency (hereinafter referred to as “JICA”) dispatched a preparatory study team, and a scope of work was agreed and signed between the authorities concerned of Colombia and the preparatory study team in July 2000. In accordance with the agreed scope of work, JICA dispatched a team for the Study (hereinafter referred to as the “Study Team”) in December 2000, and the Study actually commenced. After Phase-1 stage of the Study (December 2000 – March 2001) was completed, the result of the Study was already reported as a “Progress Report”. The result of the Phase I and II studies were described in a “Interim Report”. This “Final Report” presents the sequence of the whole study including Phase I, II and III.

(2) Objectives of the Study

The objectives of the Study, targeting the whole area of the Bogotá Plain, are as given below:

- To evaluate potential of groundwater in Bogotá Plain.
- To investigate the current situation of the environment related to groundwater
- To formulate a development plan of groundwater and
- To conduct technical transfer programs for counterpart personnel in the course of the Study.

(3) The Study Area

Targeted area of the Study is Bogotá Plain, where the capital city of Columbia, Bogotá D.C., and its neighboring cities of Cundinamarca department are located. According to GIS database prepared in the Study, the Study area is 4,268 km2 including 31 municipalities.

(4) Scope and Contents of the Study

The Study has been implemented over three (3) phases.

Phase-1: General Comprehension of Present Conditions

<12/2000 – 03/2001>

The Team conducted field reconnaissance & surveys and preliminary analysis in order to clarify the present conditions of the Study, and to get necessary data for groundwater potential evaluation using such methods as geophysical survey and exploratory drilling.

Phase-2: Study on Groundwater Potential

<05/2001 – 02/2002>

The Team conducted a preliminary evaluation of groundwater potential with data collected and measured in Phase-1 and Phase-2. Effective and efficient evaluation was pursued with more volume of and more precise data obtained using groundwater simulation and GIS (geographic information system).

Phase-3: Formulation of a Master Plan for Groundwater Development

< 05/2002 – 01/2003 >

Master Plan including well drilling plans, water supply plans and plan for operation & maintenance has been formulated for the Study Area, while groundwater potential being settled. The Team shall plan a sustainable projection in respects of construction funds and maintenance aspects, considering such conditions as financial situation, managing performance and financial procurement.

1.2 Summary of Study Result

(1) General Condition of the Study Area

<Socio-economic Conditions>

The Study Area consists of Bogotá D.C. and 30 municipalities of Cundinamarca Department. The socio-economic conditions of the Study Area are summarized as Table-1.1

Table-1.1 Socio-economic Conditions of the Study Area

Items		Conditions		
Area		: 4,268.7 km^2		
Population	:Year 2000	: 7.4 million		
GRDP	:Year 1999	Study Area	Col$37.6 trillion	: 25% of GDP
		Bogotá D.C.	Col$33.0 trillion	: 22% of GDP
		Cundinamarca D.	Col$ 7.5 trillion	: 5% of GDP
GRDP/Capita	:Year 1999	Study Area	Col$5,094 thousands	: US$2,890 (1.4 x GDP/capita)
		Bogotá D.C.	Col$5,261 thousands	: US$3,000 (1.4 x GDP/capita)
		Cundinamarca D.	Col$3,594 thousands	: US$2,050 (1.0 x GDP/capita)
Economic Sector		Agriculture	Crops	: Potatoes (75% of Cultivated Area)
			Livestock	: Pastureland (42% of the Study Area)
			Floriculture	: 5,800 ha（92% of the Country）
		Manufacturing	Bogotá D.C.	1) Textile/Garment, 2) Food/Beverage
			Cundinamarca D.	1) Food/Beverage、2) Ceramic/Glass

<Natural Conditions>

Geology and Topography: Altitude of the Study Area is, i) approximately 2,600m in Bogotá Plain, and ii) from 2,600 to 3,000 in the mountains and hills. Topographical classification of the Study Area is, i) Alluvial plain along the existing rives, ii) Diluviual plains, iii) gentle slopes in the foot of mountains formed by Colluvial deposit, and iv) the mountains and hills formed by Tertiary and Cretaceous. The geological classification of the Study Area is, i) Chipaque Formation - Guadalupe Group of Cretaceous, ii) Guaduas Formation - Chaco Formation - Bogota Formation - Regadera Formation - Usme Formation of Tertiary, and iii) Tilata Formation -Sabana Formation - Terraze Formation - Alluvium of Quaternary. Geological structure of the Study Area is complicated with the folding and Faults.

Meteorology: Annual average rainfall of the Study Area is 600mm to 1,300mm. Precipitation is higher in the mountains and hills, and lower in plains. The peak of the monthly precipitation is seen in May and November. In the Study area, i) the average annual temperature is from 10℃ to 14℃, ii) the average annual humidity is from 70% to 80%, iii) the average annual pan-evaporation is 800mm～1,200mm, iv) the average annual solar radiation is from 115cal/cm^2/day to 140cal/cm^2/day, v) the average annual sunshine hour is from 3.5 hours/day to 5 hours/day, and vi) the average annual wind speed is from 1.8m/s to 4.2m/s.

