No.

Capital District of Bogotá and Soacha Municipality
The Republic of Colombia

THE STUDY ON MONITORING AND EARLY WARNING SYSTEM FOR LANDSLIDES AND FLOODS IN SELECTED AREAS IN THE CAPITAL DISTRICT OF BOGOTÁ AND SOACHA MUNICIPALITY IN THE REPUBLIC OF COLOMBIA

FINAL REPORT

VOLUME 3 SUPPORTING REPORT

MARCH 2008

JAPAN INTERNATIONAL COOPERATION AGENCY

PACIFIC CONSULTANTS INTERNATIONAL
OYO INTERNATIONAL CORPORATION

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(T.R.M. for January 1, 2008)

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SUPPORTING REPORT

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TOPOGRAPHY AND GEOLOGY

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CHAPTER 1 TOPOGRAPHY AND GEOLOGY OF COLOMBIA

1.1 The Andes

The Andes are huge South American mountain system that extends north to south along the western coast from Panama to Tierra del Fuego. It consists of several ranges and has its highest peak at Aconcagua 6,960 m. The mountain belt is generally about 300 km wide, except in Bolivia, where it expands to twice that width. From north to south the belt can be divided into three regions: a northern section in Venezuela, Colombia, and northern Ecuador; a central section in southern Ecuador, Peru, Bolivia, and the northern regions of Argentina and Chile; and a southern section in the southern regions of Argentina and Chile.

1.2 Topography of Colombia

The territorial area of Colombia is 1,138,910 km^2, ranging between latitude 4.2 degree south and 12.4 degrees north, and between longitude 66.9 degrees west and 78.8 degrees west. Colombia faces Pacific Ocean in west side, Caribbean Sea in north side, and is bordered on the northwest by Panama, on the east by Venezuela and Brazil, and on the southwest by Peru and Ecuador.

The northern Andes in Colombia curve in an arc from northeast to southwest. The arc consists of three main parallel ranges, known as the Cordillera Occidental (Western Cordillera), the Cordillera Central (Central Cordillera), and the Cordillera Oriental (Eastern Cordillera). There are plateaus and valleys between the each cordillera in which are the most densely populated parts of the country. In addition to three main ranges, there is a coastal mountain range on the Pacific coast of Colombia, the Baudó Mountains (Serranía de Baudó). Geologically, the Baudó Mountains represent an extension of the Isthmus of Panama. They are separated from the Cordillera Occidental by the Atrato valley where the Atrato River flows and Quibdó is located.

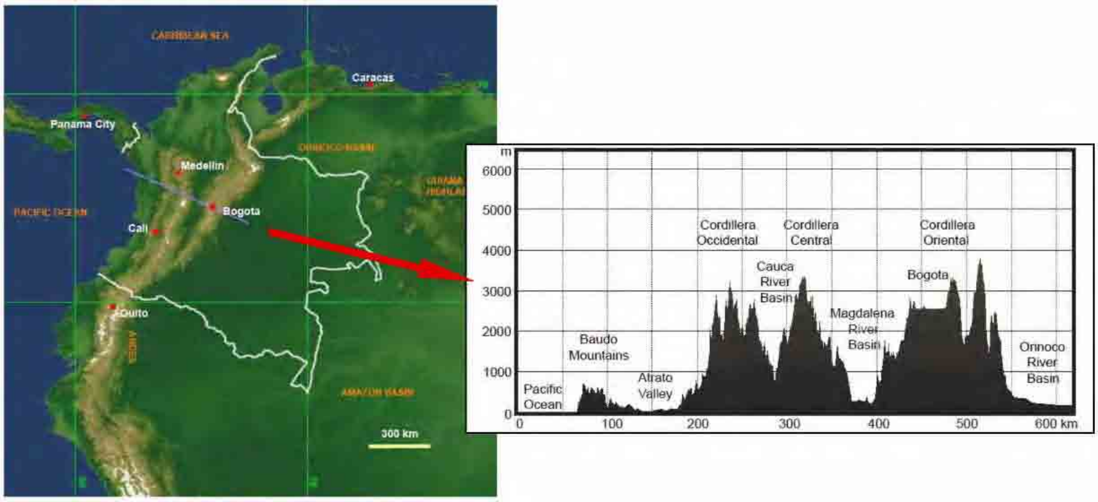
The rivers flowing toward the Pacific are short and small in volume because the rainfall on the western slopes of the mountains is limited. The streams to the east are long and supplied with an abundance of water from the trade winds, which deposit precipitation as they approach the mountains. These mountain streams are the source of the major headstreams of the three great river systems of South America: the Amazon, which flows through Peru and Brazil; the Orinoco of Colombia and Venezuela; and the Parana-Paraguay-Uruguay river system, which empties into the Rio de la Plata, a large marine estuary along the Atlantic coast between Uruguay and Argentina.

As shown in Figure S1-1-1, Bogota is located at an elevation of about 2640 m on a mountain-rimmed plateau high in the Cordillera Oriental of the Andes Mountains.

1.3 Geology

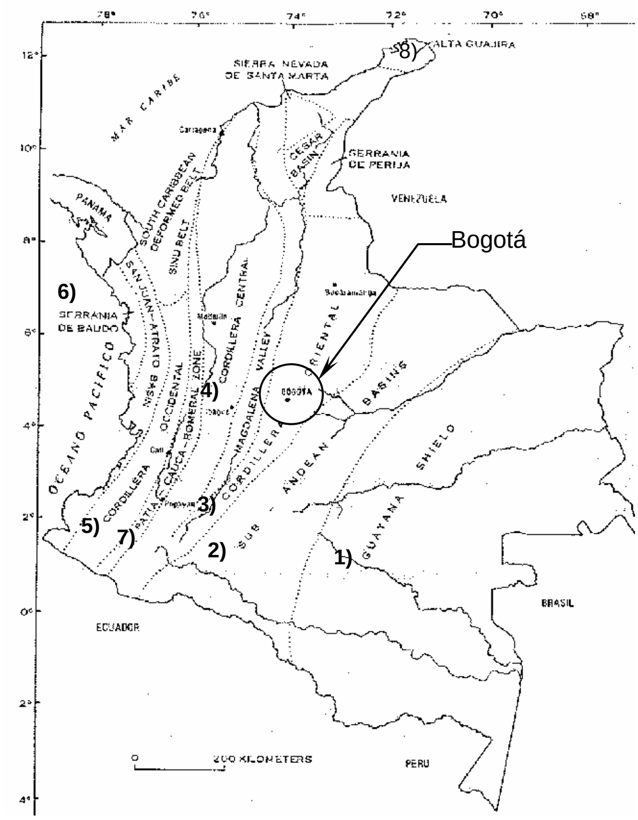
Colombia is generally classified into two measure geological areas, Orogeny and Shield. The south-eastern part of Colombia is flat land of the Shield area which is the oldest and most stable structural element of the continent. It comprises a Precambrian (before 570 million years ago) complex of igneous and metamorphic rocks. In most places the shield is overlaid by sedimentary rocks, mostly of Paleozoic age (570 million to 225 million years ago). The north-western part of Colombia is the Orogenic area where is active area of folding, faulting, and uplift of the Earth's crust to form the Andes Mountain ranges, often accompanied by volcanic and seismic activity. The Orogenic area in Colombia is the northern end of the Andean range formed by collision of eastward subjecting Nazca plate with a moving rate of 70 mm / year.

Colombia is distinguished into nine areas harmonizing furthermore with the topographic classifications, and the areas correspond with geological features as shown Figure S1-1-2 and below.



(base data : NASA SRTM-30 and SRTM-3)

Figure S1-1-1 Topographic Map of Colombia and Cross Section of Andes Mountains



(USGS-INGEOMINAS, 1984)

Figure S1-1-2 Topographic Classification in Colombia

<u>The Shield Area</u>
1) Guayama Shield
2) Sub-Andean Basins

<u>The Orogenic Area</u>
3) Cordillera Oriental, Serrania de Perija
4) Cordillera Central
5) Cordillera Occidental
6) Serrania de Baudo
7) Patia-Cauca-Romeral
8) Mountain and sedimentary basin in Guajira Peninsula
9) Inland basin between mountains

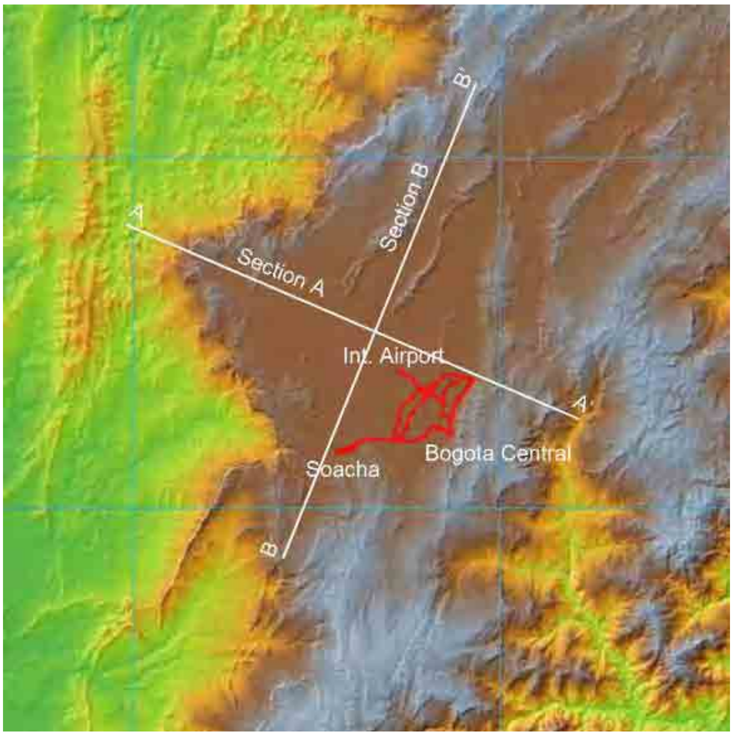
Table S1-1-1 Geological Formation and Zones in Colombia *(USGS-INGEOMINAS, 1984)*

Name of Geological Zone	Location	Geological Time	Explanation
1) Guayana Shield	Vast reaches of lowland drained by tributaries of the Amazon and Orinoco		high-grade metamorphic rock, low grade metamorphic rock, and intrusive granite series
2) Sub-Andean Basins	East of the Cordillera Oriental	Tertiary and Quaternary	Tertiary and Quaternary deposit
3) Cordillera Oriental, Serrania de Perija	Cordillera Oriental	Palaeozoic Cretaceous	metamorphic rock of Precambrian to Palaeozoic and intrusive plutonic rock covered by gravel stone, sand stone and silt stone of continental sediment in the south area, covered by sandstone and claystone of Cretaceous epi-continental sediment in the central area (Bogotá, etc)
4) Cordillera Central	Cordillera Central		crystalline rock in north area, partially metamorphic craton and oceanic deposit in central area, and volcanic association in central to south area
5) Cordillera Occidental	Cordillera Occidental	Late Mesozoic	basic deposit by submarine volcano of late Mesozoic, flysch deposit, etc
6) Serrania de Baudo	Serrania de Baudo	Mesozoic to Tertiary	mud stone, silt stone, sandstone and chert of late Mesozoic to Tertiary
7) Patia-Cauca-Romeral	Between Cordillera Central and Cordillera Occidental		central mountain range consisted of continental crust and west side mountain range consisted of oceanic crust
8) Mountain and sedimentary basin in Guajira Peninsula	Guajira Peninsula	Cretaceous and/or Tertiary	Cretaceous and/or Tertiary sedimentary rock, and granite in large mass of Jurassic and in small mass of Tertiary
9) Inland basin between mountains	Between Cordillera Oriental and Cordillera Central	Tertiary	Tertiary sedimentary basin between mountains

CHAPTER 2 TOPOGRAPHY AND GEOLOGY OF BOGOTA AND SURROUNDINGS

2.1 Topography

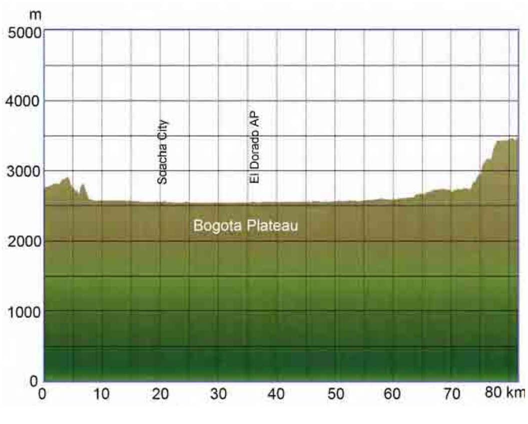
Bogota locates in a flat plateau that is namely Bogota Plateau or Sabana de Bogota, which is averagely 2,560 m above mean sea level and the height of eastern mountainous area reaches 3,000 m and more, beside the west side slope of the Cordillera Oriental as shown in Figure S1-1-1. Bogota Plateau (Sabana de Bogota) is extending about 40 km from northwest to southeast and 60 km from northeast to southwest as shown in Figures S1-2-1 and S1-2-2. City growth of Bogota in Bogota Plateau is limited by surrounding hills in the east and by Bogota River in the west.



(*base data : NASA SRTM-3*)

Figure S1-2-1 Topographic Map of Sabana de Bogota

<Section A>

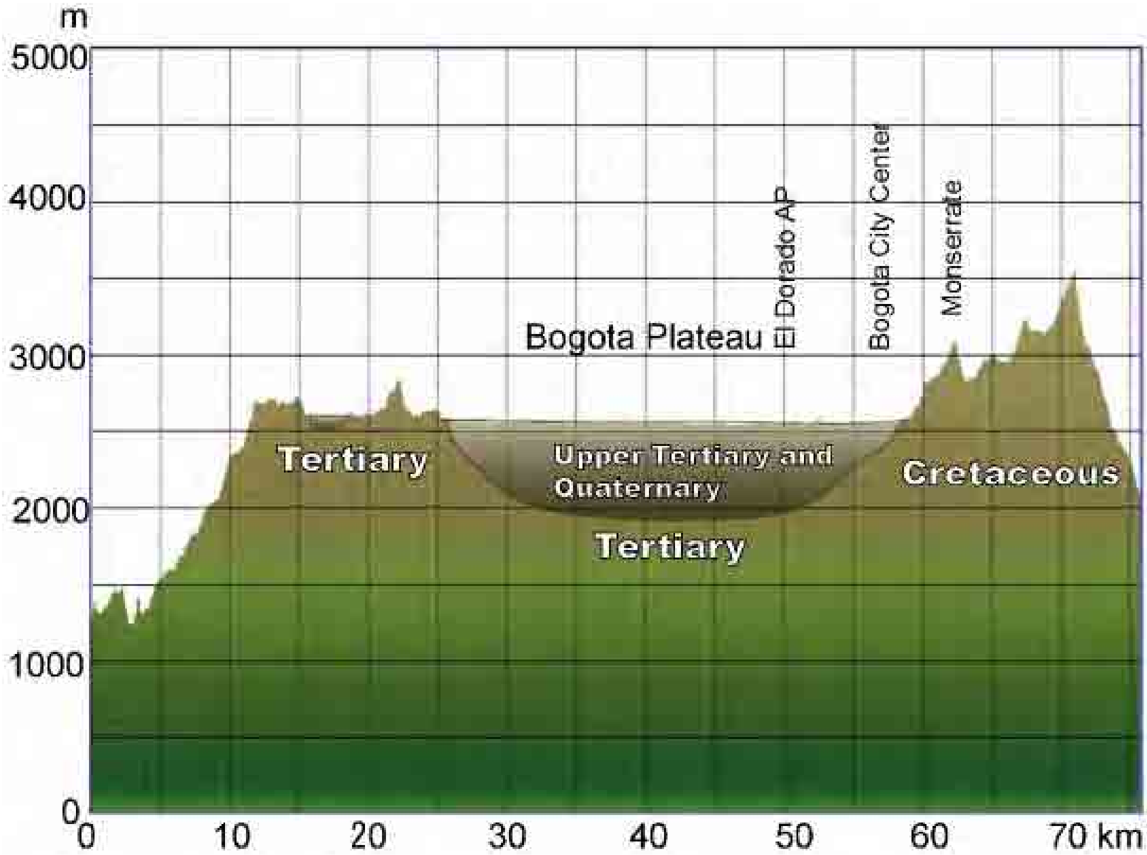


<Section B>

Figure S1-2-2 Topographical Cross Sections correspond to the Lines in Figure *(base data NASA-SRIM-3)*

2.2 Geology

Geology in the area and its environment distributes sandstone, siltstone and claystone of Cretaceous to Tertiary in mountainous area. Quaternary sediment of lake origin spreads in Bogota Plateau (Sabana de Bogota), while the mountains area in the east and south of Bogota Plateau is mostly composed of Cretaceous or Tertiary origin sediment rock. They are made of mostly sandstone or siltstone. Thickness of the Quaternary sediment in Bogota Plateau is over 500 m as shown in Figure S1-2-3.

