CHAPTER 2 METEO-HYDROLOGICAL MONITORING AND FORECASTING

2.1 Existing Situation about Hydrological-Meteorological Monitoring System

2.1.1 Allocation of Observing Stations in the Study Area

In Colombia there are a lot of meteorological observing stations. Figure S2-2-1 shows the existing meteorological and hydrological stations operated by IDEAM in Colombia, and the comparison with meteorological stations operated by JMA in Japan. The number of station in Colombia is much more than in Japan, but the number of telemeterized stations, which are operated by IDEAM, in Colombia is about 250. The number of telemeterized stations by GOES system is about 150. On the other side, the meteorological stations in Japan are telemeterized perfectly by JMA.

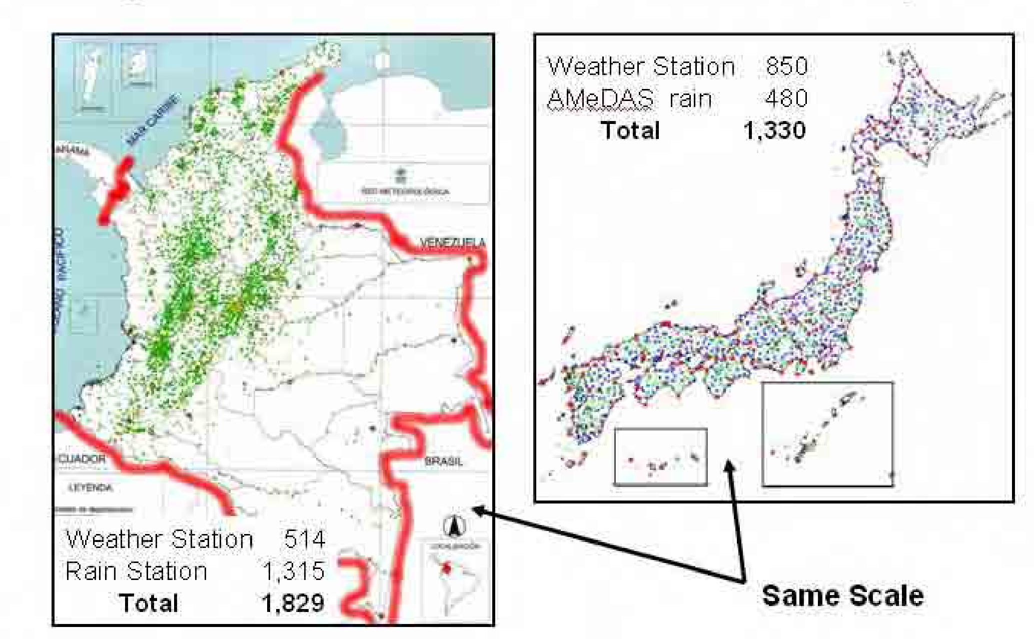


Figure S2-2-1 Meteorological and Hydrological Stations

Around the study area there are not enough meteorological and hydrological stations to monitor meteorological and hydrological conditions. They are operated by DPAE, EAAB, CAR, IDEAM and other organizations.

Generally speaking, regarding meteorological and hydrological data, in order to analyze the correlation between rainfall and water level/ flood and to monitor actual meteorological and hydrological conditions, it is desirable to fill the following two requirements. One of them is enough period of data storage (at least 10 years). If possible, it is better to storage hourly data of rainfall and water level. It is necessary to analyze the correlation between rainfall and water level for a flood disaster. The other is data monitoring system. It is better to be telemeterized and to obtain data immediately by online system. It is necessary to monitor actual meteorological and hydrological conditions, to issue kind of warning and advisory and to plan some countermeasure for expected disaster.

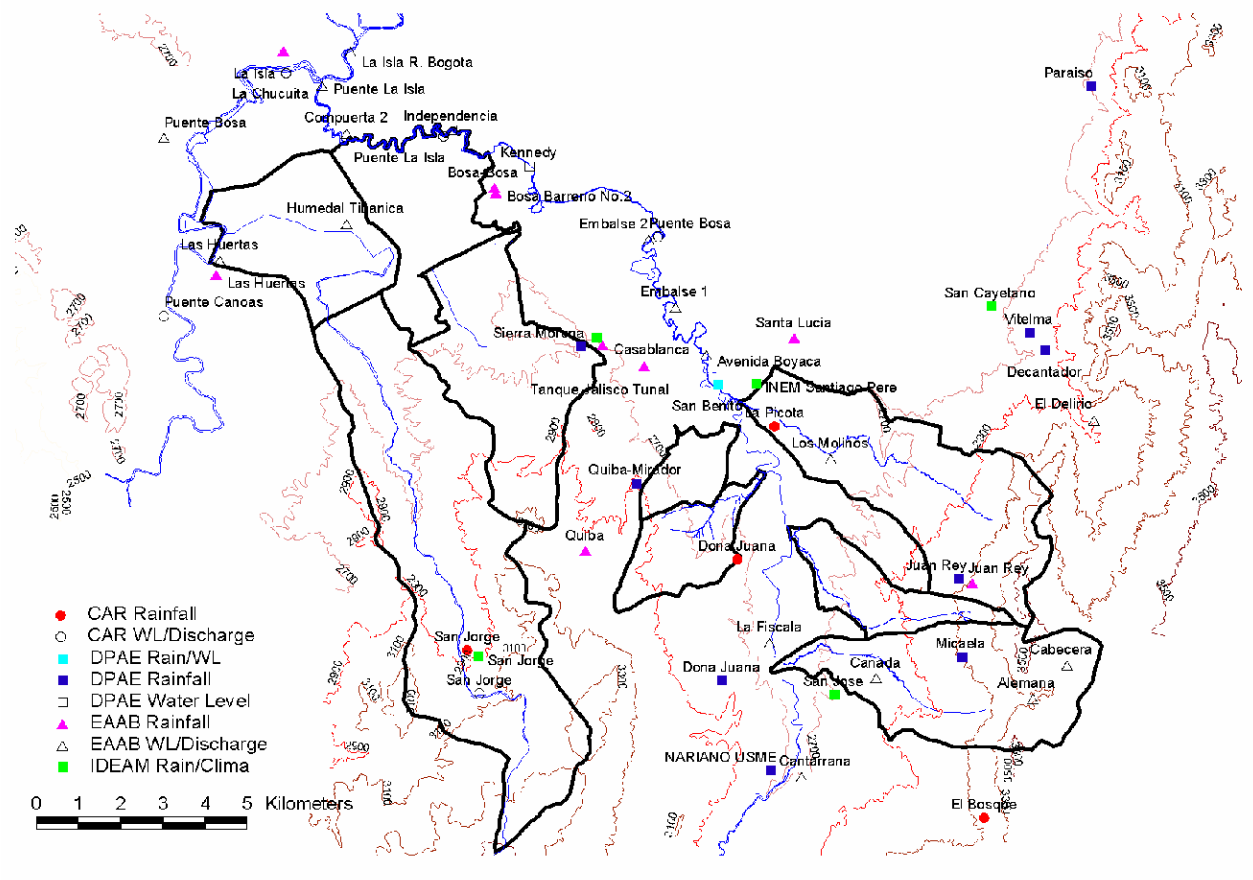


Figure S2-2-2 Meteorological and Hydrological Stations around the Study Area

Figure S2-2-3 shows that present condition of existing station network. Most of them are already telemeterized and some of them are conventional type yet. On the site of a telemeterized station, they observe an hourly (or more minute) data every day, but on the conventional site they can observe only daily data. Even on the telemeterized site, the period of data storage is not enough to analyze, they didn't analyze the correlation between rainfall and water level.

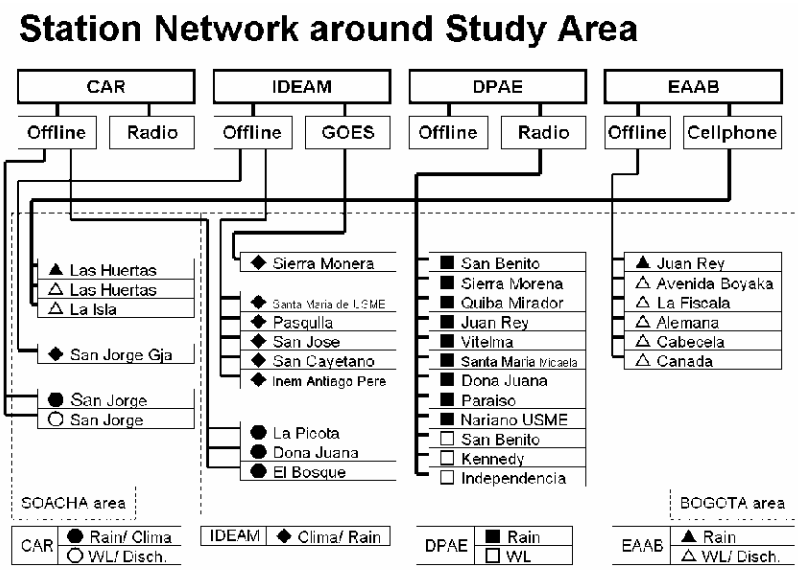


Figure S2-2-3 Station Network around the Study Area

2.1.2 IDEAM

(1) Composition of typical observing station

As a national meteorological organization, IDEAM is operating weather stations and rainfall stations nationwide. The JICA study team visited two typical stations. One is a self-reporting station Minuto de Dios, and the other is a conventional station San Jorge.

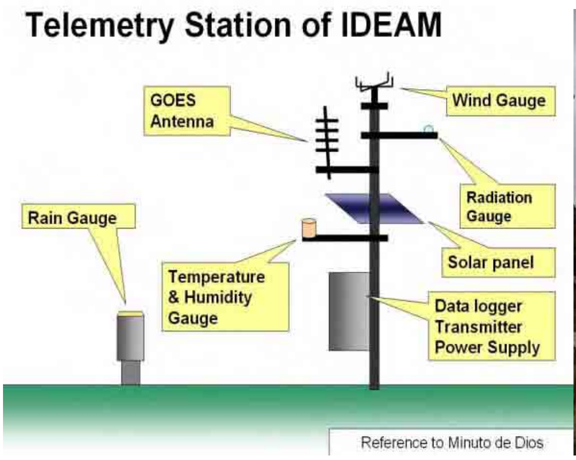


Figure S2-2-4 Composition of Minuto Station

Photo S2-2-1 Minuto Station

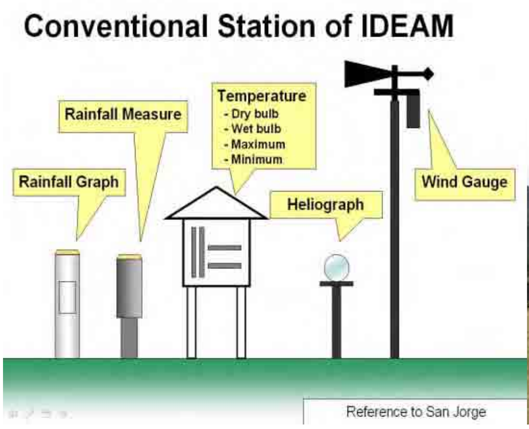


Figure S2-2-5 San Jorge Station

Photo S2-2-2 San Jorge Station

Minuto station is telemeterized by GOES (GMS: Geostational Meteorological Satellite of NOAA in USA) system. According to the regulation of WMO (World Meteorological Organization), a geostational meteorological satellite should have DCP (Data Collection Platform) function. The satellite GOES also has such DCP function. Based on the agreement between IDEAM and NOAA, almost 150 meteorological stations are operated as GOES system self-reporting stations in Colombia.

In principle a GOES system station sends observing data every hour automatically. The observing elements in Minuto are shown in Figure S2-2-4.

In contrast to a GOES station, at a conventional station some observer observes meteorological data, records data in a field book and reports to IDEAM head office. The observing elements in San Jorge are shown in Figure S2-2-5. In San Jorge station a meteorological observation is carried out at 7 am. ‘7 am’ in Colombia means ’12 am’ in GST (Greenwich Standard Time).

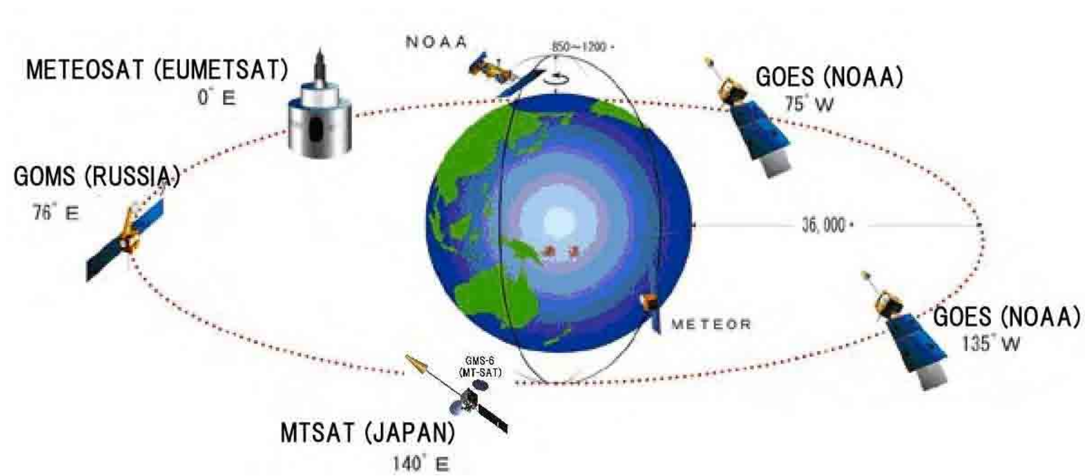


Figure S2-2-6 Geostational Meteorological Satellites around the Earth

Figure S2-2-7 GOES Antennas on the Roof of IDEAM

Table S2-2-1 Time Lag of GOES System

Receipt time	Data header time	Time lag
12:45	12:20	0:25
13:30	13:10	0:20
13:50	13:20	0:30
14:09	13:40	0:29
14:26	14:10	0:16
14:50	14:10	0:40
14:58	14:40	0:18
15:13	14:50	0:23
15:24	15:10	0:14
15:34	15:10	0:24
15:45	15:20	0:25
16:58	16:20	0:38
18:12	17:50	0:22

Since IDEAM uses the down load stream of the satellite GOES, IDEAM can receive observing data in less time delay. Table S2-2-1 shows time delay between an observing time and a receipt time. It is the result of the experiment held in November 2006 by IDEAM.