Hydrogeology: The main river of the Study Area is Bogotá River. River discharge of Bogotá River at the lowest reach on the Study Area is 31m^3/s. The Study Area was divided to 20 sub-basins in this Study in order to analyze more detailed meteorological and hydrological characteristics. The seasonal fluctuation of river discharge corresponds to the seasonal fluctuation of precipitation. The total amount of 12m^3/s of water is conveyed to the Study Area from Chingaza Dam. This water conveyance is from river basin out of the Study Area. On the other hand, a considerable amount of water is being taken from main and tributaries of Bogotá River for water supply and agricultural use.

<Water Resources Management>

Decree No. 2811 of 1974 is the fundamental law on renewable natural resources and environment protection. Decree No. 1541 of 1978 provides stipulation on non-marine water use. Law No. 99 of 1993 defines public administration for renewable natural resources and environment protection and duties of the relevant organizations. Major roles for water resources management are discharged by Regional Autonomous Corporation of Cundinamarca (CAR) and Administrative Technical Department of Environment (DAMA) of Bogotá D.C. is carious the duties in the urban zone. Problems identified after the discussion

are i) Concessions granted are not consistent, ii) Evaluation of the resource availability is not reliable, iii) Institutional capacity is not enough for the management, and iv) There is no coordination among environmental authorities.

(2) Investigation and Analysis

<Land Use Analysis with Satellite Images>

The land use conditions were mapped from analysis with Land sat 7 images. Also, to get a information about land use conditions in 20 basins divided by the Study Team, land use areas were calculated by these basins. Land use conditions in Bogotá Plain (the study area) were; forest (198.44 km^2 or 4.6%), grass (1,694.82 km^2 or 39.7%), cultivated land (1,717.23 km^2 or 40.2%), bare land (245.94 km^2 or 5.8%), water (39.61 km^2 or 0.9%), residential area (300.16 km^2 or 7.0%) and greenhouse (71.49 km^2 or 1.7%).

<Environmental Field Survey>

Bogota River: Bogota River is utilized in various activities such as water supply, agriculture and industry. However, the river water quality has been deteriorating particularly in urban areas. It is suggested to increase the volume of river water and improve natural purification process.

Wetland: There is approximately 1,500 ha of wetland in Bogota Plain and many valuable species live in the waterfront. However, the water quality has been depreciating in the recent years. It is expected to implement positive conservation measures.

Land Subsidence: Land Subsidence occurs in the plain, but there is no evidence discovered that the phenomenon associates with pumping -up of groundwater at the moment. However, no long-term observation of subsidence has been conducted and its implementation is expected.

<Geophysical Survey>

CSAMT exploration was carried out for geophysical survey of the Study. The purpose of the survey is to know the depth of distribution of the Guadalupe Group. According to the CSAMT exploration, the Guadalupe Group distributes deeper than GL-1,000m or GL-1,200 towards the center and west part of Bogota Plain. The depth the distribution becomes smaller toward the border of the Bogotá Plain. This result corresponds to the existing results of studies on the depth of the Guadalupe Group. On the other hand, in the east and and the north part of the Study Area, the Guadalupe Group distributes less deep than GL-300m in the plain.

<Exploratory Drilling>

In this Study, six Quaternary Exploration wells and four Cretaceous exploration wells were drilled. Automatic groundwater level recorders were installed to these wells. The recorders are currently observing the groundwater level continuously.

Quaternary Exploration Wells: Quaternary exploration wells were drilled in the areas where the representative Quaternary distributes. According to the exploration result, Quaternary aquifer mainly consists of clay and silt layers, and several sand layers separately distribute at different depth within clay and silt layers. These sand layers form aquifers of Quaternary. Hydraulic parameters of Quaternary aquifer at the drilling points were analyzed from the pumping test result. Yield of around 500m^3/day per one well is available from the exploratory wells. This proves that Quaternary is excellent aquifer. In the Study Area, about 78% of the groundwater is pumped up from Quaternary aquifer.

Cretaceous Exploratory Well: Four of the Cretaceous exploratory wells were drilled in Eastern Hills. Hydrogeological characteristics and hydraulic parameters of Cretaceous aquifer

in Easter Hills were analyzed. Yield of the three wells is more than 3,000m^3/day per well, which proved that Cretaceous aquifer of Eastern Hills is extremely excellent. In the past, there was not long well of Cretaceous aquifer in Eastern Hills, therefore, hydrogeological information from the four wells is also valuable.

<Groundwater Level Observation>

Groundwater level observation was carried out by two methods, i) simultaneous groundwater level observation and ii) continuous groundwater level observation by automatic recorders. The simultaneous groundwater level observation was carried out in Phase-I to Phase-III of this Study, which give information of groundwater level at different seasons (dry or wet). Based on all the observation results by the Study Team and Colombian side, groundwater level counter-line was drawn for Quaternary and Cretaceous aquifers covering all the Study Area. On the other hand, the Study Team carried out groundwater level observation by automatic recorders to know seasonal fluctuation of groundwater level. This result shows that groundwater level of Bogotá Plain, which is said to be lowering, is already constant.