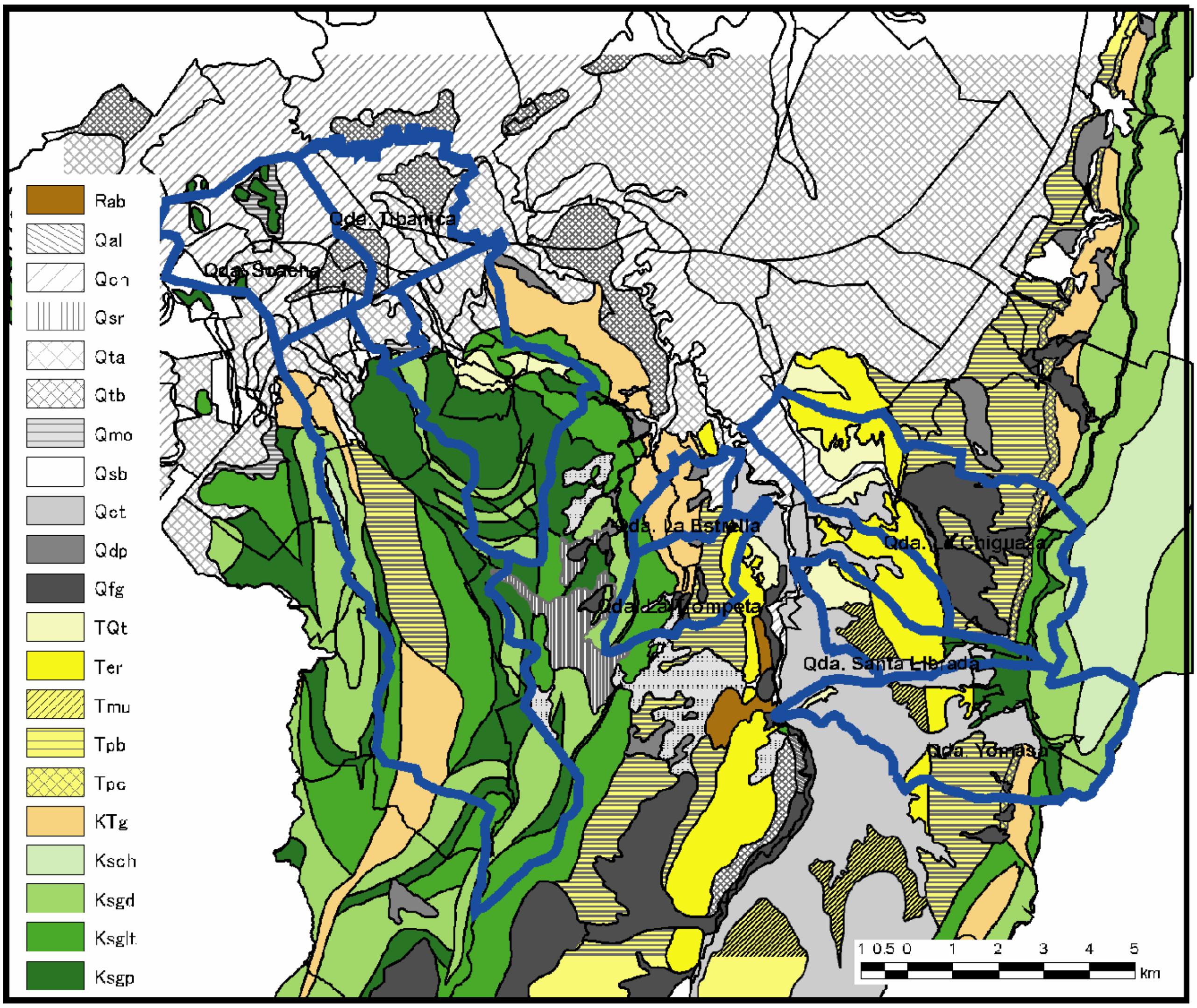


(prepared based on IGAC, 1995)

Figure S1-2-3 Sediment in Sabana de Bogota (Bogota Plateau, Section A)

2.3 Geology of Study Area

Figure S1-2-4 and Table S1-2-1 shows geology map in study area and stratigraphy and geology distribution conditions in each river basin, respectively.



(Source: existing JICA Study)

Figure S1-2-4 Geology Map in Study Area

<u>Landslides in Bogota</u>

Landslides in Bogota are generally distributed at steep slopes in the eastern part of the Bogota. Many landslides are located along Bogota Fault which runs along the eastern rim of Bogota Plateau.

<u>Landslides in Soacha</u>

There are large scale quarries, from which sand and stone as material for bricks and construction is extracted, along Soacha River. Many of the open quarries are abandoned and there are many residential houses in the abandoned quarries. Most of the landslide disasters have occurred along excavated steep slopes in the abandons quarries.

<u>Rivers</u>

The total area of the river basin in Bogota and in Soacha is 41.8 km^2 that consist of Chiguaza River (18.7 km^2), Santa Librada River, (15.4 km^2), Yomasa River (5.5 km^2), La Estrella-El Trompeta River (2.2 km^2) and is 40 km^2 that consist of Soacha River (30 km^2), Tibanica River, (10 km^2), respectively

Table S1-2-1 Geological Stratigraphy and Geology Distribution in each River Basin

GEOLOGICAL AGE		GEOLOGICAL UNIT	LEGEND	LITHOLOGICAL DESCRIPTION	Chi	San	Yom	Est	Tib	Soa
Quaternary		Artificial fill, garbage	Rab	Garbage deposits technically formed or disposed in the creeks beds			○			
		Chia Formation	Qch	Lacustrine clay and/or flood origin locally silt stone and diatomic clay.	○			○	○	○
		Slope Deposit	Qdp	Supported matrix deposit. Pebble and quartz sandstone blocks, inside a clayey matrix and clayey sand. Clastic-supported deposit specially sandstone blocks	○			○		
		Mondoñedo Formation	Qmo	Slope silt deposit locally sand with fragments of sub-angular rock, with black and grey soil						○
		Residual Soil	Qsr	Clayey sand material, product of weathering and alteration from parental material, especially over soft formations						○
		Lower Terrace Deposit	Qtb	Mud and clay, in part organics that are forming the soft infilling of the Sabana de Bogotá					○	○
		High Terrace Deposit	Qta	Constituted by conglomerates, angular, clastic-supported. Transported materials and deposited on the transition zone, between the rocky formations and the flat zone.	○			○	○	○
		Sabana Formation, Sabana Soil	Qsb	Red soil, brownish and black soil complex in the high part f the hills.				○		○
		Tunjuelito Formation	Qct	Gravel, boulder and rounded to sub-rounded blocks, inside a mud-clayey matrix	○	○	○	○		
		Fluvial - Glacial Deposit	Qfg	Sandstone blocks and pebbles of sub-rounded to angular forms, flattened, and embedded in a clayey silt matrix, produced by transport of big flows provided from Sumapáz Paramo.	○		○	○		
Tertiary – Quaternary	Pleistocene	Tilata Formation	TQt	Clay and clayey sand of white color, peat and small size pebbles levels.	○	○	○	○	○	
Tertiary	Oligocene – Miocene	Usme Formation	Tmu	Bright grey colored mudstone bands, with quartz and feldspar sandstone, fine grained, in mid parallel bands.		○	○			
	Middle Eocene	La Regadera Formation	Ter	The superior group is conformed by bands of quartz-feldspar sandstone and claystone, and inferior group by quartz-feldspar sandstone, course grained to conglomeratic, grey colored.	○	○	○	○		
	Upper Paleocene to Eocene	Bogota Formation	Tpb	Mudstone, siltstone and claystone, separated by soft clayey sandstone stratum.	○		○	○		○
	Upper Paleocene	Cacho Formation	Tpc	Claystone violet colored.	○		○			

GEOLOGICAL AGE		GEOLOGICAL UNIT	LEGEND	LITHOLOGICAL DESCRIPTION	Chi	San	Yom	Est	Tib	Soa
Cretaceous – Tertiary	Upper Maestrichtian to Lower Paleocene	Guaduas Formation	K-Tg	Superior group: Claystone bands with thin mantles of coal Mead group: Sandstone on the base and laminated sandstone on the ceiling, separated by compact claystone which contains mantles of coal Inferior group: Dark grey colored claystone.	○		○		○	○
Cretaceous	Maestrichtian	Guadalupe Group	Ksgl-t	Soft sand stone: Sandstone course grained to conglomeratic, with thin mudstone bands, silt stone and clay stone Labor sand stone: Sandstone fine grained, clayey, compact, separated by thin bands of claystone Hard sandstone: Constituted by a sequence of sandstone in thick banks, with bands of siltstone, mudstone, lidite rock and claystone, in fine layers. Plaeners: Sequence of siliceous claystone and lidite rock. Bands of siliceous siltstone, green claystone and thin stratums of fine to mid grained sandstone. Between lutites rocks are found thin layers of fine grey sandstone, associated to coal and discontinuous sandy layers.	○	○	○	○	○	○
	Lower Maestrichtian	Guadalupe Group, Planeners Formations	Ksgp	Siliceous siltstone, porcelainite, lidite and fine grain size.	○	○	○	○	○	○
	Upper Coniasian to Campanian	Guadalupe Group, Dura Sandstone Formation	Ksgd	Sandstone in very thick banks with thin siltstone, mudstone and claystone intercalations	○	○	○	○	○	○
	Cenomanian to Coniacian	Chipaque Formation	Ksch	Dark lutites with calcareous-sand intercalations	○		○			○

**: Abbreviation of the river basin; Chi: Ciguaza, San: Santa Librada, Yom: Yomasa, Est: Estrella and Trompeta, Tib: Tibanica, Soa: Soacha*

SUPPORTING REPORT

S2

METEOROLOGY AND HYDROLOGY, MONITORING SYSTEM AND RAINFALL AND DISASTER RECORD

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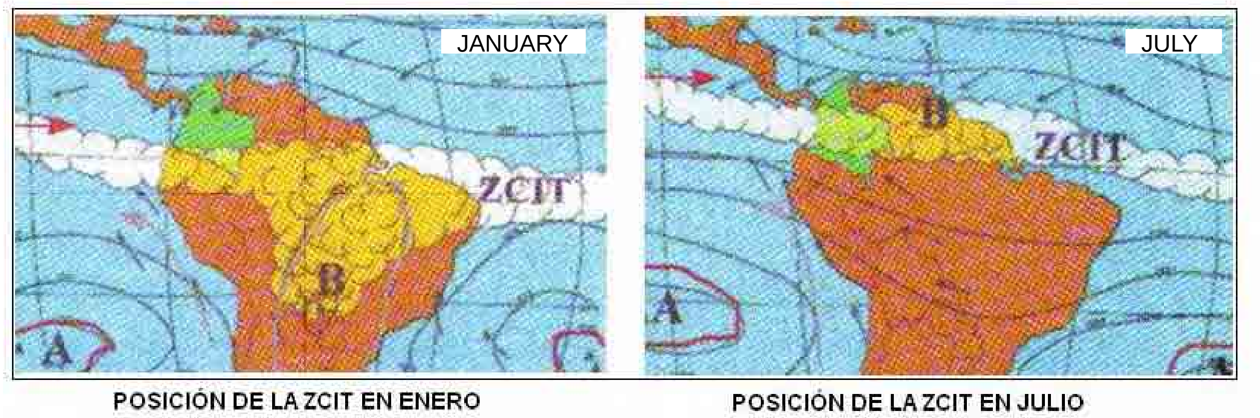
CHAPTER 1 METEOROLOGY AND HYDROLOGY

1.1 General Description in Cundinamarca including the Study Area[1, 2]

Colombia is located in the equatorial zone and presents an inverse relationship between clouds cover and sun brightness, registering a high cloud covering with high rainfall. The climate is affected by the relief, whose more important effect is the temperature conditioning. In the west cordillera that influences Cundinamarca, the variation of the temperature is 0.63°C for each 100 meters in their west flank (Sabana de Bogotá and Bogota's east hills), this variation is known as "Thermal Floors" or "Pisos Térmicos" in Spanish. According with this, Sabana de Bogotá corresponds to the cold thermal floor among 2000-3000m (height above sea level) and its temperatures is among 12-18°C.

In Colombia, the rainfall values varied due to interaction between equatorial zone and Andes cordillera. Colombia is included in the Inter tropical Convergence Zone (ITCZ), for this reason, the trade winds from northeast and southeast to get into the territory, generating the rains for convective phenomena. The ITCZ is displacing in latitudinal sense, and is located at the south in the first months of the year, and in the northern extreme of the country during July - August, with intermediate position during the rest of the year. Displacement of ITCZ is shown in Figure S2-1-1.



(Source: ("Fig.25,ESTUDIO DE LA CARACTERIZACIÓN CLIMÁTICA DE BOGOTA Y CUENCA ALTA DEL RIO TUNJUELO", FOPAE - IDEAM, 2006)

Figure S2-1-1 Displacement of ITCZ

The ITCZ displacement generate two (2) types of temporary rain fluctuation, registering in Cundinamarca the bimodal pattern, that is to say, two (2) wet or rainy periods alternated with two (2) dry periods. The varied relief is conditioning for the rainfall regime, because it serve as an obstacle for the air currents and it originates high rainfall volumes when the winds collide with the cordillera, and the air masses ascend and are condensed. The forced ascent for the air masses due to the relief, produce an orographic rain type that are characteristic for the Andean zone. In some sectors will be produced some temporary droughts in the interior area caused by masses of air that ascend by windward and they descend for leeward, warming and drying off (Phenomena of Fohen).

The inter-Andean valleys, such as the cordilleras above the 2,000 meters, present different annual rainfall amount (≈ 1,500 - 3,000 mm/year) with a bimodal regime of two (2) dry periods alternating with two (2) high rainfall periods.

In general, the relative humidity varies from high to low through the year. In the middle Magdalena valley including Cundinamarca, the relative humidity is contrasting the values below 60% during the first months of the year and from July to September with the values of about 80 % in other period. On the other hand, the relative humidity in Sabana de Bogota is almost constant in 76-85% through the

[1] IGAC, 2002, Atlas de Colombia
[2] IDEAM, 2000, Proyecto red de alertas hidrometeorológicas para inundaciones y fenómenos de remoción en masa

year. The example of monthly humidity in San Jorge station located in Soacha is shown in Table S2-1-1.

Table S2-1-1 Monthly Humidity in San Jorge (GJA) Station (IDEAM)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SAN JORGE (GJA) (IDEAM)	81	81	82	84	83	82	82	82	82	83	84	82	82

(Source: "Tabla 2,ESTUDIO DE LA CARACTERIZACIÓN CLIMÁTICA DE BOGOTA Y CUENCA ALTA DEL RIO TUNJUELO", FOPAE - IDEAM, 2006)

The average temperature in Bogota (Multi-Annual Average Temperature, MAT) is registered in Table S2-1-2, and monthly temperature in San Jorge station is shown in Table S2-1-3.