(2) Data Collecting System

The data collection work in IDEAM is operated by three ways. One of them is the GOES system, the second is the radio communication system and the last one is manned observation (off-line type). The first two data are collected automatically to the IDEAM head office and the last data are reported to the IDEAM head office by observers through telecommunication line and mail.

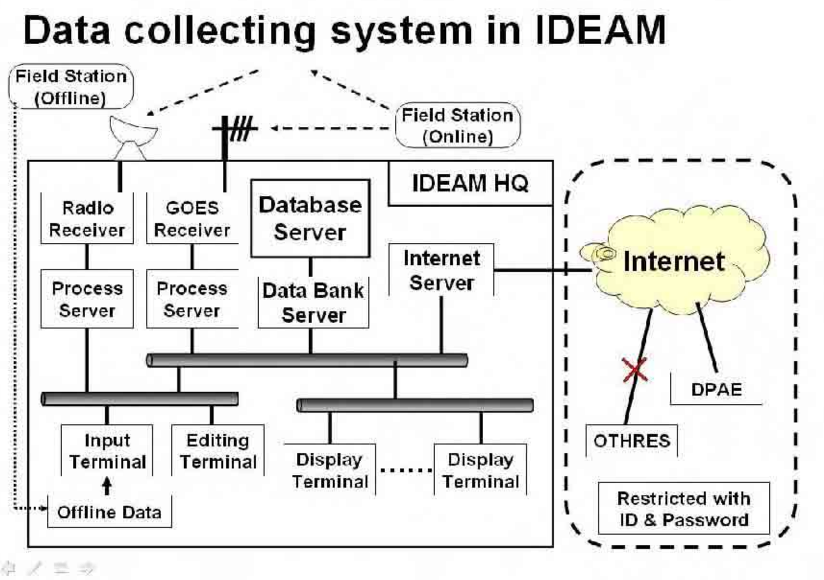


Figure S2-2-8 Data Collecting System in IDEAM

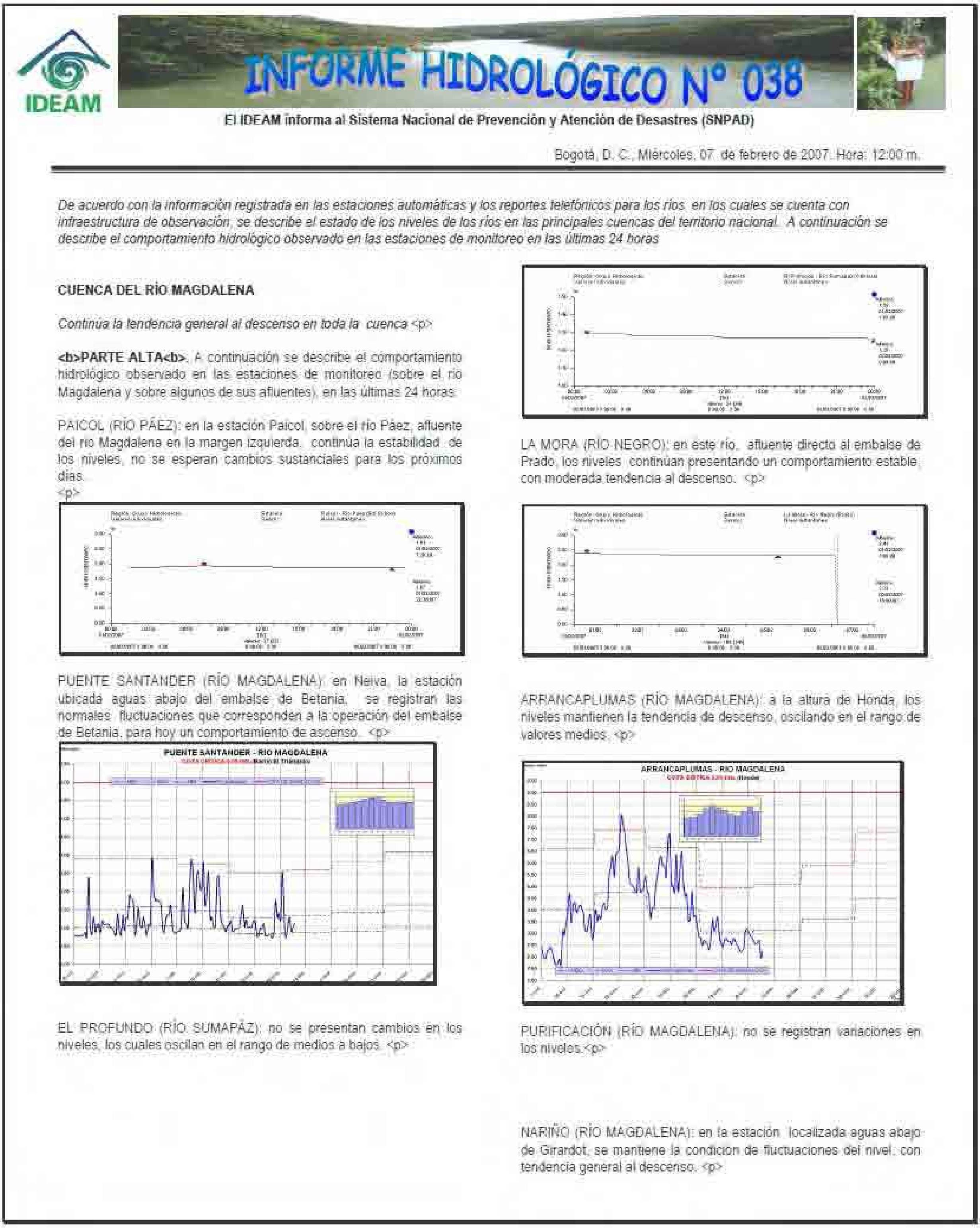
Generally speaking, when DCP function is utilized, the collecting data are transmitted through the GTS. So using the GTS circuit is to be able to carry on observations in low cost and stably. There are two reasons. One circuit (Global Telecommunication System regulated by WMO). At first the observing data are sent to the geo stational meteorological satellite and they are sent to the ground control center in the satellite owner country. After that the observing data are converted, translated to the telegraphic code and sent to IDEAM through the GTS circuit from NOAA. The merit of them is that the satellite GOES is already operated by NOAA in order to take photos of cloud image.

The other is that the GTS circuit is also operated and the meteorological data exchange and is carried on already. So an additional cost to use the DCP function and the GTS circuit is not needed. The maintenance cost that is requested to the users is only the maintenance cost of their own observing stations. The demerit of DCP system is that we have to expect a time delay for about one hour or more.

But in the case of IDEAM, IDEAM receives the down load stream of the satellite directly. ‘The down load stream’ is the transmission line from the satellite to the ground control center. In order to receive the down load stream IDEAM has to install receiving and decoding system itself. Actually on the top of IDEAM building there are large parabola antennas. One of them is for receiving satellite images and the other is for receiving the down load stream signal.

(3) Disclosure of Information

The observing data are not published directly but they are processed to the weather information and published as weather forecast information and warning information in its web site. The observing data are disclosed in its web site, but it is strictly restricted with ID and Password. Additionally IDEAM observes a water level in five major rivers. The observing data can be seen in the IDEAM web site for free access.



IDEAM

INFORME HIDROLÓGICO N° 038

El IDEAM informa al Sistema Nacional de Prevención y Atención de Desastres (SNPAD)

Bogotá, D. C., Miércoles, 07 de febrero de 2007. Hora: 12:00 m.

De acuerdo con la información registrada en las estaciones automáticas y los reportes telefónicos para los ríos en los cuales se cuenta con infraestructura de observación, se describe el estado de los niveles de los ríos en las principales cuencas del territorio nacional. A continuación se describe el comportamiento hidrológico observado en las estaciones de monitoreo en las últimas 24 horas

CUENCA DEL RÍO MAGDALENA

Continúa la tendencia general al descenso en toda la cuenca <p>

<b>PARTE ALTA<b>. A continuación se describe el comportamiento hidrológico observado en las estaciones de monitoreo (sobre el río Magdalena y sobre algunos de sus afluentes), en las últimas 24 horas.

PAICOL (RÍO PÁEZ): en la estación Paicol, sobre el río Páez, afluente del río Magdalena en la margen izquierda, continúa la estabilidad de los niveles, no se esperan cambios sustanciales para los próximos días.
<p>

PUENTE SANTANDER (RÍO MAGDALENA): en Neiva, la estación ubicada aguas abajo del embalse de Betania, se registran las normales fluctuaciones que corresponden a la operación del embalse de Betania, para hoy un comportamiento de ascenso. <p>

PUENTE SANTANDER - RIO MAGDALENA

EL PROFUNDO (RÍO SUMAPÁZ): no se presentan cambios en los niveles, los cuales oscilan en el rango de medios a bajos. <p>

LA MORA (RÍO NEGRO): en este río, afluente directo al embalse de Prado, los niveles continúan presentando un comportamiento estable con moderada tendencia al descenso. <p>

ARRANCAPLUMAS (RÍO MAGDALENA): a la altura de Honda, los niveles mantienen la tendencia de descenso, oscilando en el rango de valores medios. <p>

ARRANCAPLUMAS - RIO MAGDALENA

PURIFICACIÓN (RÍO MAGDALENA): no se registran variaciones en los niveles.<p>

NARIÑO (RÍO MAGDALENA): en la estación localizada aguas abajo de Girardot, se mantiene la condición de fluctuaciones del nivel, con tendencia general al descenso. <p>

Figure S2-2-9 Sample of the River Data in IDEAM Web Site

2.1.3 DPAE

(1) Composition of typical observing station

DPAE is one of the most important organizations to reduce and prevent disasters in Bogota metropolitan district. It has some hydrological meteorological stations in Bogota metropolitan district. There are more than ten rainfall and water level observing stations around the study area. The JICA study team visited some typical stations.

As mentioned DPAE is in charge of disaster prevention and reduction, so in the many cases it observes rainfall and water level and most of them have been telemeterized. Basically an electric power is supplied by solar panel and battery.

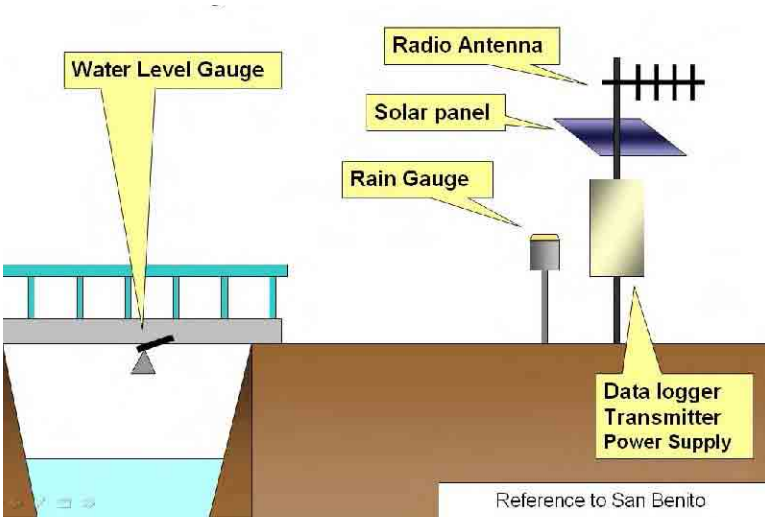


Figure S2-2-10 Composition of San Benito Station

Photo S2-2-3 and S2-2-4 show an appearance and inside of Sierra Morena station. The station is composed with a rain gauge, data converter, data logger, transmitter, power supply (solar panel and battery), radio antenna and cabinet box. The radio frequency is 403.075 MHz of UHF band.

Photo S2-2-3 Sierra Morena Station

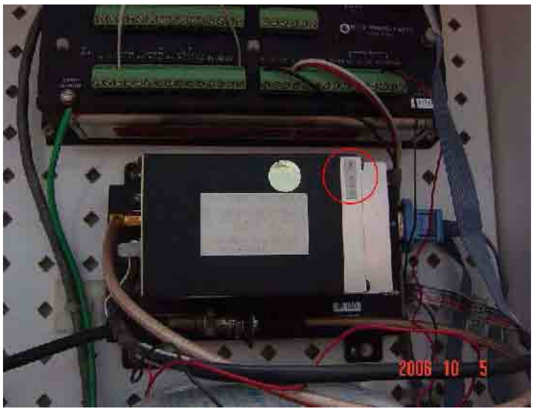


Photo S2-2-4 Transmitter

(2) Data collecting system

The data collection work in DPAE is operated by two ways. One of them is the radio communication system and the other is manned observation (off-line type). The first data are collected automatically to the DPAE head office. In a normal condition, the data collecting is carried out every hour but in emergency situations it can be changed every five minutes from the DPAE head office.

