BOGOTÁ WATER SUPPLY
AND SEWAGE COMPANY
(ACUEDUCTO)

STUDY ON SUSTAINABLE WATER SUPPLY FOR BOGOTÁ CITY AND SURROUNDING AREA BASED ON THE INTEGRATED WATER RESOURCES MANAGEMENT IN THE REPUBLIC OF COLOMBIA

FINAL REPORT
SUMMARY REPORT

March 2009

JAPAN INTERNATIONAL COOPERATION AGENCY

YACHIYO ENGINEERING CO., LTD.

Exchange Rate

US$1.00 = Col.$1,912.15 = ¥105.65

Average between May to November 2008

PREFACE

In response to a request from the Government of the Republic of Colombia, the Government of Japan decided to conduct a study on the Study on Sustainable Water Supply for Bogotá City and Surrounding Area Based on the Integrated Water Resources Management, in Republic of Colombia, and entrusted the study to the Japan International Cooperation Agency.

JICA selected and dispatched a study team headed by Mr. Hiroshi Nakamura of Yachiyo Engineering Co., Ltd. to Colombia, three times between November 2006 and January 2009.

The team held a series of discussions with the officials concerned of the Government of Colombia and conducted field surveys at the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to the promotion of this project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of the Republic of Colombia for their close cooperation extended to the study.

March 2009

Mr. Ariyuki Matsumoto
Vice President
Japan International Cooperation Agency

March 2009

Mr. Ariyuki Matsumoto,
Vice President
Japan International Cooperation Agency

Dear Mr. Matsumoto

LETTER OF TRANSMITTAL

We are pleased to submit to you the final report of the Study on Sustainable Water Supply for Bogotá City and Surrounding Area Based on the Integrated Water Resources Management in the Republic of Colombia. The report took into account of the advices and suggestions of your Agency. Also included are comments made by Bogotá Water Supply and Sewerage Company.

Water is conveyed to Bogotá city from the dam reservoir 40km away through mountain tunnel. However, it is pointed out from before that water supply will be suspended by collapse of the tunnel when natural disaster such as a large earthquake happed, which will give serious impact on water supply of Bogotá city. Bogotá city has faced this problem for a long period time. As one of measures against the problem, groundwater resources around Bogotá city are paid attention with high expectation.

This report consists of Master Plan and Feasibility Study for emergency water supply by use of the groundwater for Bogotá city and surrounding area, targeting the year of 2020. In view of the urgent necessity for implementation of projects of emergency water supply, we recommend that Government of Colombia will implement urgently the projects proposed in the Feasibility Study. Emergency response in water supply will be improved greatly by use of the results of this Report.

We wish to take this opportunity to express our sincere gratitude to your Agency and the Ministry of Foreign Affairs. We also wish to express our deep gratitude to the Bogotá Water Supply and Sewerage Company and the relating organizations for close cooperation and assistance extended to us during our investigation and study.

Very truly yours,

中村浩

Hiroshi Nakamura
Team Leader
The Study on Study on Sustainable Water Supply for Bogotá City and Surrounding Area Based on the Integrated Water Resources Management in the Republic of Colombia

	
Codito area in Eastern Hills. Residential area is distributed in the slope.	Soacha area in Southern Hills. Residential area is distributed in the slope.
	
Proposed drilling site of the Eastern project, near E-12 well point.	Proposed drilling site of Southern project, neat B-3 drilling point.
	
Proposed drilling site of Yerbabuena project, near Y-18 drilling point.	Drilling work by JICA in Ciudad Bolivar, which is candidate for future pilot project.

Drilling work by Acueducto in La Aguadora, which is candidate for future pilot project.

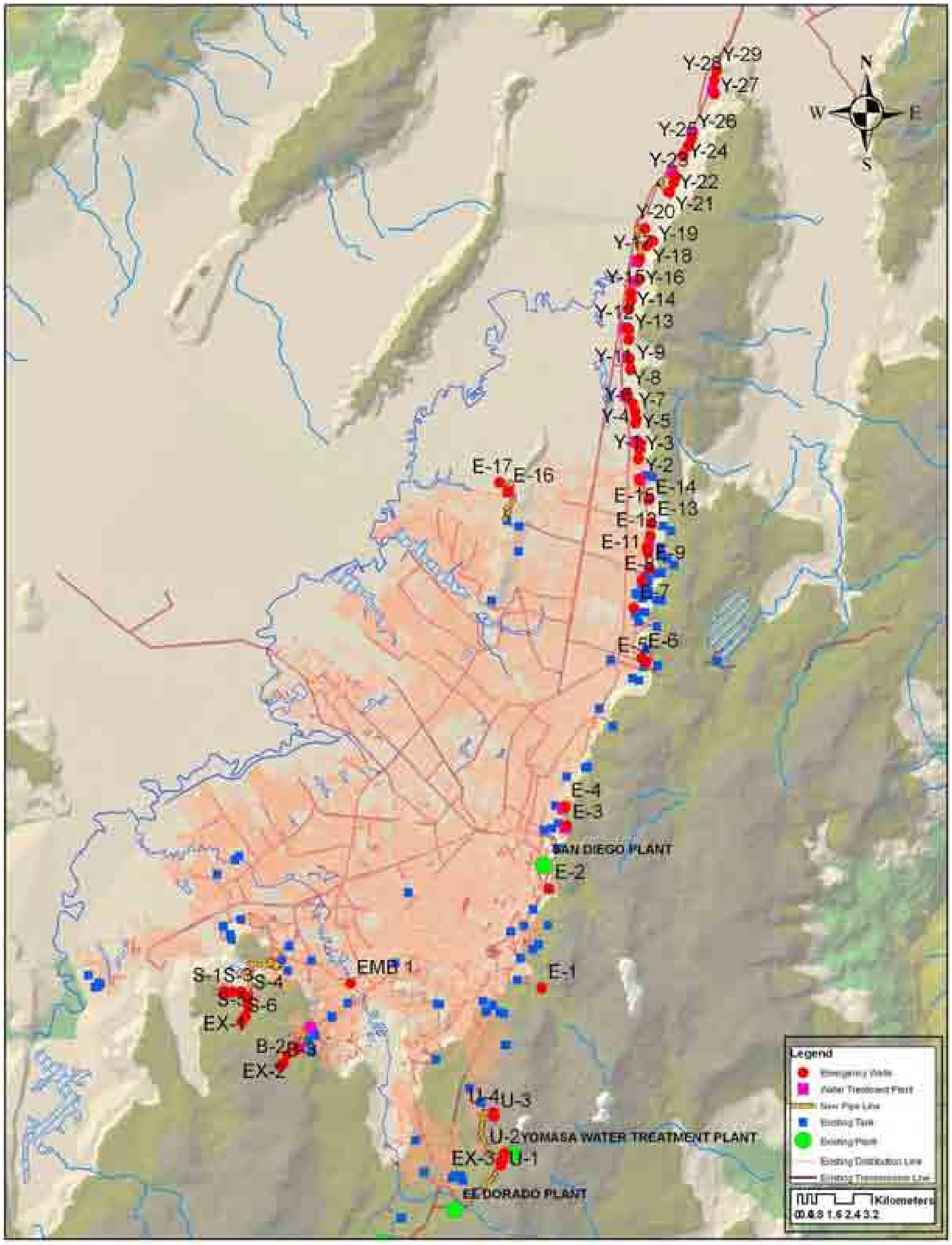
Site for Pilot Project in Vitelma, which will be implemented form April 2009 by Acueducto.

Site for Pilot Project in La Salle, which will be implemented form April 2009 by Acueducto.

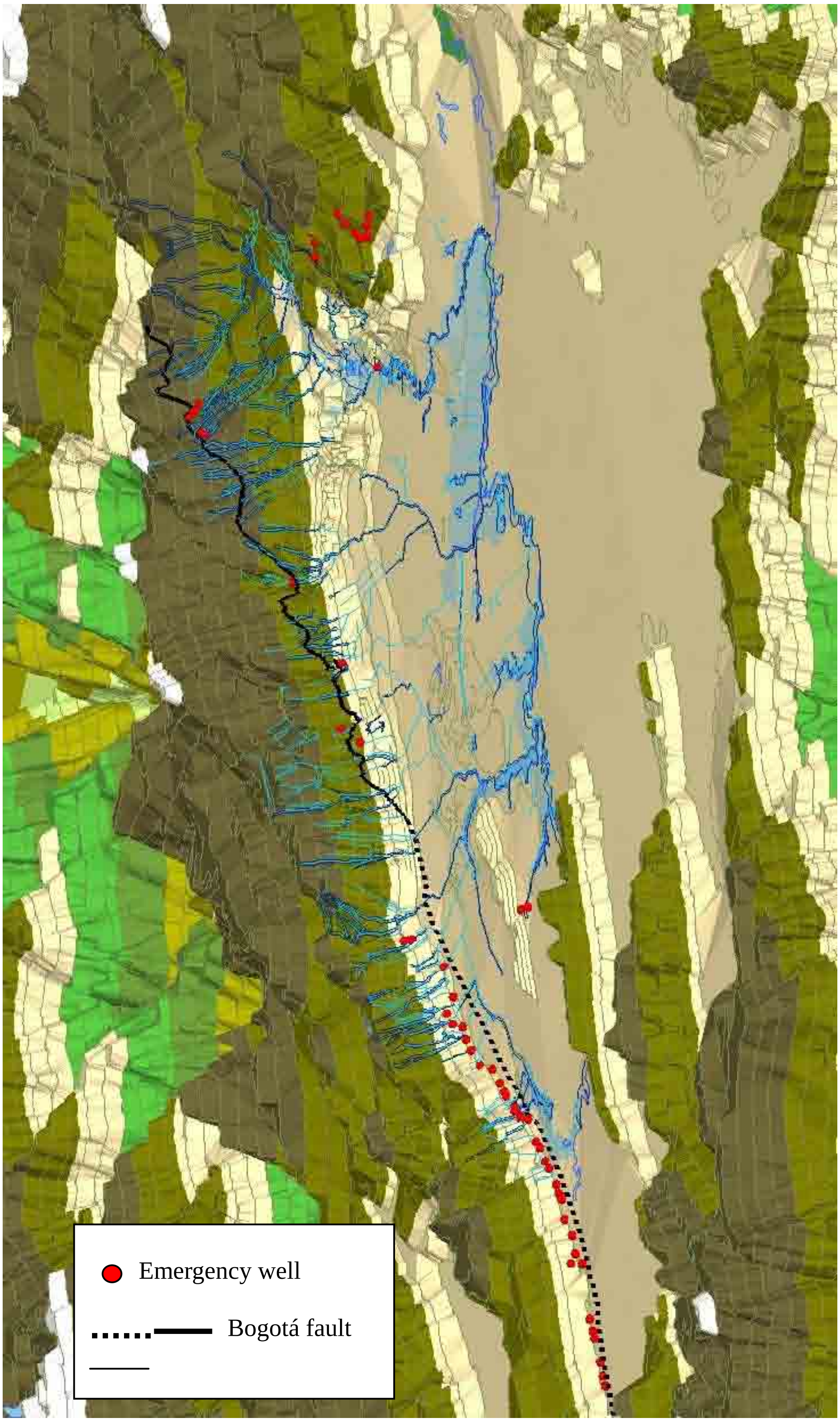
Water treatment facility for groundwater in Tocancipa. Proposed facilities for water treatment in this JICA Study is more compact than this.

Mountain fire happens every year in Eastern Hills of Bogta. Groundwater in Easter hill can be used for fire-fighting.

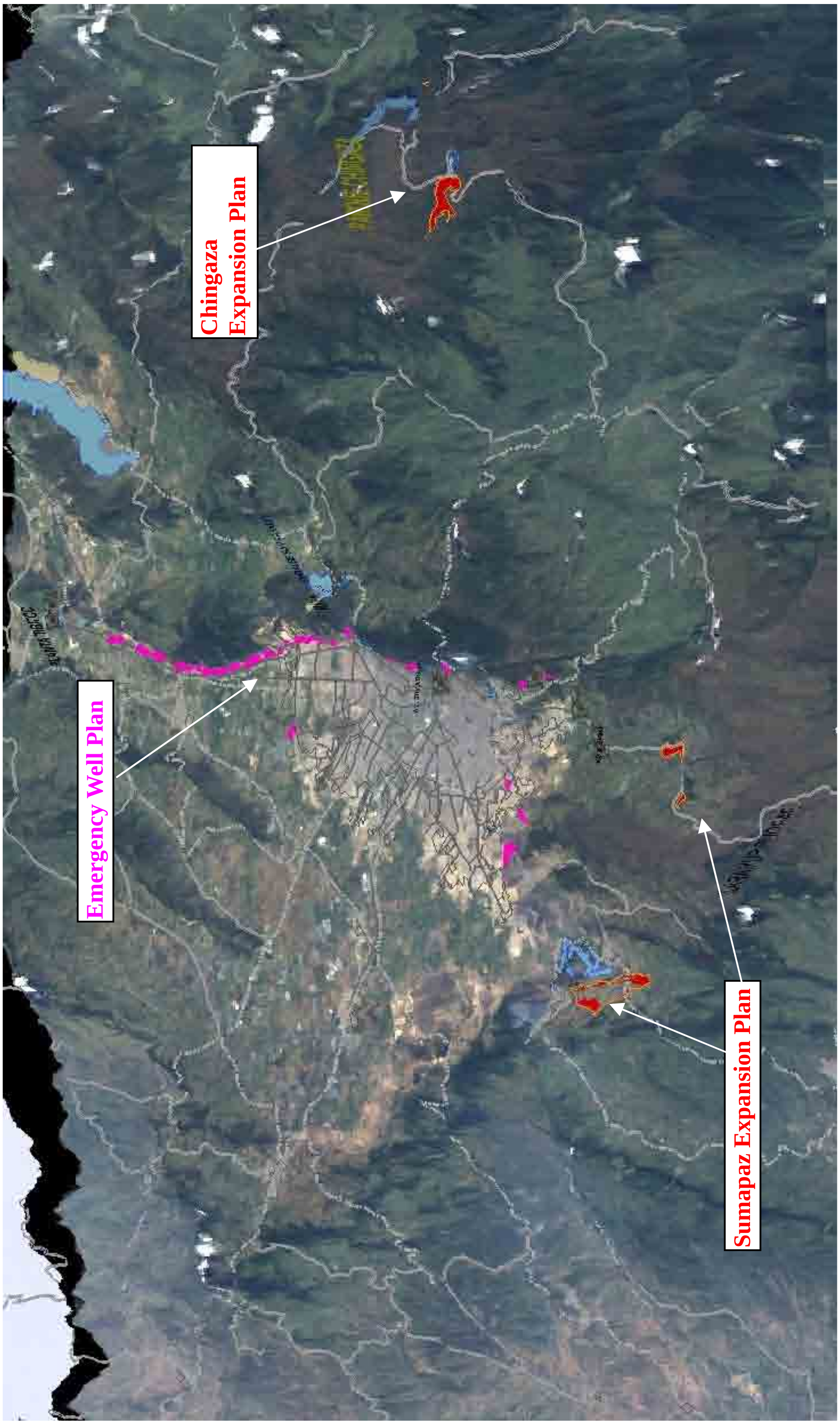
Landscape of Eastern Hills. Steep slope consists of the Cretaceous rock, and gentle slope consists of the Tertiary rock. Boundary between them is Bogotá fault.



Study Area < ● **Emergency well** >



Emergency Wells and Bogotá Fault



Existing Water Resources Expansion Plan and Emergency Well

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THE STUDY ON SUSTAINABLE WATER SUPPLY FOR BOGOTÁ CITY AND SURROUNDING AREA BASED ON THE INTEGRATED WATER RESOURCES MANAGEMENT, COLOMBIA

FINAL REPORT
SUMMARY REPORT

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List of Abbreviations

Abbreviation	Spanish	English	Japanese
Acueducto	Empresa de Acueducto y Alcantarillado de Bogotá	Bogotá Water Supply and Sewerage Company	ボゴタ上下水道公社
AWWA	Asociación Americana de Acueductos	American Water Works Association	米国水道協会
ACCIÓN SOCIAL	Agencia Presidencial para la Acción Social y la Cooperación Internacional	Presidential Agency for the Social Action and International Cooperation	コロンビア社会開発・国際協力庁
a.s.l.	Sobre el nivel del mar	Above sea level	海抜
ASOCOLFLORES	Asociación Colombiana de Exportadores de Flores	Colombian Flower Exporters Association	コロンビア花卉輸出業者組合
B/C	Relación Beneficio-Costo	Benefit-Cost Ratio	便益対費用比
BOD	Demanda Bioquímica de Oxígeno	Biochemical Oxygen Demand	生化学的酸素要求量
CAR	Corporacion Autónoma Regional de Cundinamarca	Regional Autonomous Corporation of Cundinamarca	クンディナマルカ地域公社
COD	Demanda Química de Oxígeno	Chemical Oxygen Demand	化学的酸素要求量
CORPOGUAVIO	Corporación Autónoma Regional del Guavio	Regional Autonomous Corporation of Guavio	グアビオ地域自治公社
CORPOORINOQUIA	Corporación Autónoma Regional del Orinoco	Regional Autonomous Corporation of Orinoco	オリノキア地域自治公社
CPI	Indice de Precio al Consumidor	Consumer Price Index	消費者物価指数
DANE	Departamento Administrativo Nacional de Estadística	National Administrative Department of Statistics	国立統計局
D.C.	Distrito Capital	Capital District	首都圏
DPAE	Dirección de Prevención y Atención de Emergencias	Prevention and Attention Emergencies Direction	ボゴタ首都圏都市防災局
DEM	Modelo Digital de Elevación	Digital Elevation Model	数値標高モデル
EEEB	Empresa de Energía Eléctrica de Bogotá	Bogotá Electric Power Company	ボゴタ電力会社
EIA	Estudio de Impacto Ambiental	Environmental Impact Assessment	環境影響評価
EIRR	Tasa Interna de Retorno Económico	Economic Internal Rate of Return	経済的内部収益率
EMGESA	Empresa de Generadora de Energía S.A.	Electric Power Generation Company	発電会社
FAO	Organización de las Naciones Unidas para la Agricultura y la Alimentación	Food and Agriculture Organization of the United Nations	国際連合食糧農業機関
FC	Capacidad de Campo	Filed Capacity	圃場容水量
FIRR	Tasa Interna de Retorno Financiero	Financial Internal Rate of Return	財務的内部収益率
F/S	Estudio de Factibilidad	Feasibility Study	フィージビリティスタディ
FY	Año Fiscal	Fiscal Year	会計年度
GDP	PIB (Producto Interno Bruto)	Gross Domestic Product	国内総生産
GIS	Sistema de Información Geográfica	Geographic Information System	地図情報システム

Abbreviation	Spanish	English	Japanese
GL	Nivel de Terreno	Ground Level	地盤高
GOBERNACION DE CUNDINAMARCA	Gobernación de Cundinamarca	Cundinamarca Government	クンデイナマルカ県庁
GPS	Sistema de Posicionamiento Global	Global Positioning System	全地球測位システム
GRDP	Producto Interno Bruto Regional	Gross Regional Domestic Product	域内総生産
IDB	Banco Interamericano de Desarrollo	Inter-American Development Bank	米州開発銀行
IDEAM	Instituto de Hidrología, Meteorología y Estudios Ambientales	Institute of Hydrology, Meteorology and Environmental Studies	水文気象環境調査庁
IEC	Comisión electrotecnica internacional	International Electrotechnical Committee	国際電気技術委員会
IEE	Examinación Ambiental Inicial	Initial Environmental Examination	初期環境評価
IGAC	Instituto Geográfico “Agustín Codazzi”	“Agustín Codazzi” Geographic Institute	国土地理院
INGEOMINAS	Instituto de Investigación e Información Geocientífica, Minera Ambiental y Nuclear	Institute of Geoscientific, Mining Environmental, Nuclear Research and Information	国立地質科学鉱山環境核調査情報研究所
ISO	Organización Internacional para la Estandarización	International Organization for Standardization	国際標準化機構
IVA	Impuesto al Valor Agregado	Value Added Tax	付加価値税
JBIC	Banco de Cooperación Internacional del Japón	Japan Bank for International Cooperation	日本国際協力銀行
JICA	Agencia de Cooperación Internacional del Japón	Japan International Cooperation Agency	日本国際協力機構
Kc	Coeficiente de Cultivo	Crop Coefficient	収穫率
NGO	Organización No Gubernamental	Non-governmental Organization	非政府組織
MAVDT	Ministerio de Ambiente Vivienda y Desarrollo Territorial	Ministry of Environment, Housing and Land Use Development	環境・住宅・土地開発省
M/P	Plan Maestro	Master Plan	マスタープラン
DO	Oxigeno Disuelto	Dissolved oxygen	溶存酸素
PML	Evaluación por pérdida Máxima Probable	Evaluation for Probable Maximum Loss	予想最高損害額評価
POMCA	Plan de Ordenamiento y Manejo de Cuencas	Settlement and Management Plan of Basins	流域管理計画
POMCO	Plan de Ordenamiento y Manejo de la cuenca de los Cerros Orientales	Settlement and Management of the Eastern Hills Basin	東部山地帯流域管理計画
POT	Plan de Ordenamiento Territorial	Territory Settlement Plan	土地利用計画
SCADA System	Control supervisor y Adquisición de Datos	Supervisory Control and Data Acquisition System	監視制御データ収集システム
SDA	Secretaría Distrital de Ambiente	District Secretary of Environment	ボゴタ首都圏地区環境局
SDP	Secretaria Distrital de Planeación	District Secretary of Planning	ボゴタ首都圏都市計画局
SISBEN	Sistema de Seleccion de Beneficiarios para programas	System of Selection of Beneficiates for social programs	社会保障年金制度

Abbreviation	Spanish	English	Japanese
	sociales		
S/W	Alcance del Trabajo	Scope of Work	実施細則
TEM	Método de Tiempo de Dominio Electromagnético	Time Domain Electro-magnetic Method	時間領域電磁探査法
UAESPNN	Unidad Administrativa Especial de Sistema de Parques Nacionales Naturales	Special Administrative Unit of National Natural Parks System	国立自然公園システム特別管理ユニット
UAESP	Unidad Ejectiva Servicios Público	Executive Unit of Public Services	ボゴタ首都圏地区公共事業局
WB	Banco Mundial	World Bank	世界銀行
WHO	Organización Mundial de la Salud	World Health Organization	世界保健機構
WMO	Organización Metereológica Mundial	World Meteorological Organization	世界気象機関
WTP	Planta de Tratamiento de Agua	Water Treatment Plant	浄水場
WWTP	Planta de Tratamiento de Aguas Residuales	Waste Water Treatment Plant	下水処理場

SYNOPSIS

The Study on Sustainable Water Supply for Bogotá City and Surrounding Area
Based on the Integrated Water Resources Management in Republic of Colombia

Study Period: November 2007 － March 2009
Recipient Agency: Bogotá Water Supply and Sewerage Company

1. Background of Study

Population of Bogotá city and surrounding area (Bogotá urban area and 10 surrounding municipalities), is 7.6 Million in year of 2005, which is political and economic center of Colombia, where 20% of total population is concentrated with high population growth rate. EAAB (Acueducto) is in charge of water supply for Bogotá city and surrounding 10 municipalities. Acueducto satisfies every requirement in water supply, such as unit consumption rate, water quality, water supply ratio, with stable financial condition. However, currently Acueducto faces vulnerability in emergency water supply. Measures against emergency in water supply are now under preparation, with both soft and hard aspects. Adding above measures, it is pointed out that groundwater should be developed around Bogotá city for emergency water sources, in case water pipelines are damaged by occurrence of large earthquake. Responding to requirement of Colombian side, this study was commenced to solve the problem.