Table S2-1-2 Multi-Annual Average Temperature in Bogota

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MAT (°C)	12.8	13.3	13.0	13.0	13.4	12.8	12.6	12.9	13.0	12.8	12.8	12.8	12.9

Table S2-1-3 Monthly Temperature in San Jorge (GJA) Station (IDEAM)

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
SAN JORGE (GJA) (IDEAM)	Average	11.5	11.6	11.8	11.9	11.9	11.6	11.1	11.3	11.5	11.5	11.7	11.6	11.6
	Maximum	20.8	20.6	20.2	19.4	20.2	19.4	19.4	19.0	20.0	19.4	19.6	20.0	20.8
	Minimum	0.5	0.2	0.2	2.0	0.7	0.5	0.0	3.8	0.5	0.7	3.2	1.0	0.0
	Average Maximum	16.5	16.7	16.6	16.0	16.2	15.6	15.0	15.4	15.8	16.0	16.0	16.2	16.0
	Average Minimum	6.3	6.9	7.3	7.7	7.5	7.3	7.2	7.1	6.9	7.1	7.2	6.8	7.1

(Source: "Tabla 3,ESTUDIO DE LA CARACTERIZACIÓN CLIMÁTICA DE BOGOTA Y CUENCA ALTA DEL RIO TUNJUELO", FOPAE - IDEAM, 2006)

The historical winds mean values registers 8-10.7 m/s with NE-SW direction and 10.8-13.8 m/s with E-W direction. The calm period of the wind is 21% of the year.

1.2 Meteorological/Hydrological Stations in and around the Study Area

Quite a few meteorological and hydrological stations exist or existed in and around the Study Area, which are/were monitored and operated by DPAE, EAAB, CAR, IDEAM and other organizations. Some of the stations are telemetering stations, but most of the stations are conventional. Figure S2-1-2 shows the location map of meteorological and hydrological stations managed by DPAE, EAAB, CAR and IDEAM in and around the Study Area, and Table S2-1-4 shows the list and conditions of the stations.

Meteorological and hydrological data for the Study are collected from within the stations shown in Table S2-1-4. The list of collected data is shown in Table S2-1-5 to S2-1-8.

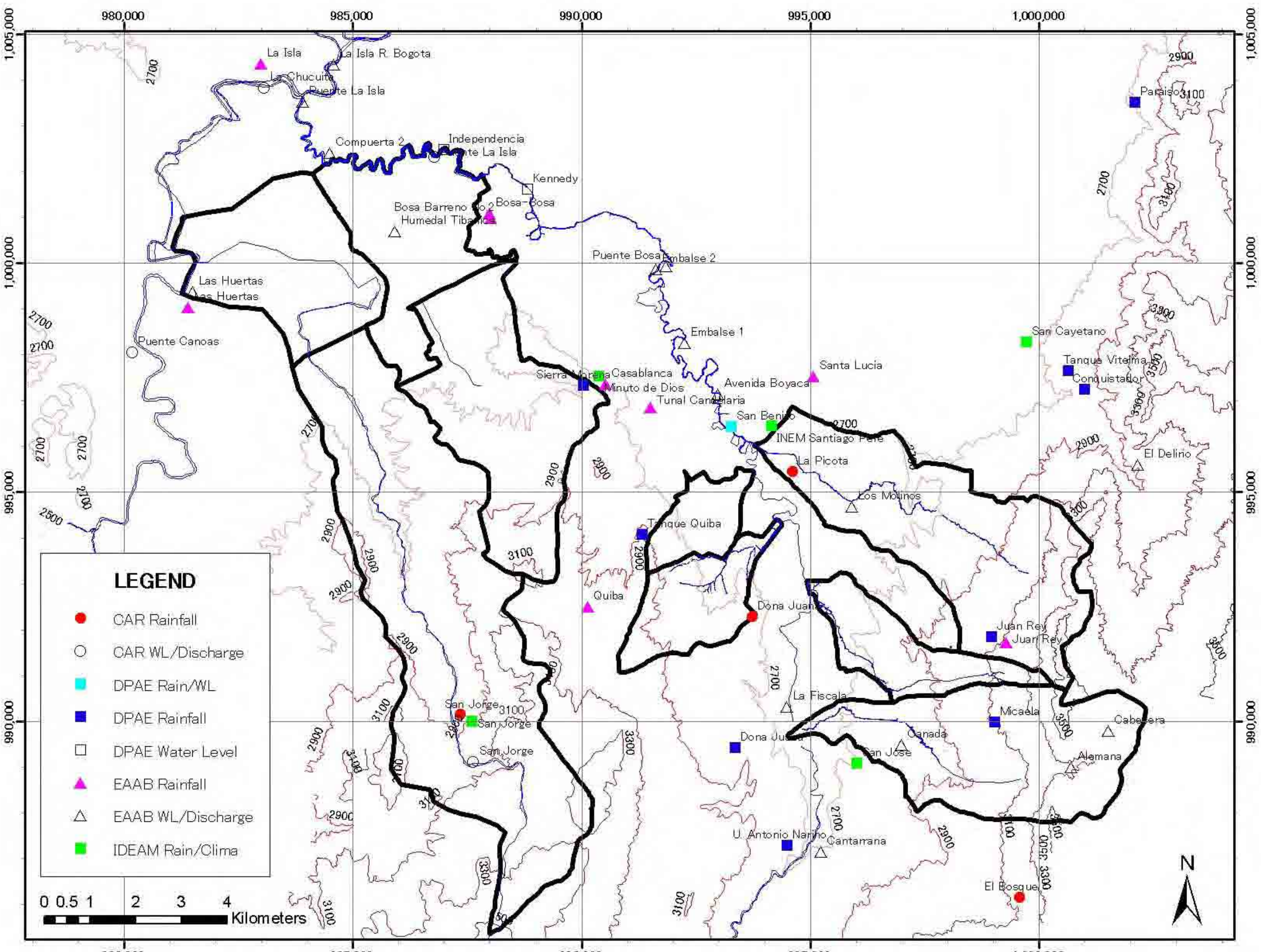


Figure S2-1-2 Location Map of Meteorological/Hydrological Stations in and around the Study Area

Table S2-1-4 List of Meteorological/Hydrological Stations in and around the Study Area

ENTITY	CODE 1	CODE 2	TIPO	NAME	SUBCUENCA	DEPTO.	MUNICIPI	COORD	Elevation	INST DATE	SUSP DATE	Status in Oct. 2006	Telemeter	TYPE	Present Situation/Remarks
DPAE			PG,LG	San Benito	Tunjuelito	BOGO	BOGOTA	043351N740817W	2590	200010			Telemeter (Radio)	DPAE Rain/WL	
DPAE			PG	Sierra Morena	Tunjuelo	BOGO	BOGOTA	043430N741014W	3078	200010			Telemeter (Radio)	DPAE Rainfall	
DPAE			PG	Tanque Quiba (Quiba-Mirador)	Tunjuelo	BOGO	BOGOTA	043235N740921W	3078	200010			Telemeter (Radio)	DPAE Rainfall	
DPAE			PG	Conquistador (Escuela de Logistica)	San Cristobal	BOGO	BOGOTA	043428N740435W	2780	200010			Telemeter (Radio)	DPAE Rainfall	Out of study area
DPAE			PG	Juan Rey	Q. Chiguaza	BOGO	BOGOTA	043108N740520W	3160	200010		No Function	Telemeter (Radio)	DPAE Rainfall	
DPAE			PG	Tanque Vitelma	San Cristobal	BOGO	BOGOTA	043431N740418W	3078	200010			Telemeter (Radio)	DPAE Rainfall	Out of study area
DPAE			PG	Micaela (Santa Maria Micaela)	Q. Yomasa	BOGO	BOGOTA	043021N740511W	2900	200010			Telemeter (Radio)	DPAE Rainfall	
DPAE			PG	Dona Juana	Tunjuelo	BOGO	BOGOTA	043002N740815W	3078	200010			Telemeter (Radio)	DPAE Rainfall	
DPAE			PG	Paraiso II	Rosales	BOGO	BOGOTA	043742N740331W	2820	200010		No Function	Telemeter (Radio)	DPAE Rainfall	Out of study area
DPAE			PG	U. Antonio Narino (Nariano USME)		BOGO	BOGOTA	042854N740331W	2820	200010			Telemeter (Radio)	DPAE Rainfall	Out of study area
DPAE			LG	Kennedy	Tunjuelo	BOGO	BOGOTA	043650N741053W	2577	200303			Telemeter (Radio)	DPAE Water Level	
DPAE			LG	Independencia	Tunjuelo	BOGO	BOGOTA	043719N741154W	2576	200010			Telemeter (Radio)	DPAE Water Level	
EAAB	P-042	2120057	PG	Santa Lucia	Tunjuelo	BOGO	BOGOTA	043410N740701W	2618	195607				EAAB Rainfall	
EAAB	P-051	2120154	PG	Bosa Barreno No.2	Tunjuelo	BOGO	BOGOTA	043646N741106W	2578	-				EAAB Rainfall	
EAAB	PS-91	2120154	PG	Bosa-Bosa	Bosa	BOGO	BOGOTA	0436N7412W	2640	195705	195812			EAAB Rainfall	
EAAB	P-081	2120204	PG	Juan Rey	Q. Chiguaza	BOGO	BOGOTA	0431N7405W	2985	199008				EAAB Rainfall	
EAAB	P-090	2120205	PG	Quiba	Bogota	BOGO	BOGOTA	0432N7410W	3000	199001				EAAB Rainfall	
EAAB	P-092	2120211	PG	Las Huertas	Bogota	CUND	SOACHA	0435N7414W	2572	196811			Telemeter (GSM)	EAAB Rainfall	
EAAB	P-083	2120209	PG	La Isla	Bogota	BOGO	BOGOTA	0438N7413W	2537	196510				EAAB Rainfall	
EAAB	P-045	2120059	PM	Tunal Candelaria	Tunjuelo	BOGO	BOGOTA	0434N7409W	2599	195704				EAAB Rainfall	
EAAB	P-031	2120197	PM	Casablanca	Tunjuelo	BOGO	BOGOTA	0434N7410W	2665	197605				EAAB Rainfall	
EAAB	L-192		L	Puente La Isla	Tunjuelo	BOGO	BOGOTA	-	-	-				EAAB WL/Discharge	
EAAB	L-036	2120701	LG	Puente Bosa	Tunjuelo	BOGO	BOGOTA	0436N7412W	2550	192607			Telemeter (GSM)	EAAB WL/Discharge	
EAAB	L-005	2120806	LG	Las Huertas	Bogota	CUND	SOACHA	0435N7414W	2572	196811			Telemeter (GSM)	EAAB WL/Discharge	One of the main station in EAAB.
EAAB	L-004	2020802	LG	La Isla R. Bogota	Bogota	BOGO	BOGOTA	0438N7413W	2537	196510			Telemeter (GSM)	EAAB WL/Discharge	
EAAB	L-026	2120705	LM	El Delirio	San Cristobal	BOGO	BOGOTA	0433N7404W	2890	192701				EAAB WL/Discharge	
EAAB	L-033	2120750	LM	Cantarrana	Tunjuelo	BOGO	BOGOTA	0430N7407W	2643	195508				EAAB WL/Discharge	
EAAB	L-058	2120858	LM	La Fiscala	Tunjuelo	BOGO	BOGOTA	0430N7408W	2460	198811				EAAB WL/Discharge	
EAAB	L-070	2120904	LM	Embalse 1	Tunjuelito	BOGO	BOGOTA	0435N7409W	2586	199009				EAAB WL/Discharge	
EAAB	L-071	2120905	LM	Embalse 2	Tunjuelito	BOGO	BOGOTA	0435N7409W	2583	199009				EAAB WL/Discharge	
EAAB	L-034	2120943	LM	Humedal Tibanica (Compuesta 1)	Tunjuelo	BOGO	BOGOTA	0437N7413W	2600	198603		No Function		EAAB WL/Discharge	
EAAB	L-035	2120944	LM	Compuerta 2	Tunjuelo	BOGO	BOGOTA	0437N7437W	2600	198701		No Function		EAAB WL/Discharge	
EAAB	L-039	2120945	LM	Alemana	Q. Yomasa	BOGO	BOGOTA	0429N7404W	3300	198501		No Function		EAAB WL/Discharge	It was stolen march 2000.
EAAB	L-111	2120956	LM	Los Molinos	Q. Chiguaza	BOGO	BOGOTA	0433N7407W	2800	199001		No Function		EAAB WL/Discharge	
EAAB	L-038	2120957	LM	Cabecera	Q. Yomasa	BOGO	BOGOTA	0430N7404W	3360	198507		No Function		EAAB WL/Discharge	
EAAB	L-094		LM	Canada	Q. Yomasa	BOGO	BOGOTA	-	-	-				EAAB WL/Discharge	
EAAB	L-060	2120836	LM	Avenida Boyaca	Tunjuelito	BOGO	BOGOTA	0434N7409W	2630	198811				EAAB WL/Discharge	1 year ago, some equipment was stolen, since then the station has been operated as "LM".
CAR		2120630	CP	Dona Juana	Tunjuelito	BOGO	BOGOTA	0430N7410W	2700	198903				CAR Rainfall	
CAR		2120085	PG	El Bosque	Tunjuelito	BOGO	BOGOTA	042820N740458W	2880	196212				CAR Rainfall	One of the main station in CAR.
CAR		2120156	PG	La Picota	Q. Chiguaza	BOGO	BOGOTA	0434N7408W	2580	198006				CAR Rainfall	
CAR		2120172	PG	San Jorge	Soacha	CUND	SOACHA	0431N7412W	2890	196004				CAR Rainfall	
CAR		2120755	LM	San Jorge	Soacha	CUND	SOACHA	0430N7411W	2952	196004				CAR WL/Discharge	
CAR		2120771	LM	Puente La Isla	Tunjuelo	BOGO	BOGOTA	0437N7412W	2569	196402	196712	No Function		CAR WL/Discharge	
CAR		2120772	LM	La Chucuita	Bogota	BOGO	BOGOTA	0438N7414W	2538	196402	196612	No Function		CAR WL/Discharge	
CAR		2120829	LM	Puente Canoas	Bogota	CUND	SOACHA	0431N7415W	2550	195809				CAR WL/Discharge	It was replaced by Las Huertas (EAAB).
IDEAM		2120664	CO	San Jose	Tunjuelito	BOGO	BOGOTA	0430N7407W	2700	200111				IDEAM Rain/Clima	
IDEAM		2120665	CO	San Cayetano	Tunjuelito	BOGO	BOGOTA	0435N7405W	3100	200111				IDEAM Rain/Clima	
IDEAM		2120666	CO	INEM Santiago Pere	Tunjuelito	BOGO	BOGOTA	0434N7408W	2565	200111				IDEAM Rain/Clima	
IDEAM		2120572	CO	San Jorge	Soacha	CUND	SOACHA	0431N7412W	2900	196004				IDEAM Rain/Clima	
IDEAM			CO	Minuto de Dios (Sierra Morena)	Tunjuelo	BOGO	BOGOTA	043436N741003W	-	-			Telemeter (GOES)	IDEAM Rain/Clima	

Table S2-1-5 Collected Hydrological Data from DPAE

NOMBRE	Tipo de Datos
Rainfall	
SAN BENITO	10 Minutes Rainfall
SIERRA MORENA	10 Minutes Rainfall
TANQUE QUIBA (QUIBA - MIRADOR)	10 Minutes Rainfall
CONQUISTADOR (ESCUELA DE LOGISTICA)	Hourly Rainfall
JUAN REY	Hourly Rainfall
TANQUE VITELMA	10 Minutes Rainfall
DOÑA JUANA	10 Minutes Rainfall
MICAELA (SANTA MARIA MICAELA)	10 Minutes Rainfall
U. ANTONIO NARIÑO (NARIANO USME)	Hourly Rainfall
Water Level	
INDEPENDENCIA	5 Minutes WL
SAN BENITO	5 Minutes WL