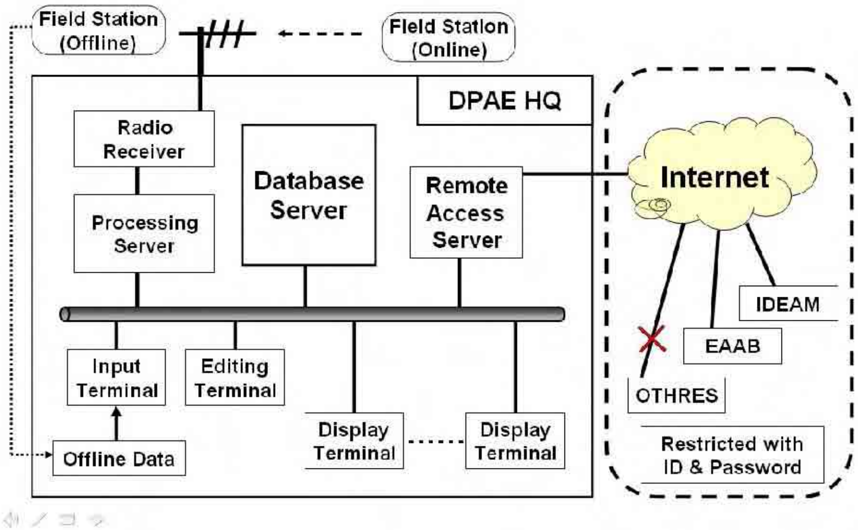


Figure S2-2-11 Data Collecting System in DPAE

(3) Disclosure of information

The data disclosure concept is as same as IDEAM. The observing data are not published directly to the public people. The observing data are disclosed in its web site, but it is strictly restricted with ID and a password. Few people (organizations) who are provided ID and Password can see the web site. If anywhere we can see some observing information from the DPAE's web site below.

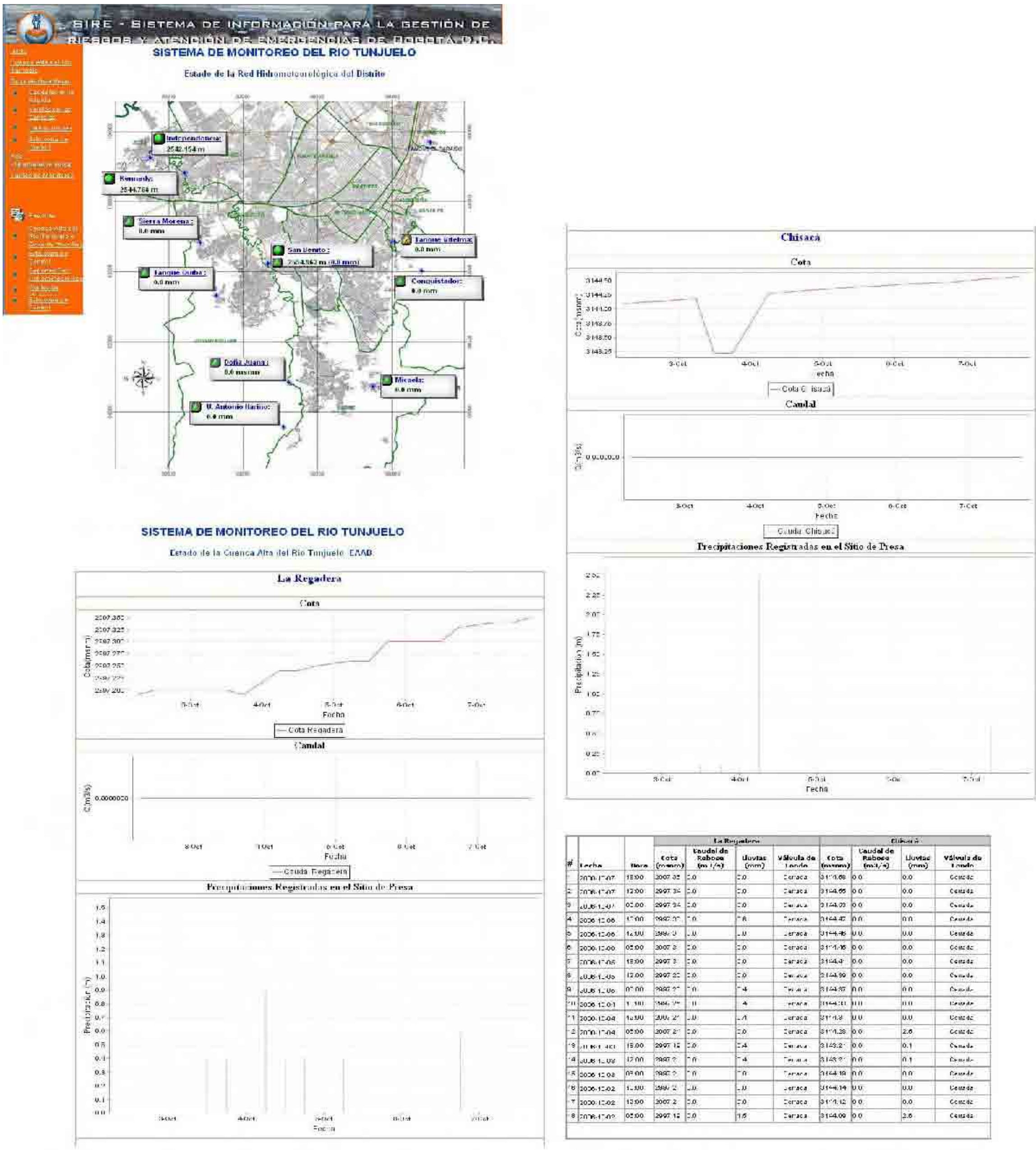


Figure S2-2-12 Sample of the DPAE Web Site

2.1.4 EAAB

(1) Composition of typical observing station

EAAB is one of the most important organizations to be in charge of river improvement, flood control and water supply and sewage line in Bogota metropolitan district. In order to carry on its mission smoothly it has some hydrological meteorological stations in Bogota metropolitan district. There are about twenty-five rainfall and water level observing stations around the study area. The JICA study team visited some typical stations.

EAAB is in charge of river improvement and water line maintenance, so in the many cases it observes rainfall, water level and discharge. Most of them have not been telemeterized, because the mission of EAAB is less urgent than DPAE. But important stations have been already telemeterized by cell phone system. Usually the electric power is supplied by solar panel and battery recently.

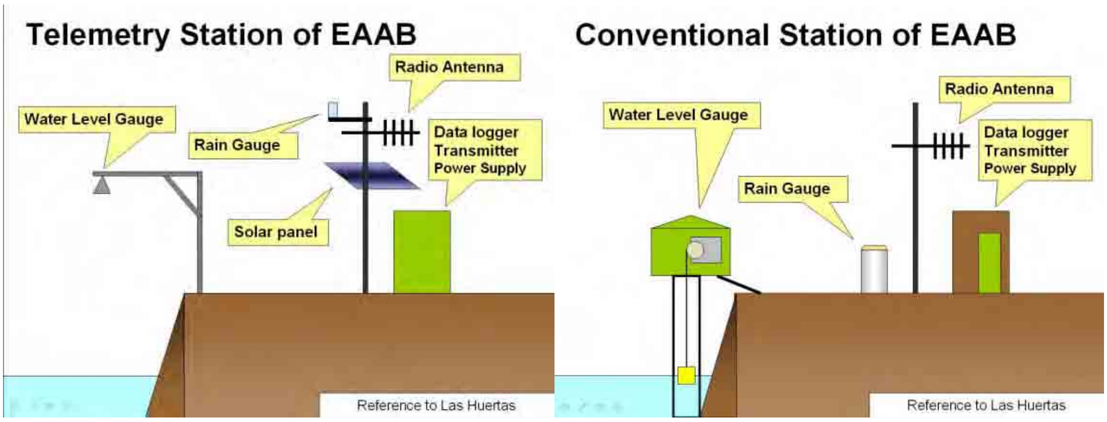


Figure S2-2-13 Composition of Las Huertas Station (Telemetry & Conventional)

Photo S2-2-5 Las Huertas Telemetry Station

(2) Data collecting system

The data collection work in EAAB is operated by two ways. One of them is the cell phone communication system and the other is manned observation (off-line type). The first data are collected automatically to the EAAB head office. In a normal condition, the data collecting is carried out every hour.

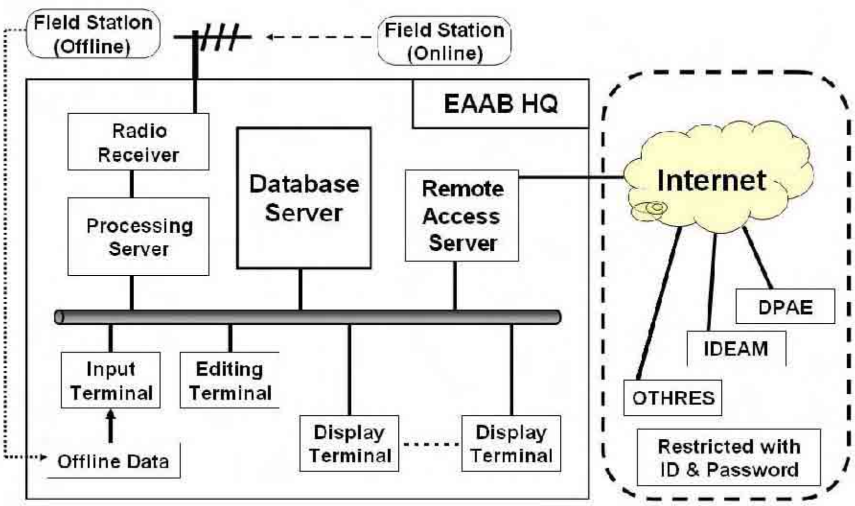


Figure S2-2-14 Data Collecting System in EAAB

(3) Disclosure of information

At the beginning of this study, the data disclosure concept of EAAB is as same as IDEAM and DPAE. The observing data are not published directly to the public people. The observing data are disclosed in its web site, but it is strictly restricted with ID and a password. Few people (organizations) who are provided ID and Password can see the web site.

But changed its policy and the observing information has been disclosed to every one since November 2006. The URL is http://www.acueducto.com.co/

With the URL above, we can see the observing information from the EAAB's web site below.

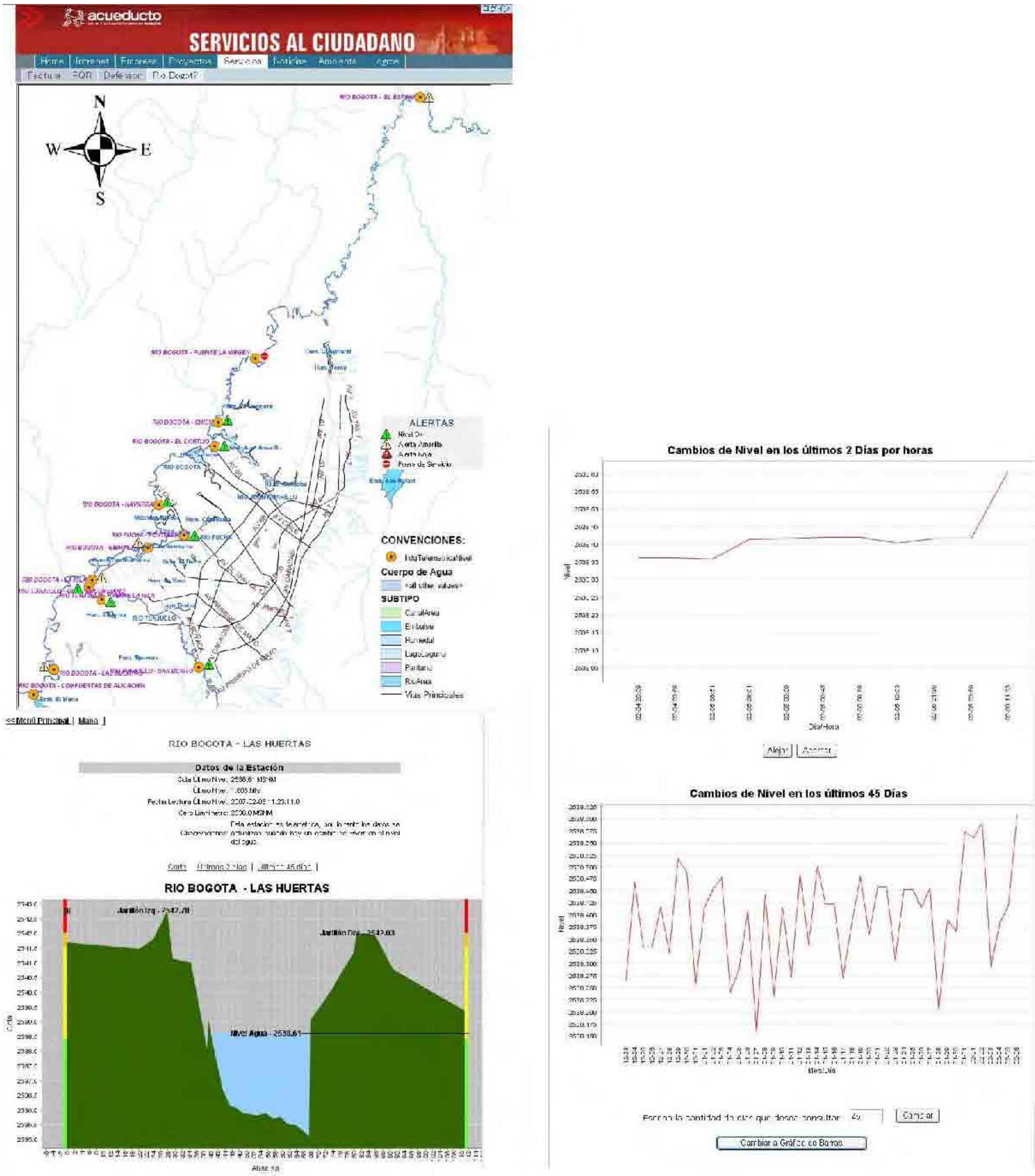


Figure S2-2-15 Sample of the EAAB Web Site

2.1.5. CAR

(1) Composition of typical observing station

CAR is one of an autonomous corporation in charge of benefit of the district residence. In that point of view, CAR observes hydrological meteorological conditions in the district. There are seven rainfall, water level and discharge observing stations around the study area. The JICA study team visited some typical stations. There is no station to be telemeterized, all of them are operated as conventional observing station. At least in the study area, CAR doesn't have any automated stations. Additionally in the study area, some stations are broken down and left.