2. Purpose of Study

Purpose of this Study is as follows:

a) Master Plan for emergency water supply by use of groundwater will be formulated, with target year of 2020.
b) Feasibility Study will be implemented for high priority project proposed in the Master Plan Study.

3. Outline of Master Plan for Emergency Water Supply by Use of Groundwater

(1) Existing Plan for Expansion of Water Supply System by Acueducto and its Problem

Responding to increase in water demand of Bogotá city in the future, Acueducto has plan of new development of water resources in Chingaza area. This project is expected to have high financial efficiency, and Acueducto intends to place more weight in Chingaza system for the future. On the other hand, water of Chingaza system will be conveyed from the reservoir in remote area to Bogotá city though single mountain tunnel with 40km length. Thus, there is high risk of interruption of water conveyance by tunnel collapse. Damage by water supply interruption of Chingaza system will be more serious, because importance of Chingaza system will be higher in the future.

(2) Strategy of Master Plan

Water conveyance from Chingaza water sources is vulnerable to natural disaster. Consequently, it was proposed to formulate the plan for emergency water supply by use of groundwater near Bogotá city. Based on above strategy, Master Plan for emergency water supply was formulated in this Study.

(3) Scenario of Emergency Water Supply

Two scenarios were prepared for emergency water supply as listed below:

Table-1 Scenario of Emergency Water Supply

Scenario	Emergency Water Supply
Senario-1	Pipelines for water supply are seriously damaged throughout Bogotá city just after earthquake, and groundwater near Bogotá city is only source for water supply.
Senario-2	Water conveyance from Chigaza system is stopped for a long period of time due to collapse of tunnel, and the other alternative sources for water supply are restored including groundwater.

(Source：JICA Study Team)

Senasrio-1 and scenario-2 are most serious situation in water supply, and measure against 2 scenarios are main target of this Master Plan. Beside 2 scenarios, water shortage by draught and water supply interruption by maintenance works of the facilities are included into the emergency.

(4) Water Demand for Emergency Water Supply

Water demand in emergency water supply by groundwater was planned as shown below:

Table-2 Water demand for Emergency Water Supply by Groundwater

Scenario		Period for recovery	Groundwater demand		Note
			year	Demand (m^3/s)	
Senario-1	Damage of pipelines within Bogotá city	60 days	2007	1.18	Unit water consumption of 15ℓ/person/day is target of Acueducto
			2020	1.68	
Senario-2	Dame to water conveyance tunnel from Chingaza	9 month	2007	2.20	Shortage in water supply by the recovered water system will be supplemented by groundwater
			2020	6.10	

(Source：JICA Study Team)

(5) Groundwater Development

Sixty two (62) wells were proposed for emergency water supply. Aquifer of the wells is the Cretaceous sandstone along the Eastern and Southern hills, which was proved to have high groundwater productivity.

(6) Optimum Yield of Emergency Wells

Optimum yield from sixty two (62) emergency wells were evaluated based on water balance analysis and groundwater simulation. As a result of the analysis, draw-down of groundwater level by pumping from emergency wells was forecasted for the Cretaceous and Quaternary aquifer. Based on this analysis, yield of $1.44m^3/s$ from sixty wells (62) wells was finally proposed as optimum yield.

(7) Project Plan and Project Cost

Entire project consists of three projects as listed in Table-3. Total amount of 1.44m3/s will be pumped up for water supply from sixty two (62) wells. Purpose of groundwater development is emergency water supply, and water supply from groundwater is only for case of emergency, period of which will be less than 9 months.

Table-3 Emergency Water Supply by Use of Groundwater（Master Plan）

Project		No. of Wells	Groundwater development (m^3/s)	Project Cost (Col$ Million)
a)	Eastern Project	29	0.67	Col$46,310
b)	Southern Project	16	0.38	Col$33,500
c)	Yerbabuena Project	17	0.39	Col$28,800
Total		62	1.44	Col$108,610

(Source: JICA Study Team)

(8) Organization for Emergency Water Supply by Groundwater

By organizational reform of Acuedcuto in 2007, sustainable groundwater development and its use were added to responsibility of water supply division, which takes main part of water supply in Acueducto. Moreover, it was proposed to establish new unit within Master System Department, in charge of emergency water supply by use of groundwater.

(9) Project Evaluation

Initial Environmental Evaluation (IEE)

Initial Environmental Evaluation was implemented by the Study Team. As result of the IEE, it was concluded that proposed project in Master Plan will not cause serious impact on social and natural environmental. Therefore, proposed project is classified into "B" rank of JICA categories.

Economic Evaluation

Proposed project is for emergency water supply. For such a project, economic evaluation by monetary base is difficult. . Consequently, proposed project was evaluated by following 4 view points, and was concluded to be economically highly efficient: i) scattering of emergency wells can reduce risk of interruption of water supply in emergency, ii) cost for groundwater development is cheaper than that for surface water development, iii) emergency well can be located near Bogotá city that has high water demand in case of emergency, iv) groundwater development can postpone projects for Chingaza expansion, of which implementation is planned after year of 2021.

Financial Evaluation

Proposed project is for emergency water supply. From such a project, financial profit can not be expected. Total project cost was estimated Col$108,610 Million, which occupy only 7.2% of long term investment plan of Acueducto. It is concluded that Acueducto can afford the capital and interest for entire proposed project, even though the entire budget for the projects are procured within Colombia. Business profit of Acueducto is steadily increasing every year, and additional budget for the proposed project will give only small impact to financial condition of Acueducto

Social Evaluation

Social profit expected from the proposed project is as follows: a) Increase in population that can be supplied water in case of emergency, b) water for fire fighting, c) increase in employment for facilities construction of the project

4. Feasibility Study of High Priority Project

Master Plan for Emergency Water Supply by Use of Groundwater was approved by Colombia side. Following the Master Plan, feasibility Study was implemented for high priority projects proposed in Master Plan. Priority was given to each project as shown below:

Priority	Project		
i)	Pilot Project	→	Prior project
ii)	Eastern project	→	1st Period Project
iii)	Southern project	→	2nd Period Project
iv)	Yerbabuena project	→	3rd Period project

Feasibility Study was implemented for entire projects, considering that the total project scale is not large, and each project is important having strong relation with each other for emergency water supply.

4.2 Outline of Project

Projects proposed in Master Plan were reviewed in Feasibility Study, and content of the projects was finally decided as follows:

(1) Prior Project: Pilot Project for Groundwater Use

Pilot project has important purpose to resolve technical problem of emergency water supply by groundwater. Pilot project should be implemented at 8 sites within Bogota urban area, prior to the other projects. Pilot project, as sample facilities for emergency water supply, will promote implementation of proposed projects throughout Bogotá city.

(2) 1st Period Project: Eastern Project

In Eastern Project, facilities for emergency water supply was planned to be constructed in the Eastern hills. The centre of Bogotá city is near the Eastern hills, from which groundwater of wells can be quickly delivered to the city centre. Easy access form Eastern hills to the city centre make Eastern Project as main project of emergency water supply. Number pf emergency well is thirty three (33), and planned yield is 685,000m3/day, which can provided water to 4,565,000 persons with unit consumption rate of 15ℓ/person/day.

(3) 2nd Period Project: Southern Project

In Southern Project, facilities for emergency water supply was planned to be constructed in the Southern hills. The epicentre of large earth quake is assumed in the Southern hills, where there are many houses on the slope of the hills. Damage by earthquake, including damage to water supply facilities, is expected more serious than other area of Bogotá city. Number pf emergency well is fourteen (14), and planned yield is 13,100m3/day, which can provide water to 872,000 persons with unit consumption rate of 15ℓ/person/day.

(4) 3rd Period Project: Yerbabuena Project

Yernabuena area is located to the north of Bogotá city, in Chia and Sopo municipalities. In case of emergency, groundwater from wells in Yerbabuena area can be delivered by water wagons or be conveyed through pipelines to Bogotá city and the surrounding area. Yerbabuena area is located relatively far from the center of Bogotá urban area, so that priority of Yerba Bueba Project is lower than the other projects, though groundwater development potential of this area is high. Number pf emergency well is seventeen (17), and planned yield is 34,000m3/day, which can provide water to 2,266,000 persons with unit consumption rate of 15ℓ/person/day.

4.3 Project Cost

Total cost for proposed three projects (Eastern, Southern and Yerbabuena Project) was estimated 122,300 million pesos. Average annual cost for the projects implementation was estimated 15,400 million peso, under assumption that construction works for the entire projects will be completed in 7 years.

Table-4 Project for Emergency Water Supply by Use of Groundwater（Feasibility Study）

Project		No. of Wells	Groundwater development (m^3/s)	Project Cost (Col$ Million)
a)	Eastern Project	33	0.79	Col$67,500
b)	Southern Project	14	0.15	Col$23,000
c)	Yerbabuena Project	17	0.39	Col$32,800
Total		64	1.33	Col$123,300

Note) Number of well and yield, which was proposed in M/P, were reviewed and modified in F/S.

4.4 Project Evaluation

(1) Technical Evaluation

- Location and number of facilities for emergency water supply were planned, taking into account of relating conditions, such as hydrogeology, land use and accessibility in emergency. Amount of water to be produced from emergency wells can meet water demand of Bogota urban area in emergency.

- From result of water balance analysis, planned pumping rate from emergency wells were concluded to be optimum. Groundwater use by private wells will not be interrupted by draw-down of groundwater level, which will be caused by pumping from emergency wells during less than 9 month. It was also concluded that land subsidence will not take place by the pumping.
- Water quality of groundwater of the Cretaceous sandstone, which is aquifer for emergency wells, is excellent. It needs only chlorination and simple water treatment to remove iron and manganese. Water treatment facilities were planed to satisfy water quality standard of Colombia.
- Point water supply in emergency can be efficiently implemented by water wagons or usual trucks with water tank. For water tanks to be loaded on trucks, light plastic tanks are effective.
- Proposed facilities for emergency water supply meet design criteria of Colombia, and can be constructed by Colombian engineering technology.

(2) Social Environmental Consideration.

Initial Environmental Examination (IEE) was implemented for the proposed projects based on JICA Guideline for Social Environmental Consideration. According to the result of the examination, it was judged that proposed projects would not give serious impact to social environment of the project area, and the projects were classified into JICA Category B.

(3) Economic Evaluation

Purpose of the proposed project is to secure water supply in emergency. As for emergency water supply, it is difficult to implement economic evaluation of the project on monetary base. Consequently, appropriateness of the proposed project was proved by three advantages of the projects below:

a) Dispersion of risk of water source failure
b) Lower water resource development cost
c) Development of water sources near water consumption area

(4) Financial Evaluation

Total cost of the proposed project is 123,300 million pesos. Judging from financial condition, Acueducto can afford the entire debt payment, even under condition that entire cost will be loaned from domestic banks. The incremental cost of interest and depreciation generated by the proposed projects do not affect seriously the expected profit of Acueducto.

(5) Social Evaluation

The project is expected to generate several social benefits to the project areas as shown below:

a) Increase of served population in emergency, b) Water supply to forest fire fighting, c) Increase of employment opportunity.

4.5 Pilot Project

The Pilot Project has evolved into an elaborated process by stages, which could decrease the costs of the Feasibility Study. The operation manual which involves mobile treatment and operation solutions must be taken to account based in the fact that the simultaneousness of the catastrophic events does not occur in foreseeable places, but in random ones. Therefore, the result of using different scenarios alternatives will reduce costs and would only require the construction of the 64 wells in different times.

PART 1 INTRODUCTION

CHAPTER 1. OUTLINE OF STUDY

(1) Background of Study

The Population of Bogotá Metropolitan Area (Bogotá Capital District and 10 neighboring cities) has reached to 7,600,000 inhabitants by 2005, which is the center of the politics and economy of Colombia where 20% of population of the country concentrates. The population growth rate was 2.3% in the past 10 years during 1993-2003, exceeding country average growth rate of 1.8%, which reflects inflows of internally displaced persons.

Bogotá Water Supply and Sewage Company (Acueducto) takes responsibility for water supply in Bogotá D.C. Acueducto has been expanding its water supply areas to neighboring 10 cities with the expansion of "Bogotá urban area (distrito urbano)", which is defined in Plan of Land Use Regulation of Bogotá D.C. Although unaccounted rate for water is as high as around 35%, Acueducto satisfies basic management standards, such as the gap between water supply and demand, water quality, ratio of service coverage and financial situation.

However, Acueducto faces the problem of water supply in emergency cases. Natural disasters (earthquakes/landslides) frequently occur in the Bogotá Metropolitan Area. Acueducto mainly carries out the urgent measures with assumption of earthquakes, and performs physical countermeasures, such as anti-earthquake reinforcement of water tanks, and countermeasures of software, such as strengthening of coordination with relating organizations and preparation of manuals. In addition, it is necessary to secure groundwater as water sources when pipeline for water supply are suspended by natural disaster. Technical assistance by the Government of Japan was requested necessary to solve these problems.

(2) Objetive of Study

Implementing agency of this Study is Bogotá Water Supply and Sewage Company (Acueducto), and purpose of this Study is as follows:

a) Formulate an emergency water supply master plan for Bogotá Metropolitan area, using groundwater and develop it completely for the year 2020.

b) To implement Feasibility Study on high priority projects selected in the Master Plan

(3) Study Area

Study Area: Bogotá plain, Chingaza river basin, Sumapaz River basin (Bogotá D.C. and 10 neighboring cities)

Land Area: About 4,305km^2

Population of Study Area: 7,600,000 (2005)

(4) Scope of Study and Major Ourputs

This Study will be implemented in two phases. Major outputs of each phase are shown in Table-1.1-1.

Table-1.1- 1 Scope of Study and Main Output

Phase	Content
Phase-1: Formulation of Master Plan (M/P)	[1st year] 1) Analysis of current situation and possibility of groundwater use for water supply
	[2nd year] 2) Exploratory drilling 3) Formulation of Master Plan and selection of priority projects
Phase-2 : Feasibility Study for priority projects (F/S)	[3rd year] 4) Formulation of implementation plan of high priority project 5) Promotion of understanding on M/P (water supply plan by groundwater) for Colombian side

CHAPTER 2. STUDY ORGANIZATION AND OPERATION

2. 1. Study Organization

The Study Team and Colombian side discussed and decides study organization as below:

Colombian counterpart organizations are comprised of ten institutes, namely, a)Bogotá Water Supply and Sewerage Company (Acueducto), b) Ministry of Environment, Housing and Land Use Development (MAVDT), c) Regional Autonomous Corporation of Cundinamarca (CAR), d) District Secretary of Environment (SDA), e) District Secretary of Planning (SDP), f) Prevention and Attention Emergencies Direction (DPAE), g) Institute of Geoscientific and Mining Environmental Research and Information (INGEOMINAS) and h) Institute of Hydrology, i) Meteorology and Environmental Studies (IDEAM), j) Cundinamarca Government and k) Presidential Agency for the Social Action and International Cooperation (ACCIÓN SOCIAL).

The Steering Committee has been established for this Study. The Steering Committee is organized with members representing from above 10 organizations.

2. 2. Main Meeting

The following main meetings were held for the study between the Study Team and the counterpart organizations. Refer to Appendix-2: Minutes of Meeting.

Table-1.2- 1 Main Meeting

No.	Date	Content
1	1st December, 2006	Content of the Inception Report was discussed between Colombian side and JICA Study Team.
2	11th January, 2007	Study organization and content of the Study was discussed between Colombian side and JICA Study Team.
3	15th February, 2007	Content of the Report on Study Progress was discussed between Colombian side and JICA Study Team.
4	4th July, 2007	Continuity of this Study was discussed. Definition and necessity of emergency water supply was discussed between Colombian side and JICA Study Team.
5	23rd November, 2007	Progress of the Study was discussed between Colombian side and JICA Study Team. Comment was made from the Colombian sides to the previous JICA Report, and it was agreed that the comments should be taken in to account in the next JICA report.
6	28th December, 2007	Discussion was made on 4 items, which are criteria of continuity of this Study between Colombian side and JICA Study Team.
7	7th July, 2008	Progress of M/P Study was explained and discussed between Colombian side and JICA Study Team.
8	14th May, 2008	Discussion was made on content of Interim Report between Colombian side and JICA Study Team.
9	3rd September, 2008	Content of F/S and priority Project was discussed between Colombian side and JICA Study Team.
10	4th October, 2008	Progress of F/S was explained by the Study Team and discussion was made between Colombian side and JICA Study Team.

Source: JICA Study Team

2. 3. Workshop

The following workshops have been held covering all aspects of the Study. Presenter from JICA Study Team has contributed to the workshop program as shown below.

Table-1.2- 2 Content of Workshop

No.	Date	Topics	Content	Speaker
WS1-1	11th January, 2007	Content of study for analysis of water resources development potential	Hydrological analysis	Lei
			Geological and topographic survey	Inoue
WS1-2	2nd,February, 2007	Geophysical Survey and Result of the Previous JICA Study	Geophysical Survey	Fujita
			The Result of the Previous Study	Nakamura
WS1-3	8th February, 2008	Environmental Issue and Result of the Previous JICA Study	Water Purification for Lakes and Marches	Ueda
			The Result of the Previous Study	Nakamura
WS1-4	7th February, 2007	Field Technical Transfer for TEM Survey	TEM Field Measurement with TEM-FAST48HPC	Fujita
WS1-5	16th February, 2007	Analysis of TEM Data	Procedures to process and analyze TEM Data	Fujita
WS2-1	2nd October, 2007	Surface water resources development potential	Water balance analysis for surface water	Lei
WS2-2	17th October, 2007	Groundwater resources development potential	Water balance analysis for groundwater	Lei
WS2-3	26th October, 2007	Water resources development potential	Water development Potential in the Study Area	Lei
WS2-4	23rd December, 2007	Environmental consideration and example of water resources development of Japan	Environmental consideration	Ueda
			Example of water resources development of Japan	Nakamura
WS2-5	3rd December, 2007	Groundwater simulation	Introduction of groundwater simulation	Yasuda
WS2-6	4th December, 2007	Master Plan of Emergency Water Supply by Use of Groundwater	Summary of the Project.	Nakamura
			Groundwater development potential and Design of Water Supply facilities.	Nakamura
			Plan for Pilot project for groundwater development.	Nakamura
			Lowering of groundwater level by groundwater development.	Yasuda
			Organization, operation and maintenance of the facilities for emergency water supply.	Hara
			Cost Estimate	Fujii
			Financial and Economic Evaluation	Osakabe
			Social situation of the hills area	Elsa
			Exploratory well.	Ikeda
WS2-7	22nd January,2008	Pilot project for groundwater use	Water treatment for pilot project of groundwater use	Nakamura
WS3-1	17th September , 2008	Groundwater Simulation	Groundwater Simulation	Nakamura
WS3-2	24th September , 2008	Result of groundwater level Monitoring by Automatic Recorders	Result of groundwater level Monitoring by Automatic Recorders	Nakamura
WS3-3	1st September , 2008	Pumping Test	Pumping Test	Nakamura
WS3-4	3rd October, 2008	Design and Cost Estimate of Feasibility Study	Design and Cost Estimate of Feasibility Study	Fujii
WS3-5	8th October , 2008	Operation method of Visual Modflow	Operation method of Visual Modflow	Nakamura
WS3-6	15th October , 2008	Geophysical Survey and Groundwater Study	Geophysical Survey and Groundwater Study	Nakamura
WS3-6	22nd October, 2008	Groundwater simulation	Theory and application of groundwater simulation	Lei
WS3-7	29th October, 2008	Groundwater simulation		Lei
WS3-8	31st October, 2008	Groundwater simulation		Lei
WS3-9	7th October, 2008	Analysis for groundwater potential	Result of groundwater simulation	Lei

Source: JICA Study Team

2. 4. Seminar

First Technical Transfer Seminar

The First Technical transfer seminar was held on 13th of May, 2008. Presentation was made by the Study Team and relating organizations. Content of the seminar is summarised in Table-1.2-3.