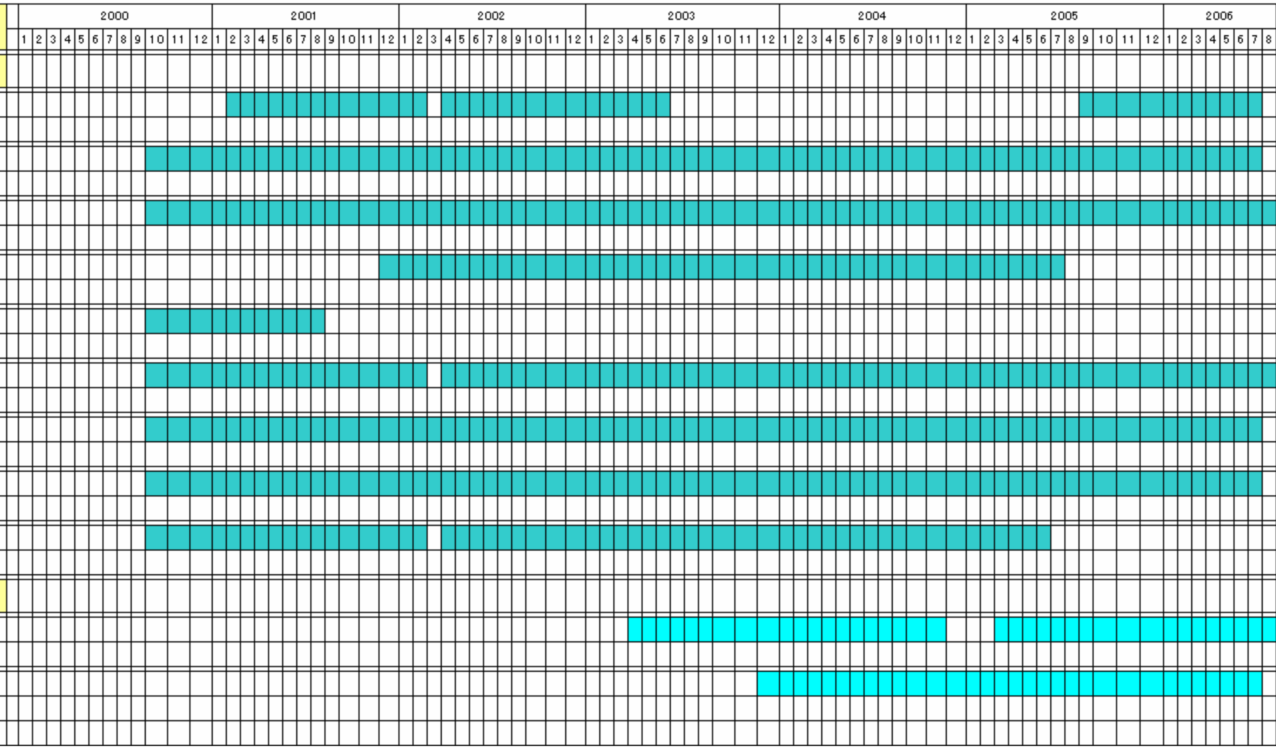


Table S2-1-6 Collected Hydrological Data from EAAB

NOMBRE	Code	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	Tipo de Datos
Rainfall																																																																				
JUAN REY	F-081																																																		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	Daily Rainfall (Diaria)
LAS HUERTAS	F-092																																																		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	Daily Rainfall (Diario)
BOSA BARRENO No.2	F-051		■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■									■		■	■	■	■		■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	Daily Rainfall (Diaria (24Hrs))
Waterlevel/Discharge																																																																				
AVENIDA BOYACA	L-060																																																	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	Daily Discharge (Diaria)
AVENIDA BOYACA	L-060																																																	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		Daily Water Level (Diaria)
LA FISCALA	L-058																																																	■	■	■												■	■			Daily Discharge (Diaria)
ALEMANA	L-039																																													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							Daily Discharge (Diaria)
CABECERA	L-033																																													■	■	■	■	■	■	■																Monthly Discharge (Mensual)
CANADA	L-094																																																											■	■	■	■	■	■	■	■	Monthly Discharge (Mensual)
CANADA	L-094																																																											■	■	■	■	■	■	■		Daily Discharge (Diaria)
LAS HUERTAS	L-005																																	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	Daily Discharge (Diaria)
LAS HUERTAS	L-005																																									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		Daily Water Level (Diaria)
LAS HUERTAS	L-005																																																																■	■	Hourly Water Level (Hourly)
PUENTE BOSA	L-035																											■	■			■	■	■	■	■	■	■	■	■	■								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		Daily Water Level (Diaria)
PUENTE LA ISLA	L-192																																																											■	■	■	■	■	■			Daily Water Level (Diaria)
LA ISLA	L-004																																■	■	■							■											■		■		■	■	■	■	■	■	■	■	■	■			Daily Water Level (Diaria)
LA ISLA	L-004																										■	■																																							■	■	Hourly Water Level (Hourly)

Table S2-1-7 Collected Hydrological Data from CAR

NOMBRE	Code	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	Tipo de Datos
Rainfall																																												
LA PICOTA	2120156																																											Daily Rainfall
																																												(Diaria)
DONA JUANA	2120630																																											Daily Rainfall
																																												(Diaria)
SAN JORGE GJA	2120172																																											Daily Rainfall
																																												(Diaria)
EL BOSQUE	2120085																																											Daily Rainfall
																																												(Diaria)
Waterlevel/Discharge																																												
SAN JORGE GJA	2120755																																											Daily Discharge
																																												(Diaria)

Table 2-1-8 Collected Hydrological Data from IDEAM

NOMBRE	Code	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	Tipo de Datos
Rainfall																			
SAN JOSE	2120664																		Daily Rainfall
																			(Diaria)
SAN CAYETANO	2120665																		Daily Rainfall
																			(Diaria)
INEM ANTIAGO	2120666																		Daily Rainfall
																			(Diaria)
SAN JORGE GJA	2120572																		Daily Rainfall
																			(Diaria)
MINUTO DE DIOS	-																		Hourly Rainfall
(SIERRA MORENA)																			(10 minutes)

1.3 Characteristic of Rainfall in and around the Study Area

1.3.1 Annual Rainfall

Annual Rainfall Distribution in area in 2002, 2003 and 2004 are shown in Figure S2-1-3 to S2-1-5. Annual rainfall amount in the Study Area varies by the area from 530 mm to 1150 mm in 2002, from 470 mm to 1040 mm in 2003, and from 600 mm to 1590 in 2004, respectively. Its spatial distribution has a similar tendency that rainfall amount is high in eastern hilly area in Bogota and southern mountain area in Soacha, and it is low in lowland area such as along the Tunjuelo river and near the confluence of the Tunjuelo river and the Bogota river.

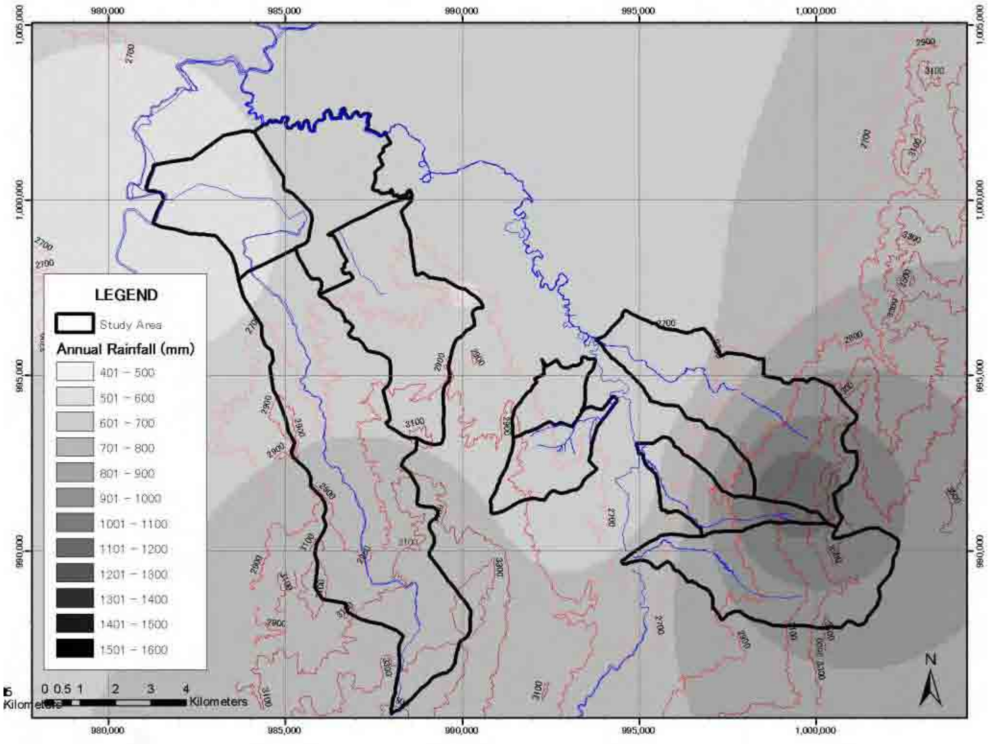


Figure S2-1-3 Annual Rainfall Distribution (2002)

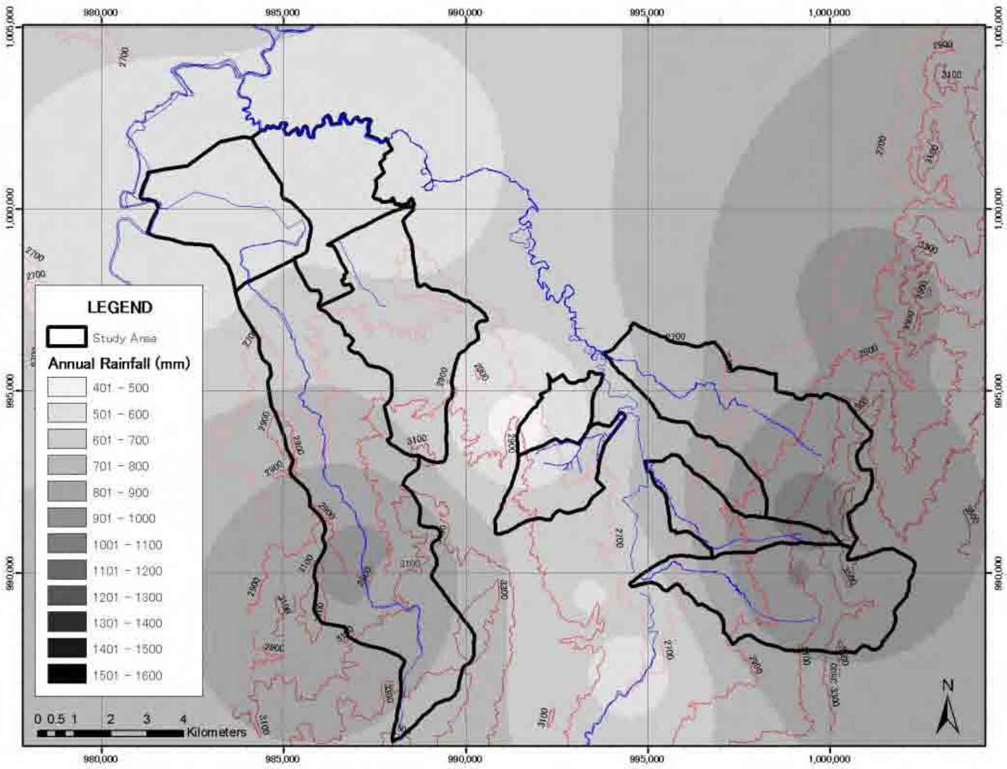


Figure S2-1-4 Annual Rainfall Distribution (2003)

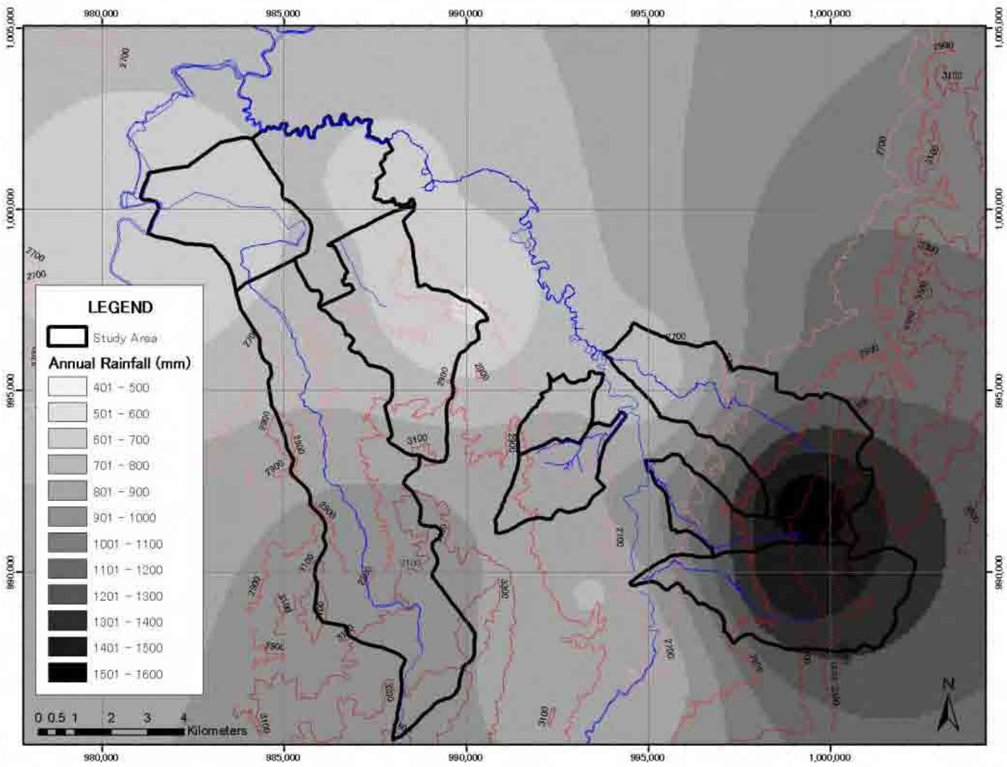
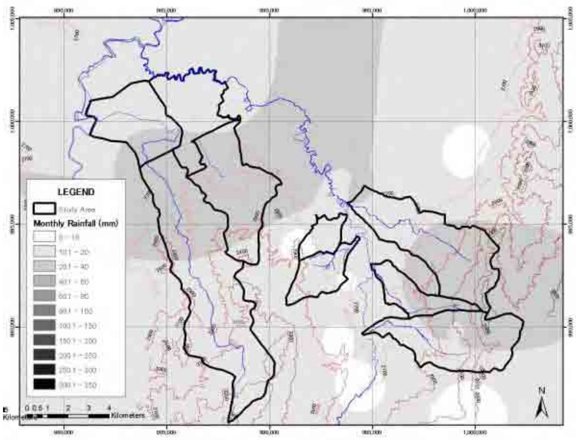


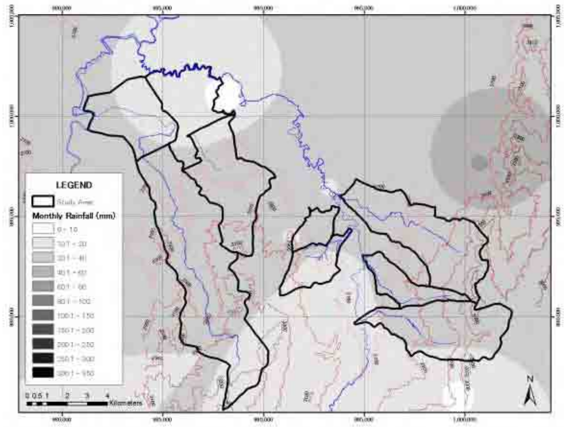
Figure S2-1-5 Annual Rainfall Distribution (2004)

1.3.2 Monthly Rainfall

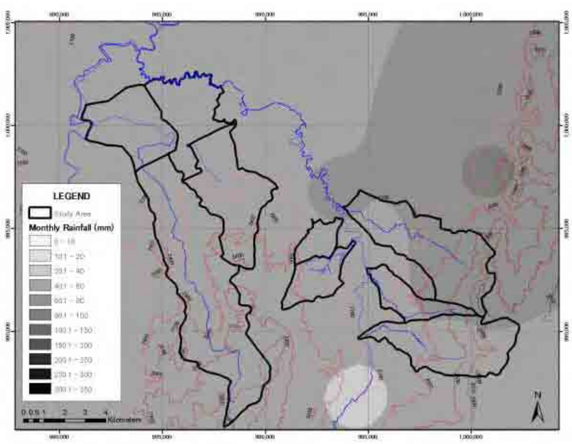
Monthly rainfall distribution in 2003 and monthly rainfall variation in several stations in the Study Area are shown in Figure S2-1-6 and S2-1-7, respectively. As described in “(1) General Description in Cundinamarca including the Study Area” in this Chapter, there are two (2) rainy season from March to May and from September to November in the Study Area. As for the characteristic of the Study Area, rainfall amount is comparatively high in eastern hilly area in Bogota and southern mountain area in Soacha through the year, and especially rainfall amount in July is also high in these areas apart from the two (2) rainy seasons as typified by Micaela station located in eastern and southern hilly area in the Study Area. This trend is seen also in other years such as 2002, 2004 and 2005.