<Water Quality test for Well>

Water quality test for 6 analytical areas (*e.g*. pesticides) was conducted at approximately 100 wells, which covers the whole Study Area in each phase. The result reveals groundwater contains high concentration of iron, manganese, ammonia, hydrogen sulfide, barium and total *E. Coli* in the wide area. It is hypothesis iron, manganese, ammonia and hydrogen sulfide originates from the geological condition. On the other hand, there is no sign of agricultural and industrial contamination. Geochemical analysis shows that groundwater moves from the edge of the Study Area toward the center. This result matches with the consequence of groundwater simulation.

<Isotopic Analysis>

The age of the groundwater is in the range of 1,700 and 33,000 years. Although it may be younger than expected, there is no water younger than 40 years found. Duterium and oxygen-18 analysis indicates the groundwater originates in precipitation.

<Well Inventory>

Well Inventory Survey was carried out for all the wells in the Study Area. The Study Team collected well data from CAR, DAMA, INGEOMINAS, and these data were compiled and analyzed to obtain characteristics of wells of the Study Area. According to the results of the Well Inventory Survey, it was estimated that the total number of wells of the Study Area is approximately 7,081, and the total yield from the wells is 320,000m^3/day (3.7m^3/s). 78% of the total yield is pumped up from Quaternary aquifer and only 19 % from Cretaceous aquifer. Most of the groundwater from Quaternary aquifer is pumped up in the central and the western part of Bogotá Plain, and a considerable amount of pumped water is used for agriculture and flower production. From this result, it is confirmed that in the Study Area, the current groundwater development has concentrated only in Quaternary aquifer. To the contrary, Cretaceous aquifer has not yet been fully developed so far comparing its high production capacity.

<Meteorological Observation>

The Study Team installed 11 meteorological observation stations in the Study area to strengthen the existing meteorological network. 11 sites are located mainly in the mountains and hills where meteorological data was not enough in the past. The installed 11 stations were involved into the existing network of meteorological observation, and are contributing to the meteorological observation by providing precious information of the mountains and hills of

the Study Area.

(3) Pilot Study

The Study Team carried out Pilot Study for artificial recharge in the Vitelma site that is located in Eastern Hills of the Study Area. Surplus river water can be injected into the aquifer through the artificial recharge well, and the stored groundwater in the aquifer can be pumped up when groundwater is necessary. The artificial recharge has the purpose as mentioned above. The Pilot Study in the Vitelma site was carried out to estimate the amount of water that can be injected into Cretaceous aquifer at that point. From the result of the Pilot Study, it is concluded that Cretaceous aquifer in Eastern Hills has higher capacity of water injection than the pumping capacity.

<Preparation of GIS Database>

The Study Team has prepared GIS database aiming at supporting the survey activities of the Study Team, and managing the related data under the control of one institution. Until now, respective organizations in Colombia have been managing their data themselves and never shared it with other organizations. Once GIS preparation has been completed, and then respective organizations can use the data freely. Besides, the visualization of digital data with GIS makes the database more useful. On the other hand, GIS supported the survey activities of the Study Team. GIS was used and much helpful in a lot of fields, management, analysis and visualization of the data collected by the Study Team and as a tool for many analysis works such as groundwater simulation, water balance calculation and meteorology analysis.

(4) Evaluation of Groundwater Potential

<Hydrogeological Analysis>

The Study Team made geological sections covering the most of Cundinamarca Department, for the purpose of implementation of groundwater simulation. Based on these geological sections, three-dimensional aquifer model was formulated covering the most of Cundinamarca Department. In addition, the Study Team made more detailed geological sections of the Study Area. Based on these geological sections, three-dimensional aquifer model was formulated for the Study Area. Aquifer parameters were analyzed from the result of the existing pumping test data. The Study Team examined the mechanism of the groundwater recharge and the groundwater flow. The mechanism is assumed: “rainfall of the Study Area”→ “rainfall infiltration to soil” → ”vertical infiltration to deep aquifer” → ”groundwater flow in aquifer” →”groundwater flow-out from the Study Area”.

<Water Balance and Groundwater Recharge>

The Study Team carried out water balance analysis. Based on this result, groundwater recharge was estimated. Water balance analysis was carried out for all the basins of the Study Area. In this analysis, precipitation, river discharge, real evapo-transpiration and soil moisture were calculated, and groundwater recharge was estimated from the balance of above items. For the estimation of real evapo-transpiration, a water balance simulation was carried out using soil model. From this result, real evapo-transpiration was expressed as function of precipitation, soil moisture and potential evapo-transpiration. From the result of water balance analysis, the average groundwater recharge of the Study Area was calculated 144mm/year ($19.5m^3/s$).