Table-1.2- 3 Content of Technical Transfer Seminar

Time	Presentation	Lecturer	Organization
8:00 - 8:15	Opening speech	Mr.Kazunori HAYASHI	JICA Colombia Office
8:20 - 9:00	Water Resources Management by CAR	Mr. Alfredo Molina	CAR
9:05 - 10:20	Groundwater resources and Emergency water Supply	Mr. Hiroshi NAKAMURA	JICA Study Team
10:50 - 11:30	Forest Protection Area in Eastern Hills	MS. Myriam Amparo Andrade	CAR
11:35 - 12:15	Proposal for Emergency Water Supply	Mr. Guillermo Escobar	DPAE
13:25 - 14:05	Current situation of Groundwater in Bogotá	Mr. Ismael Martinez	SDA
14:10 - 14:50	Long term Water Demands of Bogotá	Mr. Nestor Raul Garcia	Acueducto
14:50 - 15:00	Closing speech	Mr. Alberto Groot	Acueducto

Source: JICA Study Team

Topics on water resources development and management in Bogotá D.C. were presented by CAR and JICA Study Team. Regulation on water resource development was explained by CAR, and emergency water supply was explained by DPAE and JICA Study Team. SDA made presentation on current groundwater environment of Bogotá City.

Attendants of the seminar had common recognition on necessity of emergency water supply in Bogotá city. Active discussion was made among the attendants, how to develop groundwater for emergency water supply. There is the forest protection area in Eastern Hill, where activity for economic development is regulated. Groundwater resource development is also regulated in the forest protection area. The attendants discussed whether it is correct or not to regulate groundwater development for emergency water supply.

Second technical transfer seminar

The second technical transfer seminar was held on the 21st of January, 2009. Presentations shown in Table -1.3-4 was made by the Study Team and relating organizations.

Table-1.3-4 Content of 2nd Technical Transfer Seminar

Time	Presentation	Lecturer	Organization
8:30 - 8:35	Opening Seminar	Mr.Kiyoshi YOSHIMOTO	JICA Colombia Office
8:35 - 8:45	Opening Speech	Mr. Alberto Groot	Acueducto
8:45 - 10:00	Sustainable Water Supply for Bogotá City and Surrounding Area based on the Integrated Water resources Management	Mr. Hiroshi NAKAMURA	JICA Study Team
10:00 - 10:30	Use and Conservation of Groundwater in Bogotá	Mr. Oscar Osorio	SDA
10:45 - 11:05	Protection Hills of Bogotá, Proposal for modification and adjustment of the PMA	Mrs. Miriam Amparo Andrade	CAR
11:05 - 11:25	Hydrogeology in the Eastern Hills of Bogotá	Mr. Romulo Camacho	CAR
11:25 - 12:00	Water Supply in Emergency for Bogotá	Mr. Guillermo Escobar	DPAE
12:00-12:30	WTP for Groundwater and Emergencies	Mr. Alvaro Sanjinez	VALREX
13:30-14:30	Site Visit to Aguadora Well		
14:30-15:00	Water Supply Plan of Groundwater in Emergency for Bogotá	Mr. Alberto Groot	Acueducto
15:00-15:30	Potable Water Quality in cases of Emergencies.	Mr. Jorge Arboleda	HIDROSAN
15:30-15:45	Close	Mr. Alberto Groot	Acueducto

Source: JICA Study Team

The final result of this JICA Study was presented by the JICA Study Team in the seminar. Necessity on emergency water supply and current issues on this topic were made clear by presentation of the seminar. Attendants of the seminar have fully understood importance of emergency water supply. Media also attended the seminar, and they introduced result of this JICA Study by the broadcast, which was expected causing wide interest on this JICA Study from many people. Furthermore, Acueducto implemented pumping test on the day of the seminar at the exploratory wells, which were drilled near the seminar hall. Scene of pumping test was broadcasted and appealed to many people.

SDA made presentation on the use and conservation of groundwater inside Bogotá city. CAR explained about the regulations on the eastern hills of Bogotá and explained about the proposal for modifying and adjusting the environmental management plan. Also CAR did a technical presentation regarding hydrogeology in the Eastern Hills of Bogotá. DPAE explained about the water supply in emergency for Bogotá City. A presentation on water treatment plants for emergencies was presented by VALREX. Acueducto with JICA Study explained about the plan for water supply by groundwater in cases of emergency for Bogotá city. Water Quality in cases of emergency was discussed by HIDROSAN providing guidelines for emergency cases.

PART 2 MASTER PLAN STUDY

CHAPTER 1 GENERAL CONDITION OF THE STUDY AREA

1.1 Current Situation of the Study Area

1.1.1 Socio-economic Conditions

(1) Study Area

The Study Area is comprised of both the Bogotá District Capital (Bogotá D.C.; 1,605 km^2) and 10 municipalities of the Cundinamarca Department (1,173 km^2). Bogotá D.C. is divided into 20 localities. The Study Area includes 19 urban localities of Bogotá D.C.

The Cundinamarca Department is divided into 15 provinces (*provincias*), and these provinces are divided into 116 municipalities (*municipios*). The Study Area extends to 4 provinces and 10 municipalities of the Department.

(2) Population

<COLOMBIA>

The census population of year 2005 was 41.5 million inhabitants. The population increased by 8.4 million over the 12 year period from the previous census year of 1993. The annual growth rate between the census of 1993 and 2005 was 1.9%, which slowed down from 2.2% between the censuses of 1985 and 1993.

<THE STUDY AREA>

The census population of year 2005 totaled 7.6 million inhabitants, an increase of 2.2 million from the previous census of 1993. The annual growth rate between the censuses of 1993 and 2005 was 2.9%, which also slightly slowed down from 3.0% between the censuses of 1985 and 1993.

- The census population of Bogotá D.C. in 2005 increased by 1.9 million or by 2.7% per annum compared with that in 1993.
- The census population of the 10 municipalities of the Cundinamarca Department increased by 0.4 million compared with the 1993 census. The population growth of this area shrunk to 5.0% from the previous rate of 6.7%; however the growth is remarkably high, especially in Mosquera, Chía and Tocancipá.

<GRDP> in 2006

Area	GRDP	Ratio to GDP	Growth Rate	GRDP/capita
Bogotá D.C.	Col$94 trillion	24.5%	7.3%	US$5,740
Cundinamarca Dept.	Col$20 trillion	5.3%	8.9%	US$3,700

<Economic Activity: Contribution to GRDP>

Area	Primary Sector	Secondary Sector	Tertiary Sector	Total
Bogotá D.C.	0.3%	22.8%	76.9%	100%
Cundinamarca Dept.	22.1%	31.0%	46.8%	100%

Gross Regional Domestic Product

GDP of Colombia grew by 4.7% in 2005 and reached at Col$ 285 millions of millions.

GRDP of the Bogotá D.C. in 2005 grew by 5.5% and reached at Col$ 64 millions of millions that accounted for 23% of GDP of Colombia; while that of the Cundinamarca Department in 2005 was Col$ 15 millions of millions that was 5% of GDP.

GRDP as well as GDP have turned to the positive growth since 2000 in spite of the sharp negative growth due to the economic stagnancy in 1999.

GRDP per capita of the Bogotá D.C. was US$ 3,840 in 2005 that is larger by 44% than GDP per capita of Colombia. Meanwhile, GRDP per capita of the Cundinamarca Department was US$ 2,830 in 2005 that is almost as same as GDP per capita of Colombia.

(3) Economic Activities

<BOGOTÁ D.C.>

The service sector is a predominant economic activity in Bogotá D.C., which accounted for 67% of GRDP in 2005. Especially, commercial/hotel/restaurant, real estate and financial sectors are remarkable in the city.

The industrial sector also plays a big role in the economic activity in the Bogotá D.C., representing by 32% of GRDP in 2005. Textile/garment, food/beverage and petroleum/chemical are the three largest industries of the Bogotá D.C.

<CUNDINAMARCA DEPARTMENT>

The agriculture is an important sector of the Department, accounting for 28% of the GRDP of the Department. The main agriculture products of the Study Area are such transitory crops as tomato, carrot, and pea. Also the floriculture is a very important economic sector of the Study Area.

The industry sector accounted for 30% of the GRDP in 2005. The most remarkable industries in the Department are 1) Food and Beverage, 2) Ceramic & Glass, and 3) Cement.

1) Consumer Price Index and Exchange Rate

CPI of the years of 1990's recorded more than 15% every year. It fell sharply to 9% in 1999. CPI has continuously fallen since 1999 and recorded a historical low level of 4.5% in 2006 during these last 15 years.

Colombian peso has been devaluated in 2002 and 2003 due to the South American financial crisis. However, it has been stabilized since 2004 or even restored to the year 2000 level in 2007. In October end, the exchange rate of Colombian peso against US dollar quoted at 1,999.44.

1.1.2 Institution for Water Supply and Water Resources Management

(1) Current Legislation on Water Resources Management

The 1991 Constitution of the Republic vests the ownership of subsoil, natural and renewable resources on the state. Major decrees, laws, resolutions related to water resources management are as follows.

<Decree-Law No. 2811 of 1974-National Code of Renewable Natural Resources and Environmental Protection>

Decree-Law 2811 of December 18, 1974, named as "National Code of Renewable Natural Resources and Environment Protection", is the fundamental law of water resources management. All water resources in any condition and any location within the territory of the Republic are recognized as renewable natural resource. In the Code, renewable natural resources are deemed as common property of the nation, and the state shall participate in their preservation and management as social interests.

<Decree No. 1541 of 1978 and Accord of CAR No. 10 of 1989>

Decree No. 1541 of 1978, gives provisions on non-marine water based on the National Code of Renewable Natural Resources and Environmental Protection. The Decree defines types of domains, such as public or private, of non-marine water as well as riverbeds. Main part of the decree is destined for manners and procedure for giving rights to use non-marine water and watercourses to individual persons, including juridical ones.

<Law No. 99 of 1993>

Law No. 99 of 1993 institutes organizations for public administration of environmental protection and conservation as well as renewable natural resources management, such as Ministry of Environment, National Council of Environment, Institute of Hydrology, Meteorology and Environmental Study (IDEAM), Regional Autonomous Corporations. The Law also provides duties and jurisdictions of the relevant organizations. The Law stipulates that Regional Autonomous Corporations, with financial independence and their own properties, administer environment and renewable natural resources according to the laws and polices of the Ministry.

<Law No. 373 of 1997>

Law No. 373 of 1997 provides programs for efficient use and saving of water.

<Accord of CAR No. 8 of 2000>

Accord of CAR No. 8 of 2000, determines water right charge. Basic charges by municipality are calculated taking account of factors on i) aridity, ii) unsatisfied basic necessity, as socio-economic conditions, and iii) availability of water resources.

<Resolutions of DAMA (previous name of SDA) on Groundwater Management>

Resolution No. 250 of DAMA, 1997, determines formula to calculate rate for abstraction of groundwater. The resolution No. 251 of DAMA, 1997 gives obligation of registration of wells located in the urban zones of the Capital District to SDA.

<Legislation on Water Basin Management>

Decree No. 1604 of 2002 stipulates members of a Joint Commission and its functions based on Law No. 99 of 1993. Decree No. 1729 of the same year gives provisions of concept, objectives, compositions, implementation, and financing for the implementation of Regulation and Management Plan of Water Basin (POMCA).

(2) Legislation on Prevention and Attention of Emergencies

Decree No. 332 of 2004 of Bogotá D.C. organizes regime and system for prevention and attention of emergencies in Bogotá D.C. The Decree defines situations of emergencies of the district, activities for prevention and mitigation of the risks including District Plan for Prevention and Attention of Emergencies, District System for Prevention and Attention of Emergencies and provides other relevant dispositions.

Decree No. 423 of 2006 of Bogotá D.C. provides policies, general objectives, lines of actions, scenarios, programs of the District Plan for Prevention and Attention of Emergencies. The Decree set up seven general objectives of the Plan, as shown in Table-2.1-1. The Decree also identifies territorial scenarios. The scenario related to water supply is the network scenario, which includes networks of i) water supply and sewerage system.

Table-2.1- 1 Expected Results for the Management of Networks

General Objective
Safe Location
Safe Construction
Safe Operation
Including of Risk Management in Culture
Visibility and responsibility
Integrated Attention of Emergencies
Resilience in Front of the Disaster

Source: Decree No. 423 of 2006.

(3) Organizations for Water Use and Water Resources Management

Organizations that have relation to water use and water resources management are as follows:

<Acueducto>

Water Supply and Sewerage Company of Bogotá (Acueducto) is a public company, without any private capital, in charge of water supply and sewerage services in Bogotá D.C. Acueducto also supplies water to some surrounding 10 cities, such as Cajicá, Sopó, Chía, Tocancipá, La Calera, Gachancipá, Soacha, Funza, Mosquera, Madrid, under contracts with each of the municipalities. At present, water sources for Acueducto are mostly of surface water. Acueducto implements customer attention through five Management Office of Zones. The office for Zone 1 is located in Usaquén and that for Zone 4 in Santa Lucia, while other offices (Zone 2, 3 and 5) are located in the same place as the Headquarters Office of Acueducto.

<Ministry of Environment, Housing and Land Use Development>

Ministry of Environment, Housing and Land Use Development is in charge of management of environment and renewable natural resources, such as water resources. The ministry formulates policies of the matters at national level, while regional entities, such as CAR or SDA are in charge of policy formulation and implementation for the management for their jurisdictions. Special Administrative Unit of Natural Park System gives concession for water use located in the National Natural Park.

<CAR>

CAR takes main role in environmental conservation and management of the renewable natural resources, including water resources. CAR was originally established as a water basin management entity and changed its name as the present one by the Law No. 99 of 1993. Its territory has also been changed from areas of basins to areas of administrative units. Sub-directorate of Management of Shared Environment implements inventory of natural resources and Sub-directorate of Management of Shared Environment examines use of natural water resources. General Secretariat and Legal Support deals environmental license and permission.

<SDA>

SDA is one of the Administrative Technical Departments of the Government of Bogotá District (Alcaldía Mayor) in charge of managing the environment and renewable natural resources within the urban perimeter of Bogotá D.C. In fact, however, SDA grants water rights of groundwater but not of surface water due to the scarce availability of it in the area and bad water quality.

<IDEAM>

IDEAM is in charge of hydrological, meteorological and environmental investigations, researches and studies for the policy formulation by the Ministry of Environment.

<INGEOMINAS>

INGEOMINAS is a technical center of geology or any matters related underground, including groundwater.

<CORPOGUAVIO>

Corporación Autónoma Regional del *Guavio* has jurisdiction area in upper-stream area of Guavio River basin. CORPOGUAVIO has almost same function as CAR, which is in charge of formulation of policy and plan, implementation of project and program. They have authorization to give environmental license and concession for water right in their jurisdiction area.

<CORPOORINOQUIA>

Corporación Autónoma Regional de la Orinoquía has jurisdiction area in upper-stream area of Orinoco River Basin. CORPOORINOQUIA has almost same function as CAR and CORPOGUAVIO, which is in charge of formulation of policy and plan, and implementation of project and program. They have authorization to give environmental license and concession for water right in their jurisdiction area.

1.1.3 Natural Condition

(1) Meteorology

Formation of water resources in a region is closely related to climatic division of the region. It is commonly known that under a humid and rainy climate, the water resources are generally abundant and that on the other hand, under dry and arid climate, the recharge to surface and groundwater is small. Climatic division was done by Koeppen method.

(a) Distinction of Precipitation Pattern

Bogotá River Basin has an over 30 mm minimum monthly precipitation (35.6 mm) and the ratio between the values of the wettest and driest months is 2.47 (= 97.6 / 35.6), being much smaller than 10. Thus its climate is classified under the annual precipitation Pattern (f).

(b) Arid boundary Calculation

In determining the climatic zone, it is most important to distinguish between dry and wet climates. To do this, the arid boundary “r” is calculated using the following formula:

$$r = 20 \times (t + x)$$

The “r” is the Arid Boundary which is defined as the amount of water evaporated from a given region in one year. In the formula “t” is the annual average temperature, “x” is the factor determined based on the precipitation pattern. In the case of Bogotá River Basin, the value is seven (x = 7). Since the annual average temperature in Bogotá River Basin is 13.3°C (see Figure-3.8), the arid boundary is calculated as follows:

$$r = 20 \times (13.3 + 7) = 406\ mm$$

(c) Climatic Classification

Based on the analysis of the meteorological data collected from the 60 stations, the annual average precipitation in Bogotá River Basin is calculated to be 825 mm. This is more than 200% of the calculated arid boundary value “r”. Bogotá River Basin is, then, classified under the Humid Climate (C).

(d) Monthly Variation of Annual Precipitation

In Bogotá River Basin, the precipitation is rather uniformly distributed throughout a year and the difference between the minimum and maximum monthly precipitation is small. January is the month with the smallest precipitation and the precipitation shows a bi-modal pattern. The first peak is around April and May, the second October and November.

(e) Temperature

The monthly average temperature of the Study Area shows small variation, falling between 13°C and 14°C.

(f) Evaporation

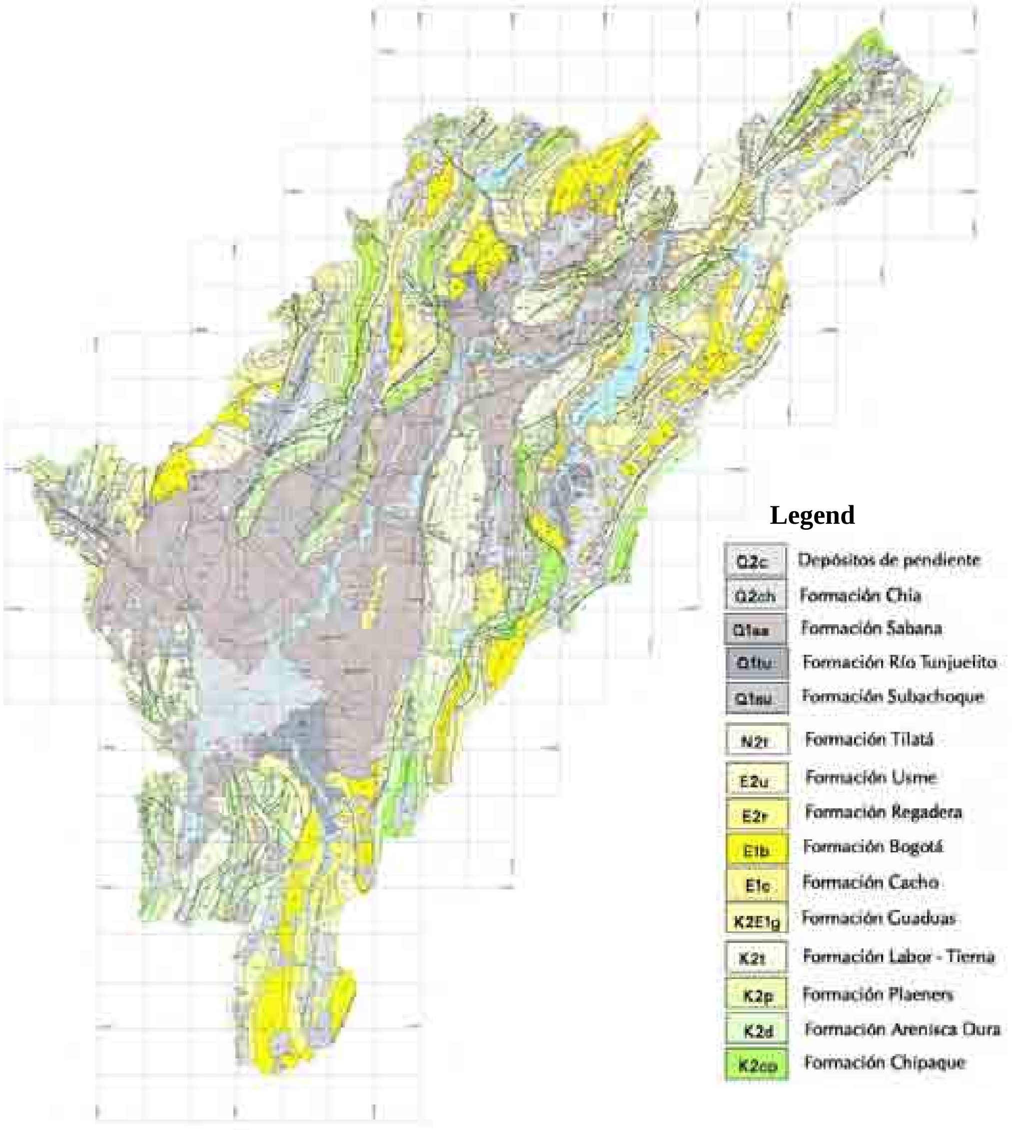
The seasonal fluctuation pattern of evaporation shows the highest peak in January and hits the bottom around May to July.

(2) Topography and Geology

Study Area is located in a basin spreading out in the top of the western slope of East Mountain Range, which traverses from south to north in the eastern part of the Colombian country. This basin is called Bogotá Plain, of which bottom has elevation of 2,500-2,600m, and the geographical surface of the basin is almost flat. On the other hand, the basin is surrounded by a mountain range and a hill.

The geological map of Bogotá Plain which contains Study Area is shown in Figure-2.1-1. The Bogotá Plain is composed of sedimentary rocks and sediments of Cretaceous-Quaternary, and igneous rocks are not distributed. The upper formations than the Chipaque Formation of Cretaceous are found in the Study Area.

The comprehensive geological structure of Bogotá Plain is characterized by the repetition of anticline and syncline having axis of NNE-SSW or NE-SW direction. The large-scale fault is mainly longitudinal one along the geological structure such as above mentioned. But, the geological structure in the Southern Hill area is irregular partly by a fault of NW-SE direction.