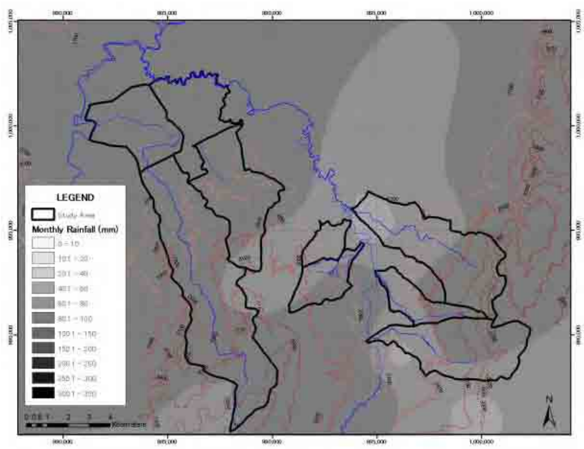
January



February



March



April

Figure S2-1-6 Monthly Rainfall Distribution (January - December, 2003) (1/3)

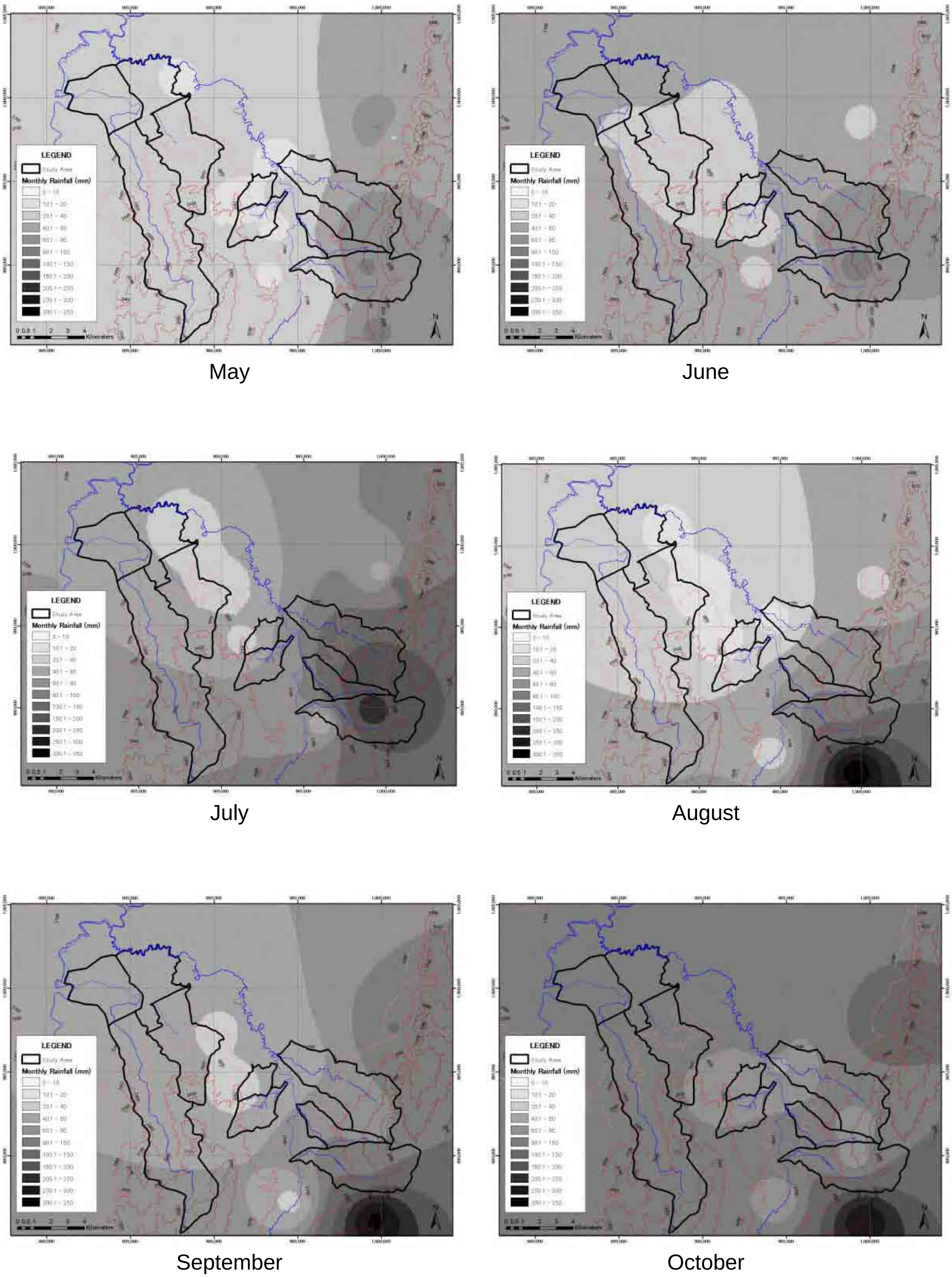
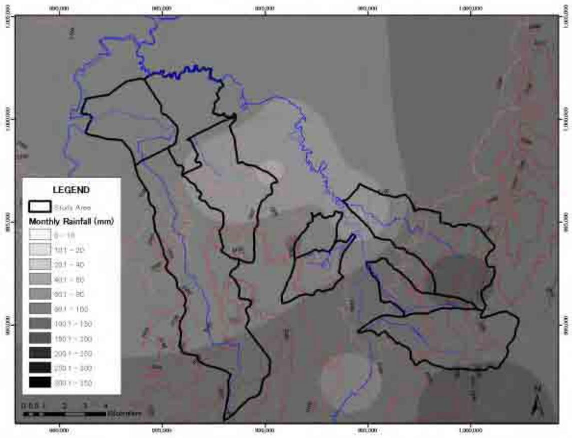
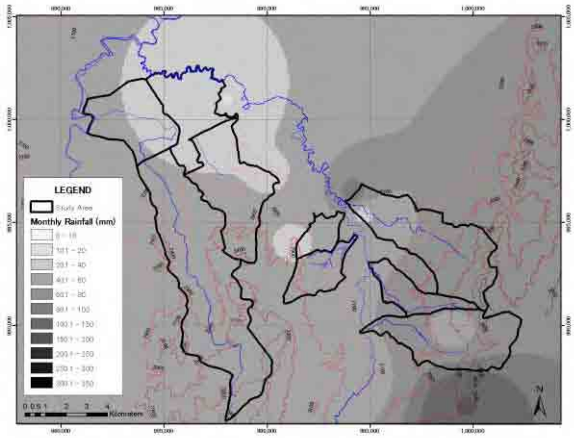


Figure S2-1-6 Monthly Rainfall Distribution (January - December, 2003) (2/3)



November



December

Figure S2-1-6 Monthly Rainfall Distribution (January - December, 2003) (3/3)

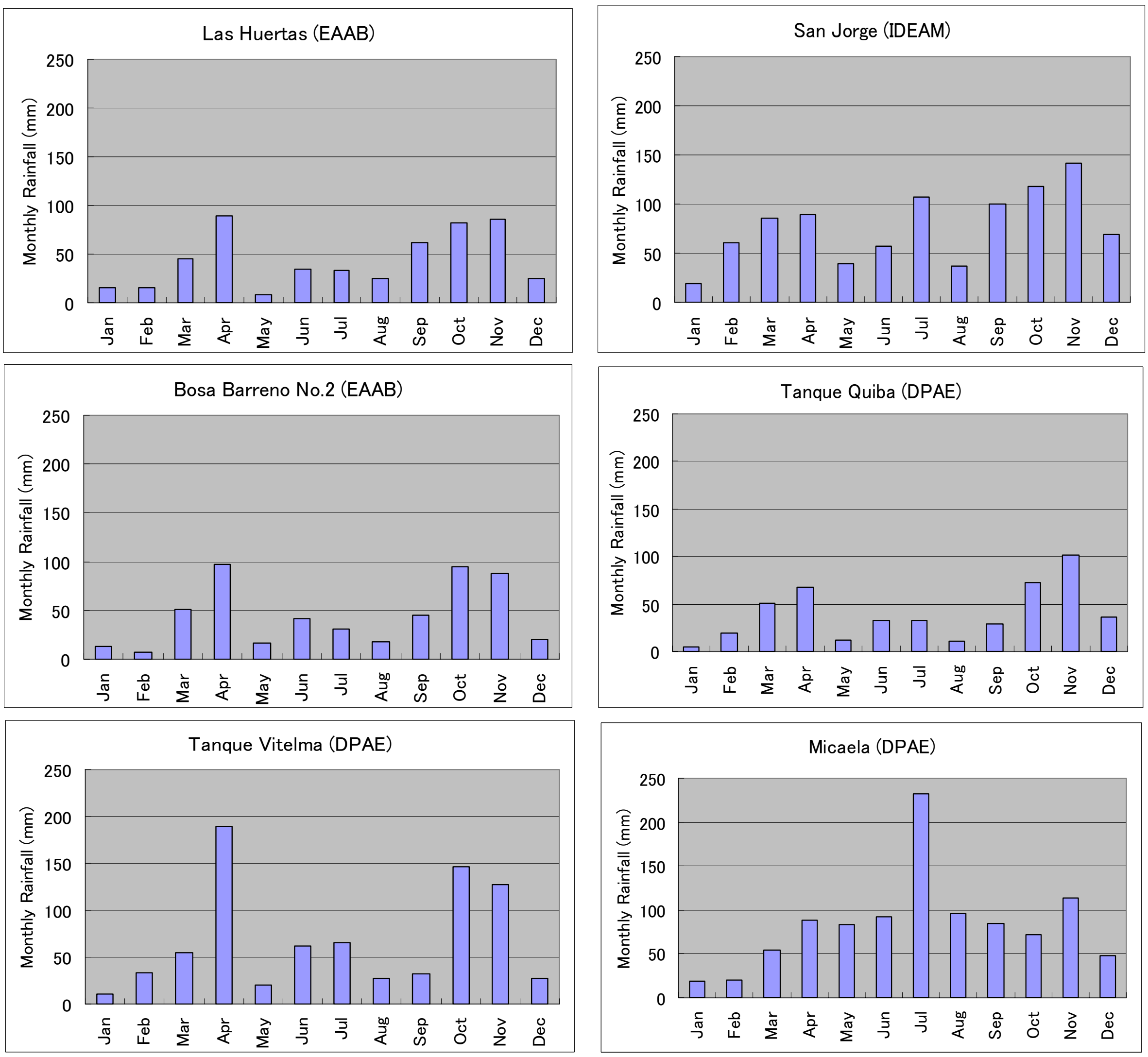


Figure S2-1-7 Monthly Rainfall Variation in 2003

1.3.3 Number of Rainy Days in Month

Table S2-1-9 and Figure S2-1-8 shows the number of rainy days in month in 2003, when rainfall amount more than 0.1 mm was recorded, in the same stations as Figure S2-1-7. High numbers of Rainy days are recorded in April, July, October and November in all stations. The monthly variation among the stations is almost similar except Micaela station. The highest number of rainy days of 29 days is recorded in May in the Micaela station.

Table S2-1-9 Number of Rainy Days in 2003

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Las Huertas (EAAB)	1	6	14	16	6	11	19	13	13	19	20	9	147
San Jorge (IDEAM)	1	8	11	16	11	13	13	10	8	17	15	5	128
Bosa Barreno No.2 (EAAB)	1	8	13	14	7	12	15	11	14	19	21	7	142
Tanque Quiba (DPAE)	1	11	13	17	11	12	15	9	8	18	19	8	142
Tanque Vitelma (DPAE)	3	12	14	21	19	20	23	20	18	24	27	13	214
Micaela (DPAE)	2	11	15	21	29	21	26	24	21	21	20	15	226

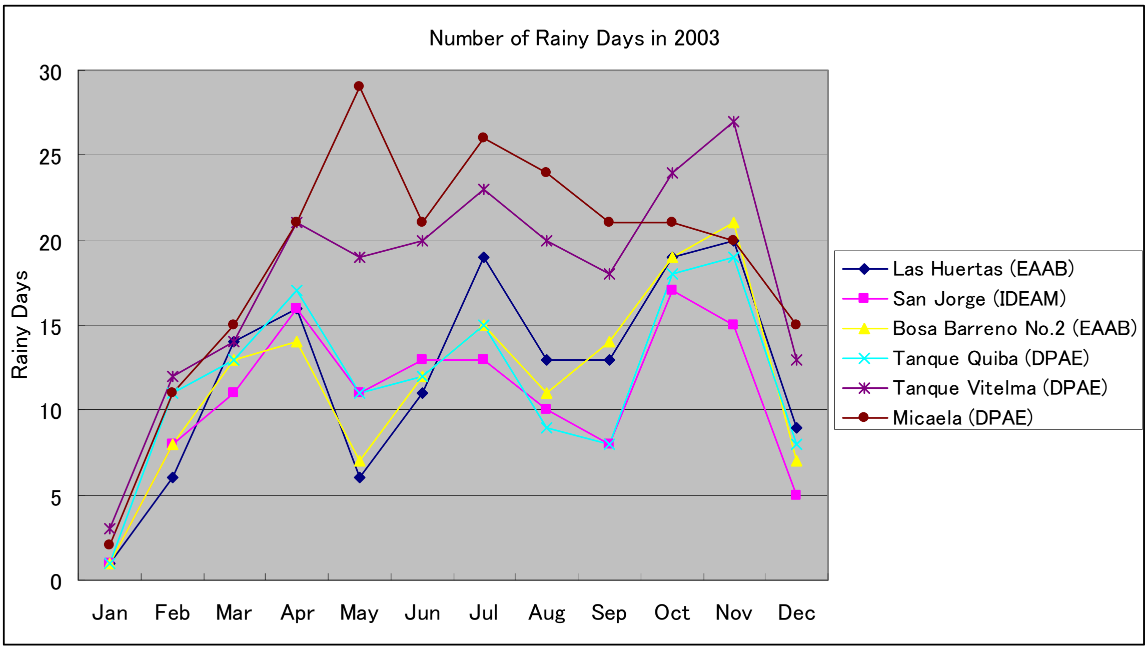


Figure S2-1-8 Rainy Days in Month in 2003

1.3.4 Daily Rainfall

Figure S2-1-9 and 2-1-10 show the monthly maximum daily rainfall in DPAE stations from October 2000 to August 2006. Figure S2-1-9 shows the value of eastern side of Rio Tunjuelo, and Figure S2-1-10 shows the value of western side. As a general trend, daily rainfall is bigger in eastern side than western side. In eastern side, daily rainfall is heavy in June and July as well as rainy season, although the daily rainfall in western side tends to be heavy in rainy season. Maximum value of 54.2 mm is recorded in May 3, 2005 in Tanque Vitelma station located in eastern side.

Table S2-1-10 shows the probable daily rainfall amount with several return periods in 5 (five) stations. It was analyzed by Gumbel method using collected data in this Study.