<Groundwater Simulation>

The Study Team carried out two types of Groundwater simulation, i) groundwater simulation of the large area and ii) groundwater simulation of the Study Area.

Groundwater Simulation of Large Area: The Study Team made simulation model covering the most of Cundinamarca Area and carried out groundwater simulation to examine the condition of the groundwater-flow of the large area. In the formulation of the model, three-dimensional geological model was made and estimated groundwater recharge was given to the model. Based on the result of the simulation, it was concluded that the groundwater of the Study Area is connected to the groundwater out of the Study Area. Moreover, the groundwater of the Study Area is involved in the groundwater-flow system that originates in the Study Area and extends to the southwest direction to Magdalena River.

Groundwater Simulation of the Study Area: The Study Team carried out groundwater simulation of the Study Area. Three-dimensional geological model was made and aquifer parameters were given to this model. Then boundary condition was given to the model based on the result of the large area groundwater simulation, and the current distribution of pumping wells and yields were given to the model. Moreover, the estimated groundwater recharge of 144mm/year, which was calculated by water balance analysis, was given to the model. Then the current groundwater level of the Study Area was simulated to judge the accuracy of the estimated groundwater recharge. According to the result of the simulation, it was concluded that the estimated groundwater recharge of 144mm/year is reasonable.

<Groundwater Development Potential>

The result of the Study showed that the groundwater development potential of the Study Area is 144mm/year (19.5m^3/s). In the past, it was said that the groundwater of the Study Area was not flowing. However, from this Study, it was confirmed that the groundwater resource of the Study Area is renewable and receives water-recharge from precipitation. Therefore, the estimated groundwater recharge of 144mm/year can be called as the maximum sustainable groundwater development potential of the Study Area. However, if 100% of groundwater recharge is developed, considerable lowering of groundwater level will occur and it will affect the existing wells. The current rate of groundwater-use (groundwater-use ÷ groundwater recharge) by basin has highest value of 65% (in Chicu Basin). Considering current situation of groundwater level, it can be said that lowering of current groundwater level is allowable. Therefore, it is proposed that safe yield should be less than 60% of groundwater recharge, which corresponds to highest rate of current groundwater use.

(5) Groundwater Development, Conservation and Management Plan

< Basic Policy of the Plan>

Optimum groundwater development corresponding to safe yield

In new groundwater development plan, production well should be designed considering safe yield (60% of groundwater recharge) of the basin of which groundwater level will be affected by this groundwater development. Amount of groundwater by new development should be less than remaining safe yield (= safe yield – current pumping rate) by basin. Groundwater development of small/medium-scale, which will cause only small influence, should be planed considering remaining safe yield by basin. Groundwater development of large-scale, which will cause large influence to several basins, should be planed considering total of remaining safe yield of these basins.

* **Quaternary:** Quaternary aquifer is classified into two areas, i) area where groundwater has been already developed fully, and ii) area with little current development. In the area of fully developed, new groundwater development should be subject to restriction, and groundwater conservation is necessary to continue the current groundwater use. On the other hand, in area with little current groundwater development, groundwater development should be promoted from now on depending on its water demand.

* **Tertiary:** Only little water can be pumped up from wells of Tertiary aquifer. Small-scale groundwater development is possible in the future in Tertiary aquifer as well as now.
* **Cretaceous:** Cretaceous System of the Study Area distributes in mountains/hills and deep part of ground in entire Bogotá Plain. This Cretaceous system has high capacity of groundwater production. However, only little groundwater of Cretaceous has been developed in every basin of the Study Area so far. It is concluded that Cretaceous aquifer is most promising in new groundwater development. However, groundwater development of deep Cretaceous aquifer will cost high and has considerable risks. On the other hand, groundwater development of Cretaceous aquifer that distributes in mountains/hills has little risks and has high possibility. Consequently, new groundwater development of Cretaceous aquifer should be implemented in mountains/hills of Bogotá Plain depending on water demand. As Cretaceous aquifer distributes entire Study Area and has high production capacity, this aquifer is suitable for large-scale groundwater development. Moreover, Cretaceous aquifer extends beyond river basins, and groundwater sometimes can be developed more than safe yield of basin where groundwater development sites locate.

Basic policy of groundwater development by basin

* **Area of high groundwater utilization (rate of current groundwater use is more than 40%):** In this area, new groundwater development should be subject to restriction. Moreover, groundwater conservation is necessary to continue current groundwater use.
* **Area of medium groundwater utilization (rate of current groundwater use is 20-40%):** There is groundwater development potential still remaining in this area. However, careful planning for new groundwater development is necessary based on remaining safe yield. At the same time, groundwater conservation plan should be formulated.
* **Area of low groundwater utilization (rate of current groundwater use is less than 20%):** In this area, the amount of current pumping is much less than safe yield. Groundwater development should be strongly promoted depending on water demand of this area.

Basic Policy of Groundwater Conservation Plan

Groundwater conservation plan is proposed for each area as shown below.