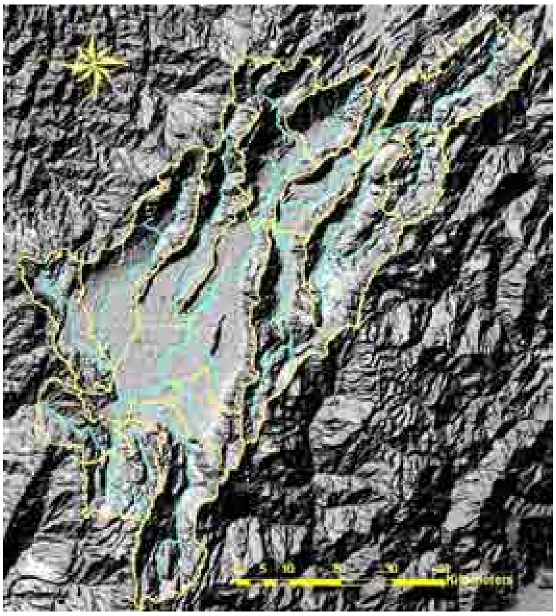
Source: INGEOMINAS

Figure-2.1- 1 Geological Map of Study Area

(3) Hydrology

(a) River System

The Study Area is the River Basin of Bogotá D.C. and the principal river is the Bogotá River. The area of the basin is 4,396 km^2 and it has an elongated shape extending in NE-SW direction. The Bogotá River main stream originates in the north-eastern part of the basin and flows southwest. The river eventually flows out of the basin in the southwest from the point where Tequendama waterfall is located. Bogotá River Basin has been divided into a total of 16 parts consisting of one basin of the main river stream and 15 others for the primary sub-basins as illustrated in Figure-2.1-2 and Figure-2.1-3.



Source: US-NASA

Figure-2.1- 2 Geological Map of Study Area

Source: US-NASA

Figure-2.1- 3 Redefined Division of Bogota River Basin River Basin based on DEM Data

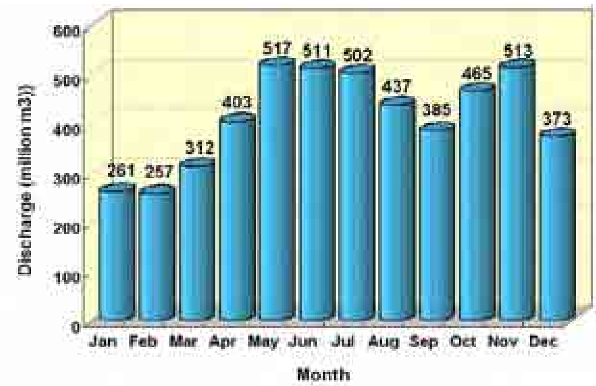
(b) Basic Characteristics of the River Regime

a) Average Flow Volume

The hydrological analysis revealed that the average flow volume at the terminal of the river stream in Bogotá River Basin (south-western exit) is 1.07 x 10^9 m^3 (approximately 33.9 m^3/sec).

b) Annual Flow Variation

Reflecting the annual precipitation pattern discussed earlier, the monthly river discharge is relatively stable throughout the year. The discharge pattern shows two peaks in May and November, which is comparable to the bimodal distribution of monthly precipitation.



Source: JICA Study Team

Figure-2.1- 4 Variation of Monthly Average River Discharge for 37 Rivers in Bogotá River Basin

(4) Hydrogeology

a) Aquifer Classification

Each stratum distributed in the Study Area is characterized by the geological age and its rocks.

Quaternary Aquifer

Groundwater currently pumped up by wells in the Study Area is stored in sand and gravel layers of Sabana Formation. Quaternary Aquifer consists of sand and gravel layers, which distribute irregularly in different depth with poor continuity.

<u>Tertiary Aquifer</u>

In the Study Area, Tertiary mainly consists of clayey sediments. Only small sand and gravel strata locally included in clayey strata can form aquifer. Tertiary is difficult for large scale groundwater development because the aquifer is too small.

<u>Cretaceous Aquifer</u>

Cretaceous system consists of Guadalupe Group (Labor-Tierna Formation, Plaeners Formation, Arenisca Dura Formation) and Chipaque Formation in the Study Area. Guadalupe Group forms excellent aquifer including Sand Formation. On the other hand, Chipaque Formation mainly consists of shale, and it can not be expected as an aquifer.

b) Hydrogeological Structure

Hydrogeological structure of the Study Area is strongly dominated by complicated geological structure, and distribution and continuity of aquifers are influenced by faults and folding. It seems that Quaternary, Tertiary and Cretaceous Aquifer form confined aquifers. Superficial aquifer of the Quaternary seems to form small-unconfined aquifer.

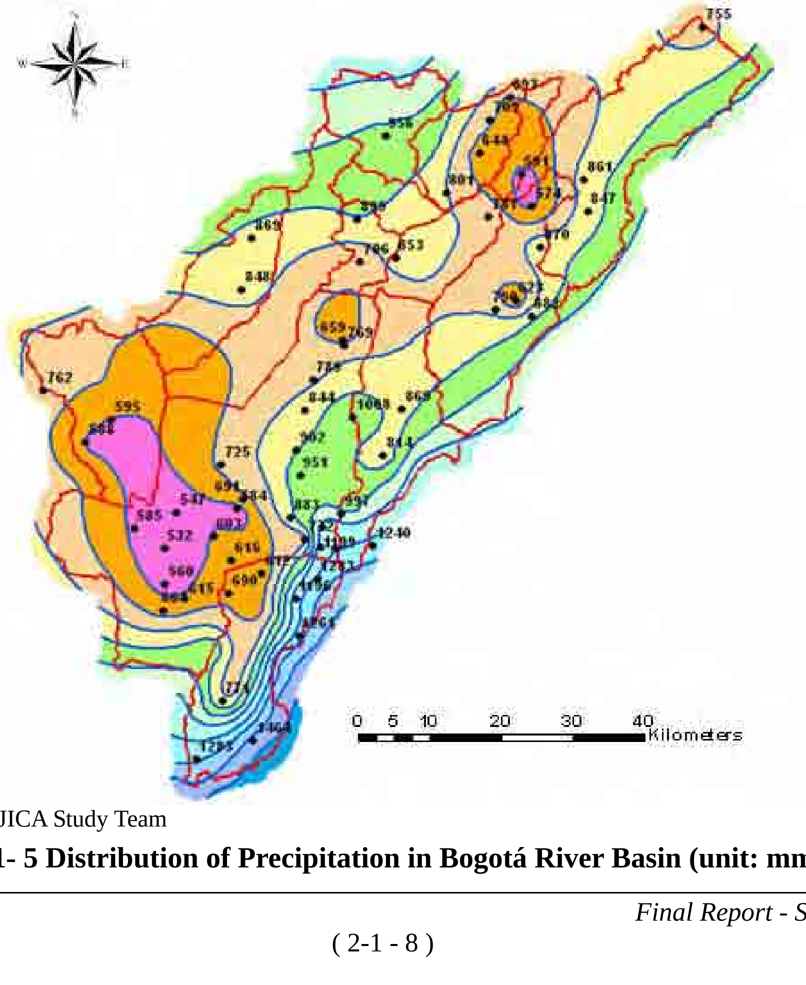
1.2 Water Resources in the Study Area

1.2.1. Surface Water

Surface water is the most important water resources in Bogotá River Basin and is used in many sectors. Due to the topographic characteristics of the basin, there are no inflows of both surface and groundwater from other basins, unless water is artificially transferred across watersheds. Therefore, precipitation is the only source of replenishing the water resources in Bogotá River Basin.

(1) Rainfall Distribution in Bogotá River Basin

Based on the precipitation data collected from the 60 observation stations for rainfall analysis, the average annual precipitation was found to show a large fluctuation ranging from 532 mm to 1,464 mm. the average annual precipitation in Bogotá River Basin was calculated to be 825 mm.



Source: JICA Study Team

Figure-2.1- 5 Distribution of Precipitation in Bogotá River Basin (unit: mm/year)

(2) Surface Water Resources in Bogotá River Basin

The specific discharge values for each sub-basin were calculated using the data from the gauging stations and their distribution by sub-basin was mapped out. Table-2.1-2 presents river discharge values along with precipitation values for all sub-basins in Bogotá River Basin.

Table-2.1- 2 Summary of Surface Water Resources in Bogotá River Basin

NAME	Method	Area	Discahrge	T_Disch.	Precip.	R_pcntg	D_runoff
Los Arboles	Estimation	62.7	11.5	11.5	667.6	27.5	155.4
Checua	Estimation	170.1	29.3	30.5	782.2	22.0	179.5
Neusa	Observation	68.5	23.3	65.7	940.7	21.1	198.7
	Estimation	261.9	42.4				
Chicu	Observation	142.9	35.8	53.7	795.0	20.5	162.8
	Estimation	186.8	17.9				
Subachoque	Observation	214.4	20.3	39.5	753.0	13.2	99.2
	Estimation	183.5	19.2				
Bojaca	Observation	93.5	24.0	42.1	684.9	27.9	191.3
	Estimation	126.6	18.1				
Sub Total		**1,511**	**241.7**		**793.0**	**20.2**	**160.0**
Bogota(U)	Estimation	337.1	98.4	98.4	851.3	34.3	247.0
Bogota(M)	Estimation	152.3	22.2	22.2	759.8	19.2	123.2
Bogota(L)	Observation	7.4	2.9	88.5	699.3	20.4	142.7
	Estimation	613.1	85.6				
Bogota(E)	Estimation	154.8	43.4	43.4	691.3	40.6	214.6
Sub Total		**1,265**	**252.4**		**792.1**	**25.2**	**199.6**
Sisga	Estimation	154.3	48.3	48.3	880.4	35.6	265.0
Tomine	Observation	94.7	76.0	150.7	840.9	44.4	373.1
	Estimation	309.3	74.7				
Teusaca	Observation	160.9	82.5	109.8	963.6	34.0	327.6
	Estimation	174.3	27.3				
Fucha	Observation	25.6	22.4	37.3	925.8	30.5	281.9
	Estimation	106.7	14.9				
Tunjuelo	Observation	383.7	168.8	170.4	1,030	41.8	431.0
	Estimation	11.8	1.6				
Soacah	Estimation	199.2	59.2	59.2	778.7	38.2	226.5
Sub Total		**1,620**	**575.8**		**915.5**	**38.8**	**355.4**
Total		**4,396**	**1,070**		**825**	**29.5**	**243.4**

Source: JICA Study Team

Note: Area : Square kilometer (km2)

Discharge: Observed discharge and estimated discharge for the area where the discharge could not be obtained from observation result. (Unit: Million m^3)

T_Discharge: The combination observed and estimated discharges for each basin.

R_pcntg: The ratio in percentage of runoff to precipitation

D_runoff: depth of runoff. Average depth in mm/year

1.2.2. Groundwater

Groundwater is an important source of water in Bogotá River Basin although its domestic consumption is small. The amount of groundwater used in year 2000 was 0.32 million m^3/day. This accounts for 14% of the total water use volume of 2.672 million m^3/day across the whole Bogotá River Basin. When groundwater is developed, it is important to plan the consumption amount in careful consideration of possible recharge amount. Otherwise, improper use of groundwater can cause excessive drawdown of groundwater table and other negative consequences.

CAR, INGEOMINAS, and JICA study team analyzed and estimated the amount of recharge from precipitation to groundwater in the past and reported the values of 36 mm/year (CAR), 8 mm/year (INGEOMINAS), and 145 mm/year (JICA, 2003) respectively. All these three studies employed the water balance method to calculate the groundwater recharge values. The estimated values of evapotranspiration showed large differences and this led to the significant variation in the final estimated values of groundwater recharge. In estimating evapotranspiration, many parameters are required. Thus, if there is any difference in any of these parameters, the calculation results will generally be different as well. Furthermore, calculation units (daily or monthly etc.) can also affect the results.

In this study, the same method was adopted as the principal tool to calculate groundwater recharge amount for easier comparison of the calculation process and the results. However, as mentioned previously, a large error may be expected depending on the choice of values for each input parameters. Therefore, in this study, some other methods were concurrently employed to estimate groundwater recharge. The methods employed and their results are summarized below.

a). Water balance method

b). Climatic Division Method

c). River Discharge Method

d). Tank Model Method

1.2.3. Water Quality Survey

(1) Water quality in the Study Area

a) Bogotá River

From the standpoint of pollution, water quality in the Bogotá River Basin can be divided into four sectors ranging from upstream to downstream. Details on water quality are described in the Supporting Report.

Sector from river source to Villapinzón

The water quality of this section is very good, with a BOD lower than 2 mg/ℓ.

Sector from Villapinzón to Chocontá

There are a total of 171 tanneries within the sector. Effluents from these factories are discharged untreated into the Bogotá River significantly compromising water quality. Further downstream, however, the influx of discharge from numerous tributaries into the Bogotá River has an auto-cleaning effect serving to improve water quality.

Middle reaches of the Bogotá River (urban Bogotá area)

As the Bogotá River pass though the urban area, water quality worsens dramatically. The domestic waste of the entire population of Bogotá, which is 6.4 million, is discharged into the Bogotá River. Main rivers flowing Bogotá urban area are the Salitre River, Fucha River and Tunjuelo River. The only Wastewater Treatment Plant within the Bogotá Metropolitan, the Salitre WWTP area is located at junction of Bogotá River and Salitre River. This plant carries out only primary treatment and organic treatment is not carried out. It results in a low BOD elimination rate. Untreated sewage water is discharged into the Bogotá River through Fucha River and Tunjuelo River.

Sector from Subachoque River to Magdalena River

From urban area up to Tequendama falls, auto-purification of river discharge cannot be expected due to low flow velocity. However, in the sector from Tequendama Falls to the junction with the Magdalena River, BOD is 18-34 mg/ℓ and OD is 2-7 mg/ℓ indicating a recovery in water quality.

As described above, water quality in urban area (mid reaches of the Bogotá River) exhibits degradation. Responding to above situation, Acueducto and CAR have already formulated plans for sewage infrastructure improvement and are now at the stage of moving to implement these projects. It is anticipated that implementation of the projects will significantly improve water quality of the Bogotá River.

Chingaza and Sumapaz River Basin

From Water quality test results for the Chingaza River Basin, it is concluded that river water is a safe source of potable water.

(2) Groundwater Quality

a) Quaternary Aquifer

Numerous wells exhibit water quality that exceeds Colombian standards in coloration, turbidity, bacillus *Coli*, ammonia, pH, Fe and Mn. Furthermore, although there is no water quality stipulations in Colombia standard, Ba, H_2S values exceed WHO water quality standards (guideline). Accordingly, it is concluded that drinking untreated groundwater from Quaternary Aquifer poses a significant health risk.

b) Cretaceous Aquifer

Although values exceeding standards in H_2S, Mn, Fe and coloration are observed in groundwater from Cretaceous Aquifer, these are minimal in degree compared to groundwater from Quaternary Aquifer. A major difference with the Quaternary Aquifer is the fact that almost no NH_4 is detected in groundwater from Cretaceous Aquifer. It can accordingly be concluded that there is a difference in the groundwater quality between the Cretaceous and Quaternary Aquifer.

(3) Supplementary water quality survey

a) Survey sites

Groundwater and surface water in the Study Area was sampled, and water quality of the sampled water was analyzed. The sampling was done covering the entire Bogotá Metropolitan Area. For this survey, 20 existing well sites and 15 river sites were selected for water sampling.

b) Results of supplementary water quality testing

c) Rivers

In the case of the Bogotá River, Cr^{+6} (hexavalent chromium) has been detected around Tibitóc due to inflow of tannery effluents in the upper reach. Other items are generally satisfactory. Nevertheless, water quality degrades dramatically as river passes through the urban area. For example, although turbidity value is 6-50 NTU at the upper reach of urban area, this value rises to 200 NTU at lower reach of the urban area. Dissolved oxygen (OD) value is zero because wastewater is released untreated from Bogotá urban area into the rivers. Cr^{+6} values are a high 0.1-0.3 mg/ℓ. NH4 values are also high, which is attributed to the anaerobic characteristic of river sedimentation.

d) Wells

A large number of the wells exceed the standard value for the items of Fe, Mn and NH_4 throughout the Study Area. It is clear that the high concentration of Fe and Mn is related to the geological condition of the area. By the comparison in geological condition, the concentration of Mn in the Quaternary groundwater is much higher than that in the Cretaceous groundwater. Overall, groundwater quality is good in the Eastern Hills (Cretaceous Aquifer) even though it exhibits a little high concentration of Fe and Mn. NH_4 and hydrogen sulphide (H_2S) was detected in the groundwater. However, it can not be by groundwater contamination.

1.3 Water Use and Management of Water Resources

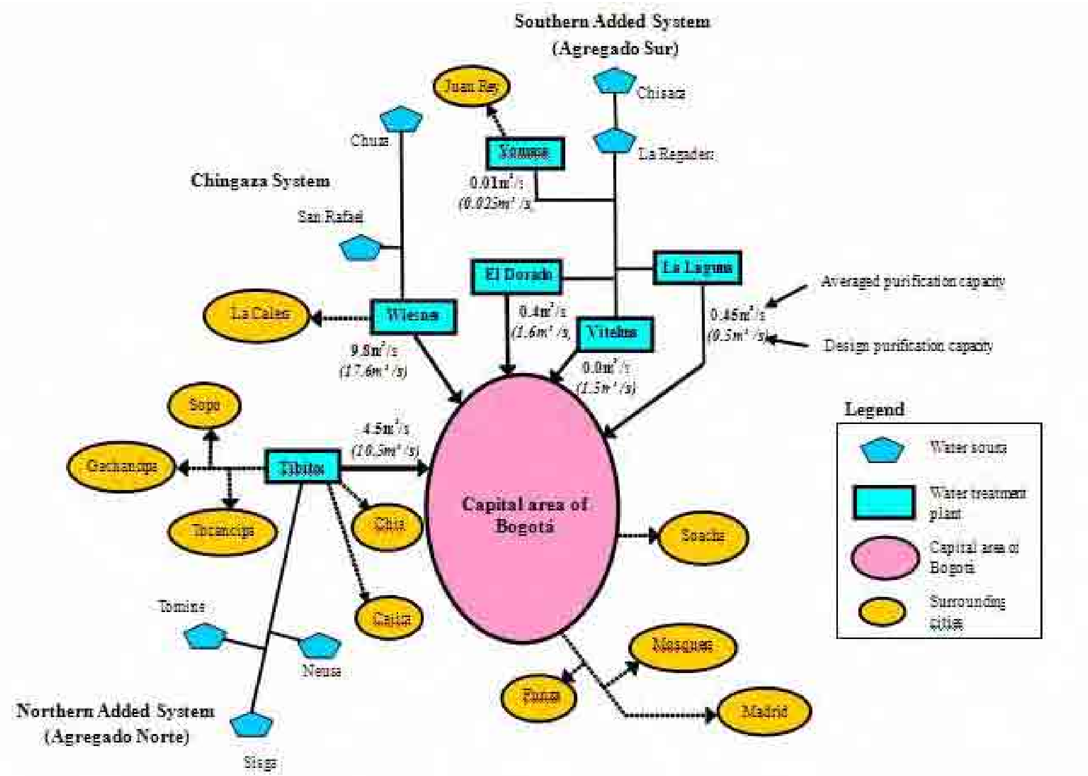
1.3.1 Existing Water Supply Facilities

(1) Outline of Water Supply System of Bogotá

Acueducto is responsible for water supply and sewerage services in the capital district and surrounding 11 cities. Coverage ratio of water supply has reached to about 100%. Acueducto is well-organized and has been conducting proper operation and maintenance with a high level of technology. Water sources for Water Supply System of Acueducto are divided into the following:

- Chingaza System.
- Northern added System (*Agregado Norte*).
- Southern added System (*Agregado Sur*).

There are seven (7) Water Treatment Plants where the raw water is conveyed from the above water sources. However, among these plants, five (5) plants are in normal operation and two plants out of the five plants are operated alternatively. The conceptual drawing for Water Supply System of Bogotá and the surrounding cities are as shown below:



Source: Acueducto

Figure-2.1- 6 Conceptual Drawing for Water Supply System of Bogotá and Surrounding Cities

(2) Water Source and Water Conveyance System

As mentioned before, there are three (3) water sources for Water Supply System of Bogotá Capital Area: Chingaza, Northern added System and Southern added System. Capacity of each reservoir is as shown in Table-2.1-3.

Table-2.1- 3 Water Sources for Water Supply System of Bogotá Capital Area

Water Source	Reservoir	Effective Storage Volume (MCM)
Chingaza System	Chuza	223.0
	San Rafael	70.0
Northern Added System (Agregado Norte)	Sisga	101.2
	Tominé	691.0
	Neusa	101.0
Northern Added System	Aposentos	0.8
Southern Added System (Agregado Sur)	Chisacá	6.7
	La Regadera	3.7

Source: Acueducto

(3) Water Purification System

Allocated volume under the water right for each water source, the related water treatment plants and their design/current production volume are as shown in Table-2.1-4.

Table-2.1- 4 Water Sources and Production Volume of Water Treatment Plants

Water Treatment Plant (WTP)	Water Source	Design Purification Capacity (m^3/s)	Averaged Purification Volume (m^3/s)
Tibitoc	Northern added system	10.50	4.50
Wiesner	Chingaza system	17.60	9.80
El Dorado	Southern added system	1.60	0.40
La Laguna	Southern added system	0.50	0.50
Vitelma	Southern added system	1.50	0.00
San Diego	Southern added system	0.21	0.00
Yomasa	Southern added system	0.02	0.01
Total	-	31.94	14.71

Note: El Dorado WTP and La Laguna WTP has the same water source. Usually, El Dorado WTP is operated. However, La Laguna WTP will be operated in case of some accident or periodical maintenance in El Dorado WTP.

Source: Acueducto

(4) Water Transmission and Distribution System

Water Transmission and Distribution System in Bogotá is divided into three (3) primary systems as follows:

- Wiesner System.
- Tibitóc System.
- El Dorado System.

Wiesner System and Tibitóc System are inter-connected and thereby water supply can be manipulated in case of accidents or emergency. El Dorado System is separated from other two primary systems and it covers Southern hill area.