Table S2-1-10 Probable Daily Rainfall (unit:mm)

Station	Return Period (year)					
	3	5	10	25	50	100
Las Huertas (EAAB)	29.19	32.03	35.60	40.12	43.47	46.79
San Jorge (IDEAM)	35.38	38.74	42.96	48.30	52.26	56.19
Bosa Barreno No.2 (EAAB)	33.56	37.23	41.83	47.65	51.97	56.25
Juan Rey (EAAB)	47.74	52.98	59.56	67.88	74.06	80.18
La Picota (CAR)	35.91	40.33	45.89	52.91	58.11	63.28

Figure S2-1-11 shows the spatial distribution of daily rainfall from May 8 to May 12, 2006 in the Study Area. Heavy inundation occurred on May 11 in Soacha.

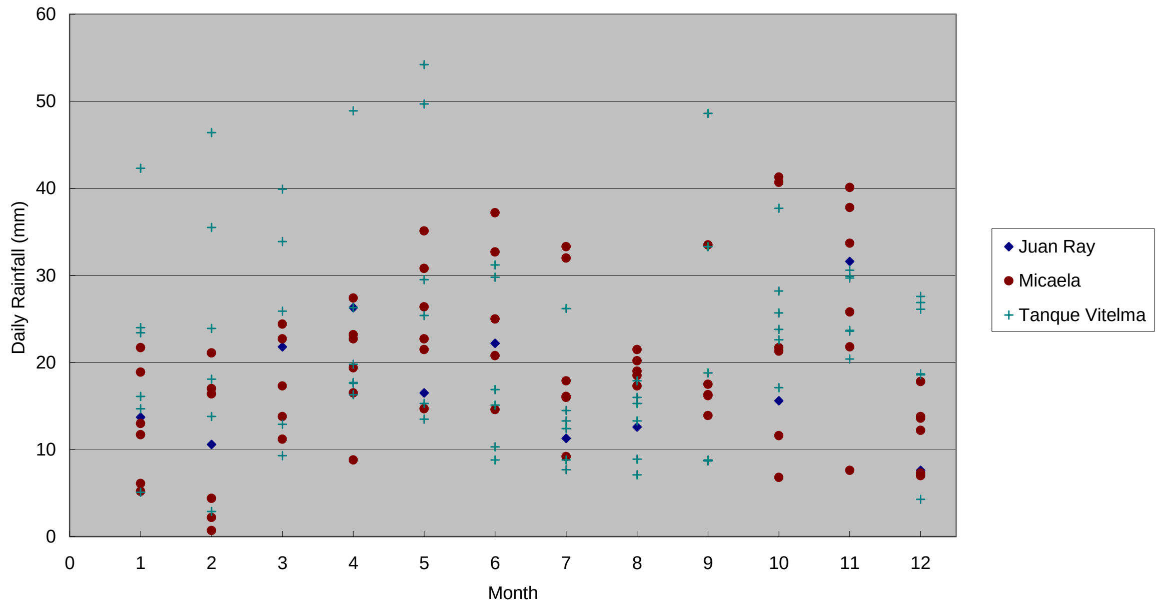


Figure S2-1-9 Maximum Daily Rainfall in DPAE Stations in Eastern Side of Rio Tunjuelo from 2000 to 2006

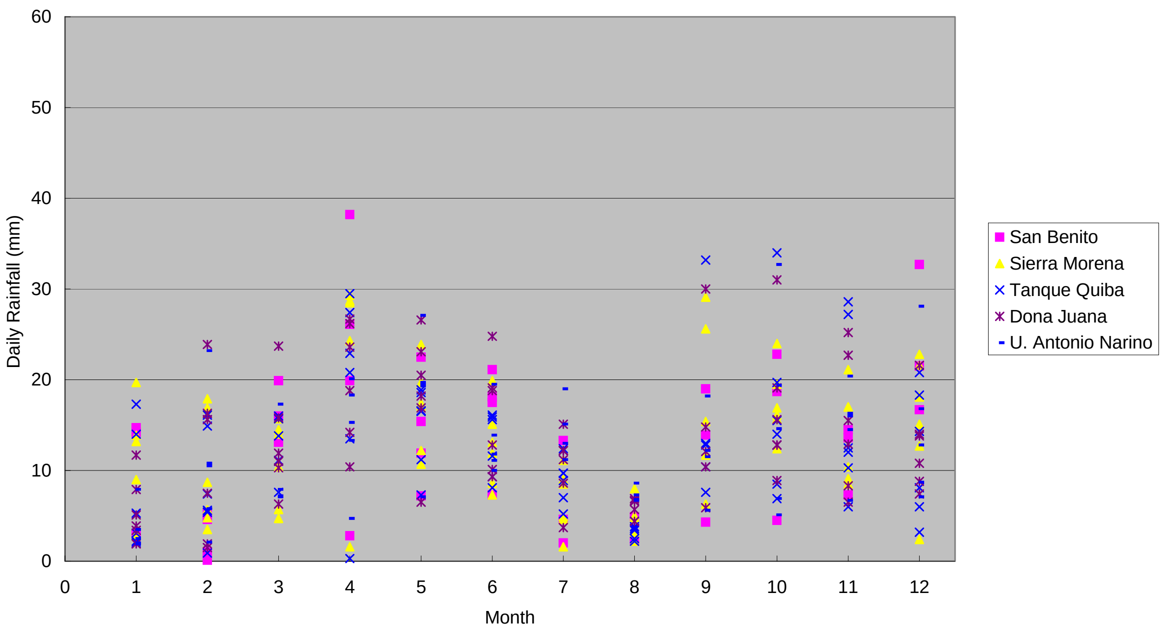


Figure S2-1-10 Maximum Daily Rainfall in DPAE Stations in Western Side of Rio Tunjuelo from 2000 to 2006

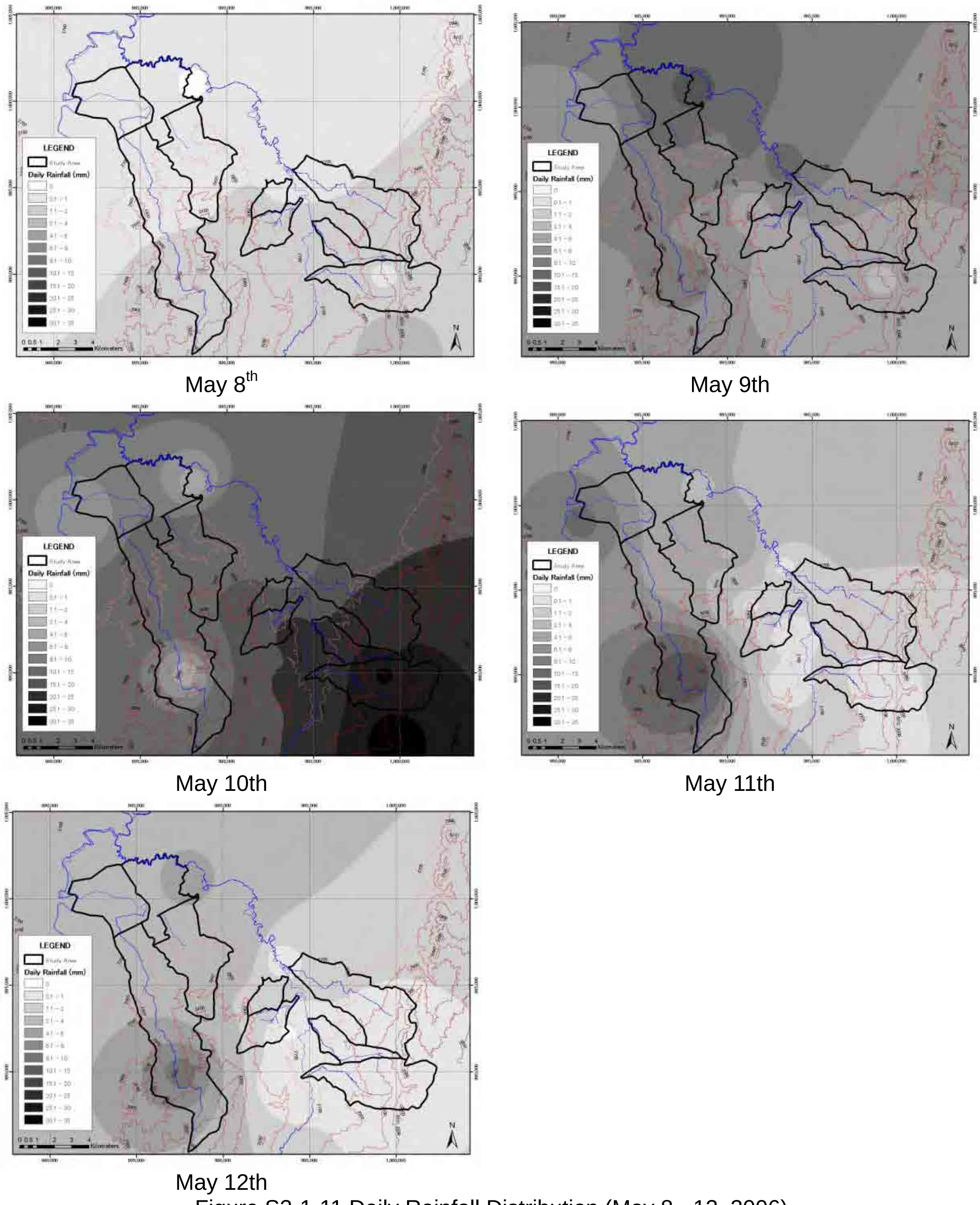


Figure S2-1-11 Daily Rainfall Distribution (May 8 - 12, 2006)

1.3.5 Hourly Rainfall

Figure S2-1-12 and S2-1-13 show the monthly maximum hourly rainfall in DPAE stations from October 2000 to August 2006. Figure S2-1-12 shows the value of eastern side of Rio Tunjuelo, and Figure S2-1-13 shows the value of western side. Hourly rainfall is bigger in eastern side than western side as is the case with daily rainfall. In both side, the value of maximum hourly rainfall is heavy in rainy season. Hourly rainfall of eastern side in June and July is comparatively low unlike with the tendency of the daily rainfall. It shows that rainfall intensity of eastern side in June and July is not strong whereas rainfall duration is long. Maximum value of 42.1 mm is recorded in September 25, 2005 in Tanque Vitelma stations.

Figure S2-1-14 shows the zoning of rainfall pattern by EAAB, 1995, with Study Area. Almost all the Study Area is included in zone of Z4, Z5 and Z7. Rainfall pattern varies by the zone. Rainfall intensities in several return periods in each zone by EAAB, 1995 are shown in Table S2-1-11.

Figure S2-1-15 shows the relation between daily rainfall and hourly rainfall in DPAE stations in 2000-2006. The daily rainfall is maximum value of each month from 2000 to 2006, and the hourly rainfall is also the maximum value of each month from 2000 to 2006. From the figure, the percentage of hourly rainfall amount to the daily rainfall amount is about 40-60%, which means the heavy rainfall finishes in short time. Figures S2-1-16 and S2-1-17 show rainfall distribution, in 1:00-24:00 for Tanque Quiba and Micaela stations, respectively. These 10 examples in each figure are top 10 of high daily rainfall amount from October 2000 to August 2006 in Tanque Quiba station, and from October 2000 to July 2006 in Micaela station. In Tanque Quiba station, rainfall distribution can classify two (2) patterns. One is comparatively moderate curve such as 2002/4/25 and 2003/4/12 and 2002, and other is very steep curve such as 2005/9/25 and 2006/4/30, which highest hourly rainfall almost equals daily rainfall amount. In Micaela station, rainfall distribution can classify also two (2) patterns. One is very moderate curve such as 2001/11/12 and 2002/6/22, and other is comparatively steep curve such as 2003/9/27 and 2005/10/23. Figure 2-1-18 shows the synthetic rainfall distributions for USA by USDA, 1986. When this classification of rainfall distributions is intended to apply in the Study Area for analysis, for example, I and II is regarded to fit in La Estrella basin near the Tanque Quiba station and IA and III to fit in Yomasa basin where Micaela station located.

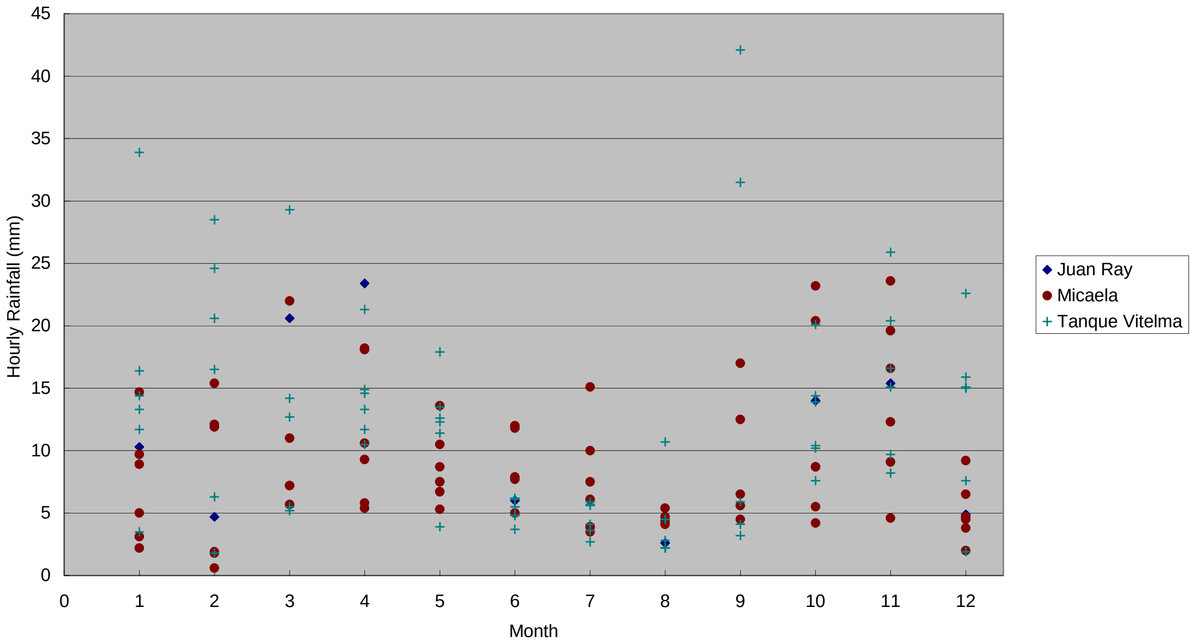


Figure S2-1-12 Maximum Hourly Rainfall in DPAE Stations in Eastern Side of Rio Tunjuelo from 2000 to 2006