*Area where rate of groundwater use is medium to high.

*Area where large-scale groundwater development is planed

* **Area where Rate of Groundwater Use is Medium to High:** Central and western part of Bogotá Plain is classified into this area. Agricultural production is high and rate of groundwater use is also high in this area. Groundwater conservation is necessary to continue the current groundwater use. Method of conservation is proposed as follows.
  - **Groundwater artificial recharge:** Groundwater artificial recharge is proposed to compensate groundwater storage of Quaternary aquifer that was consumed by pumping. Surplus river water of tributaries of up-stream in the central and western Bogotá Plain will be stored in settling ponds. This water will be injected into Quaternary aquifer though recharge wells. This artificial recharge will contribute to stabilization of water supply for agriculture use in Bogotá Plain.

- **Lightening of burden in water use from groundwater:** In order to lighten the burden in water use from groundwater, countermeasures below should be promoted: Use of alternative water resource for flower culture production (reuse of drained water, use of rainfall and river water of Bogotá main River), change of sites for new flower production, promotion of study on improvement of irrigation efficiency.

* **Area where Large-scale Groundwater Development is planed:** Groundwater recharge to Cretaceous aquifer by rainfall is limited, though Cretaceous aquifer has high productivity. Consequently, in large-scale groundwater development, artificial recharge using surplus river water should be implemented in order to minimize influence by development.

< Demand Forecast of Groundwater>

Water Supply System of EAAB

Actual water supply and production capacity of EAAB in 2001 was 14.6m^3/second that equaled to 56 % of year 2001 production capacity (This has enlarged to 26.3m^3/second in 2001 due to newly established El Dorado Plant). The water supply volume has been declining due to consumption decrease caused by such as 1) a sharp rise of tariff, 2) a reduction of water transfer pressure, 3) a campaign of saving water and 4) a nationwide economic slowdown.

The production capacity was judged enough until year 2015 for the highest demand of the projection. EAAB currently may hold sufficient supply capacity against actual and future demand until 2015. Nevertheless, EAAB relies almost half of the production capacity on Wiesner Plant, water resources of which are located at a distant place. Consequently, the Plant is regarded vulnerable against disasters. So, it is widely concerned to develop and keep safe and reliable water against them as well as emergencies such as droughts that may occur to the Bogotá River and other rivers, also valuable water resources for EAAB.

Groundwater Demand of the Study Area

Groundwater is used; for domestic use in 12 municipalities (39% of all municipalities), for non-domestic use in 18 municipalities (58%), for flower irrigation in 24 municipalities (77%) and for agriculture irrigation in 20 municipalities (71%). It is assumed that irrigation use would be the most predominant in the Study Area. The 3 largest groundwater demand areas by river basin are: 1) Subachoque River Basin (2), 2) Chicu River Basin, and 3) Bogotá River Basin (3) – West. Groundwater demand is estimated at 403,000 m^3/day (4.65m^3/s) in target year of 2015, based on the current trend of groundwater use..

Water Demand in the Development and Conservation Plan Area

* **Groundwater Development and Conservation Plan for Eastern Hills:** Development area consists of 2 areas; Eastern Hills of Bogotá City and Northern Part of Eastern Hills. Eastern Hills of Bogotá City consists of 3 areas; 1) Bogotá City eastern hills, 2) Suba hills and 3) Soacha hills. Population of the Area is estimated to reach 750,000persons in 2015 or 7% of the total population of Bogotá D.C. and Soacha. Groundwater demand in the Eastern Hills of Bogotá City is estimated at 1.145m3 in 2015. On the other hand groundwater development amount in the Northern part of Eastern Hills is planed at 1m3/second. The development volume will benefit to 750,000 persons. Thus the total water demand of 2 areas is estimated at 2.611 m3/second in 2015.

* **Groundwater Water Resource Conservation Plan for Central of Bogotá Plain:** The conservation plan in Central Area of Bogotá Plain contains 6 river basins. In the Area the irrigation use for such as flower and agriculture is overwhelming for groundwater demand, which is estimated at 2.611 m3/second in 2015.

<Groundwater development and conservation plan>

Groundwater Development and Conservation Project in Eastern Hills of Bogotá Plain (Eastern Project)

* **Project Area:** Areas of this project are located in Eastern Hills that includes Soacha area, Vitelam area, San Diego area, Santa Ana & Chico area, Cerros Norte area, Yerba Buena and Suba area.
* **Purpose of project:** This project is public works of environmental improvement with purpose of water supply and improvement of water environment.
  - **Water supplu for Bogota City:** To ensure stable water supply for Bogota City, groundwater of 2m3/s (for usual case: all year) and 4m3/s (for emergency: during 6 months, once/15 years) will be developed in proposed project.
  - **Improvement of water environment:** New groundwater development for water supply will decrease water-intake at Tibitoc treatment plant. This decreased water-intake increase net discharge of Bogotá River and will contribute to improvement of water quality of Bogotá River. Increased discharge of Bogota River i) will increase dissolved oxygen and contribute improvement of water quality in the down-stream of Tibitoc purification plan, and ii) will contribute to increase of hydroelectric generation of power station (Current operation of 20m3/s for all year) that is located at down most of Bogota Plain.
* **Content of Project:** Productions wells are designed to achieve propose of project considering groundwater potential and design water demand. Moreover, artificial recharge wells are designed for conservation of groundwater of this area. In this area, total amount of 0.5m3/s can be used for artificial recharge, which is currently taken by Vitelma purification plant in San Cristibal River and San Diego plant of San Francisco River. This water will become surplus water for artificial recharge, because both plants have been decided to be out of use. However, in case of emergency, recharge wells will be used for production wells.