Wiesner System is considered as the most important system in Bogotá, accounting for approx. 70% of the total water distribution volume in the capital city. Tibitóc System covers approx. 30% and El Dorado System accounts for less than 1%.

(5) System for Controlling Water Supply and Sewerage Facilities

Water supply and sewerage facilities managed by Acueducto are all monitored and/or controlled by SCADA System at the central control center located west of Bogotá city.

1.3.2 Water Consumption

(1) Actual Water Consumption of Bogotá, Soacha and Gachancipá

Acueducto supplies water directly to the users in Bogotá, Soacha and Gachancipá.

Table-2.1-5 presents the water consumption (m^3/month) from 2002 until 2006.

Table-2.1- 5 (Consumption 2) (1,000 m^3/month)

Sector	Classification	2002		2003	2004	2005	2006		Increase [1]
Residential	Estrato 1	1,071.7	**6%**	1,152.3	1,225.0	1,266.8	1,309.5	**8%**	**237**
	Estrato 2	5,773.9	**33%**	5,762.6	5,736.8	5,769.8	5,695.1	**33%**	**-78**
	Estrato 3	6,568.4	**38%**	6,546.0	6,271.8	6,301.5	6,158.7	**36%**	**-410**
	Estrato 4	2,129.7	**12%**	2,141.5	2,090.6	2,123.9	2,175.8	**13%**	**46**
	Estrato 5	958.1	**6%**	927.2	894.0	915.0	931.6	**5%**	**-26**
	Estrato 6	886.1	**5%**	857.8	850.2	892.5	884.3	**5%**	**-2**
	Subtotal	17,387.9	**100%**	17,387.4	17,068.4	17,269.4	17,155.0	**100%**	**-233**
Non-residential		5,465.5	-	5,687.6	5,128.5	5,312.6	5,543.4	-	**78**
Total		22,853.4	-	23,075.0	22,196.9	22,582.0	22,698.4	-	**-155**

Note: 1) Consumption of 2006 that increased or decreased compared with that of 2002. 2) Average of the year.

Source: JICA Study Team based on the data of Acueducto (Gerencia Corporativa Servicio al Cliente)

Table-2.1-6 presents the estimated unit water consumption, litter/day/capita, from 2002 until 2006.

Average unit consumption of year 2006 was estimated at 100 litter/day/person as shown in Table-2.1-6.

Table-2.1- 6 Estimated Unit Consumption (litter/day/person)

Sector	Classification	2002	2003	2004	2005	2006
Residential	Estrato 1	107	110	101	97	97
	Estrato 2	112	115	109	105	100
	Estrato 3	105	109	103	99	96
	Estrato 4	103	112	105	102	99
	Estrato 5	126	130	125	122	119
	Estrato 6	140	149	147	145	137
	Average	109	114	108	104	100
Non-residential	liter/day/ establishment	1,261	1,548	1,281	1,288	1,275

Note: For the calculation of the unit consumption, census figure of 4.0 persons per household were applied for every year.

Source: JICA Study Team based on the data of Acueducto (Gerencia Corporativa Servicio al Cliente)

Table-2.1-7 shows the average water charge of the year to the users from 2002 until 2006. The average charge has been continuously rising; however, due to the drastic tariff change in July 2004 – see (3) of this chapter -, the charge to Estrato 1 decreased from 2005, and that to Estrato 2 and Estrato 3 also from 2006.

Table-2.1- 7 Water Charge of the Year (Col$/m^3)

Sector	Classification	2002	2003	2004	2005	2006
Residential	Estrato 1	550	733	823	816	732
	Estrato 2	936	1,133	1,277	1,415	1,401
	Estrato 3	1,551	1,878	2,067	2,306	2,252
	Estrato 4	1,956	2,184	2,210	2,316	2,326
	Estrato 5	2,999	3,389	3,186	3,223	3,596
	Estrato 6	3,761	4,085	3,672	3,464	3,863
	Average	1,527	1,783	1,868	2,009	2,019
Non-residential		1,977	2,007	2,258	2,393	2,436

Note: Water charge is an average of the year.

Source: JICA Study Team based on the data of Acueducto (Gerencia Corporativa Servicio al Cliente)

1.3.3 Facilities for Sewage Drainage and Treatment

(1) Present Status of Sewage Systems in Bogotá Urban Area

The sewage service coverage in Bogotá urban area is 85-90%.On the other hand, not all collected sewage is subsequently treated. Main sewage pipeline and wastewater treatment facilities exist only within the Salitre System. Although sewage pipelines are under construction in some parts of Bogotá, sewage at present runs untreated into tributaries of the Bogotá River. Even in the case of the Salitre treatment plant, BOD elimination rate is around 65%.

The following three main tributaries within the Bogotá urban area as well as the Soacha area are under the sewage treatment jurisdiction of Acueducto.

a). Salitre System

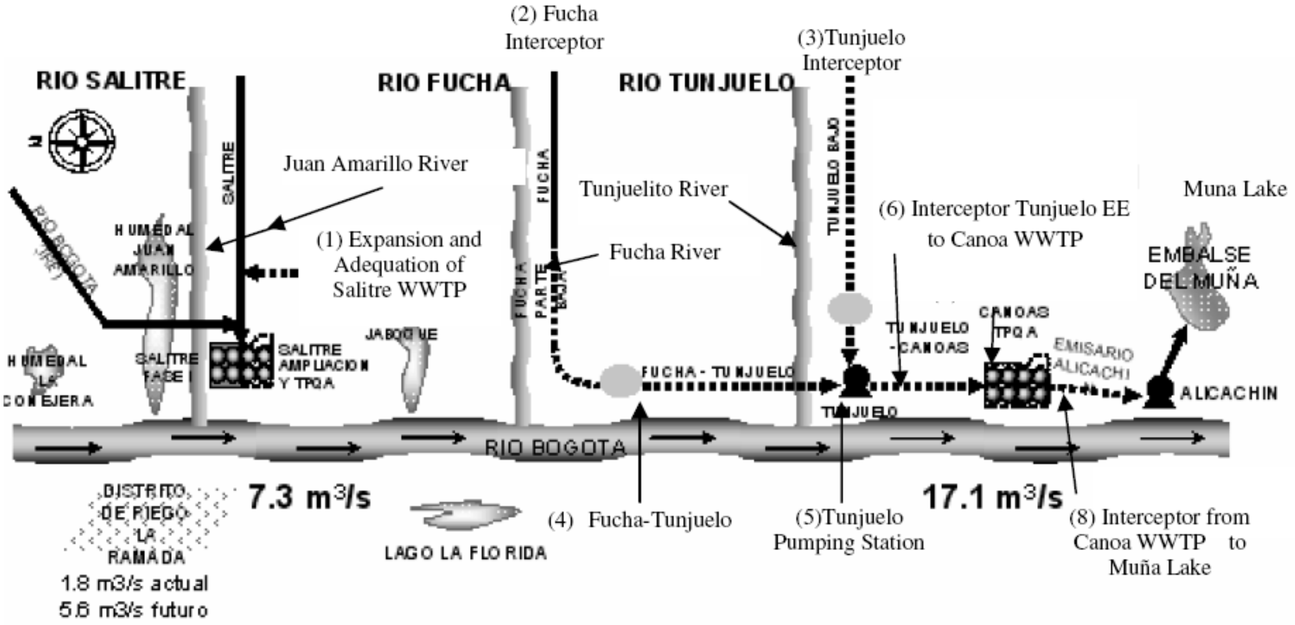
b). Fucha System

c). Tunjuelo System

d). Soacha System

(2) Ongoing and Future Sewage Infrastructure Projects

In order to upgrade measures to cope with sewage from the Bogotá Metropolitan area, Acueducto is either currently executing, or planning for the future, the projects described below. Figure-2.1-7 gives an overview of the target area.



Source: Acueducto

Figure-2.1- 7 Overview of sewage infrastructure projects

(3) Doña Juana Waste Disposal Plant

Solid waste from the Bogotá Metropolitan area as well as neighboring municipalities is processed at the Doña Juana waste disposal plant. Bogotá municipal agency with jurisdiction over the plant is UAESP.

Type of waste

The plant processes (by landfill) 6,000 tons/day of general waste, 12 tons/day of medical waste, and 150 tons/day of sewage sludge. The plant does not handle industrial waste.

(4) Sewage Infrastructure outside the Bogotá Metropolitan Area

Outside the Bogotá Metropolitan area, CAR directly carries out construction, operation, administration and maintenance of sewage infrastructure.

Project for water quality improvement by CAR

CAR implemented the construction of small-scale wastewater treatment plants at 27 locations in 24 municipalities. CAR oversees project facility design and construction. Authority for facility operation and maintenance then shifts to the respective municipality (*municipio*) after completion of construction.

Current problem in existing sewerage

After handing over from CAR, the municipality cannot bear cost as well as technical requirements in terms of facility maintenance. As a result, facilities have gone without operation. Accordingly as of October 2005, CAR has consigned operation and maintenance of sewage treatment facilities to the private sector.

New project for water quality improvement

As of October 2006, a new funding agreement for US$ 5 million was signed with IDB. This funding will be directed at both expanding water service infrastructure and improving sewage facilities.

1.3.4 Water Resource Management

Water resources management in Bogotá Plain is implemented by CAR and SDA in quantity and quality. Water user in Bogotá Plain must be registered to SDA and CAR. This registration system has important function for water resources management by SDA and CAR.

Water resources management by SDA

SDA is in charge of management of groundwater resources in Bogotá urban area. Every users of groundwater has to be registered to SDA. Currently, around 400 wells are registered to SDA. Owners of the registered wells have to pay for water use. Monitoring of registered well is conducted by SDA every month for management of groundwater resources.

Water resources management by CAR

CAR implements water resources management based on the result of analysis for water resources development potential on surface water and groundwater that was analyzed by CAR. Water resources management in quantity is implemented by restriction and control of water right. Therefore, every user of water resources in Bogotá Plain has to be registered to CAR. The water user can get concession for water use based on the development potential that was evaluated by CAR. CAR collects tariff of water right from the registered users.

1.3.5 Water quality management and monitoring system

Water quality of rivers flowing through and from the Bogotá Metropolitan area is managed and monitored by SDA and Acueducto. In the case of rivers and wells outside the urban area within the Bogotá Plain, water quality is managed and monitored by CAR.

(1) Acueducto

Acueducto possesses a laboratory. Acueducto has established 155 locations for gathering drinking water samples. Samples are taken at 52 locations each day. Surface water samples are taken at 60-70 sites one time every four months. In addition, SDA and Acueducto jointly carry out water quality testing for effluents from almost all factories (approximately 800) within Bogotá urban area.

(2) SDA - Secretaria Distrital de Ambiente de Bogotá

The SDA performs water quality management for river discharge, factory wastewater, wells, groundwater and marshland. Specifically, effluents from 800 factory sites are tested, and rectification guidance is provided in cases where test results exceed acceptable level. SDA is empowered to fine or suspend operations in the case of a factory that fails to improve substandard effluent water quality.

(3) CAR - Corporación Autónoma Regional

CAR carries out water quality management and monitoring in the entire Cundinamarca Department outside the Bogotá urban area. The agency carries out regular water quality testing of surface water, groundwater, domestic wastewater, industrial wastewater and discharge from waste treatment plants. In the course of water quality testing, CAR collects surface water samples at 280 locations four times per year and groundwater samples at 101 locations one time per year. In addition to water management, CAR investigates the results of water quality testing when they evaluate granting water rights or environmental license.

1.3.6 Ecosystem and Natural Environment

(1) Bogotá River Basin

Economic development and environmental conservation

In Colombia, the Bogotá River Basin is the most economically diversified area. About the land use within the basin area, the flower crops are main production in the agriculture, which represents 80% of the total of the national production. On the other hand, the breeding of cattle and the dairy industry are the economic basis of this area. The hydraulic resources are used for many different purposes, agriculture, cattle-breeding, industries, mining, water supply, hydroelectricity, etc.

Urbanization and water balance

In addition, rapid urbanization leads also to an increase in the water demand. The increase in the supply and demand of water due to the expansion of socio-economic activities causes restrictions in the use of the water resources in quantity aspect, which sometime makes disputes over the water right and is controlled by the water resources management. In the quality aspect, it must be considered that the Bogotá River receives the sewage of 6.4 million inhabitants from the Metropolitan area of Bogotá and 430 thousand inhabitants from the 26 municipalities that are located in the Bogotá River Basin. The pollution is extremely critical because of the erosion and the accumulation of soil, waste treatment and untreated sewage.

Bogotá Wetland

In relation to the wet lands within the urban area of Bogotá, there are only 13 remaining along the Bogotá River. However, dwellings are already encroaching upon these wet lands. The water quality was also found to be quite polluted and in risk conditions due to the houses invasion, factories construction and the flushing of domestic and industrial water. The Environmental Department of Acueducto and SDA are in charge of the environmental conservation of the 13 wet lands within the urban area of Bogotá. This is not related to the CAR plan for the wet lands recovery.

(2) Ecosystem and Natural Environment Affected by Groundwater Development in the Eastern and Southern Hill

Forest protection area

The Eastern and Southern Hills are located at elevations of 2,600-3,000 m. Elevations in the Eastern above 2,700-2,750 m comprise forest reserve (*protección forestal*) as controlled by the CAR. Tree felling trees and building structure within this area is strictly controlled.

None of the Southern Hill has been designated as forest reserve. Urbanization has proceeded within the Bogotá Metropolitan area outside the forest reserve. There are accordingly no natural forests, or no rare and endangered wildlife species within this urban area.

Water resources

The catchment area of the Eastern Hill is small, characterized by the absence of any major rivers. Small mountain streams disappear during the dry season. Rivers in the area account for only about 1% of potable water source.

Impact by groundwater development

The target area in the Eastern Hill for groundwater development by the proposed project comprises vacant land and grazing land located between the urban area and the forest reserve. This area will require no human resettlement by the project. Also, the groundwater development area within the Southern Hill lies outside the belt of concentrated human habitation, and solely comprises livestock grazing land. There is neither natural forest nor lakes within this grazing land area.

(3) Ecosystem and natural environment affected by the Chingaza No. 2 Dam and the Sumapaz diversion plan

The planned sites for Chingaza No. 2 Dam (Playa Dam) and Sumapaz diversion plan are located between elevations 3,000-4,000 m in the mountainous Páramo zone. Annual average temperatures within this area ranges 0-10°C, and the natural environment comprises low scrub, high altitude vegetation, peatland and wetland.

(4) Socio-environmental Impacts from Chingaza No. 2 Dam

Under the plan for Expansion the Water Supply System, Chingaza No. 2 Dam (Playa Dam) and the Sumapaz diversion plan (Chisacá Dam and Muña Dam) will have the greatest impact on the natural environment.

Impact to natural environment

Project impact on the natural environment will occur in the highland of the Paramo area, which is populated with rare plant and animal species. Specifically, dam construction will have a large impact on the natural environment. Nevertheless, due to the fact that the area is highland with little forest, there will be no large scale cutting of the forest.

Impact to social environment

In terms of social impact, the project area is uninhabited and therefore entails no resettlement of residents. Furthermore, Acueducto will not require land acquisition, as necessary land has already been appropriated for the Chingaza II project at the time of implementation of the Chingaza I project.

Environmental impact assessment

The Chingaza II project EIA (environmental impact assessment) was prepared in 2002. However, due to postponement of project implementation, the EIA report has not yet been submitted to MAVDT and other concerned agencies.

1.3.7 Artificial Groundwater Recharge

Artificial groundwater recharge was proposed in the previous JICA Study in view point of groundwater conservation. According to the pilot study of the previous study, the Cretaceous Aquifer in the Eastern Hills showed high capacity of artificial recharge. Groundwater artificial recharge is effective for conservation of groundwater resources of the Eastern Hills.

Use of facilities for Artificial Recharge

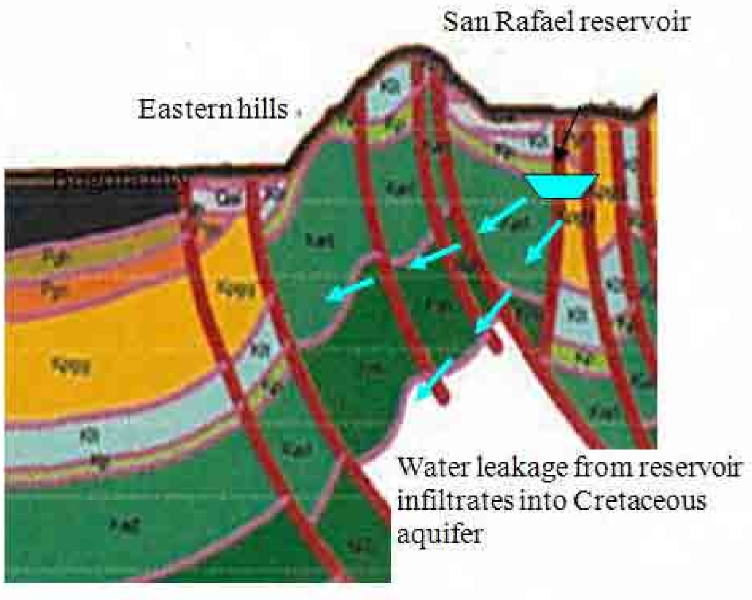
Facilities for artificial recharge still remain in the Vitelma site, which can be operated again in future for artificial recharge.

Perennial rivers in the Eastern Hills are limited to few rivers, such as San-Cristobal River, San-Francisco River and Yomasa River. Artificial recharge is available in upper part of above three rivers.

(1) Groundwater Recharge from San-Rafael Reservoir

San-Rafael Dam is located over Cretaceous formation of the Eastern Hills. It is assumed that some amount of water of the reservoir is infiltrating into the Cretaceous Formation though bottom of the reservoir,as shown in Figure-2.1-8.

Water leakage from bottom of the reservoir was evaluated by daily-calculation during January 1998 to March 2001.



Source: JICA Study Team

Figure-2.1- 8 Water leakage from San Rafael Reservoir

According to the calculation result, monthly average of water leakage from San-Rafael Reservoir is 3.7 m^3/s. This amount of water is infiltrating into the Cretaceous Aquifer of the Eastern Hills, which will increase groundwater development potential on the area.

In formulation of groundwater development in the Eastern hill, possibility of water leakage from the San-Rafael reservoir, which will act same as groundwater recharge, should be taken into account.

1.3.8 Result of Groundwater Monitoring

It is said that groundwater level of Quaternary aquifer is continuously going down. Groundwater level automatic recorders were installed into 10 wells in Bogotá Plain during the previous JICA Study, in year of 2001. Auceducto is still continuing the monitoring of groundwater level by the automatic recorders until now. Sites for monitoring wells are shown in Figure-2.1-9.

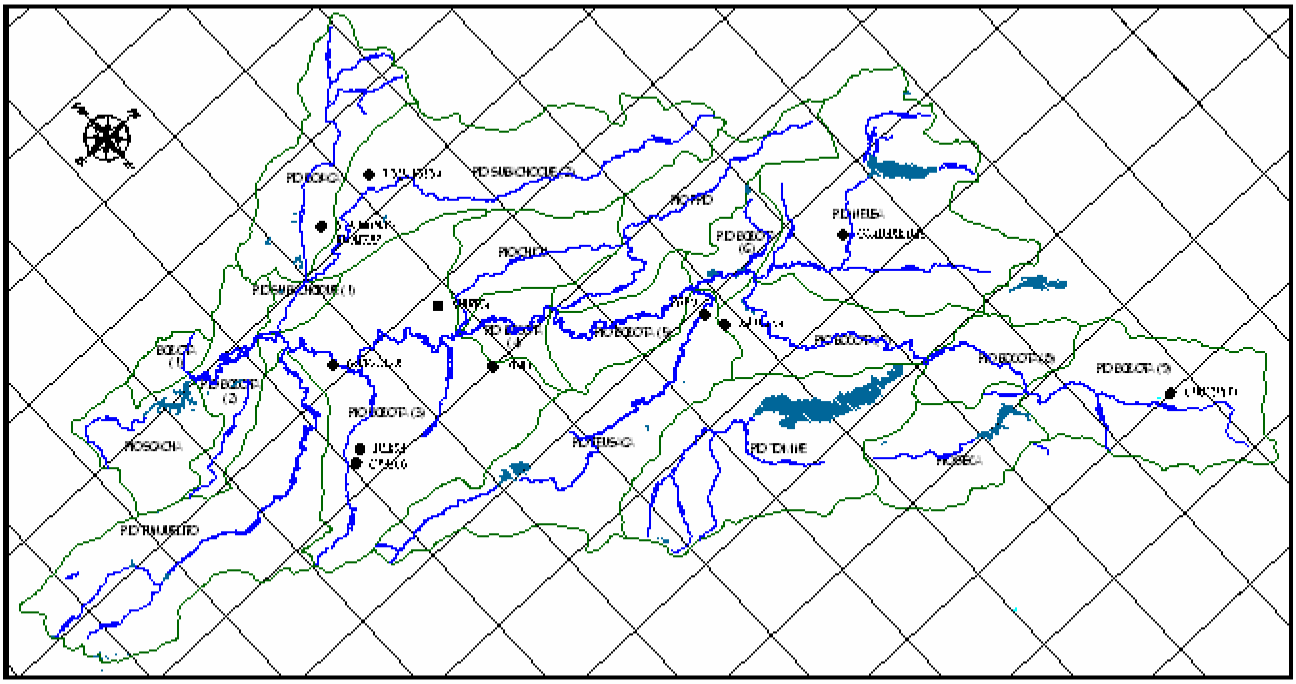


Figure-2.1- 9 Monitoring Site

(1) Result of Monitoring

Groundwater level was recorded by automatic recorders during 2001-2008 at 10 monitoring sites. Three (3) different fluctuation of groundwater level are found in long-term monitoring results. These are:

a). Long-term trend

b). Seasonal fluctuation

c). Daily fluctuation

From above analysis, important conclusions below were resulted.