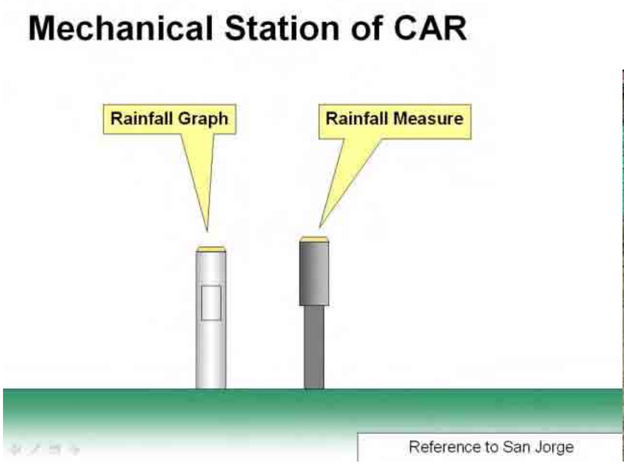


Figure S2-2-16 San Jorge Station

Photo S2-2-6 San Jorge Station

(2) Data collecting system

Therefore it is supposed that CAR doesn't have any special data collecting system and data collection work is carried out by manned work.

(3) Disclosure of information

In my studying I couldn't find out any observing information in CAR's web site. But CAR has made up these data into historical records, so JICA study team could obtain hydrological meteorological records around the study area from CAR.

2.1.6 Data Exchange among Organizations Concerned

(1) On-line data exchange through internet

Regarding real time data exchanging, DPAE and IDEAM have a strong relation ship each other and carry on an operational collaboration, for example, maintenance, data sharing, planning and so on. DPAE and IDEAM are exchanging observation data each other. DPAE and EAAB are also in a cooperative relationship, they are exchanging data each other.

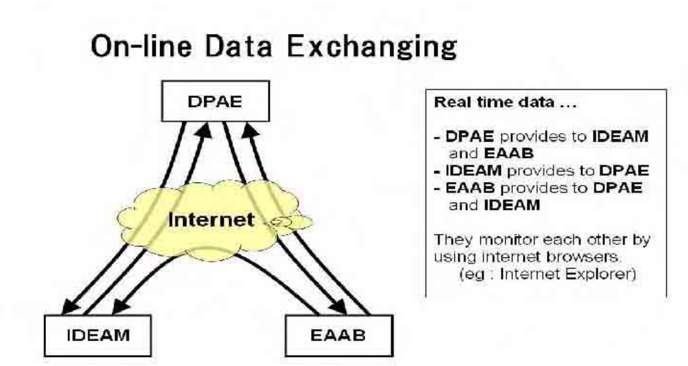


Figure 2-2-17 On-line Data Exchanging via Internet

(2) Off-line data exchange

IDEAM is collecting meteorological data as a national meteorological organization in Colombia. In the study area, IDEAM is provided quality controlled data by DPAE and EAAB through some magnetic media.

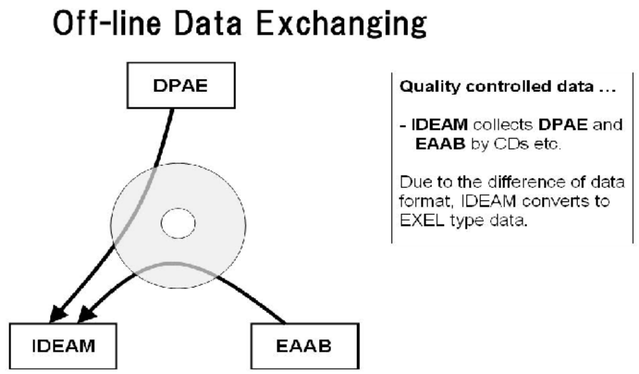


Figure S2-2-18 Off-line Data Exchanging

2.2 Weather Forecasting by IDEAM

2.2.1 Weather Forecasting

(1) Types of weather forecasting and target area

IDEAM issues some types of weather forecasting, as a position of the national meteorological organization. In Colombia there are five districts and thirty two departments (prefectures). IDEAM rezone these five districts into ten regions as the targets of weather forecasting. IDEAM has three targets for the weather forecasting. The first is the whole country, the second is five regions, and the third is forty-one major cities. IDEAM shows such information in its web site.

Table S2-2-2 Contents of Weather Forecasting by IDEAM

Target	Area		Contents
1	Nation	Colombia	- General weather outlook of today - Special note of region - National weather distribution
2	Region	Amazonia, Andina, Caribe, Pacifico, Insular Caribe, Mar Caribe, Insular Pacifico, Oceano Pacifico, Orinoquia, Sabana de Bogota	- General weather outlook of today - General weather outlook of tomorrow
3	Major cities	41 major cities including Bogota, Medellin and etc.	- Weather, temperature (max. min.) and lunar age for latest 3 days (today, tomorrow and a day after tomorrow)

The weather forecasting is also can be seen on newspapers, radio and television. For example in Bogota, El Tiempo news paper places a weather forecasting (only temperature) almost every day. On radio and television we can hear and see a weather forecasting in the morning time and the evening time.

Besides a weather forecasting, IDEAM provides other meteorological information in IDEAM web site. It provides satellite GOES hourly images in previous six hours.

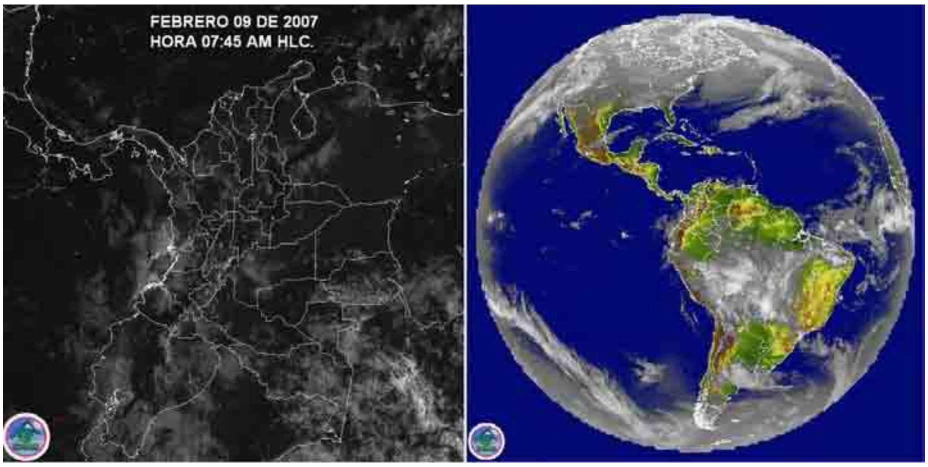


Figure 2-2-19 Enlarged and Global Satellite Image in IDEAM Web Site

2.2.2 Types of Alert and Criteria

Along with the weather forecasting IDEAM issues ten types of alert. In IDEAM web site we can find the types and contents. Table S2-2-3 shows ten types of alert. But we can’t find out any alert about a heavy rainfall. The reason is very simple, some meteorologist in IDEAM told us. With conventional meteorological observing method, we can obtain a daily amount of rainfall. We can’t obtain an intensity of rainfall (hourly data or less). Recently conventional stations have been upgraded to self-reporting automatic stations, but it has not passed over so much time and IDEAM doesn’t have data storage enough. So IDEAM doesn’t analyze a rainfall criterion yet. At this moment IDEAM tentatively adopts 20 mm daily rainfall as a criterion of heavy rainfall.

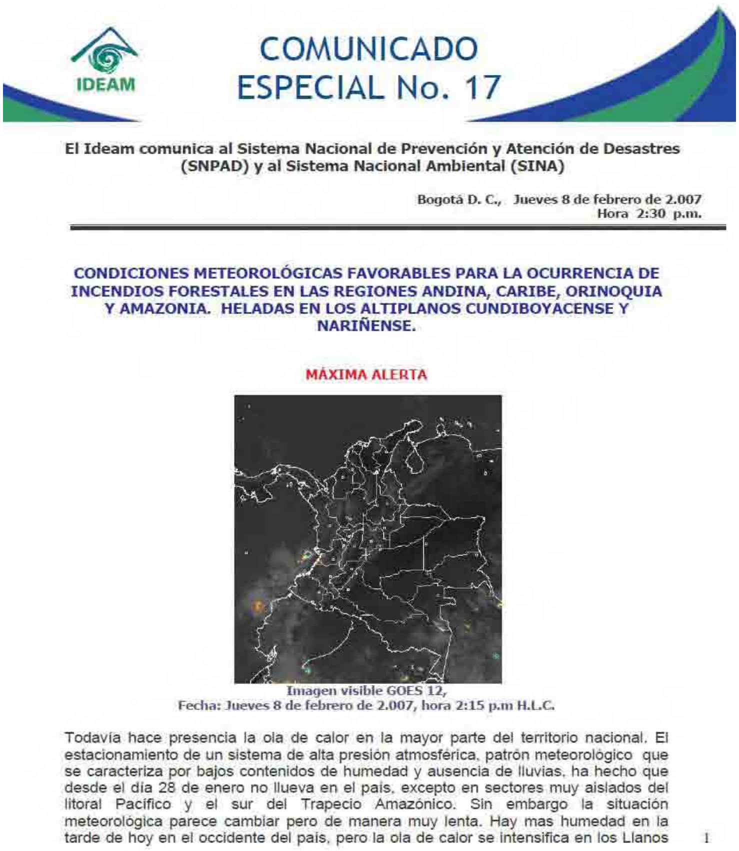
Table 2-2-3 Contents of Alerts by IDEAM

Type	Description/ Outline
Inundacion	Slow flood in a big river
Creciente	Flash flood in a small river
Avalancha	Avalanche
Represamento	River block by a cliff failure or a land slide
Helada	Frost
Huracan	Hurricane
Deslizamiento	Land slide
Incendios	Forest fire
Contaminacion	Polution
Marinas	Maritime alert

The criteria for flood disaster are uneven. It depends on the river and the location of the observing station. IDEAM makes an experimental value as a criterion in each station. IDEAM has responsibility to issue the alert for five major rivers, Magdanela, Cauca, Sinu, San Jorge and Meta. For other rivers (middle and small ones) local governments have responsibility to issue the alert. Nevertheless IDEAM provides meteorological hydrological information to local governments, if there is a slight risk of meteorological disaster. IDEAM provides three stages of information to local governments. The first step is ‘Information’, the second stage is ‘watching’ and the third step is ‘Alert’. It depends on the situation. Sometimes IDEAM provides ‘Alert’ directly when a risk of disaster is expected seriously.

The criteria of other alerts are not defined apparently. A meteorologist in charge of forecasting issues such kind of information by actual meteorological condition, objective forecasting and his/ her experiences.

In emergency IDEAM issues special information to invite a national attention.


COMUNICADO ESPECIAL No. 17

El Ideam comunica al Sistema Nacional de Prevención y Atención de Desastres (SNPAD) y al Sistema Nacional Ambiental (SINA)

Bogotá D. C., Jueves 8 de febrero de 2.007
Hora 2:30 p.m.

CONDICIONES METEOROLÓGICAS FAVORABLES PARA LA OCURRENCIA DE INCENDIOS FORESTALES EN LAS REGIONES ANDINA, CARIBE, ORINOQUIA Y AMAZONIA. HELADAS EN LOS ALTIPLANOS CUNDIBOYACENSE Y NARIÑENSE.

MÁXIMA ALERTA

Imagen visible GOES 12,
Fecha: Jueves 8 de febrero de 2.007, hora 2:15 p.m H.L.C.

Todavía hace presencia la ola de calor en la mayor parte del territorio nacional. El estacionamiento de un sistema de alta presión atmosférica, patrón meteorológico que se caracteriza por bajos contenidos de humedad y ausencia de lluvias, ha hecho que desde el día 28 de enero no llueva en el país, excepto en sectores muy aislados del litoral Pacífico y el sur del Trapecio Amazónico. Sin embargo la situación meteorológica parece cambiar pero de manera muy lenta. Hay mas humedad en la tarde de hoy en el occidente del país, pero la ola de calor se intensifica en los Llanos

1

Figure S2-2-20 Special Information by IDEAM

2.2.3 Background Information of Weather Forecasting

When meteorologists in IDEAM make a weather forecasting/ alert, they use some meteorological information. These are blow.

- Actual condition (observing data)
- Results of NWP (Numerical Weather Prediction): Global model
- Results of NWP (Numerical Weather Prediction): Local model
- Satellite images by GOES (GMS): Every 15 minutes
- Satellite images by NOAA (Orbital satellite): Several times a day

In the background information above, the result of NWP global model is provided by NOAA through GTS circuit according the agreement with NOAA. The result of NWP local model is obtained from the web site of INM (Instituto Nacional de Meteorologia) in Brazil. Several years ago IDEAM used to operate its own NWP model (MM5: Mesoscale Model 5), but the person in charge moved to another position (or quit job). So at this moment no one operates this model. Regarding both satellite images, IDEAM has its own receiving facilities in its organization.

Generally speaking, weather charts (maps) are drew and utilized in many countries. The types of weather charts are classified two categories. One is a category of time. There are analysis (the current time) and predictions (12 hour, 24 hour,……., 72 hour, week). The other is a category of height. There are surface (sea level) and upper layer (850, 700, 500 hPa,…….). Weather charts combined with these categories are utilized in many countries to predict a weather condition. But in Colombia meteorologists rarely use weather charts. The reason will be mentioned in the next section.