Table-1.2 Well Plan of Eastern project

Area	Aquifer	Well size	Well number	Maximum Capacity (m3/s)
Cerros Norte, Santana/Chico, Suba area. New wells will be drilled next to existing tank for water supply	Cretaceous	Well length: 300m Well diameter 10 inch Yield: 3,000m3/day/well Injection: 3,000m3/day/well	12	0.42
Soacha area. New wells will be drilled next to existing tank for water supply.			8	0.28
Vitelma and San Diego area.			Production wells: 13 Recharge wells: 13	0.45
Hills of Yerba Buena area, north of Bogotá City.			30	1.04
Total			Production wells: 63 Recharge wells: 13	<Production> Usual: 2.19 Emergency: 4.00 <Recharge> Usual: 0.45

* **Beneficiaries of Project:** Population of direct beneficiaries by water supply of this project is 1.3 million. Population of beneficiaries by water supply in case of emergency is more than 7.7 million that is the same as all supplied population by EAAB.

Groundwater Conservation Plan of Area of High Groundwater Use in Bogota Plain (Western Project)

* **Project Area:** Area of this project is Subachoque River Basin, Chicu River Bsin, Frio River Basin and area along middle reach to down-stream of Bogota River, where groundwater is highly used. These areas are in western and center of Bogota Plain, where groundwater is pumped up from Quaternary aquifer by more than 6,000 wells. In recent year, over-pumping is pointed out in these areas.
* **Purpose of Project:** This project is public works for environment with purpose of improvement of water quality as explained below:
  - **Groundwater recharge:** Purpose of this project is 1) sustainable groundwater use without any trouble, 2) accumulation of groundwater potential for additional groundwater use in area where groundwater is highly used for irrigation and flower production.
  - **Lightening of burden from groundwater in water use:** In order to lighten the burden from groundwater in area where groundwater is highly used, research and development of technology should be implemented until practical level. This study should include 1) utilization of alternative water resource for irrigation and flower production 2) improvement of efficiency for irrigation.
* **Content of project:** In order to achieve purpose of project, two sub-projects should be implemented. Namely, 1) groundwater recharge project and 2) research and development of technology for groundwater use.
  - **Groundwater recharge project:** Artificial recharge should be implemented in up-stream of area where pumping wells distribute. Water resource for artificial recharge

is river water of torrent in up-stream of Subachoque, Chicu and Frio River basins. In these areas, river water is highly used. Therefore, surplus water in flood in rainy season should be used for artificial recharge.

Table-1.3 Well Plan of Western Project

Area	Aquifer	Well size	Number of recharge well	Maximum recharge capacity
Subachoque Basin	Quaternary	Well length; 300m Well diameter; 10 inch Injection rate ; 1,500m3/day/well/2 sites	8 wells in 4 sites	0.14
Chicu Basin			10 wells in 5 sites	0.18
Up-stream of Frio Basin			10 wells in 5 sites	0.18
Total			28 wells in 14 sites	0.50

- **Research and development of technology for groundwater use:** Technology for sustainable groundwater use should be researched and developed to lighten the burden of groundwater use in the project area.
  - Reuse of drained water of irrigation
  - Increase in the actual use of rainfall for irrigation
  - Use of water of Bogota River for irrigation
  - Change of sites for new flower production
  - Improvement of irrigation efficiency

*** Beneficiaries of Project:** Population of beneficiaries of this project reaches 200 thousand that belongs to agricultural sector.

<Monitoring Plan>

Groundwater monitoring is necessary for Groundwater conservation. Monitoring item should be groundwater level, yield of well and groundwater quality. Monitoring plan is summarized in Table-1.4. Monitoring wells should be selected following items below.