(Conclusion-1) Groundwater level of Quaternary is not going down for long period of time

(Conclusion-2) Groundwater level of Quaternary aquifer is clearly responding to rainfall. It means that Quaternary aquifer is receiving groundwater recharge from rainfall.

More than 7,000 wells were drilled in Quaternary aquifer of Bogotá Plain, where amount of 300,000m^3/day of groundwater is pumped up every day. However, groundwater level of Quaternary is not going down, responding to seasonal and daily rainfall. Currently, groundwater recharge is much greater than pumping rate, and excessive groundwater (=groundwater recharge – pumping amount) is flowing within aquifer. Such a condition implies that there is more potential for groundwater development, as long as it is less than total groundwater recharge.

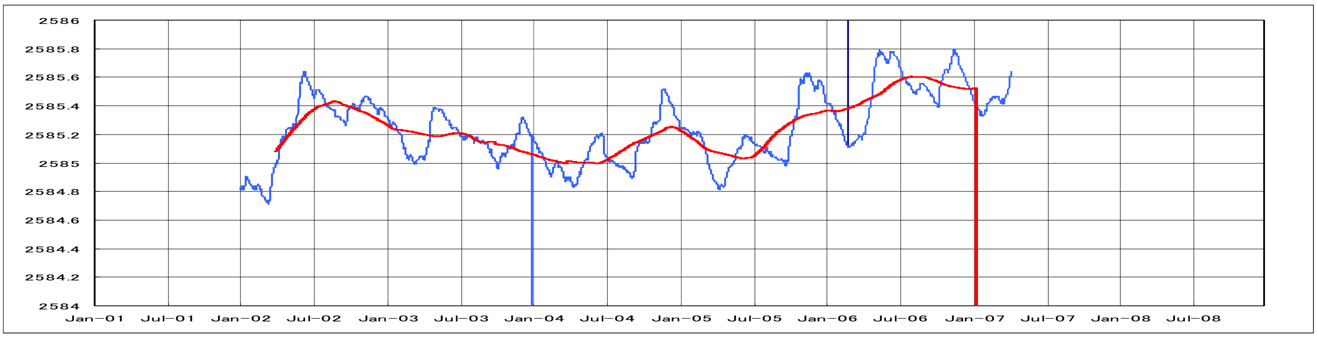


Figure-2.1- 10 Groundwater Level and Long-term Trend (Moving average)

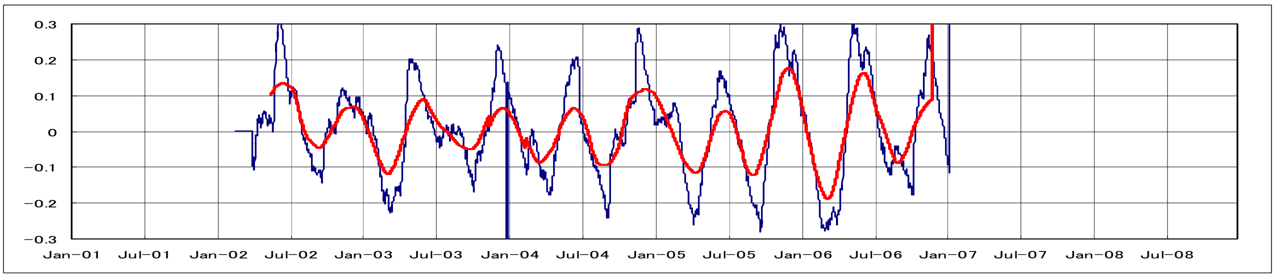


Figure-2.1- 11 GUADARRAMA Monitoring Site

CHAPTER 2. IDENTIFICATION OF ISSUES IN CURRENT WATER SUPPLY

2.1. Security of Water Supply in Emergency

The Mayor of Bogotá addressed through the Degree 332 of 2004 that public entities of Bogotá City has to establish an inter-institutional work for disaster prevention attention for emergency such as seismic events. In corresponding to this, the public entities of Bogotá have made clear of their vulnerability and formulated plan to mitigate it. They submitted the plan to DPAE in 2006. Following the background above, Acueducto has studied the components of risk in the water supply system such as water intake/conveyance/transmission/distribution, identifying seismic disaster as the emergency situation that can affect the normal operation for water supply to Bogotá City.

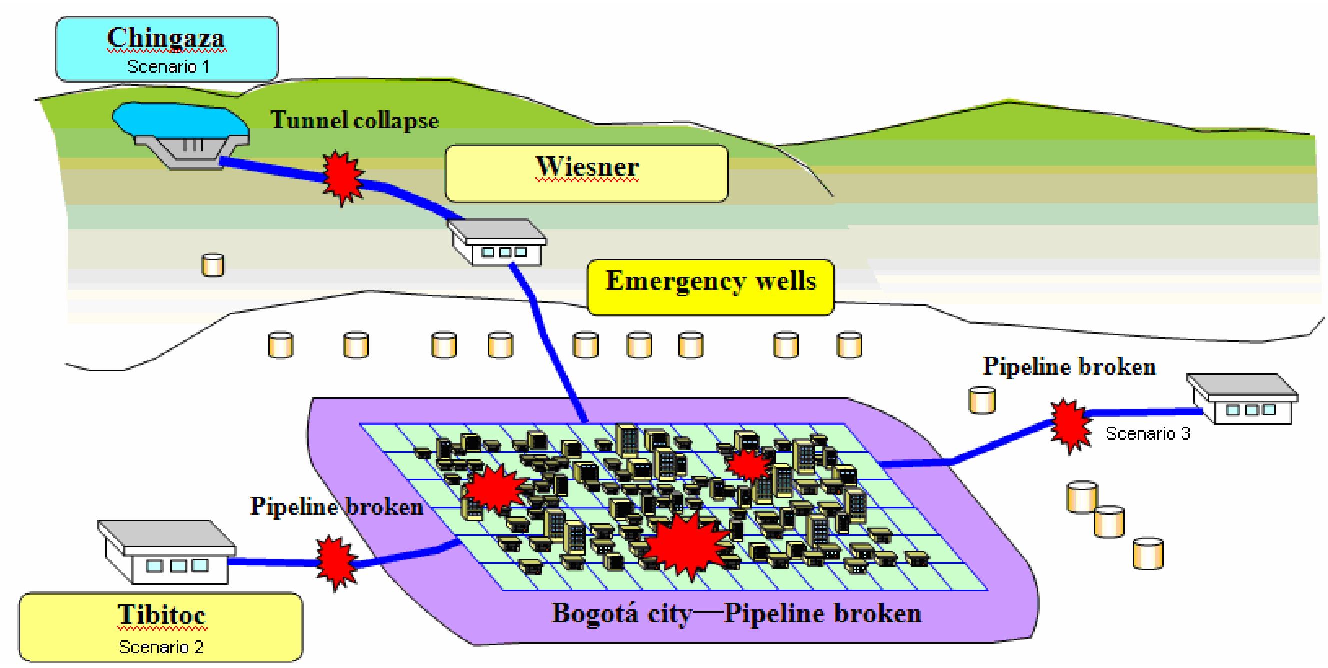
(1) Disaster Scenario by Earthquake

For formulation of Emergency Water Supply Plan, disaster scenarios are necessary. The disaster scenario for big earthquake was assessed by two reports below:

a) The Study on Disaster Prevention in Bogotá Metropolitan Area in the Republic of Colombia (JICA, 2002).

b) Evaluación por pérdida Máxima Probable (PML) por Terremoto para Infraestructura Indispensable de la Empresa de Acueducto y Alcantarillado de Bogotá (Acueducto, 2006).

The highest emergency situation is assumed as outbreak of big earthquake. Concepts of possible emergency is show in Figure-2.2-1.



Not necessarily simultaneous

Source: JICA Study Team

Figure-2.2- 1 Possible Concepts of Emergency no simultaneously

<u>Disaster Scenario by "The Study on Disaster Prevention in Bogotá Metropolitan Area in the Republic of Colombia (JICA, 2002)"</u>

In this report, damage to water supply facilities of Bogotá Metropolitan Area was analyzed. Disaster Scenario proposed by this Study was summarized as shown Table-2.2-1.

Table-2.2- 1 Disaster Scenario in Water Supply for Outbreak of Large Earthquake

Items	Earthquake Scenario		
	Case-1 La Cajita Earthquake	Case-2 Duayuriba Earthquake	Case-3 Subduction Earthquake
Peak ground acceleration	Max Acceleration 0.908g	Max Acceleration 0.361g	Max Acceleration 0.125g
Estimated Damage of water pipelines (No. of damaged points)	3,753 points	1,545 points	16 points

Source: JICA Study: Study on Disaster Prevention for Bogotá Metropolitan Area, 2002.

Situation in outbreak of La Cajita Earthquake (Case-1) is predicted as below:

< Situation in outbreak of La Cajita Earthquake >

- Water supply will be suspended by damage of water pipeline due to earthquake. Emergency water supply will be implemented. However, it will be insufficient and water shortage will occur. Acueducto will begin recovery of damaged water pipeline. It will take long time to recover water supply, and water shortage will continue for long period.
- Ground acceleration will be big in the south of Bogotá City such as Usme, Ciudad-Bolívar, San-Cristóbal and Soacha city, where damage will be more serious. Liquefaction will occur in low plains of the south of Bogotá city due to earthquake, which cause serious damage to water pipelines.

Disaster Scenario according to "Evaluación por pérdida Máxima Probable (PML) por Terremoto para Infraestructura Indispensable de la Empresa de Acueducto y Alcantarillado de Bogotá (Acueducto, 2006)"

Damage to water intake and water conveyance system by big earthquake was analyzed by Acueducto in this report. Eight (8) seismic centers were assumed along a major fault line of the Eastern Range. These seismic centers are located in the area of Chuza Reservoir of Chingaza System.

Different earthquakes simulations were performed in order to identify the power of the seismic waves and their effect under different epicenters and estimate the possible damages. The results of this simulation are in the above mentioned inform.

(2) Existing Preparedness for Disaster Prevention

(a) Emergency Response System of Acueducto

Emergency response system of Acueducto is as follows:

Reinforcement of facilities for anti-seismic

- Water supply facilities including tunnels/tanks/pipelines, which are located in dangerous area in case of earthquake, were selected. These facilities are under anti-seismic reinforcement works.
- Acueducto is conducting construction works to reinforce water conveyance tunnel.

Security of Water in case of Emergency

- Water in San-Rafael Reservoir will be used for emergency water supply. San-Rafael Reservoir can store amount of water to be treated in Wiesner Plant for three (3) months.
- Maximum capacity of Tibitóc Plant is 10.5 m^3/s, though concession for water right is currently 4.8 m^3/s given to Tibitóc Plant. However, Acueducto can take more water to increase production rate of Tibitóc Plant, under permission from CAR, when water conveyance from Chingaza is suspended.

- In case of emergency, closed plants, La-Laguna, Vitelma and San-Diego Treatment Plant, will be operated again.

(b) Immediate Response System of Acueducto

Manual for immediate response

A manual for emergency response has been prepared, which instructs activities to be performed for immediate response to disaster (see appendix-1).

Operation of the Central Control Center

The Central Control Center can monitor condition of operation system time to time. Based on monitoring result, the Center will automatically control each facility. This system can be responsive in case of emergency by natural disaster.

(c) Alternative water sources in case of emergency

In "Study on Groundwater Development for Bogotá Plain" (JICA, 2003), groundwater development in the Eastern and Southern Hills was proposed for alternative water source in case of emergency. Importance of groundwater in case of emergency was also proposed in M/P by Acueducto in 2005.

2.2. Water Supply in Residential Area of Low-income Group at High Altitude

Actual conditions of Water Supply and use, in the residential areas of low-income group at the high altitude, were studied through the following two surveys: 1) Social activities of Acueducto and 2) Socio-economic survey.

(1) Social Economic Survey

1) Survey Area

The Study Team selected finally 15 survey areas according to the following criteria:

- The area located at Eastern and Southern Hills.
- The area of the low income community located at over 2,750 m.
- The area without water supply by Acueducto.

2) Questionnaire Survey

The questionnaire survey of 200 households has been carried out in 15 areas.

3) Analysis of Survey

- In the survey area, 1,057 persons live with an average of 5.2 persons per family. The coverage ratio of public services is very low: water supply 14%, sewerage 23.3%, gas 1%, and telephone 25%.
- The inhabitants don't seem to be suffering from health problems. The reason is that most of them, 61%, are attended by SISBEN (*Sistema de Seleccion de Beneficiarios para Programas Sociales*) health system.
- Regarding the monthly income, 70% of the households earn between Col$ 300,000-1,000,000. Regarding the monthly expenses, 60% of the households spend between Col$ 300,000-1,000,000.
- Regarding the water supply, 32% of the households are supplied from the community-self supply system, and 25% are illegal intakes from Acueducto. And 24% of the households get water from local plastic tanks and springs that are prepared by Acueducto.
- As to the water quality, 45% who get water legally or illegally from Acueducto answered well. On the other hand, 32% who are supplied from the community-self supply system answered bad: neighbors like Ciudad Londres, San Manuel, La Cecilia, Caracolí, Sierra Morena, Verbenal and La Fiscala Fortuna.

4) Future Water supply for Low income Group at High Altitude Area

Social survey was carried out in the areas that have not yet received water supply by Acueducto. Acueducto has responsibility of water supply for urban area, where water supply is almost 100%. On the other hand, public water supply by Acueducto is prohibited for areas out of the urban area. According to the regulation, settlement in such an area without public water supply is illegal.

- Water supply for illegal settlement will promote further illegal settlement. Therefore, Acueducto intends not to implement public water supply for such areas.
- On the other hand, Acueducto is implementing water supply by water wagons and temporary water supply pipelines for residence out of the urban area.

It is estimated that around 40,000 people of illegal settlement does not receive public water supply by Acueducto. It is 0.6% of the total population of Bogota urban area. Their unit water consumption rate is 7 liters/person/day, which is not enough but barely satisfies water demand for human survival. Condition of water supply for illegal settlement should be improved within the current legal framework.

On the other hand, high altitude area in the Eastern and Southern hills has high groundwater development potential. However, as mentioned above, Acueducto will not implement ordinary water supply for those areas. Therefore, residents, living at high altitude out of urban area, do not become target of water supply by new groundwater development proposed in this Study.

2.3. Water Right Granted to Acueducto

(1) Water Right

Water right belongs to Government of Colombia. Water use and exploration for water resources need a) concession for water use and b) permission, respectively.

Water concession in Table-2.2-2 shows approved ones only and does not include the pending ones. Moreover, water concessions, which have been nominally kept but practically difficult to be used, are also excluded.

Table-2.2- 2 Concession for Water Use Right by System

Supply System	Organization to authorize	Water with concession (m^3/s)	
		Authorized/Applied	Current use
Chingaza	UAESPNN	12.32	9.5
	CAR	0.90	0.0
	Total	**13.22**	**9.5**
Tibitóc	CAR	4.80	4.5
South	CAR	1.00	0.5
Total		**19.02**	**14.5**

Source: Acueducto

(2) POMCO

Relating for water resources development in the Eastern Hills, "Plan for management of river basin of the Eastern Hill" (POMCO) was completed in 2006.

Water resources development and use in the Eastern Hills

Water resources development and its use needs concession from CAR and SDA. Application for concession will be submitted to CAR and SDA though committee of water use in the Eastern Hills.

Effect by POMCO in water resources development in the Eastern Hills

POMCO puts emphasis on conservation of ecosystem out of urban area of the Eastern Hills. Therefore, water resources development should be implemented within the urban area of the Eastern Hills. On the other hand, water resources development is possible even out of the urban area in the Southern Hills.

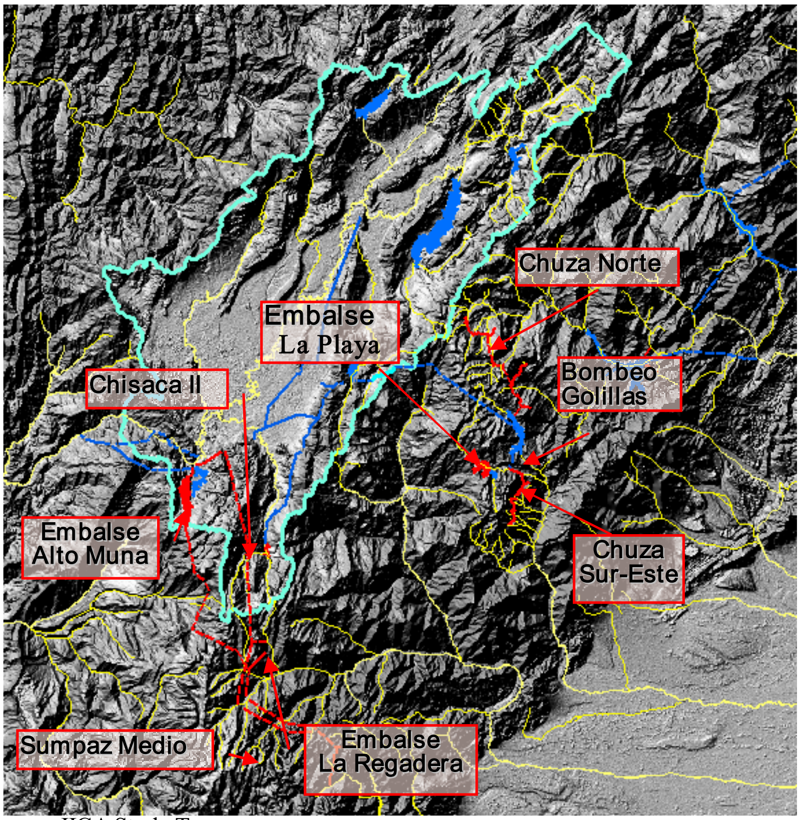
CHAPTER 3. POTENTIAL FOR WATER RESOURCES DEVELOPMENT

3.1 Surface Water Development Potential

(1) Surface Water Development

No major water shortage problems have been encountered in the water supply sector. However, taking into account of the trend of economic and population growth in Bogotá and accompanying rise in quality of life of people are considered, it is expected that new water resources development is necessary after year of 2028. In order to solve this future problem, Acueducto has a plan to introduce more water from outside the basin by expanding the capacity of Chingaza System and the others.

According to the water supply expansion plan being discussed in Acueducto, facilities expansion is planned in the Chuza Dam area and also in Sumapaz area, both outside the basin, in order to secure civil water supply. The project names and locations are given in Figure-2.3-1.



Source: JICA Study Team

Figure-2.3- 1 Acueducto Water Supply Expansion Plans and Projects Sites

(2) Chingaza Expansion Plan

The catchment area affecting the expansion project in Chingaza lies completely outside Bogotá River Basin. The average ground elevation in the catchment area is 3,393 m.a.s.l. and the total area is 223 km^2. Data for 28 years from 1971 to 1998 was used to calculate the specific discharge. The value was found to be 38.5 ℓ/sec/km^2. The amount of water to be supplied by this expansion project is, then, calculated as follows:

$$223\,km^2 \times 38.5\,l/sec/km^2 = 8.5\,m^3/sec$$

According to the Chingaza Expansion Plan, amount of water to be developed is 6.13 m^3/sec, less than above estimated value, can be realistic in hydrogeological view point.

(3) Development Plan in Sumapaz

It is located to the south of Bogotá River Basin and most of the catchment areas lie outside the basin with only a small northern portion within the basin. The average ground elevation in the catchment area is 3,434 m.a.s.l and the total area is 678 km^2. It is a general hydrological fact in Sumapaz area that the higher the altitude, the higher the precipitation.

The Development Plan in Sumapaz was evaluated using the relation above. The amount of water that can be collected for implementation of the project can be estimated by multiplying the catchment area by the specific discharge value as follows.

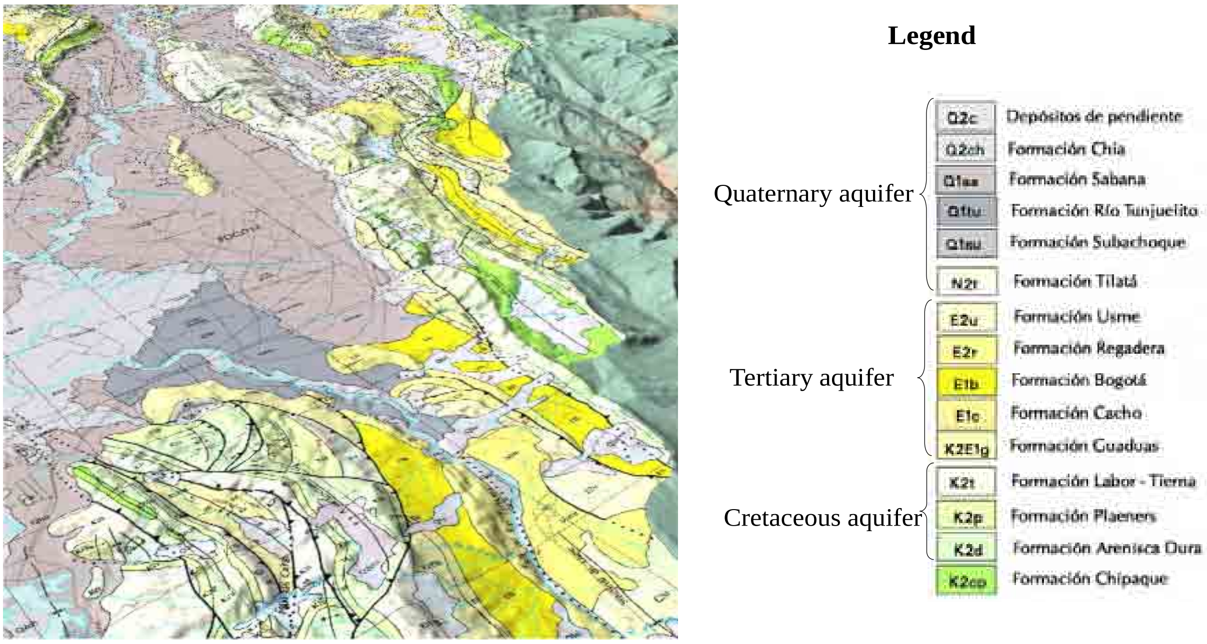
$$678\ km^2\ (Area) \times 19.1\ l/\sec/km^2\ (Specific\ discharge) = 12.95\ m^3\ /\ s$$

3.2 Groundwater

3.2.1 Distribution of Aquifer

As for the distribution area of Cretaceous Aquifer, it forms steep mountains generally. As for the distribution area of Tertiary Aquifer, it forms gentle slope of piedmont. As for the distribution area of Quaternary Aquifer, it forms low-lying plain. (Figure-2.3-2)

The Tertiary Aquifer is distributed beneath the overlying Quaternary Aquifer, and the Cretaceous Aquifer is further distributed beneath the Tertiary Aquifer continuously, of which relation is observed from the mountain area.