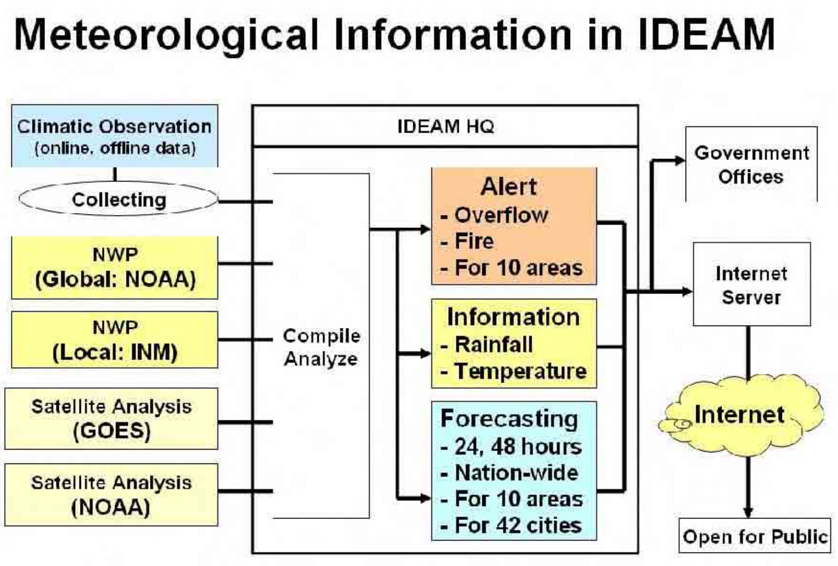


Figure S2-2-21 Data Utilization Flow in IDEAM

2.2.4 Difficulty of Weather Forecasting in Colombia

The interview was made for the 3 (three) meteorologists and some engineers in IDEAM in the study period. They say it is very difficult to predict weather condition in Colombia, especially in Bogota with one voice. They say there are four reasons.

(1) ITCZ

The first one is a global location of Colombia. It is in the tropical zone and the dominant factor of weather is ITCZ (Inter Tropical Convergence Zone). ITCZ is a phenomenon that the air masses in the north and south hemisphere converge with the equator area. So around the equator the east wind is blowing. The ITCZ moves north and south in a year. When the ITCZ passes over the country, the rainy season comes. And the ITCZ gets away from the country, the dry season comes. A slight movement and an intensity of convergence of the ITCZ affect the weather condition in Colombia. But it is not a significant phenomenon. So it is very difficult to analysis and to predict the accurate position of the ITCZ. Not to predict a position and intensity of the ITCZ is the cause of the difficulty of weather forecasting.

(2) Altitude

The second reason is a vertical location of Andes cordillera area. The altitude of Bogota is almost 2500 m. It is equivalent to 750 hPa level. In this altitude, some of weather charts (sea level, upper level less than 700 hPa) seem almost not to have any mean. The complexity of altitude makes a weather forecasting difficult. On the occasion when some meteorologist wants to predict an atmospheric condition by using NWP, the geographical reproducibility and resolution of the numerical model would be an important point.

(3) Scale of the phenomenon

Some meteorologists in IDEAM say that the scale of meteorological phenomena is smaller then in the middle latitude area. For example it's raining very hard at IDEAM area, but at the place, where is about ten km far from IDEAM, there is no rain but it is fine. They experienced such occasions many times. Since they don't have any meteorological radar, they can't assure an accurate scale of cumulonimbus which is sometimes a cause of heavy rain, lightening and thunder storm. But by the meteorological satellite image analysis the scale/ diameter of a cumulonimbus is almost is ten to twenty km, they say. Generally in the middle latitude area, a cell size of cumulonimbus is also about ten km but it rarely exists alone. In many cases they make a group (mass or line) and develop gradually. In Bogota it seems that a cumulonimbus exists alone, develops and decreases. Additionally a cumulonimbus is developing and decreasing rapidly in Colombia, especially in Bogota. It's also one factor of the difficulty of weather forecasting.

(4) Human resources (Training of meteorologists)

At this moment IDEAM faces a serious problem. It is a lack of human resources/ meteorologists. Table S2-2-4 shows a breakdown of meteorologists in IDEAM (January 2007).

Table S2-2-4 Meteorologists in IDEAM

Class	Number	Description
Class 1	6	- Majored meteorology in University and grad school - Finished oversea education
Class 2	4	- Majored meteorology in University - Finished oversea education
Hydro-Meteorological technician	25	- Finished IDEAM meteorological training course - They are dispatched regional meteorological offices for training
Aviation weather forecaster	120	- Finished IDEAM aviation forecaster training course - They are dispatched to meteorological offices in domestic and international airports - There are 28 airports in Colombia and 24 hour watching is carried on in 12 airports

Understanding easily, there are only ten meteorologists in IDEAM head office and they are in charge of issuing of weather forecasting and alerts in a shift work. Furthermore two 'class 2' meteorologists will retire in this year.

2.2.5 Upgrade of Weather Forecasting

(1) Requirement

In order to improve the accuracy of weather forecasting IDEAM has to get over some problems.

Observing and analyzing skill

- Installation/ replacement of self-reporting stations and reasonable allocation
- Improvement of observing data processing and display system
- Development of observing data analyzing and alert issuing system

Utilization of numerical information through GTS circuit

- Installation of automatic data drawing system for SYNOP (Surface synoptic observations: it is a numerical code (called FM-12 by WMO) used for reporting weather observations made by manned and automated weather stations. SYNOP reports are typically sent every six hours) and NWP (Numerical Weather Prediction)

Utilization of satellite images

- Development of cloud image analyzing system
- Development of synthesizing system for satellite image and NWP

Restart of operation of IDEAM's own NWP model

- Restructuring MM5 model (Mesoscale Model 5: Numerical Weather Prediction model)
- Restart of operation and analysis of own NWP model

Installation of meteorological radar system

- Installation of a meteorological Doppler radar system around Bogota DC
- Development of radar Doppler information and rain analyzing system
- Development of synthesizing system for radar analyzing and observing data

Development of short term precipitation prediction system

- Development of short term precipitation prediction system

Development of human resources (Meteorologists)

- Development of human resources (Capacity building)
- Training of meteorologists

(2) Existing Plan

In facing some difficult problems as mentioned above, IDEAM has been trying to do some countermeasures. At this moment in interview by JICA study team, some IDEAM personnel told us their plans.

Installation of Automated Weather Stations

- Improvement of conventional stations to automated weather observing stations.
- Collaboration with other concerned organizations to interoperate meteorological and hydrological observing stations and upgrade to self-reporting stations of existing/ new installation.
- Especially in Bogota area, IDEAM has made agreements with DPAE to improve automated observing stations. Concretely, both of them make the same specification of observing and radio transmitting and they can receive the observing data at the same time.

Human resource development

- Due to the massive retirement of meteorologist in these two years, IDEAM makes their own education programs to develop human resources. Concretely as mentioned above, IDEAM has already manages its own education programs and is developing meteorologists.

Introduction of new technologies

- In order to get new communication technologies IDEAM dispatches engineers to some international training courses. Concretely, IDEAM dispatches its communication engineer to the monthly training course in Hong Kong November 2007.
- IDEAM wants to master the DCP technologies of the meteorological satellite, but NOAA, which is operating GOES (Geostational Meteorological Satellite operated by USA), is not collaborative enough to disclose communication technologies. So IDEAM intends to use radio communication systems.
- In order to improve the accuracy of weather forecasting, IDEAM try to get advanced weather forecasting technology programs, for example installation of weather radar system, analysis of satellite images, NWP (Numerical Weather Prediction) system, criteria of alert/ advisory and so on. At this moment IDEAM could not find any best partner.

(3) Recommendation

In this study, the counter parts are local governments, Bogota city and Soacha city. But the main object of this study, disaster prevention of flood and land slide, is almost caused by meteorological phenomena. Basically meteorological phenomena are large scale and nationwide. In order to build up an effective early warning system around Bogota metropolitan area it is needed to improve and upgrade the capacity of IDEAM as the national meteorological and hydrological organization. Based on this concept JICA study team makes some recommendations follows to IDEAM.

Installation of Meteorological Radar System in Bogota

- There is a limit to install observing stations due to the funds and man power to keep them. To reach a certain level of improvement of observing stations, it is more important to obtain wide area information. As well known in the developed countries, meteorological radar system is very useful to obtain rainfall condition widely. In order to improve the accuracy of alert and to reduce the damages of disaster, it is needed to install meteorological radar system. As the detective radius of meteorological radar is more than two hundred km and the analyzing of radar information needs wide area observing data, meteorological radar system is installed and operated by national organizations in many countries.

Operation of own NWP system by IDEAM

- NWP system is one of the most effective methods to predict meteorological phenomena in these days. At first the global changing tendency of atmosphere is calculated by GSM (Global Scale Model), and the local change of atmosphere is estimated by MSM (Meso Scale Model) with using the result of the GSM output as boundary conditions. At the same time local landform and special conditions are considered and tuned up to improve accuracy. IDEAM used to operate its own NWP system. But after retiring the engineer in charge, no one could operate NWP. IDEAM wants to start again the operation of Mesoscale Model (MM5) NWP for accurate weather forecasting. But due to the lack of human resource it could not be realized.

Satellite imagery analysis technology

- Satellite imagery of GMS (gestational Meteorological Satellite) gives us a lot of useful information about meteorological phenomena. The information is useful not only to see the cloud pattern but also to analyze the information of imagery, for example the height of cloud top, category of cloud, movement of cloud, amount of water vapor in atmosphere, amount of rainfall and so on. At the same time it is possible to analyze the development and movement of Cb (Cumulonimbus) which is the cause of thunder storm. In order to use satellite imagery for disaster prevention, it is needed to master the satellite imagery analysis technology and the technology to use with the NWP result.

Composition and analysis technology of Satellite imagery and NWP result

- In order to make more accurate weather forecasting it is needed to analyze satellite imagery and NWP result together.

Development of Guidance of NWP output

- In order to utilize the NWP output for weather forecasting it is needed to translate the NWP output to atmospheric phenomena, for example temperature, humidity, pressure, wind, rainfall and so on. It is called ‘Guidance’.

Analysis of criteria for alert/ advisory based on past disasters

- In order to mitigate damages caused by meteorological disaster it is needed to issue alert/ advisory timely. To that end, IDEAM has to have definite criteria of rainfall and water level based on past disasters.

Issuing alert/ advisory for local area

- It is better to issue alert advisory more locally. But there is a technical limit to divide. At this moment, IDEAM issues alert/advisory for nationwide. In order to reduce damages of target areas alert/ advisory should be more local. For the time beginning it is desired to issue alert/ advisory to Bogota metropolitan area in Bogota and each prefecture on a nationwide scale. To that end, IDEAM has to analyze local disasters and have definite criteria for local areas.

Formulation of sharing of role for disaster prevention among organizations concerned

- In order to administrate disaster prevention program well it is needed to clarify the roles of organizations concerned, to establish a framework in each organization and to build up communication network among them.

Making long term plan as a national meteorological and hydrological organization

- In order to realize the improvement plans above, the most necessary thing to IDEAM is to make a long term comprehensive improvement plan as a national meteorological and hydrological organization, including improvement of human resources, improvement of facilities, installation of instruments, establishment of framework especially as a disaster prevention organization and total meteorological services. To that end, it is needed to dispatch meteorological experts or feasibility study to investigate the current condition of IDEAM.

2.3 Monitoring by DPAE

2.3.1 General

DPAE has been conducting real time monitoring and not forecasting. Warning by DPAE is basically issued based on the real time monitoring information.

2.3.2 Existing Warning Criteria

(1) Sorts of warning and criteria

DPAE issues some types of alert, as a position of the main organization to reduce and prevent disasters in Bogota metropolitan district.

It is understood that DPAE is watching observing data and if there is a risk of disaster DPAE will take an appropriate countermeasure. The criteria in DPAE are as same as in IDEAM. DPAE also doesn’t have clear-up criterion about rainfall. The reason is same as IDEAM. DPAE doesn’t have enough storage of intensity data of rainfall. The criterion for flood disaster is same as IDEAM. It depends on the river and the location of the observing station. DPAE also makes an experimental value as a criterion in each station.

(2) Background information of warning

As mentioned, DPAE has its own observing stations along Chiguaza river, Yomasa river and Tunjuelo river. Since most of them are already telemetalized DPAE can obtain observing data of there stations and grasp actual conditions along these rivers. Furthermore DPAE is provided meteorological information by IDEAM. When there is a slight risk of disaster DPAE is watching data. When they expect possibility of disaster they take countermeasure to meet the situation.

2.3.3 Improvement of Accuracy of Warning

(1) Requirements

In order to improve the accuracy of weather forecasting DPAE has to get over problems.

Analyzing existing data

- Analyzing the correlation between rainfall and flood/ land slide disaster
- Analyzing clear-up criteria for rainfall and water level
- Development of observing data analyzing system and alert issuing system

Observing and processing skill

- Installation/ replacement of self-reporting stations and reasonable allocation
- Improvement of observing data processing and display system

(2) Existing upgrading plan

Installation of Automated Weather Stations

- Improvement of conventional stations to automated weather observing stations.
- Collaboration with other concerned organizations to interoperate meteorological and hydrological observing stations and upgrade to self-reporting stations of existing/ new installation.
- DPAE has already made agreements with IDEAM to maintenance stations and to improve automated observing stations. Concretely, both of them make the same specification of observing and radio transmitting and they can receive the observing data at the same time.

Analysis of criteria for alert/ advisory based on past disasters

- DPAE is local governmental disaster prevention organization in Bogota city. So it has a lot of records about rainfall and water level. At this moment DEPAE is trying to analyze criteria of typical rivers in Bogota city.

(3) Recommendations

Issuing alert/ advisory for each river

- At this moment DPAE seems not to issue definite alert/ advisory for each river. In order to reduce damages of each river basin alert/ advisory should be more local.

Data exchange with IDEAM

- As mentioned above, DPAE is promoting collaboration with IDEAM to maintenance meteorological and hydrological stations. It should be promoting continuously.
- In the future, when IDEAM will install meteorological radar near Bogota city, DPAE should obtain the analyzed data from IDEAM by priority. To that end, it is very important to exchange observing data and analyzing method from now on.

CHAPTER 3 RAINFALL AND DISASTERS RECORD

In this section, analyses are conducted in order to grasp the relation between hydrological conditions, mainly rainfall, and past disasters with the aim of determining the threshold for general warning.