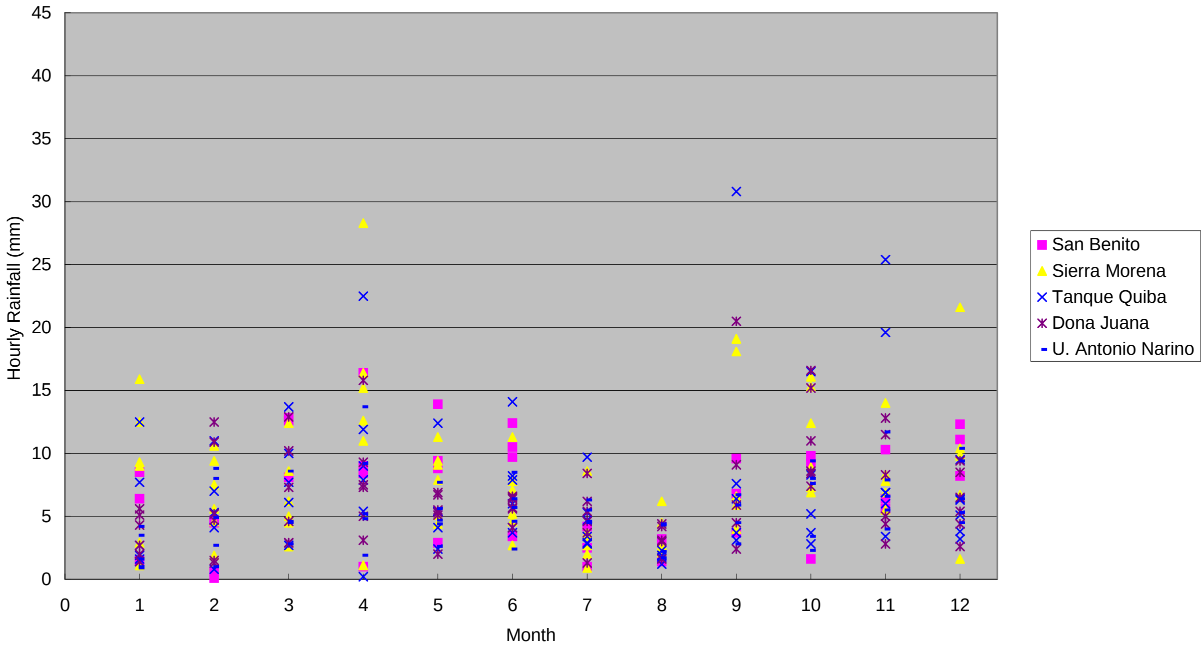
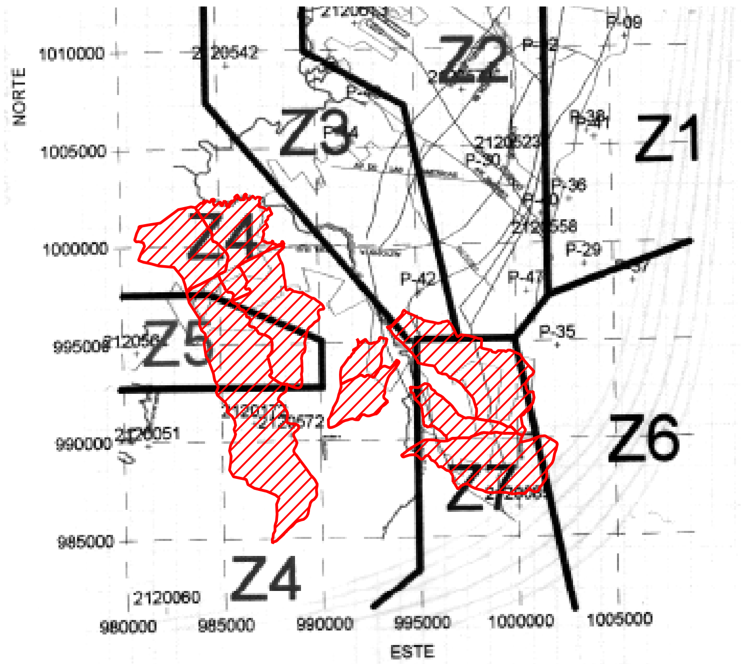


Figure S2-1-13 Maximum Hourly Rainfall in DPAE Stations in Western Side of Rio Tunjuelo from 2000 to 2006



(Source: "ESTUDIO PARA EL ANALYSIS Y CARACTERIZACION DE TORMENTAS EN LA SABANA DE BOGOTA", EAAB, November 1995)

Figure S2-1-14 Zoning of Rainfall Pattern

Table S2-1-11 Rainfall Intensity in each Zone (unit:mm/h)

Zone 4 (Z4)						
Duration (min.)	3 years	5 years	10 years	25 year	50 years	100 years
15	48.72	57.42	68.38	82.21	92.49	102.67
30	34.47	39.91	46.74	55.40	61.82	68.19
60	22.09	25.34	29.43	34.59	38.43	42.23
120	12.68	14.55	16.95	19.92	22.15	24.35
360	4.85	5.50	6.37	7.47	8.27	9.06
Zone 5 (Z5)						
Duration (min.)	3 years	5 years	10 years	25 year	50 years	100 years
15	39.30	44.10	50.10	57.70	63.40	69.00
30	27.80	31.60	36.30	42.30	46.70	51.10
60	17.50	19.90	23.00	27.00	29.90	32.80
120	10.10	11.80	13.80	16.40	18.30	20.20
360	3.70	4.30	5.10	6.00	6.80	7.50
Zone 7 (Z7)						
Duration (min.)	3 years	5 years	10 years	25 year	50 years	100 years
15	42.35	53.25	66.90	84.15	96.95	109.65
30	28.60	34.45	41.85	51.15	58.10	64.95
60	17.40	20.10	23.50	27.75	30.95	34.05
120	11.25	13.45	16.30	19.80	22.40	25.00
360	5.35	6.55	8.00	9.95	11.35	12.75

(Source: "ESTUDIO PARA EL ANALYSIS Y CARACTERIZACION DE TORMENTAS EN LA SABANA DE BOGOTA", EAAB, November 1995)

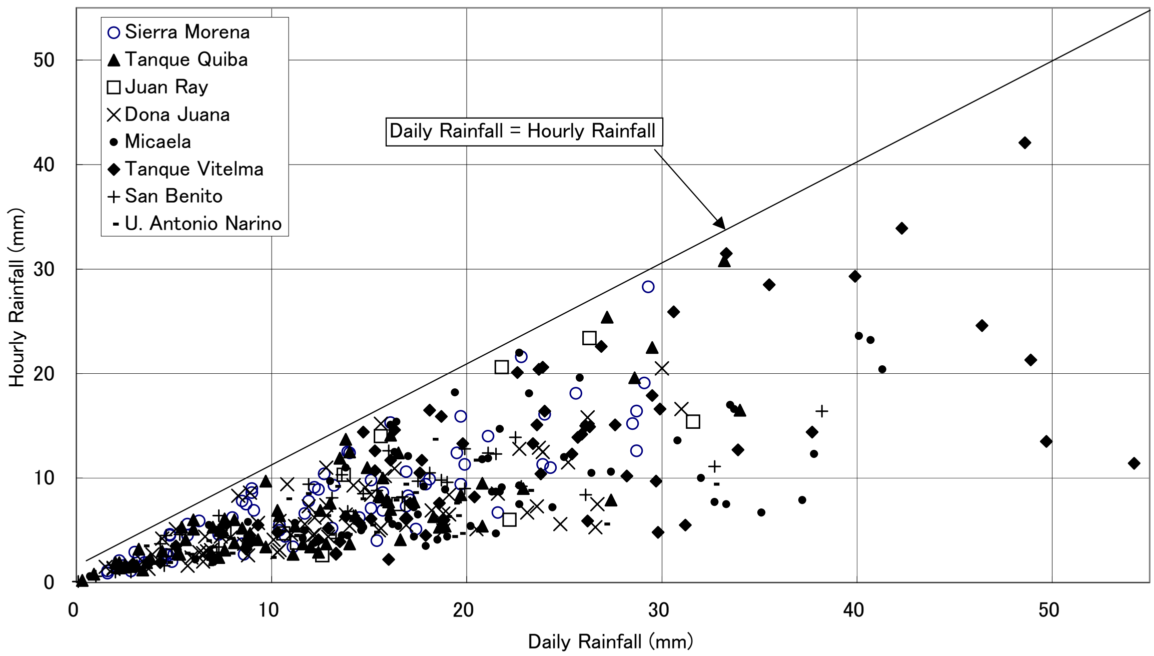


Figure S2-1-15 Relation between Daily Rainfall and Hourly Rainfall in DPAE Stations in 2000-2006

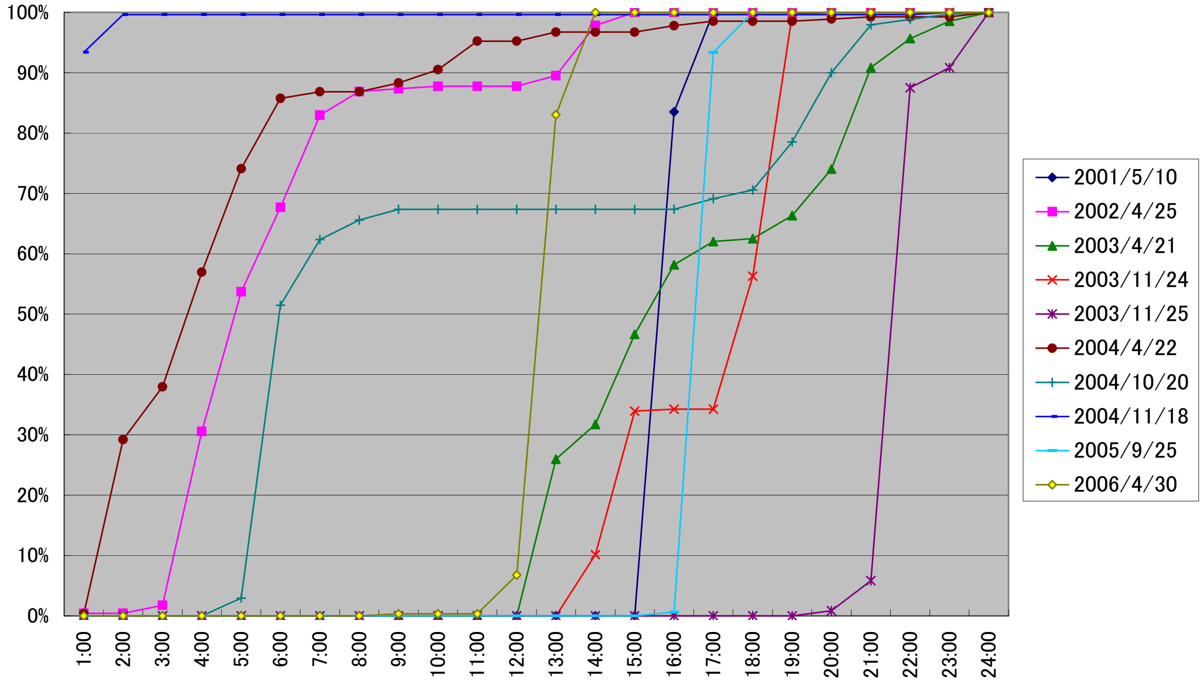


Figure S2-1-16 Rainfall Distribution in 1:00-24:00 in Tanque Quiba Station

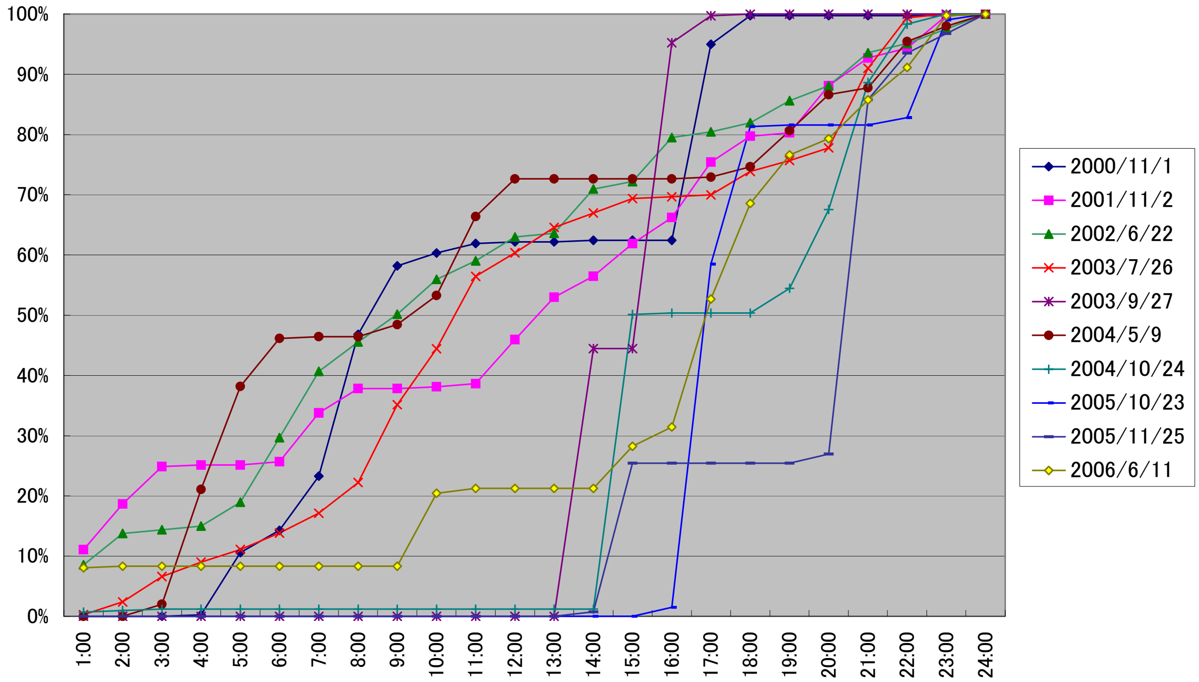
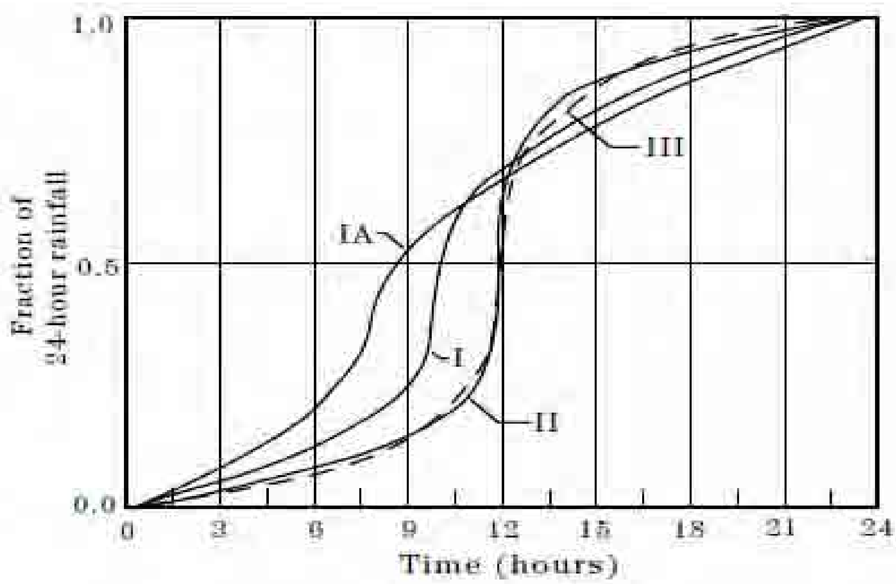


Figure S2-1-17 Rainfall Distribution in 1:00-24:00 in Micaela Station



(Source: Figure B-1of "Urban Hydrology for Small Watersheds" (210-VI-TR-55, Second Ed.), USDA, June 1986)

Figure S2-1-18 SCS 24-hour Rainfall Distributions

1.4 Correlation of Rainfall Stations - Correlation of Rainfall Pattern -

1.4.1 Correlation of Rainfall Stations in and around the Study Area

In order to examine the correlation of stations and the rainfall pattern in and around the Study area, correlation coefficient of each station is calculated using the monthly rainfall data from 2000 to 2006 and daily rainfall data in 2003. It can be said that if correlation coefficient is high between two (2) stations, rainfall pattern is similar in relevant area. Figure S2-1-19 and S2-1-20 show the result of correlation calculation of monthly rainfall and daily rainfall in and around the Study Area, respectively. Values on the lines between stations designate the square value of correlation coefficient of each station.

The correlation of the stations, particularly of daily rainfall, is summarized as follows:

- Correlation is high in each stations located in lowland area such as along the Rio Tunjuelo and northern area of Soacha
- Correlation is comparatively high in the stations of Juan Rey, Micaela, Dona Juana (DPAE) and U. Antonio Narino, which are located in southeastern part of the Study Area
- Correlation is comparatively high in the stations of Tanque Vitelma, San Benito and La Picota, which are located northeastern part of the Study Area
- Correlation of comparatively low in east - west direction

1.4.2 Correlation of DPAE Rainfall Stations

Figures S2-1-21 and S2-1-22 shows the result of correlation calculation of monthly rainfall data from 2000 to 2006 and daily rainfall data in 2003 only in DPAE rainfall stations. However, data of Juan Rey station of EAAB is used for analysis instead of Juan Rey station of DPAE because operated period of Juan Rey of DPAE is very short. Numerical characters in the figures designate the square value of correlation coefficient of each station.