Source: INGEOMINAS arranged by JICA Study Team

Figure-2.3- 2 Relationship of Topography and Aquifer distribution

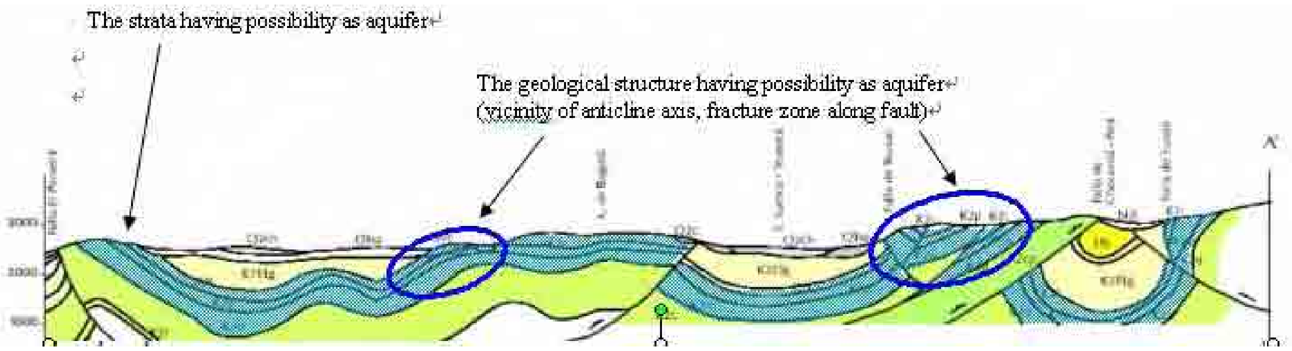
<u>**The strata having good condition for storing groundwater**</u>

A stratum, which is rich in the crack, will become a capable aquifer, because groundwater is stored in cracks. The Cretaceous rocks consisting of the sandstone, the mudstone, the claystone, and so on are distributed widely in the Study Area. Anticlines and synclines are running repeatedly in the Study Area. Many cracks will develop more easily in the sandstone than in the other rocks when they suffer a structure movement, because the sandstone is more hard and brittle than the mudstone, the claystone, and so on.

From such a viewpoint, Arenisca Dura Formation and Labor-Tierna Formation may become capable aquifer in the Study Area because they consist mostly of sandstone.

The geological structure having good condition for storing groundwater

Generally, geotectonic position, where many cracks in the rock mass will develop, is fracture zone along a fault. Moreover, open crack often develops in the vicinity of anticline axis, and it can be expected as excellent aquifer. Geological condition mentioned above is desirable for existence of aquifer.



Source: INGEOMINAS

Figure-2.3- 3 Hydrogeological Structure of the Study Area

3.2.2 Geophysical Survey

(1) Field Method of Geophysical Survey

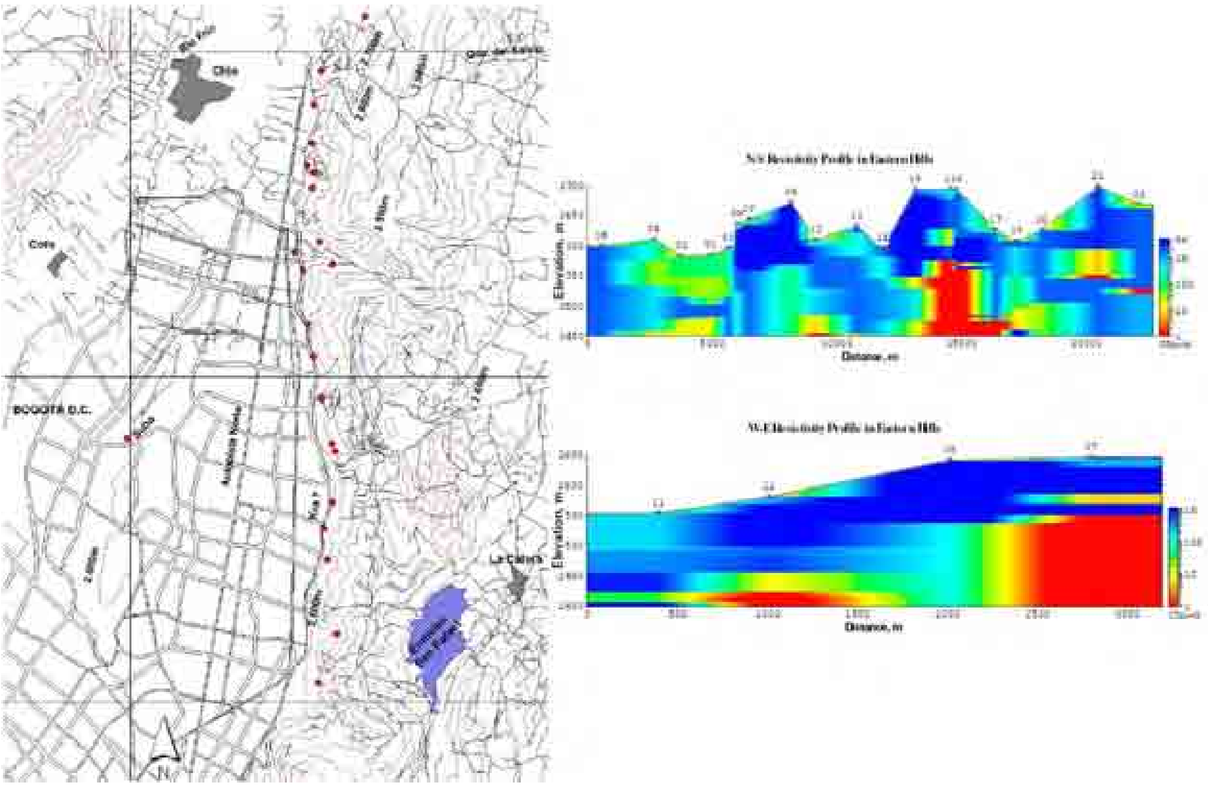
(a) TEM method was applied for geophysical survey in this Study. TEM is one of Electromagnetic (EM) geophysical techniques which induce electrical currents in the earth using electromagnetic induction.

TEM survey was carried out in three areas, Southern Hills, Eastern Hills and Usme area. TEM survey points are shown in Figure-2.3-4, Figure-2.3-5 and Figure-2.3-6.

(2) Results of Survey

a) Eastern Hills

TEM survey was conducted at 22 points in the Eastern Hills. Most of points in Eastern Hills have been interpreted as two resistivity layer model, which consists of high-resistive first layer and low-resistive second layer.



Source: JICA Study Team

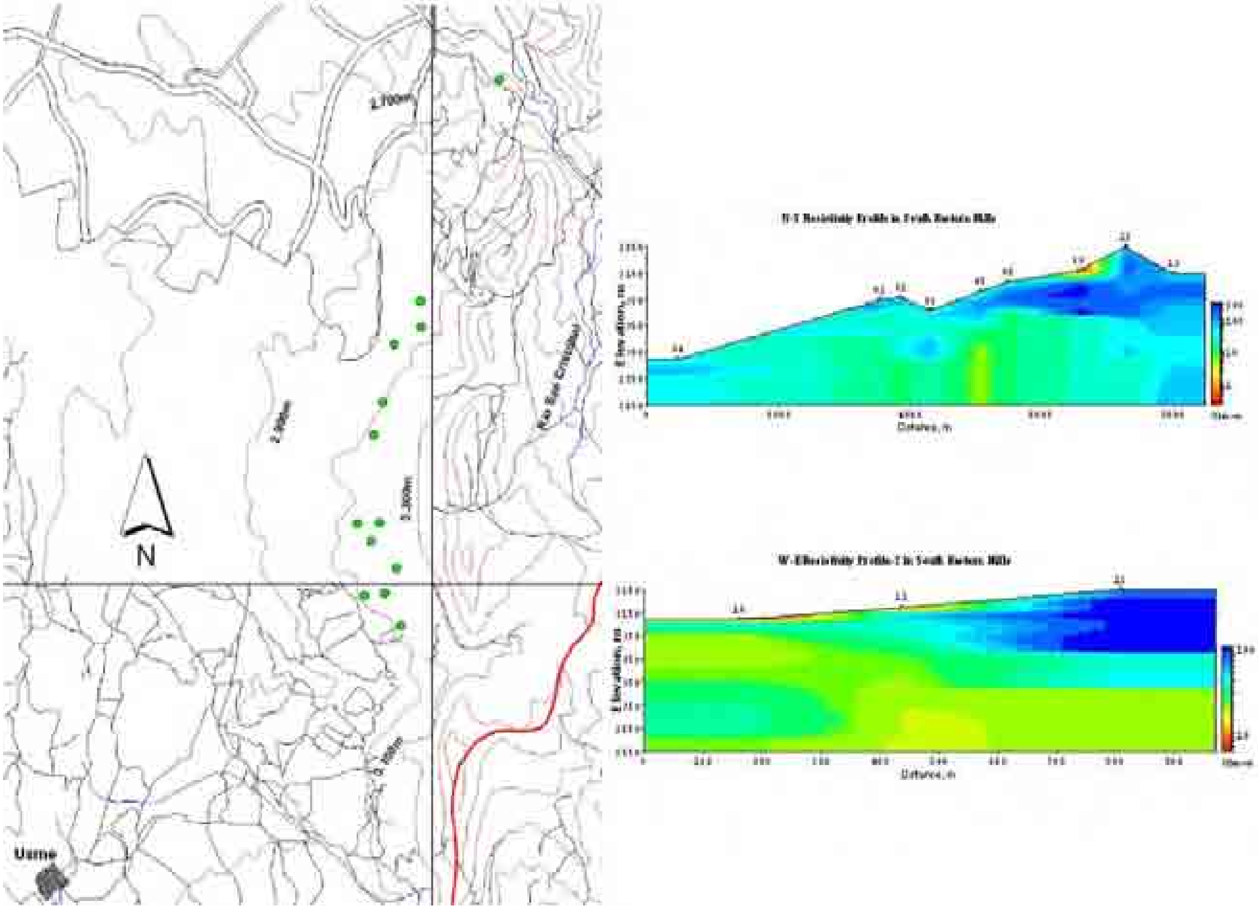
Figure-2.3- 4 TEM Survey Points and Analyzed Results in Eastern Hills

b) Usme Area

TEM survey was conducted at 13 points in Usme area. Most of points have been interpreted as two resistivity layer model, which consists of high-resistive first layer and low-resistive second layer. Generally, the first layer of the observation points, located at higher altitude of the hills, shows higher resistivity and greater thickness. On the other hand, first layer of the observation points, located at lower altitude of the hills, do not show high resistivity, which is contrast to those at higher altitude.

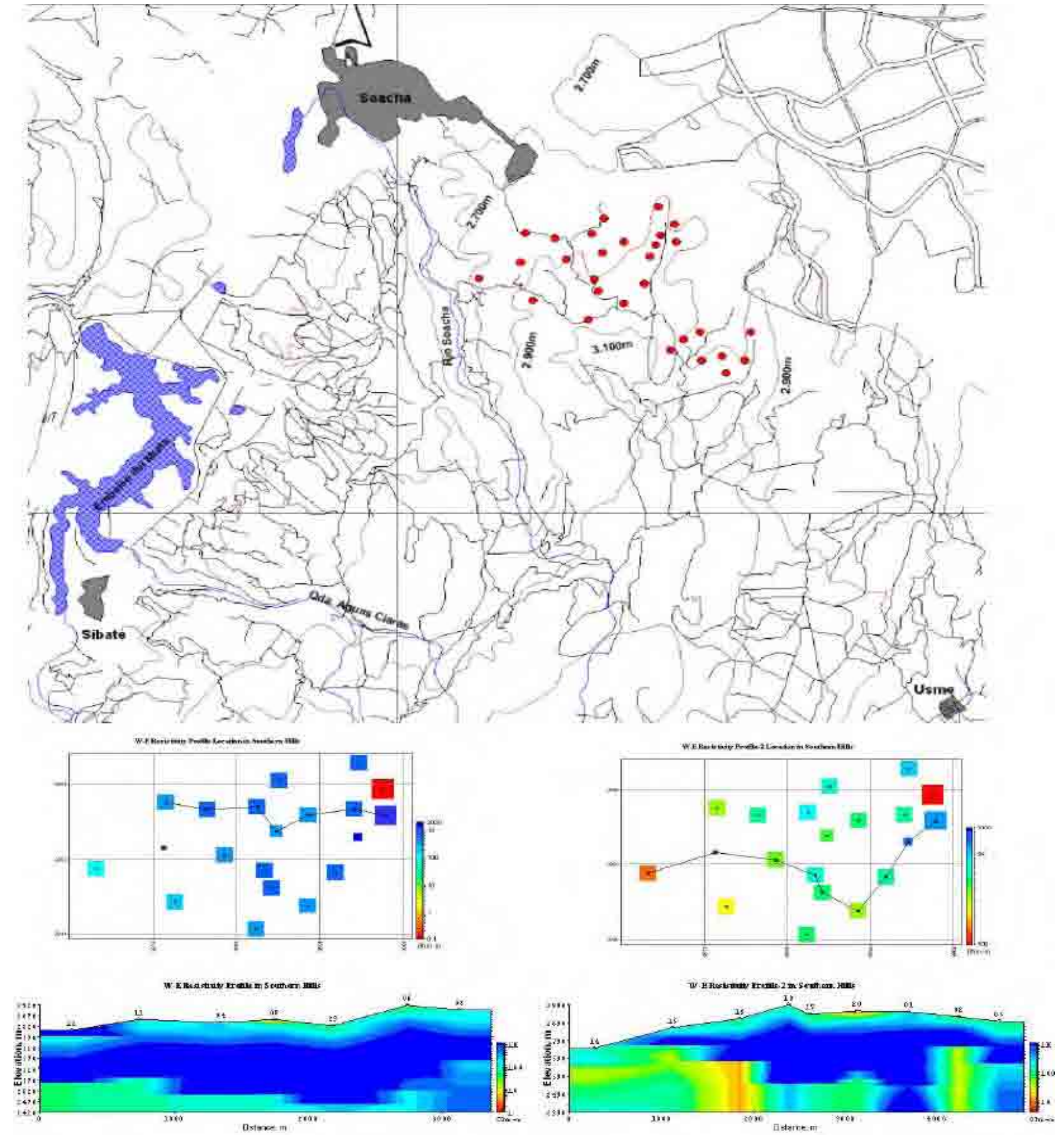
c) Southern Hills

TEM survey was conducted at 29 points in Southern Hills. Most of observation points in Southern Hills have been interpreted as two resistivity layer model, which consists of high-resistive first layer and low- resistive second layer. The first layer has extremely high resistivity more than thousands Ωm and its thickness is more than 100 m. The second layer has low resistivity less than 10 Ωm.



Source: JICA Study Team

Figure-2.3- 5 TEM Survey Points and Analyzed Results in South of Eastern Hills (near Usme)



Source: JICA Study Team

Figure-2.3- 6 TEM Survey Points and Analyzed Results in Southern Hills

(3) Interpretation of Aquifer Distribution

The Eastern and Southern Hills were classified, based on TEM survey, in hydrogeological view points. Criteria for classification are as follows:

- Stratum with electric receptivity more than 100Ωm → It is sandstone, with possibility of aquifer
- Stratum with electric resistibility less than 100Ωm → It is shale, with possibility of aquiclude

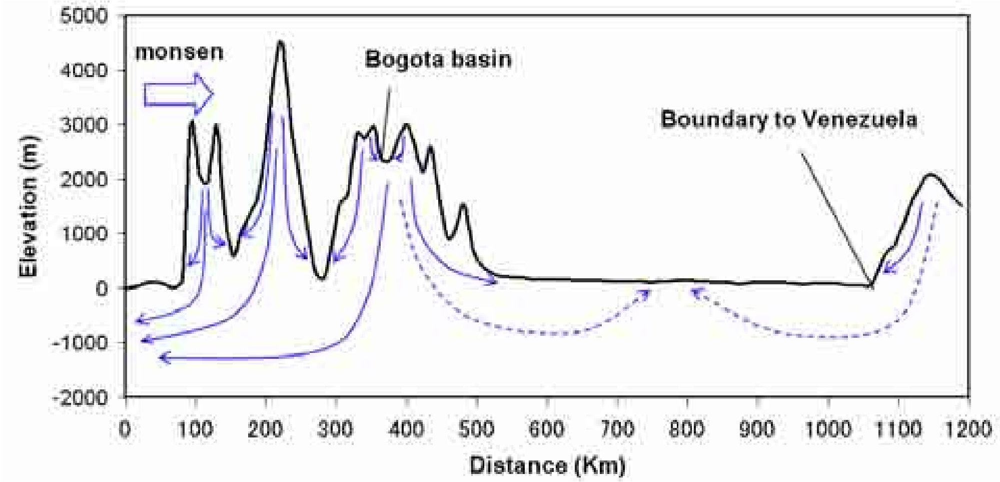
---

Sandstone and shale makes complicated alternation in the Study Area. In interpretation of TEM result, strata of the Eastern and Southern hills were simplified and classified into only two strata, i) sandstone dominant stratum and ii) shale dominant stratum.

3.2.3 Groundwater Development Potential

(1) Groundwater Flow System

Figure-2.3-7 shows a cross-section from the Pacific Ocean in the west to Venezuela in the east, crossing through Bogotá River Basin. As long as the groundwater table elevation at Bogotá River Basin is higher than those of the surrounding area, the groundwater flow from Bogotá basin to the surrounding lower elevation area is sustained. This, in return, indicates that the groundwater levels would keep on falling, if there were no recharge to groundwater in Bogotá River Basin.



Source: JICA Study Team

Figure-2.3- 7 Groundwater Flow System in Bogotá River Basin and Surrounding Areas

(2) Water Balance Method

The water balance method has been used by several institutions to analyze groundwater recharge. The following equation is derived for the water balance method.

$$P = D + E + Rd \qquad (1)$$

P : Precipitation.
D : River Discharge.
E : Evaporation or evapotranspiration.
Rd: : Recharge to deep aquifer.

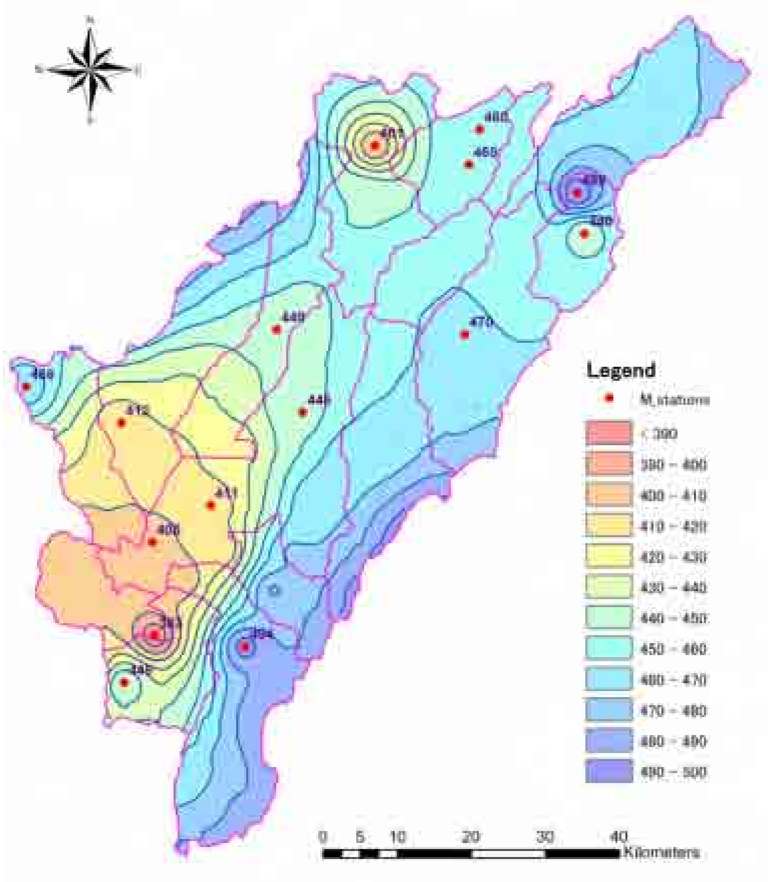
Transposing two terms in equation (1), the following relation is obtained.

$$Rd = P - D - E \qquad (2)$$

Evaluating evapotranspiration, however, is not as easy as calculating groundwater recharge by other methods. Many theoretical and empirical formula have been proposed. Since this FAO method was employed by some water resources regulatory agencies in Bogotá to calculate evapotranspiration, the same method was employed in this JICA Study.

1) Distribution of Evapotranspiration in Bogotá River Basin

The distribution of evapotransiration within Bogotá River Basin was estimated based on the result discussed above. The following map was created as Figure-2.3-8.