3.1 Analyses for Target Basins in Bogota

3.1.1 General Characteristic of Disasters and Selection of Disaster Events for Analyses

(1) Inundation

In the Study Area in Bogota, inundation phenomenons are categorized in following three (3) types: 1) High water and overflow of creeks, 2) overflow of drainage system, and 3) backwater through sewerage. In the Study area, the sewerage is connected directly to the creeks, therefore inundation due to the backwater through the sewer pipes can occur even though water level of the creek is not over the bank height. At the same time, inundation occurs in the cause of lack of drainage because storm sewerage system isn't laid down or doesn't have enough capacity in some barrios.

Figure S2-3-1 shows the frequency of inundation events in five (5) localities including target basins in Bogota. Inundation frequently occurs in two (2) rainy seasons especially in second rainy season from October to December. The frequency as shown in the figure includes all the events categorized to "Inundación (Inundation)" in disaster records of DPAE from October 2001 to June 2006, which contain not only high water and overflow of the creek but also overflow of drainage system and backwater through the sewerage as described above.

Distinction of the type of inundation is extremely difficult due to the insufficient information, whereas the main target of the analysis is the inundation by high water and overflow of the creeks. Table S2-3-1 and Figure S2-3-2 summarize the inundation events in target basins, which can recognize as much as possible to be caused by high water and overflow of the creeks out of the records of DPAE. Table S2-3-2 shows the inundation events to be caused by high water and overflow of the creeks, which are the results of the on-going study by IDEAM for DPAE. Both DPAE records and IDEAM study results don't include the enough information to comprehend the magnitude of inundation, such as inundation depth, inundated area and damage, therefore it is able to analyze only the relation between rainfall amount and occurrence of inundation. The inundation events as shown in Table S2-3-1 and Table S2-3-2 are used for the analysis of relation between rainfall and inundation.

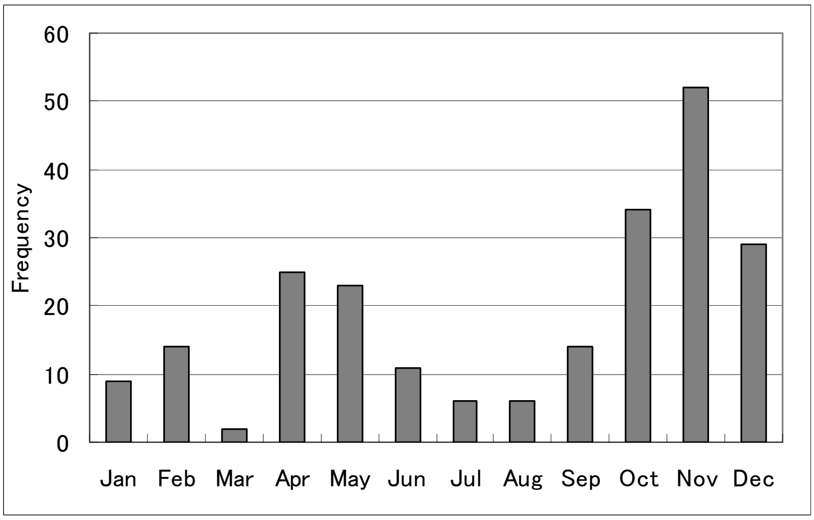


Figure S2-3-1 Frequency of Inundation Events (2001 Aug. - 2006 Jun.) in Tunjuelito, Rafael Uribe, San Cristobal, Ciudad Bolivar and USME Localities

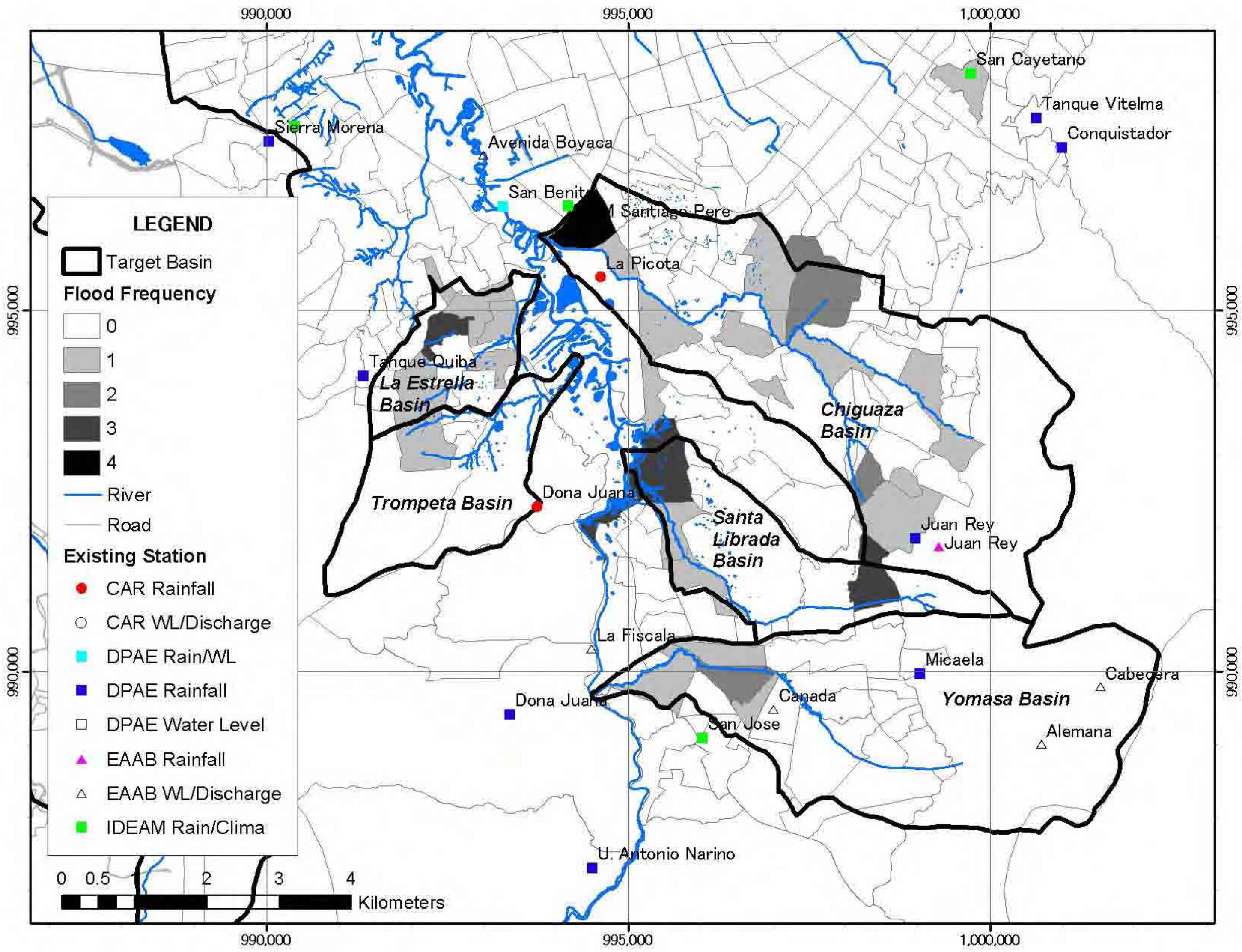


Figure S2-3-2 Inundation Frequency in Target Basin in Bogota

Table S2-3-1 Inundation Record by DPAE in Target Basins in Bogota

Date	Chiguaza	Yomasa	Santa Librada	Estrella & Trompeta
2002/1/20	Abraham Lincon			
2002/2/10	Guacamayas			
2002/2/11	Sasn matin de loba			
2002/4/28				La Alameda
2002/5/28			Santa Marta	
2002/5/29	Nueva Delly			
2002/5/31	Tunjuelito			
2002/6/4				Bellavista Lucero Alto
2002/6/9	La Belleza			
2002/6/24	Tunjuelito			
2002/10/29		Charala		
2002/12/20		Chuniza		
2003/10/5				Naciones Unidas
2003/10/26	Cerros del Oriente - El Rosal, San Martin, Las Gaviotas			La Estrella
2003/11/23			Yomasa, Santa Marta	
2003/11/25				Lucero
2003/11/26	La Belleza			
2003/11/30	Guacamayas, Villas del Diamante		Santa Librada	
2003/12/1				Tesorito
2003/12/3				Buenos Aires
2003/12/4				Lucero Bajo
2004/2/25	Tunjuelito			
2004/4/22				La Estrella
2004/5/20				El Tesoro
2004/7/31	San Benito			
2004/10/1	Tunjuelito			
2004/10/20				Bellavista Lucero Alto
2004/10/24	Juan Rey (La Paz)			
2004/10/25				Arabia
2004/11/9	Arboleda Sur			
2004/11/15		La Reforma		
2005/1/29			Santa Librada	Paraiso Quiba
2005/5/5	Diana Turbay Arrayanes			
2005/5/23		Tihuaque	Tihuaque	
2005/9/25			La Aurora	Bellavista Lucero Alto, Sotavento
2005/9/29	Abraham Lincon			
2005/12/5	Diana Turbay Cultivos, Altamira, San Martin Sur			
2005/12/7	Canada o Guira			
2006/5/10		Gran Yomasa, Monte Blanco		Sumapaz
2006/5/11	La Picota			

Table S2-3-2 Inundation Record in 2000 - 2005 by IDEAM Study in Target Basins in Bogota

Date	Chiguaza	Yomasa	Santa Librada	Estrella & Trompeta
2000/3/27				La Alameda
2002/1/20	Abraham Lincoln			
2002/2/10	San Martin de Loba, Atenas, Las Guacamayas			
2002/2/11	San Martin de Loba			
2002/4/25	La Arboleda, San Carlos			
2002/4/28				La Alameda
2002/5/29	Nueva Delhi			
2002/5/30	Nueva Delhi, Tunjuelito			
2002/5/31	Abraham Lincoln, La Gloria, El Socorro, Tunjuelito			
2002/6/4				Bellavista Lucero Alto
2002/6/9	Abraham Lincoln, El Socorro, La Belleza, Meissen			
2002/6/24	Tunjuelito			
2002/6/25	San Benito, Tunjuelito			
2002/11/7	La Peninsula			
2002/12/20		Chuniza		
2003/1/19	Juan Rey, La Belleza, Altamira		Juan Rey	
2003/8/21	San Martin de Loba			
2003/10/5				Naciones Unidas
2003/11/18	San Martin Sur			
2003/11/19	La Paz			
2003/11/23	Yomasa		Yomasa, Porvenir	
2003/11/24		Gran Yomasa		
2003/11/26	La Belleza			
2003/11/30	Nueva Gloria, Las Guacamayas			
2003/12/2				Monterrey
2004/2/20		Chapinerito		
2004/2/25	Tunjuelito, La Peninsula			
2004/3/26			El Pedregal	
2004/5/20				El Tesoro
2004/7/31	San Benito			
2004/8/25	La Picota Oriental			
2004/8/30				Gibraltar Sur
2004/10/1	Tunjuelito			
2004/10/20		San Isidro Sur		El Tesoro
2004/10/21	Santa Lucia			
2004/10/24	Juan Rey		Juan Rey	
2004/10/25				Arabia
2004/11/6			Nuevo San Andres	
2004/11/9	Arboleda Sur			
2004/11/15		La Reforma		
2004/11/17	Diana Turbay			
2004/11/28	Juan Rey, Juan Rey (La Paz)		Juan Rey	
2005/1/29			Barranquillita	
2005/5/4	Atenas			
2005/5/20	San Martin Sur			
2005/5/23			La Aurora	
2005/5/26	Canada o Guila			
2005/6/9		La Reforma		
2005/7/14	San Martin Sur			
2005/9/25			La Aurora	Quiba, Sotavento, Quintas del Sur, Bella Vista Lucero Alto
2005/9/26	La Picota Oriental			

(2) Landslide

Figure S2-3-3 shows the frequency of landslide events in five (5) localidades including target basins in Bogota. Landslide frequently occurs in latter month of first rainy season from March to May. The frequency as shown in the figure includes all events categorized to “Fenómeno de Remoción en Masa (Landslide)” in disaster records of DPAE from January 2002 to July 2006, which contain various phenomena such as slope failure, rockfall, earth flow, etc., and of which causes are presumed to vary from rainfall to accidental impacts. Many landslide events may have happened by accidental impacts regardless of rainfall. In order to confine the landslide to be caused by natural condition mainly rainfall as much as possible, the analysis is conducted targeting at only the date when a number of landslides were recorded in the same basin on the same date since the causes of landslide are difficult to specify from the information of the database. Selected events are shown in Figure S2-3-3.