The correlation of the DPAE rainfall stations, particularly of daily rainfall, is summarized as follows:

- Correlation is extremely high in the stations located along the Rio Tunjuelo in north - south direction
- Correlation is high or comparatively high in the stations located in western side of the Rio Tunjuelo
- Correlation of comparatively high in east - west direction except Sierra Morena - Tanque Quiba, Tanque Quiba - Juan Rey, and Tanque Quiba - Micaela station

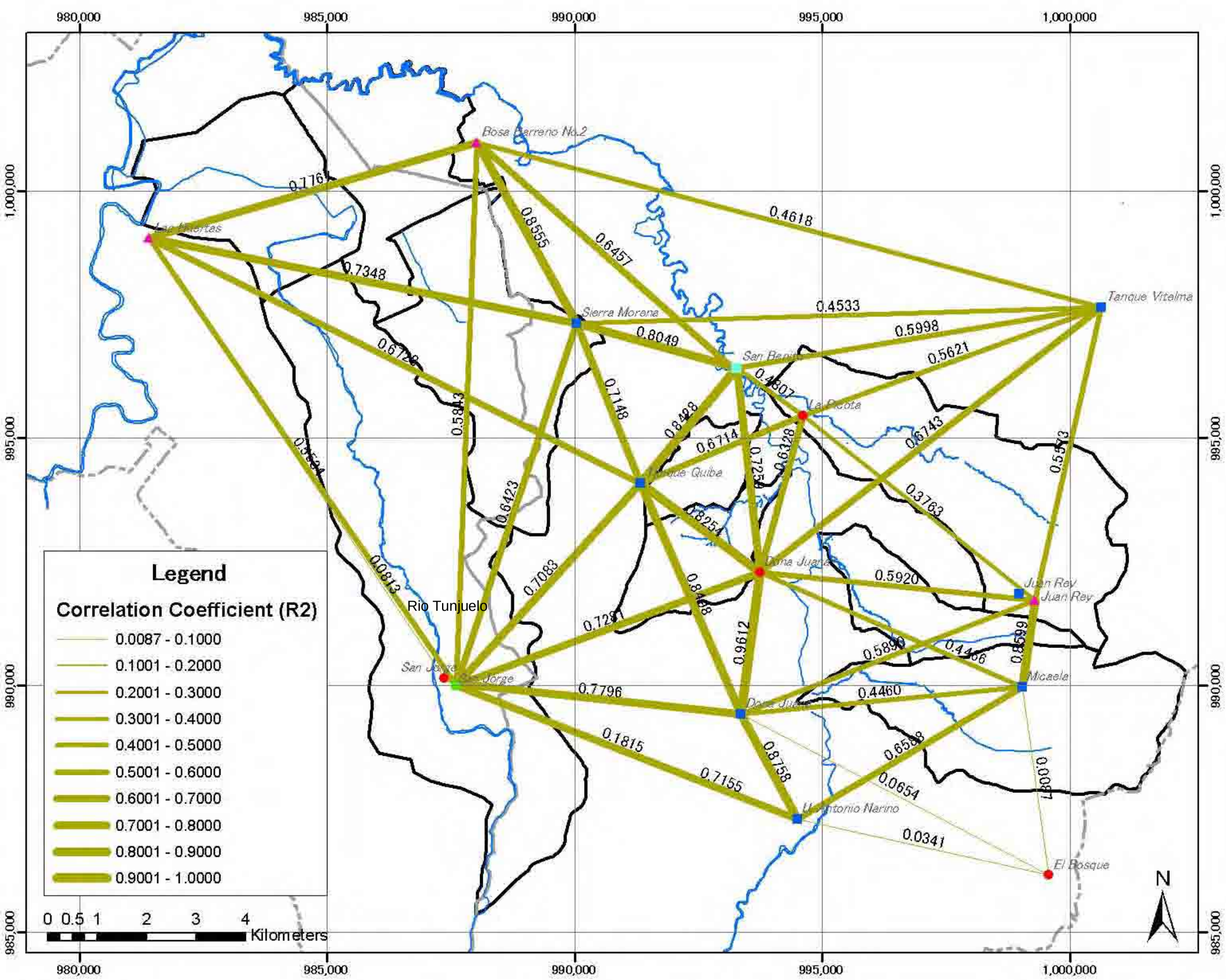


Figure S2-1-19 Correlation of Monthly Rainfall (2000 - 2006)

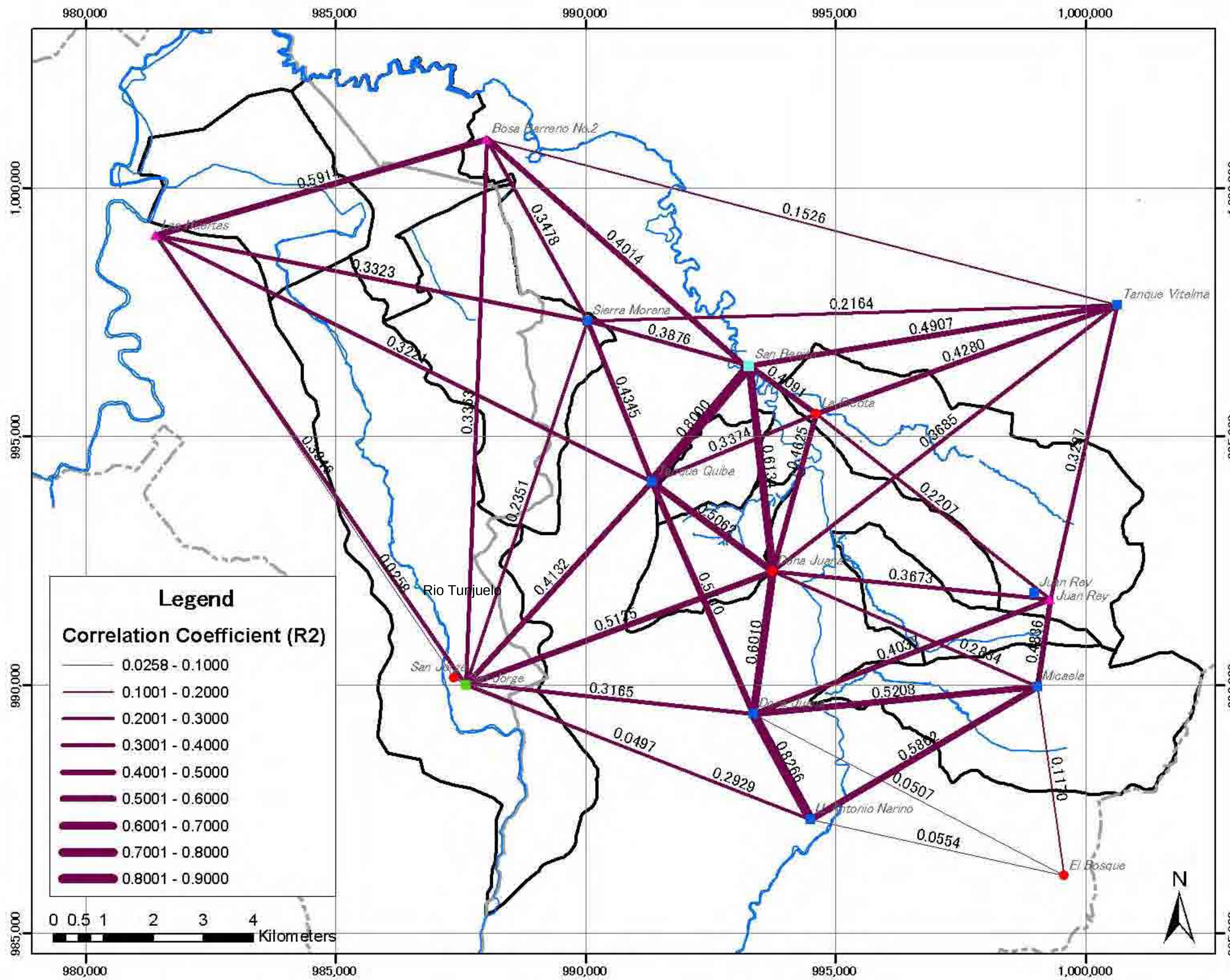


Figure S2-1-20 Correlation of Daily Rainfall (2003)

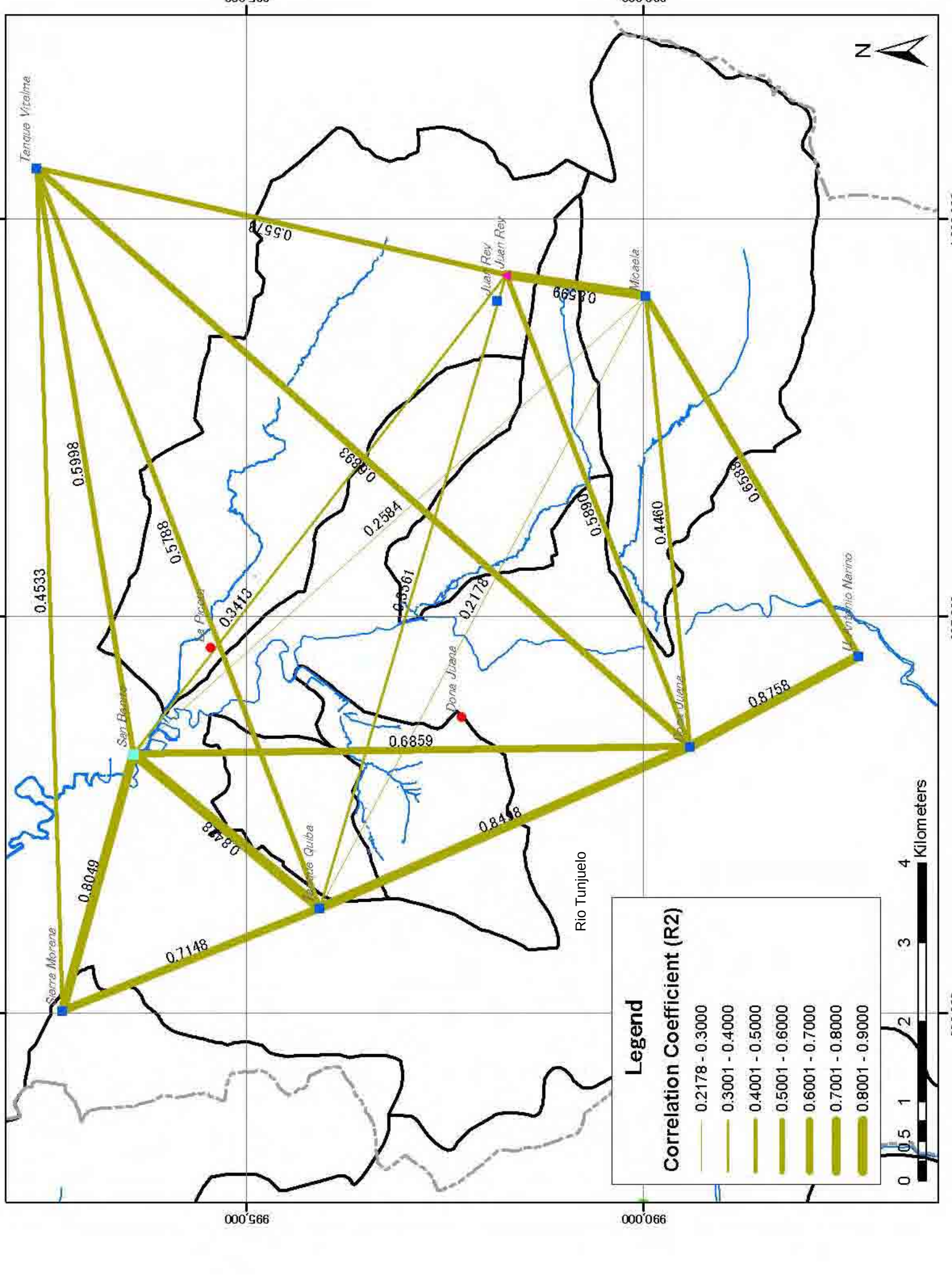


Figure S2-1-21 Correlation of Monthly Rainfall in DPAE Stations (2000 - 2006)

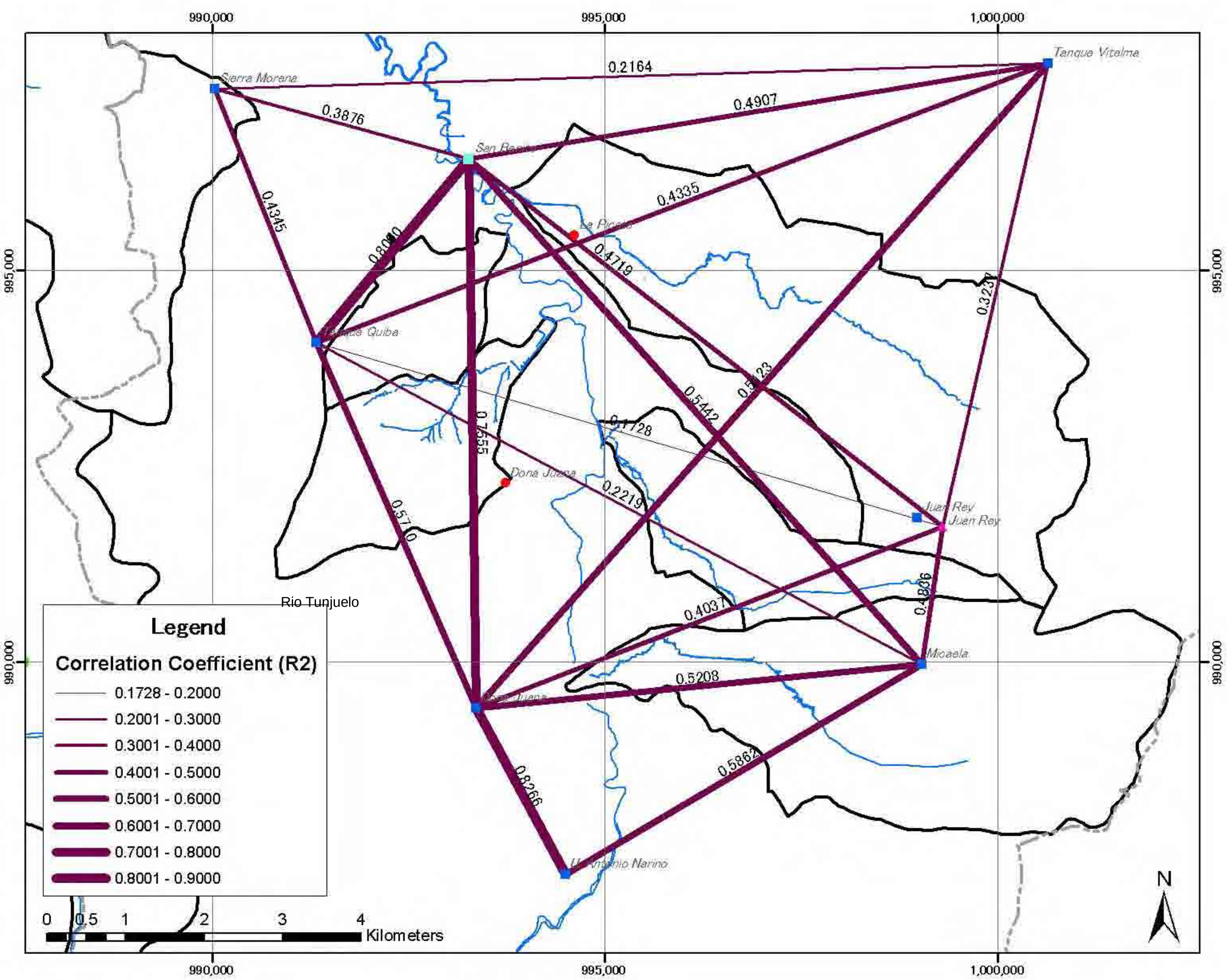


Figure S2-1-22 Correlation of Daily Rainfall in DPAE Stations (2003)