Source: JICA Study Team

Figure-2.3- 8 Distribution of Evapotranspiration in Bogotá River Basin

2) Water Balance in Bogotá River Basin

The results from hydrologic analysis and groundwater recharge estimation are compiled in Table-2.3-1. As shown the groundwater recharge of Bogotá Plain is 132 mm/year in average. In formulation of groundwater development plan, evaluated value of 132 mm/year should be taken into account for designing amount of groundwater to be developed.

Table-2.3- 1 Summary of Groundwater Recharge Estimation in Bogotá River Basin

NAME	Area	Precip.	Discharge	Evapo.	GW_Rechg
Los Arboles	62.7	668	184	458	26
Checua	170.1	782	172	453	157
Neusa	330.4	941	199	445	297
Chicu	329.7	795	163	445	187
Subachoque	397.9	753	99	440	214
Bojaca	220.1	685	191	429	65
Sub Total	**1,511**	**793**	**160**	**443**	**190**
Bogota(U)	337.1	851	292	467	92
Bogota(M)	152.3	760	146	457	157
Bogota(L)	620.5	699	143	438	118
Bogota(E)	154.8	691	280	405	6
Sub Total	**1,265**	**792**	**200**	**444**	**148**
Sisga	154.3	880	313	461	106
Tomine	404.0	841	373	462	6
Teusaca	335.2	964	328	469	167
Fucha	132.3	926	282	450	194
Tunjuelo	395.5	1030	431	470	129
Soacah	199.2	779	297	429	53
Sub Total	**1,620**	**915**	**355**	**460**	**100**
Total	**4,396**	**825**	**243**	**450**	**132**

Source: JICA Study Team

3.2.4 Groundwater Simulation

(1) Purpose of the Simulation

In this study, the groundwater flow in the Cretaceous aquifer distributed in the Eastern and Southern Hills of Bogotá River Basin was mainly investigated.

(2) Outline of the Model

1) Conceptual Model

In preparation of simulation model, assumption below was made based on hydrogeological consideration.

<u>Aquifer distribution</u>

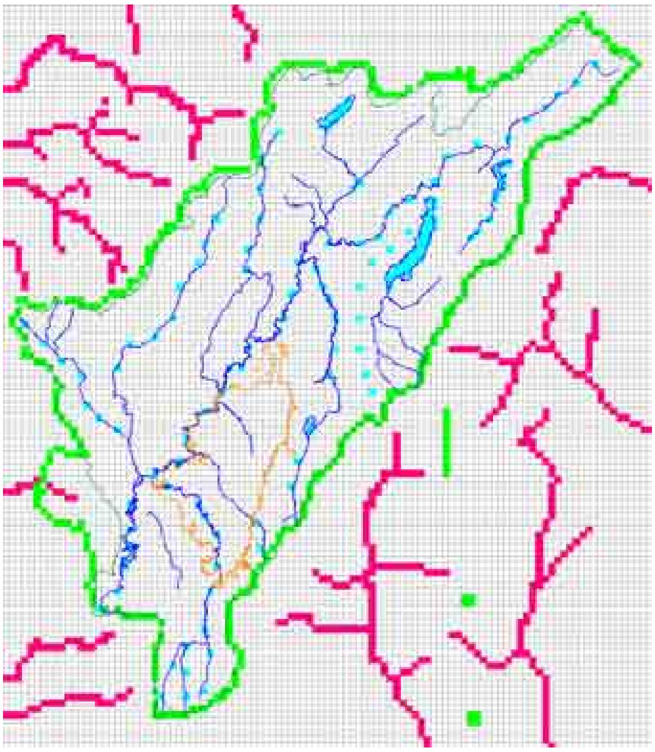
The mountainous areas that form watersheds in the south and east of Bogotá River Basin are mostly made up of Cretaceous sedimentary rocks. These rocks develop extensive fissures and thus, the permeability is considered high enough to make it an aquifer. Meanwhile, the Tertiary and Quaternary Formations above the Cretaceous Aquifer are assumed to have lower permeability considering the nature of their rock and sedimentary facies, and thus they are not good aquifers.

<u>Recharge / flow direction / groundwater level</u>

The mountain areas at higher altitudes receive more recharge by precipitation. The precipitation infiltrated into the mountain slopes slowly flows down into the groundwater basin under the Bogotá plain where Quaternary sediment is widely distributed. The Bogotá River and its tributaries flow through the Bogotá Plain and their discharge and river stages are assumed constant. The same way, the dams and retention ponds in the basin have constant water levels.

2) Structure / Parameters / Boundary condition of Model

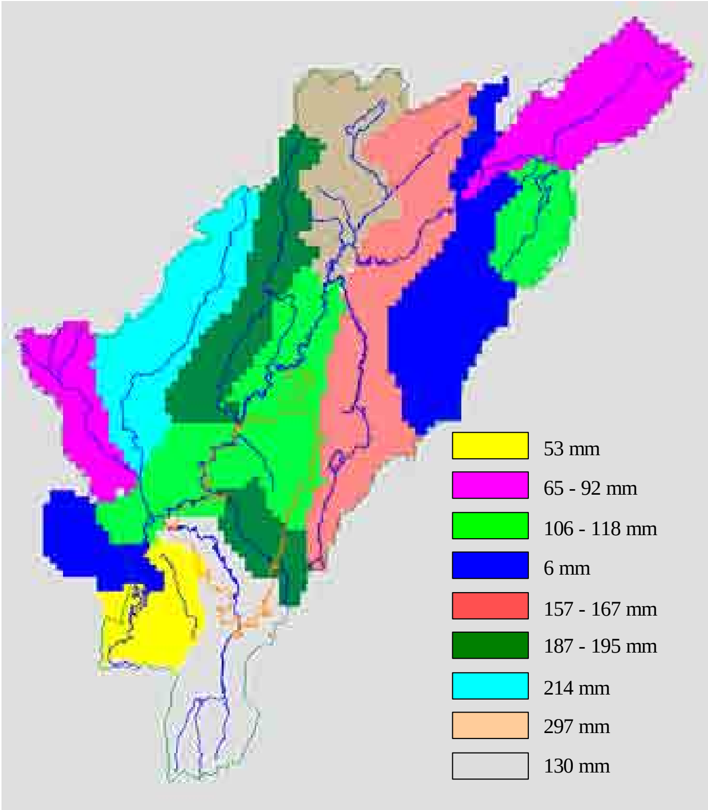
The horizontal grid and major boundary conditions in the 1st layer are shown in Figure-2.3-9. The recharge distribution is shown in Figure-2.3-10 and the location of existing pumping wells is given in Figure-2.3-11.



Note) Blue: Fixed head, Green: GHB, Red: Drain, GHB was also set for the perimeter of layer 8 and 10, The blue lines represent rivers, Orange line represents boundary of urban area.

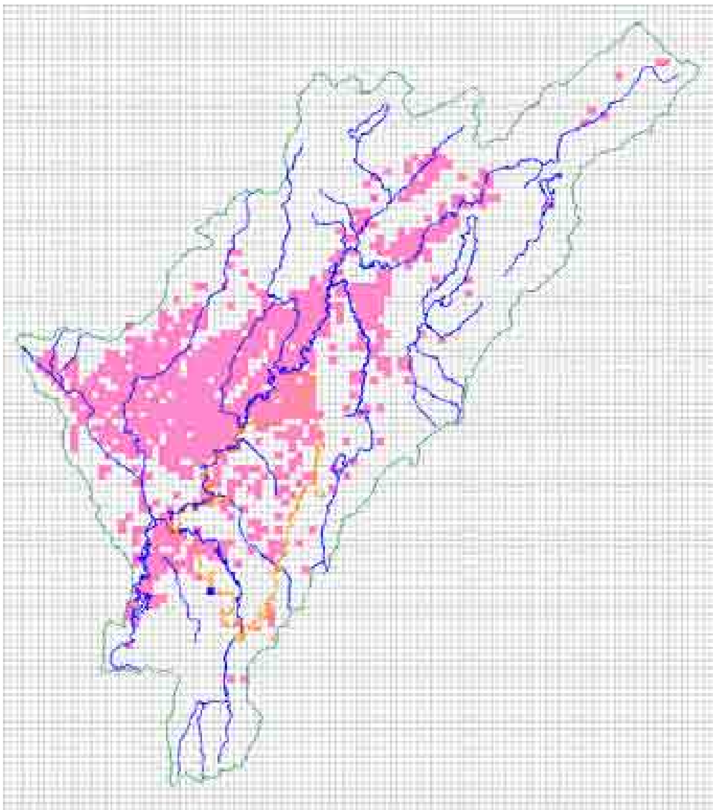
Source: JICA Study Team

Figure-2.3- 9 Model Grid and Boundary Conditions in Layer 1



Source: JICA Study Team

Figure-2.3- 10 Recharge Distribution (mm/year)



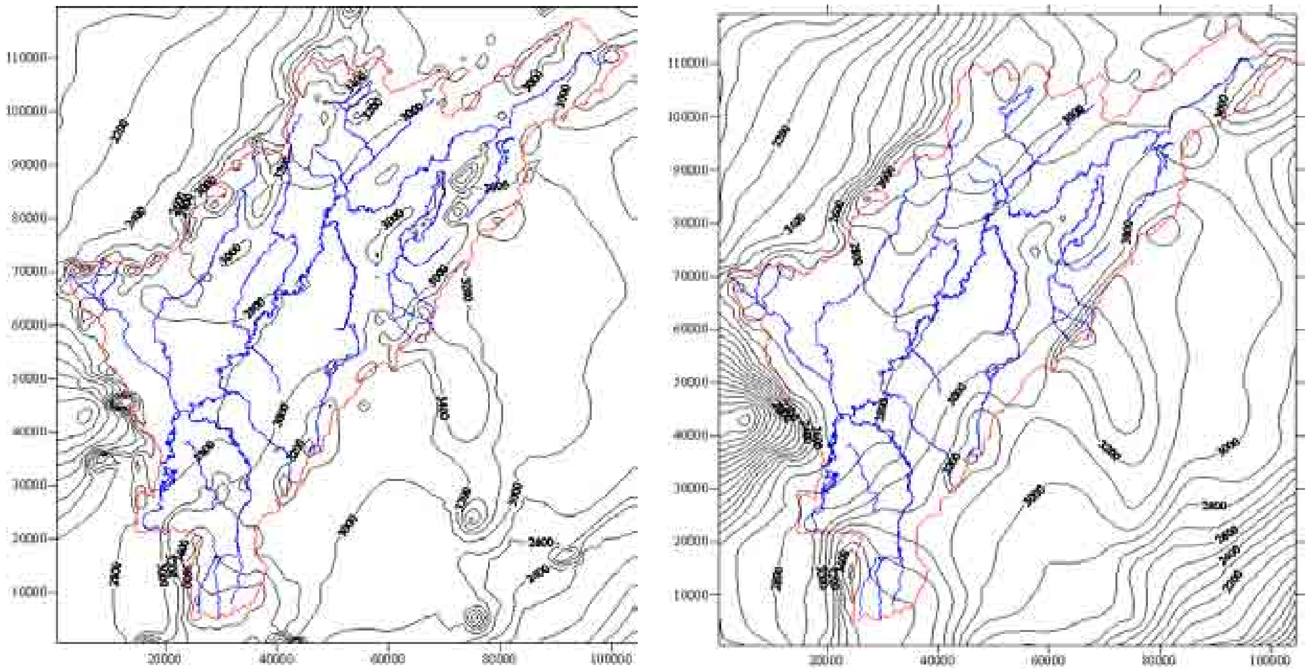
Note: The cells in pink represent those with pumping wells, total 7,000 wells are in place and total pumping rate is about320,000 m^3/day.

Source: JICA Study Team

Figure-2.3- 11 Location of Existing Wells

(3) Model Calibration

The model calibration was done by adjusting the hydraulic conductivity values of each layer within a reasonable range.



1st layer head distribution   4th layer head distribution

Source: JICA Study Team

Figure-2.3- 12 Head Distribution after Calibration of Steady State Model

3.2.5 Exploratory Well Drilling

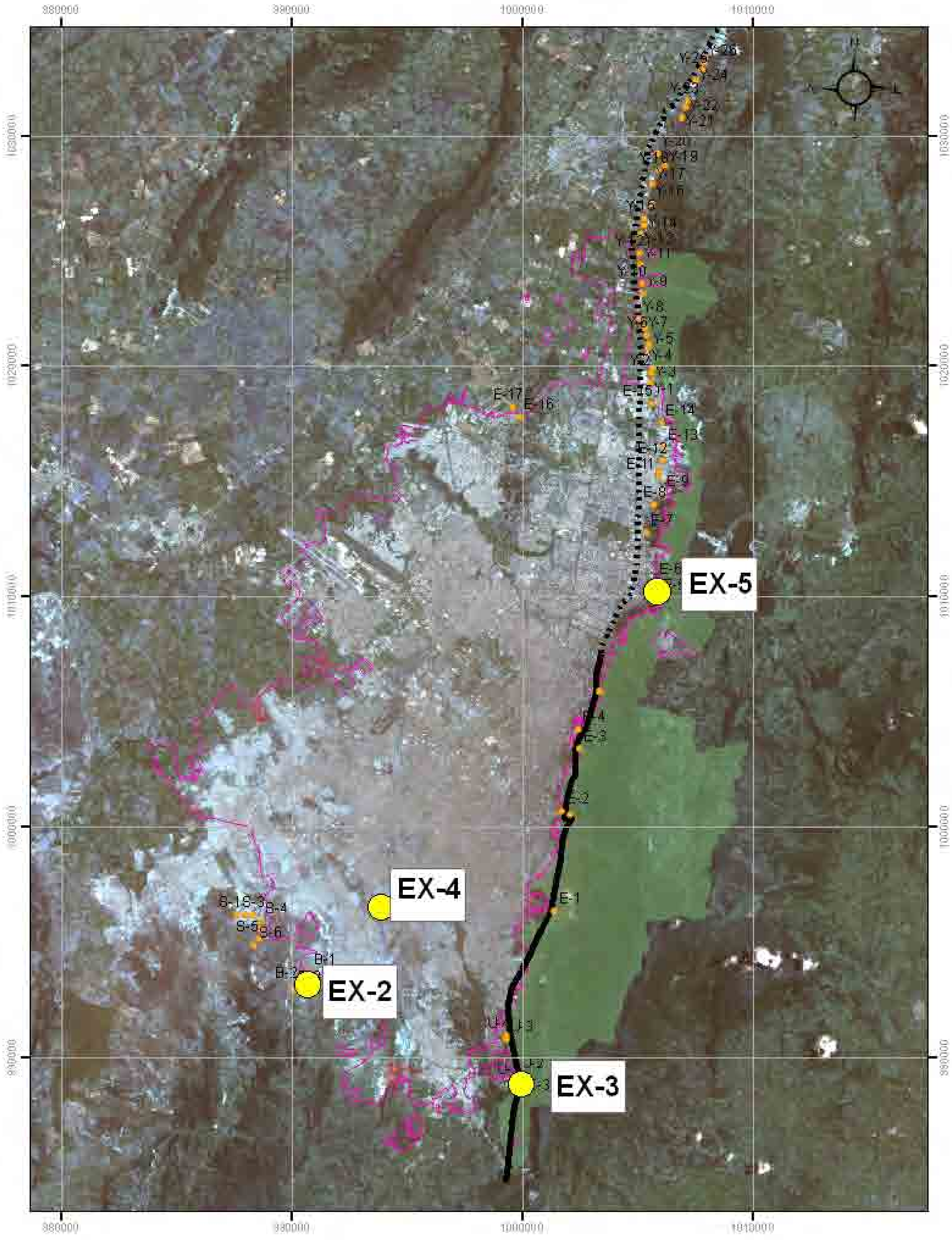
(1) Location of well

Proposed location of the exploratory wells and observation well are shown in Table-2.3-2 and Figure-2.3-13.

Table-2.3- 2 Location of Exploratory Well

Purpose	Well No.	Area	Coordinate		Responsibility
			X	Y	
Exploratory well	EX-2	Ciudad Bolivar Verbenal	4° 32'14.4"N	74° 09'51.7"W	JICA
	EX-3	Usme Cerveceria Alemana	4° 29'38.1"N	74° 04'51.5"W	JICA
	EX-5	Usaquen	4° 38'04.4"N	74° 03'20.7"W	Acueducto
Observation well	EX-4	Embalse Seco No.1	4° 33'48.84"N	74° 08'18.696"W	JICA

Source: JICA Study Team



Source: JICA Study Team

Figure-2.3- 13 Location of Exploratory Wells

(2) Result of Exploratory Drilling

<u>Drilling Result</u>

Result of exploratory drilling (EX-2, EX-3) and observation well (EX-4) are summarized in Table-2.3-3. Pumping test was carried out after completion of the wells.

Table-2.3- 3 Result of Exploratory Drilling

Well No. （Site）	EX-3 (Usme)	Ex-2 (Ciudad Bolivar)	EX-5 (La Aguadora)	EX-4 (Embalse Seco No.1)
Well depth (m)	300m	300m	300m	150m
Screen depth (GL-m)	37 - 40, 43 - 46, 48 -51, 55 - 58, 59 - 68, 70 - 73, 80 - 83, 84 - 87, 102 - 108, 111 - 114, 133 - 136, 161 - 164, 195 - 201, 212 - 215, 217 - 220, 222 - 225, 233 - 240, 242 - 248, 273 - 275, 289 - 292 (Total 80m)	40 - 46, 48 - 54, 56 - 62, 64 - 70, 76 - 82, 91 - 94, 106 - 109, 117 - 120,126 - 135, 145 - 148, 155 - 158, 174 - 177,194 - 197, 235 - 241, 253 - 256, 262 - 265, 275 - 281 (Total 80m)	109～118, 120～129, 131～140, 148～154,155～164, 165～174, 175～181, 194～197, 201～207, 216～222, 223～232, 233～242, 243～246, 256～262, 286～289, 290～299。 (Total 111m)	44- - 51, 56 - 68, 74 - 78, 110 -115, 132 – 150 (Total 50m)
Casing Diameter	8 inch	8 inch	10 inch	4 inch
Aquifer	Sandstone	Sandstone	Sandstone	Sand and Gravel
Continuous pumping test				
S.W.L [1)] (GL-m)	20.70	18.20	37.6	25.2
Yield (m3/day)	95	864 - 1,223	864	145
Drawdown	69.29	52.70	71.4	7.1
D.W.L [2)] (GL-m)	89.99	70.90	109	32.3
Specific Capacity (m^3/day/m)	1. 37	23.2	12.1	20.4
Transmissivity (m^2/day)	1.9	14.7	13.6	27.8
Conductivity (m/day)	0.023	0.18	0.17	0.56
Storativity	$6.9x10^{-4}$	$2.2x10^{-2}$	$2.06x10^{-2}$	$4.2x10^{-3}$

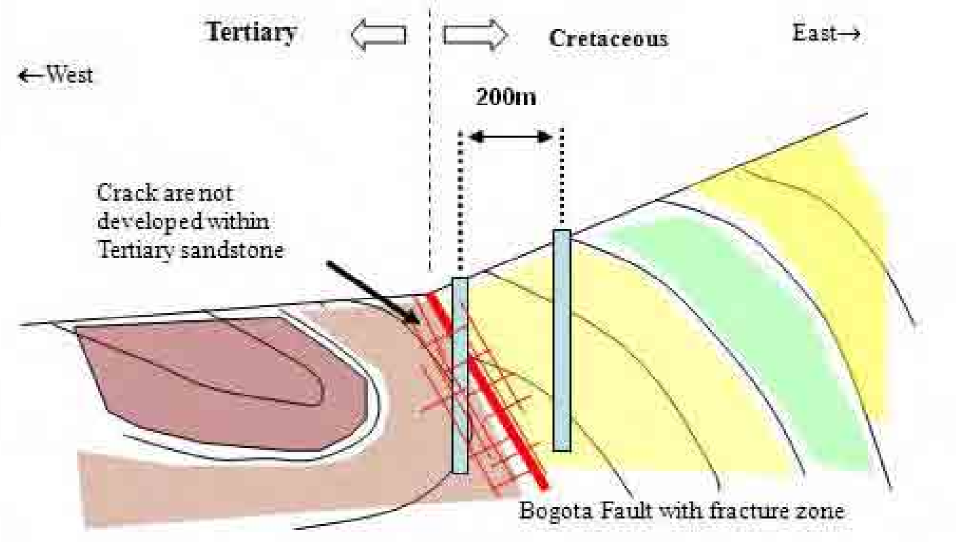
Step draw-down test	EX-3 (Usme)		Ex-2 (Ciudad Bolivar)		EX-5 (La Aguadora)		EX-4 (Embalse Seco No.1)
Step	Yeild (m^3/day)	Draw down (m)	Yeild (m^3/day)	Draw-down (m)	Yeild (m^3/day)	Draw down (m)	-
1 step	41	43.4	966	11.1	290	15.4	-
2 step	82	47.9	1,240	17.1	360	22.3	-
3 step	121	57.3	1,446	20.9	470	33.6	-

Note Conductivity and storativity were analyzed by Jacob method and recovery method
Source: JICA Study Team

Characteristics of Cretaceous aquifer

It is well known that Bogotá fault lies between Cretaceous group and Tertiary group in the eastern hill. Exploratory well of EX-3 (Usme) is located on just above Bogotá Fault. From the result of exploratory drilling of EX-3, important hydrogelogical condition below was concluded.

- Cretaceous sandstone, which is distributed in the east of Bogotá fault, is excellent aquifer in the eastern hill.
- Bogotá fault is definitely reverse fault. The reverse fault will cause drilling to encounter Cretaceous rock in shallow but encounter Tertiary rock in deep. It means that older stratum overlays younger stratum.
- It is desirable to locate drilling point as far as possible at the east of Bogotá faults. According to the example in exploratory drilling in Vitelma site, drilling point more than 200m east of Bogotá fault can escape from effect of the reverse fault (see Figure2-3-14).



Source: JICA Study Team

Figure-2.3- 14 Recommended Optimum Well Location