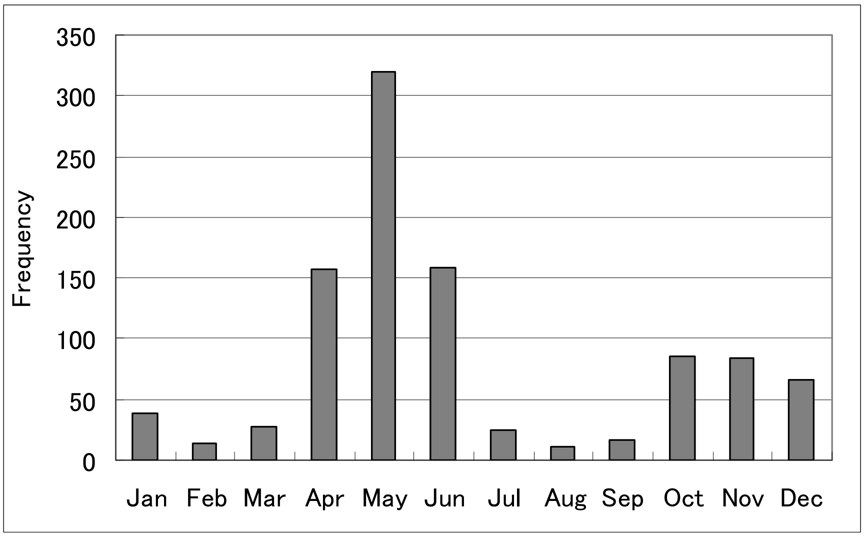


Figure S2-3-3 Frequency of Landslide Events (2002 Jan. - 2006 Jul) in Tunjuelito, Rafael Uribe, San Cristobal, Ciudad Bolivar and USME Localities

Table S2-3-3 Selected Landslide Events for Analysis in Target Basins in Bogotá

Date	Chiguaza	Yomasa	Santa Librada	Estrella &Trompeta
2004/11/16				Quiba, Bellavista Lucero Alto
2004/11/17	San Agustin (2), Los Libertadores, La Picota	Monte Blanco (2)		El Tesoro, Quiba, Bellavista Lucero Alto
2005/5/4	Canada o Guira, Diana Turbay Cultivos, Las Guacamayas, Arrayanes,			
2005/5/5	Altamira, El Playon			
2005/10/26	Moralba, Diana Turbay Cultivos			
2005/11/16	Los Alpes, Nueba Delly			
2005/12/6	Diana Turbay, Cerros de Oriente, Santa Rita Sur Oriental			
2006/1/14				Estrella del Sur, Sumapaz
2006/3/27	Diana Turbay, El Playon			
2006/4/6	Cerros de Oriente, Altamira (2)			
2006/4/12	Los Alpes, Arrayanes			
2006/4/14	El Playon (2)			
2006/4/17	Diana Turbay Cultivos (2), Quindio			
2006/5/4	Palermo Sur, Cerros de Oriente			
2006/5/5		Marichuela, La Cabana		
2006/5/6	Guiparma, Canada o Guira, Diana Turbay			Lucero del Sur, Estrella del Sur
2006/5/8	Los Libertadores, Arrayanes			Mexico, Quiba, Bellavista Lucero Alto
2006/5/9	Diana Turbay Cultivos, Los Alpes (2)			
2006/5/10	Canada o Guira, Moralba			
2006/5/10				Billavista Lucero Alto, Estrella del Sur
2006/5/11				El Tesoro (2)
2006/5/12	Canada o Guira, La Gloria Occidental			
2006/5/19	Los Molinos, Las Guacamayas			
2006/5/30	Atenas, El Playon			
2006/6/12				Quiba, Naciones Unidas

3.1.2 Analysis for Relation between Rainfall and Selected Disaster Events

(1) Rainfall Stations for Analyses

Relation between rainfall and disaster is analyzed using collected daily and hourly rainfall data, and selected disaster records.

The stations using the rainfall data for the analyses are La Picota station (CAR) for Chiguaza basin, Juan Rey station (EAAB) for Chiguaza and Santa Librada basins, Micaela station (DPAE) for Santa Librada and Yomasa basins, and Tanque Quiba station (DPAE) for La Estrella and Trompeta basins, which are selected in consideration of their locations. The selected stations for the analyses are shown in Figure S2-3-4.

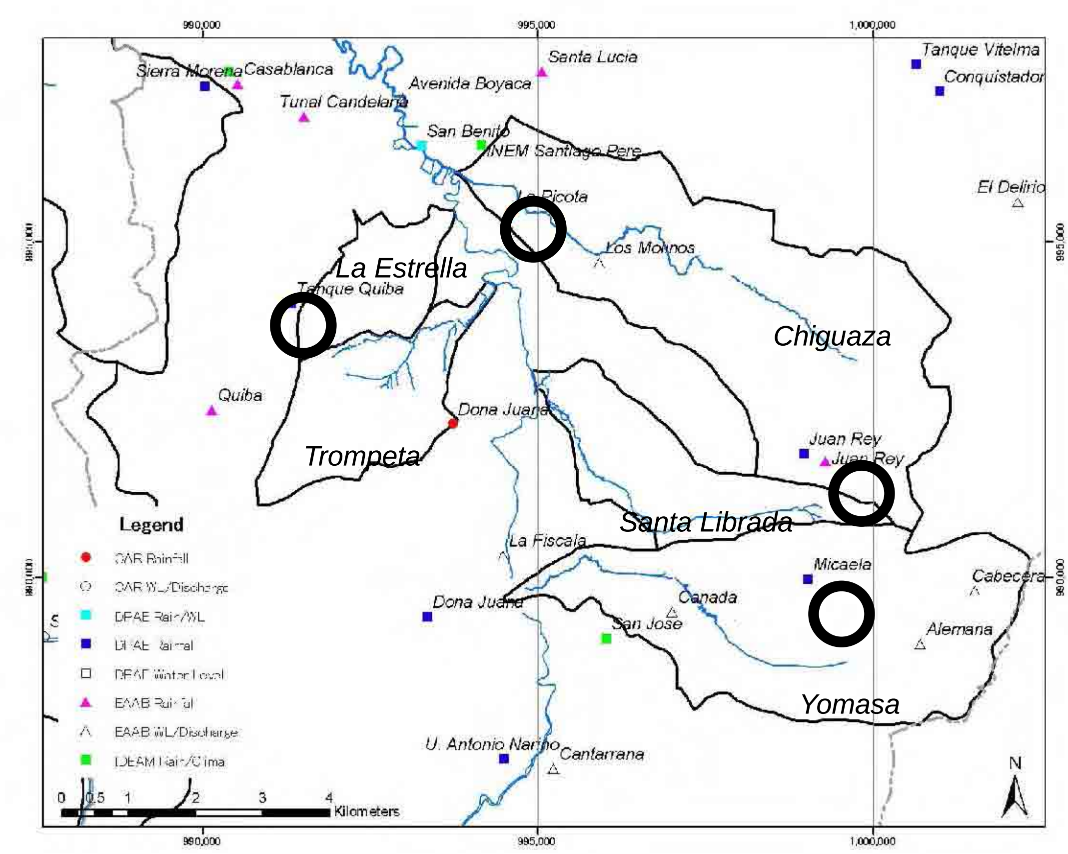


Figure S2-3-4 Selected Stations for Analysis

(2) Analyses for Inundation

Since catchment areas of Target Rivers are small and their principal river lengths are short, for example, catchment area of Chiguaza River that is largest river among the Target Rivers is about 19 km2 and its river length is about 7 km, their concentration time is regarded as a short time. In addition, rainfall data collected from the related organizations is only daily rainfall except DPAE's data. Therefore, analyses are conducted mainly using daily rainfall of the day when inundation occurred.

(A) Analysis for Relation between Annual Top 10 of Rainfall and Inundation Events

In order to grasp the rainfall characteristic in inundation, relation between annual top 10 of rainfall and inundation events is analyzed. Analysis is done by the following procedure:

1. To select the annual top 10 of rainfall in each year in selected stations from 2000 to 2006
2. To check whether inundation occurred or not in the day when annual top 10 of rainfall was recorded

Annual top 10 of rainfall in the selected stations are shown in Appendix-4. Results of analysis are shown in Figure S2-3-5 to S2-3-8 for daily rainfall and Figure S2-3-9 and S2-3-10 for hourly rainfall, and summarize in Table S2-3-4 and Table S2-3-5, respectively. In the figures, marks with basin names indicate the rainfall amount that inundation occurred. For example, in La Picota station (CAR), eight (8) inundations were recorded in the range of 10 - 25 mm of daily rainfall among the days when annual top 10 of daily rainfall was recorded as shown in Figure S2-3-5. In the Table S2-3-4 and Table S2-3-5, "No. of Days when Inundation Occurred from 2001 to 2006" literally shows all the number of the day when inundation occurred in each basin from 2001 to 2006, and values of each row show the number of inundation events in each basin, which occurred when the top 10 of daily rainfall was recorded in each station.

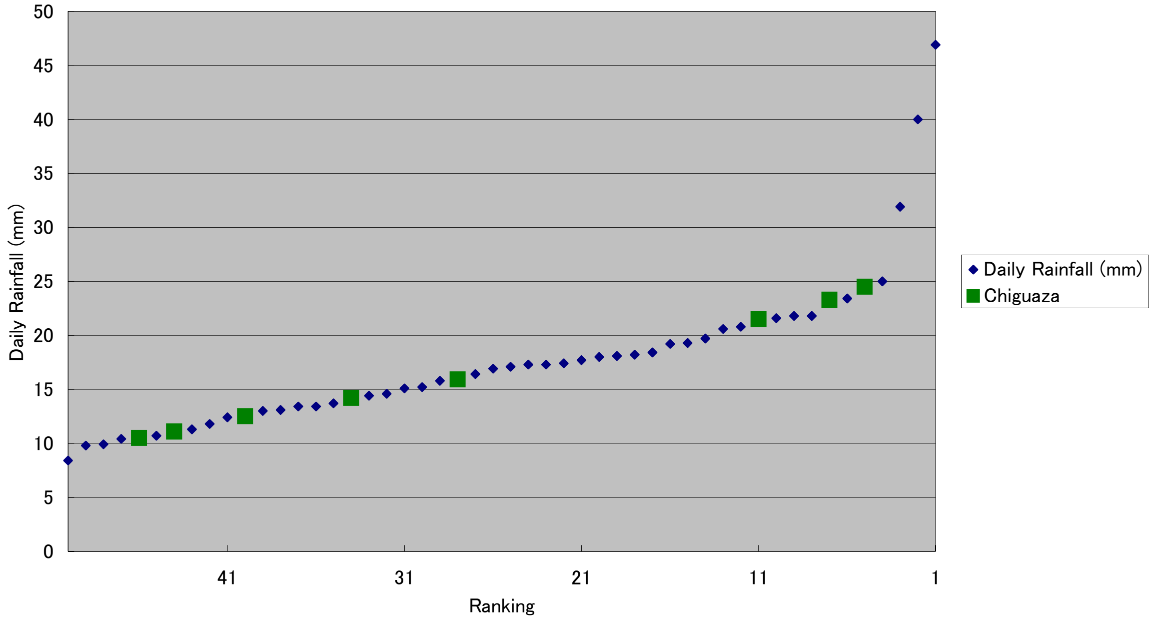


Figure S2-3-5 Relation between Annual Top 10 of Daily Rainfall in La Picota Station (CAR) and Inundation Events in Chiguaza Basin (2001 Jul – 2005 Dec)

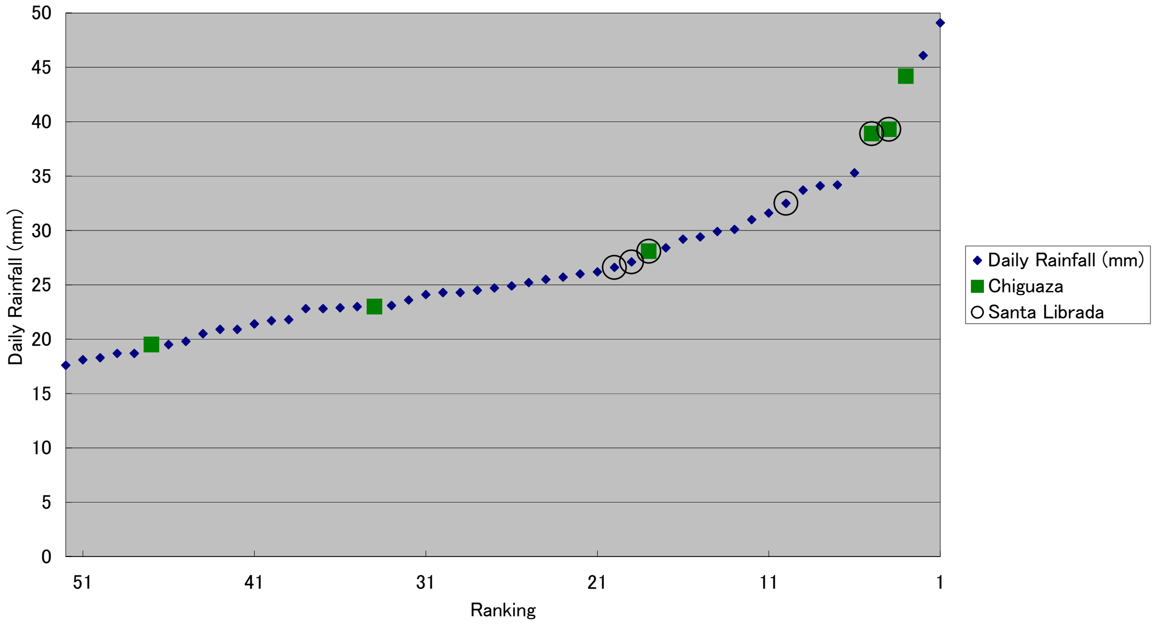


Figure S2-3-6 Relation between Annual Top 10 of Daily Rainfall in Juan Rey Station (EAAB) and Inundation Events in Chiguaza and Santa Librada Basins (2001 Jan – 2005 Dec)