Table-1.4 Monitoring Plan

Item	Number of monitoring	Frequency of observation	Observation site	Purpose of Monitoring	Organization in charge
Groundwater level	12	Automatic recorder	Quaternary wells	- Long-term groundwater level fluctuation of Bogotá plain. - Result of artificial recharge in Bogotá Plain	EAAB
	10	Automatic recorder	Cretaceous wells	- Influence by groundwater development in Eastern Hills - Effect of artificial recharge in Eastern Hills	EAAB
	About 300	4 times/year	CAR monitoring wells	- Influence by artificial recharge in Bogotá plain - Groundwater level of Bogotá	CAR
	280	Once/month	Wells registered to DAMA	- Influence by groundwater development in Eastern Hills	DAMA
Yield	About 300	4 times/year	CAR monitoring wells	- Yield	CAR
	About 280	Once/month	Well registered to DAMA	- Yield	DAMA
Water quality	20	Twice/year	Sampling sites from 100 of JICA water quality analysis.	- Change of Water quality in Bogotá Plain	CAR
	10	Twice/year	-Wells near artificial recharge wells in Eastern Hills -Wells near artificial recharge wells in Bogotá Plain	- Change of water quality by artificial recharge	DAMA EAAB
Land Subsidence	12	Twice/year	12 Quaternary wells with JICA automatic recorders	-Land subsidence by lowering of groundwater level	CAR DAMA

<Institution and Operation/Maintenance>

<u><Water Resources and Groundwater Management></u>

* **Establishment of Joint Commission for Water Basin Management and Technical Commission for Groundwater Management:** Establishment of a Joint Commission is required, as defined in Law 1604 of 2002. Establishment of a Technical Commission under and to support to Joint Commission is recommendable. The Technical Commission will be in charge of the followings:
  - To integrate monitoring (volume of abstracted water, water level and quality) activities e and valuation on groundwater potential and availability
  - To collect, analyze information on and to estimate the present and future demands for groundwater
  - To make drafts of technical standards/guidelines for groundwater management

- To make investigations and recommendations on measures for groundwater protection, conservation and development

Members of the Technical Commission would be representatives or staff specialized for hydrogeology of i) CAR, ii) DAMA, as well as, national institutes such as iii) IDEAM, iv) INGEOMINAS, v) Major Users (EAAB, ASOCOLFLORES), vi) Colombian Association of Hydrogeologists, as well as vii) drilling companies.

* **Operation for Monitoring and Evaluation:** Measurement and monitoring activities should be implemented by the entities that manage monitoring wells. The Technical Commission should carry out analysis and evaluation of the data obtained from the monitoring. The Technical Commission should develop of information system and data base to be shared by managing entities. As for data on volume of abstracted, it would better to compile data submitted from users into monitoring system. It is necessary to encourage for these well users to install meters and to submit the data on volume of abstracted water**.**
* **Zoning and Tariff Setting for Demand Control and Saving of Groundwater:** For effective demand control and the resource conservation by promotion of saving water use, water pricing should take account of conditions of demand-supply. The Technical Commission or Group should prepare the draft of zoning and tariff setting based on the results of the Study and the monitoring and evaluation for the approval of the managing entity.
* **Promotion of Well Registration and Establishment of Registration of Drillers:** It is necessary to carry out investigation of unregistered wells and to let the users or owners to register in case in use or to scrap adequately in case out of use. For the investigation and execution, it is necessary to define legal procedures as well as to carry out legal arrangement to give staff of CAR and DAMA, or contractors, legal status, such as rights to pass to private lands and buildings.

  For wells to be drilled, a system for registration of well drillers is recommendable in order to realize adequate applications for well drilling, construction works, pumping tests, applications for groundwater water abstraction. Every person who wants to do drilling business has to apply for registration. In case some illegal actions, such as drilling without application or permission, construction works discarding to the permitted design, manipulation of data of pumping tests, are detected, the registration will be revoked and the person cannot drill for a certain period.

* **Water Rights Application for Artificial Recharge:** For the artificial recharge projects, recommendable water rights system is that where water application is not to be done at times of surface water intake but at times of groundwater abstraction according to the volume abstracted. Artificial projects are not regarded as those to use water but those to conserve groundwater or to increase the availability of groundwater resources in this option.

Research and Development for Technology on Efficient Groundwater Use

The project should be implemented by CAR and ASOCOLFLORES. The two organizations should establish immediately a joint implementation unit for the project implementation. Immediate implementation of the feasibility study of the project should be conducted by the joint implementation unit.

Water right charges as well as surtax in immobile property destined to environmental and renewable natural resources conservation to be collected by the users should be used for the investment of the resource conservation. Additional funds should be complementally raised

by the two organizations.

Human Resource Development

* **Technical Transfer through this Study and the Feasibility Study and by applying JICA Training Schemes:** Methodology adopted in and results of this Study should further studied by the counterparts. Through the feasibility study applied to the Government of Japan, entities in charge of groundwater management and development should take the opportunity for technical transfer from experts to be dispatched. Since JICA has prepared various training courses, entities in charge of groundwater management and development can utilized them for technical transfer.
* **Mutual Edification through Activities in the Technical Commission:** Technical upgrade can be realized through activities in the Technical Commission recommended above by exchanging information and mutual edification among the commission members. Seminars for the drillers by the Technical Commission may contribute not only to technical upgrade but also to sound groundwater development.
* **Scholarship:** For upgrade of technical level to higher level in the field of hydrogeology, scholarship can be recommended for the young staff of CAR, DAMA, etc., to study in master courses or Ph. D. courses in Colombian or foreign universities. It can be proposed for IDEAM to give opportunity for the staff all over the country in charge of groundwater management by preparing a scheme for scholarship especially for those who want to study abroad. Scholarship should be repaid when the person will leave public entities or for water resources management within a certain period, say five to ten years after the persons finish the study.

<Design and Cost Estimate>

Facilities that are necessary for two proposed projects : ① Groundwater development project in eastern hills of Bogota Plain (Eastern Project) and ② Groundwater conservation project in area of high groundwater use in western part of Bogota Plain (Western project) is shown in Table-1.5. Cost for two projects was estimated as shown in Table-1.6.

Table-1.5 Facilities for Project

Project	Facilities
Eastern Project	Production/Recharge well, submersible pump, electric facilities, purification facilities, pipeline, access road, site
Western Project	Weir, channel, settling pond, purification facilities, regulation tank, recharge well, submersible pump, site

Table-1.6 Groundwater Development and Conservation in Bogota Plain

Item	Groundwater development and conservation project in Eastern hills	Groundwater conservation project in western area	Total
1. Construction cost	60.36	25.60	85.96
2. Research	-	9.00	9.00
3. Land Acquisition cost / compensation	1.65	0.20	1.85
4. Engineering fee	6.04	2.56	8.60
5. Administration cost	0.67	0.28	0.95
6. Contingency	6.71	2.84	9.55
＜Total＞	75.43	40.48	115.91
	27.9 Million US$	15.0 Million US$	42.9 Million US$
	3,770 million Japanese yen	2,030 million Japanese yen	6,900 million Japanese yen

Note) IVA is included in each item. unit：Million Col$

<Implementation Program>

Implementation organization, preparation of funds and implementation schedule for two projects that were proposed by this Master Plan: 1) Groundwater development and conservation project in Eastern Hills of Bogotá Plain (Eastern Project), 2) Groundwater conservation project in area of high groundwater use in western part of Bogotá Plain (Westen Project), are proposed as explained below.

Groundwater development and conservation project of Eastern Hills of Bogotá Plain

Ministry of Environment should supervise and manage this project. Organization in charge of this project should be Bogotá City. Implementation organization should be Water Supply and Sewerage Company of Bogotá (EAAB). Funds for implementation (75 Billion Pesos) should be from environmental investment of Bogotá City, and it should be taken into account to use foreign funds (soft roan) for most part of implementation.

Groundwater conservation project in area of high groundwater use in western part of Bogotá Plain

Ministry Environment should supervise and manage this project. CAR is suitable for organization in charge of this project. Implementation organization should be joint implementation unit (CAR and ASOCOLFLORES) that will be newly organized. Funds for implementation (63 Billion Pesos) should be from environmental investment of CAR, and it should be taken into account to use investment found of ASOCOLFLORES and foreign funds (soft roan) for considerable part of implementation.

Implementation Schedule

Before implementation of two environmental projects, 2 to 3 years are necessary for preparation works (F/S and procurement of consultant/construction company). After preparation, two projects should be implemented from year of 2006 to 2014.

<Initial Environmental Examination>

To determine the potential impact due to the proposed projects, an environmental examination was conducted based on screening and scooping processes. The result shows the impact of the project is unknown and continuous study is expected.

<Project Evaluation>

Economic Evaluation

Economic evaluation is carried out for 1) groundwater development project on eastern hills of Bogotá Plain and 2) groundwater conservation project in western part of Bogotá Plain after setting preconditions for the evaluation. EIRR of the two projects are 22% and 21%, respectively, and the both projects are evaluated as economically feasible, since opportunity cost in Columbia is 13% and the two EIIRs are exceed the figure.

Financial Evaluation

* **Groundwater Development Project on Eastern hills of Bogotá Plain:**

  Opportunity cost of capital of 14% is applied using the criteria of EAAB. FIRR is calculated as 23% and higher than the 14%. The project is evaluated financially feasible.

* **Groundwater conservation Project in Western Part of Bogotá Plain:**

  This project can be proposed for joint implementation by the Government and groundwater users, mainly florists affiliating to ASOCOLFLORES.

Social Evaluation

Social benefits of the projects are estimated as follows.

* **Groundwater Development Project on Eastern Hills of Bogotá Plain**
  i) Securing water supply at emergency cases
  ii) Construction of water supply facilities in the area of poverty - Soacha
  iii) Securing water for fire fighting at times of forest fires

* **Groundwater conservation Project in Western Part of Bogotá Plain**
  i) Effect of prevention of groundwater lowering by artificial recharge
  ii) Increase of groundwater availability by artificial recharge
  iii) Securing irrigation water at times of drought

* **Both Projects:** Increase in employment and subsequent vitalized economy can be foreseen. The effects of employment increase are estimated at Col. $. 1.3 billion for groundwater development project on eastern hills of Bogotá Plain and Col. $. 2.6 billion for groundwater conservation project on western part of Bogotá Plain.