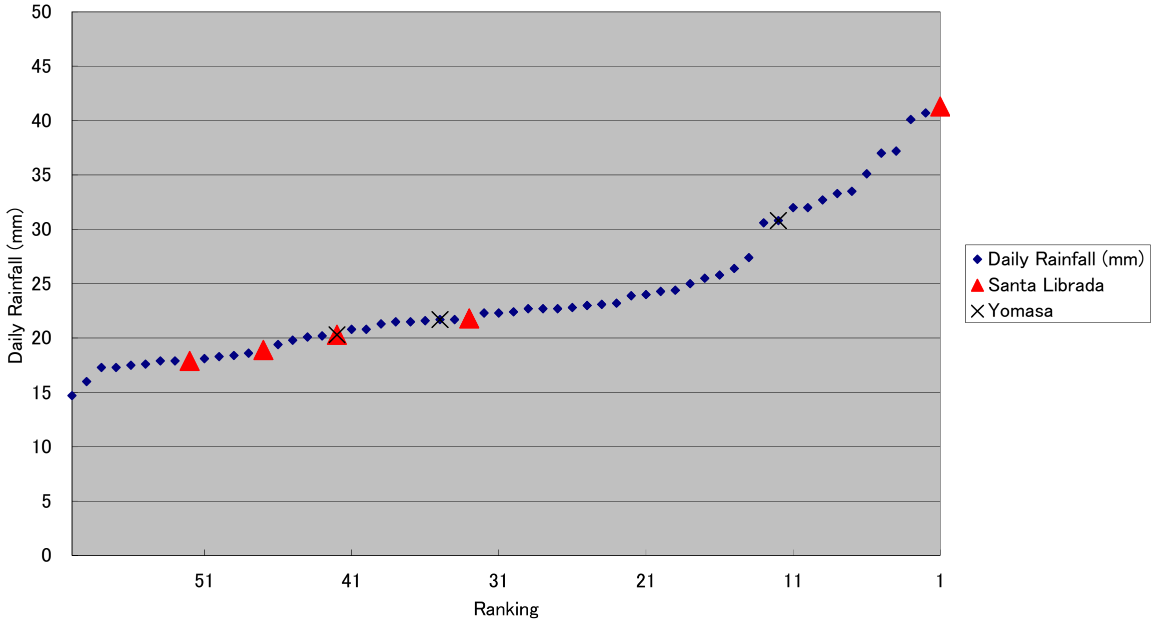


Figure S2-3-7 Relation between Annual Top 10 of Daily Rainfall in Micaela Station (DPAE) and Inundation Events in Santa Librada and Yomasa Basins (2001 Jan - 2006 Jun)

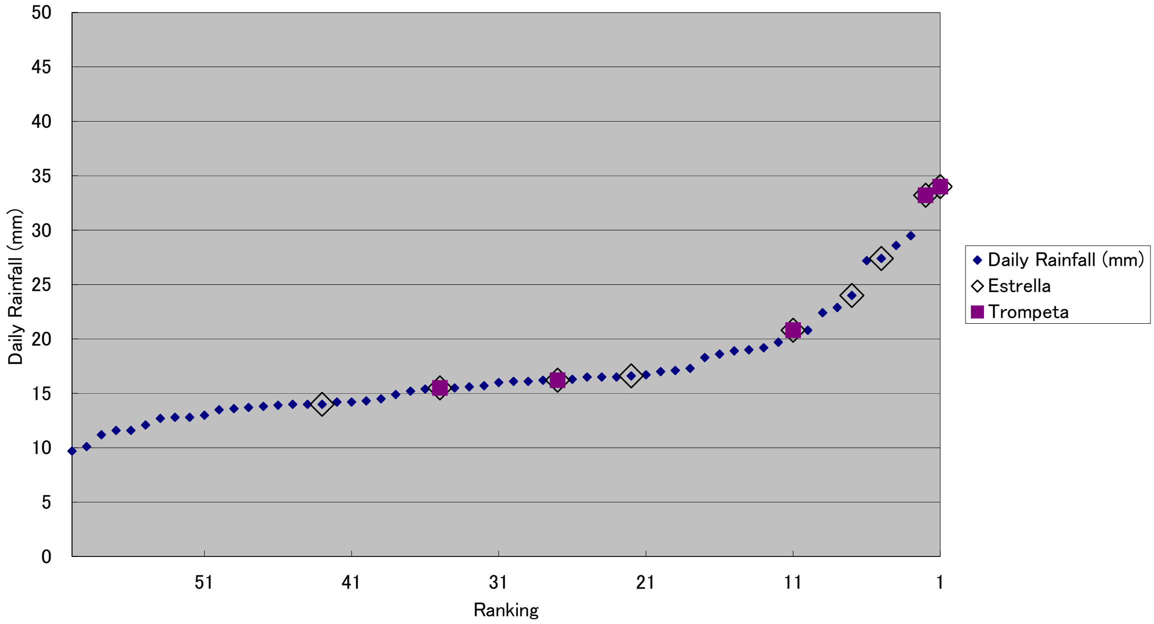


Figure S2-3-8 Relation between Annual Top 10 of Daily Rainfall in Tanque Quiba Station (DPAE) and Inundation Events in La Estrella and Trompeta Basins (2001 Jan - 2006 Jun)

Table S2-3-4 Summary of Relation between Annual Top 10 of Daily Rainfall and Inundation Events

Station / Basin	*No. of Days when Inundation Occurred from 2001 to 2006*	La Picota (CAR)	Juan Rey (EAAB)	Micaela (DPAE)	Tanque Quiba (DPAE)
Chiguaza	*38*	8	6	-	-
Yomasa	*9*	-	-	3	-
Santa Librada	*11*	-	6	5	-
La Estrella	*15*	-	-	-	9
Trompeta	*7*	-	-	-	5

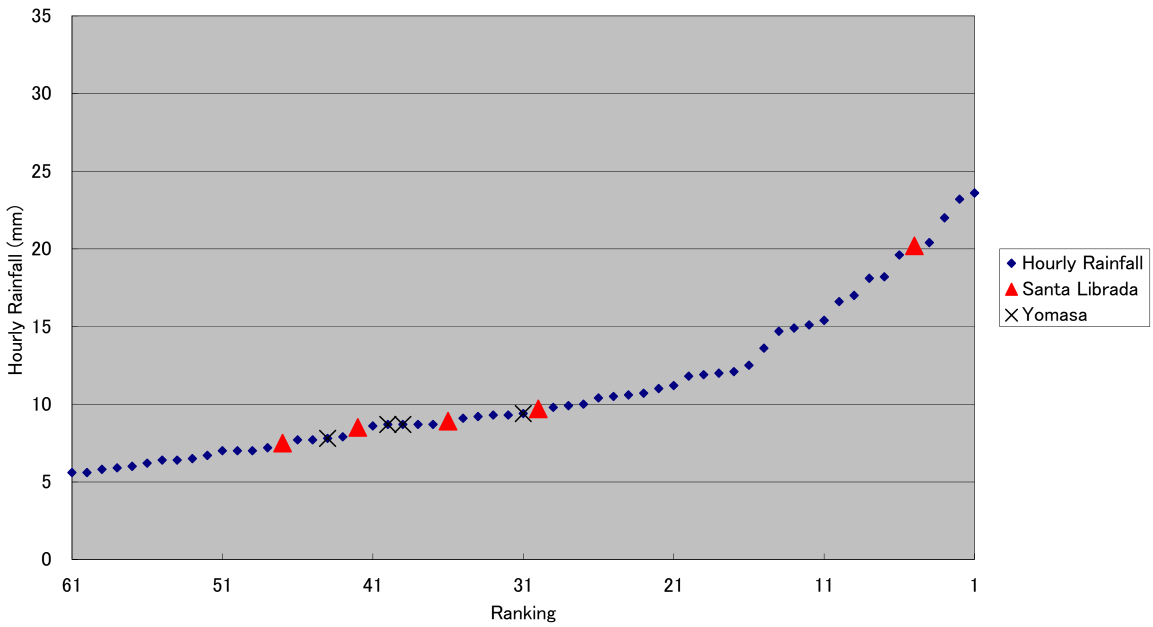


Figure S2-3-9 Relation between Annual Top 10 of Hourly Rainfall in Micaela Station (DPAE) and Inundation Events in Santa Librada and Yomasa Basins (2001 Jan - 2006 Jun)

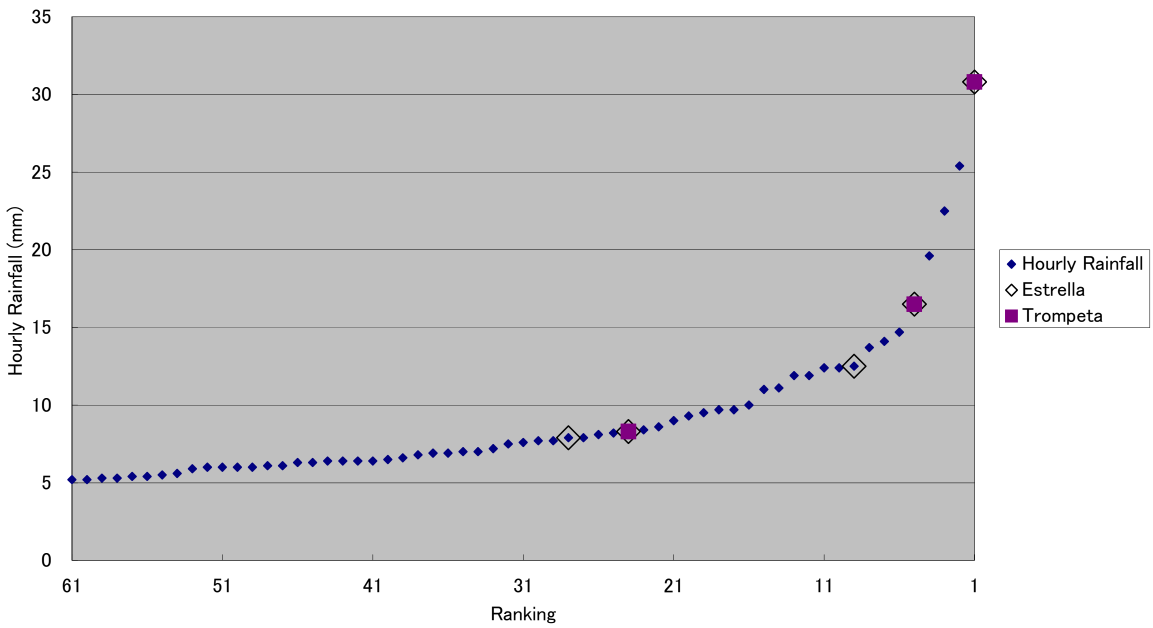


Figure S2-3- 10 Relation between Annual Top 10 of Hourly Rainfall in Tanque Quiba Station (DPAE) and Inundation Events in La Estrella and Trompeta Basins (2001 Jan - 2006 Jun)

Table 2-3-5 Summary of Relation between Annual Top 10 of Hourly Rainfall and Inundation Events

Station / Basin	*No. of Days when Inundation Occurred from 2001 to 2006*	Micaela (DPAE)	Tanque Quiba (DPAE)
Yomasa	*9*	4	-
Santa Librada	*11*	5	-
La Estrella	*15*	-	5
Trompeta	*7*	-	3

From the above results, it can be said that relation between occurrence of past inundations and heavy rainfall are comparatively high in Santa Librada, La Estrella and Trompeta basins, whereas its relation is comparatively low in Chiguaza and Yomasa basins. However, it can be hardly said that heavy rainfall is directly related to inundation.

The following reasons or possibilities can be considered as the above explanation:

1) Since catchment areas of Santa Librada, La Estrella and Trompeta basins are less than 6 km^2, nearby rainfall stations can represent the rainfall in all the basins. On the other hand, nearby stations in Chiguaza and Yomasa basins are not able to represent the rainfall in the basins because their basins have comparatively large catchment areas of about 19 km^2 and 15 km^2, respectively.

2) Spatial rainfall pattern in the Study Area may be extremely local.

In addition to the above possibilities, rainfall distribution of daily rainfall may possibly relate with the occurrence of inundation. Figure S2-3-11 and S2-3-12 show the rainfall distribution in 24 hours of maximum top 10 of daily rainfall during the all the observation/operating period in the Micaela and Tanque Quiba stations in which hourly rainfall data is available. In the figures, bold lines pointed out by arrowhead are the one which inundation occurred. Rainfall distribution can classify two (2) patterns as described in Chapter 2.1. From the figure, it can be described that inundation occurred in the pattern which rainfall concentrated in a short time although inundation didn't always occur in this pattern.

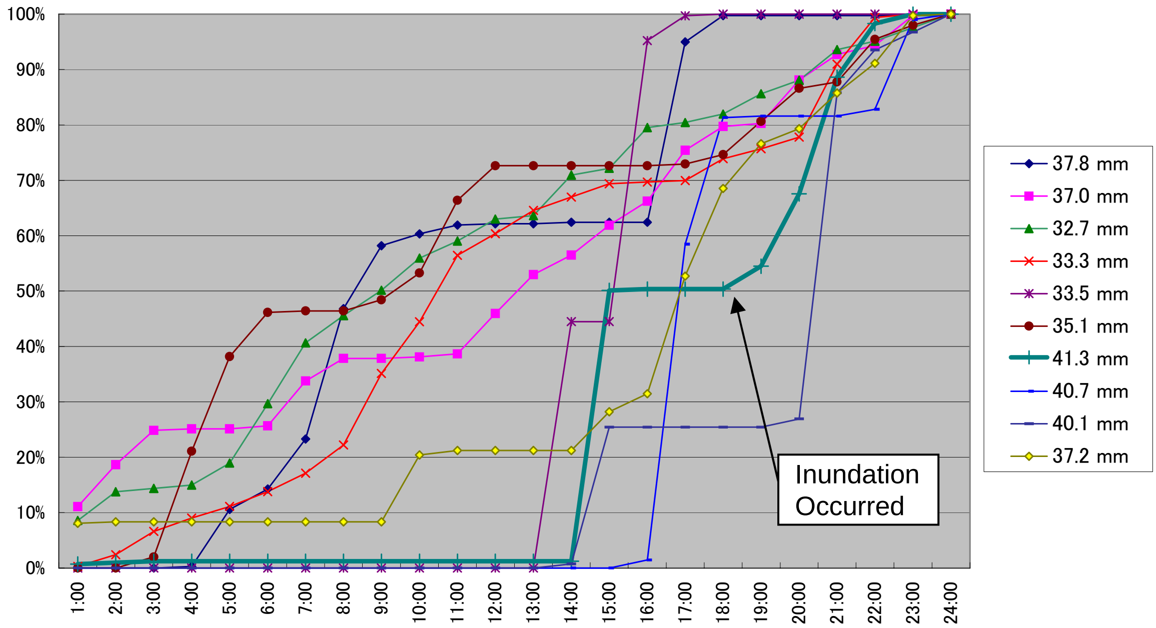


Figure S2-3-11 Rainfall Distribution in 1:00-24:00 (0:00) in Micaela Station and Inundation in Santa Librada Basin

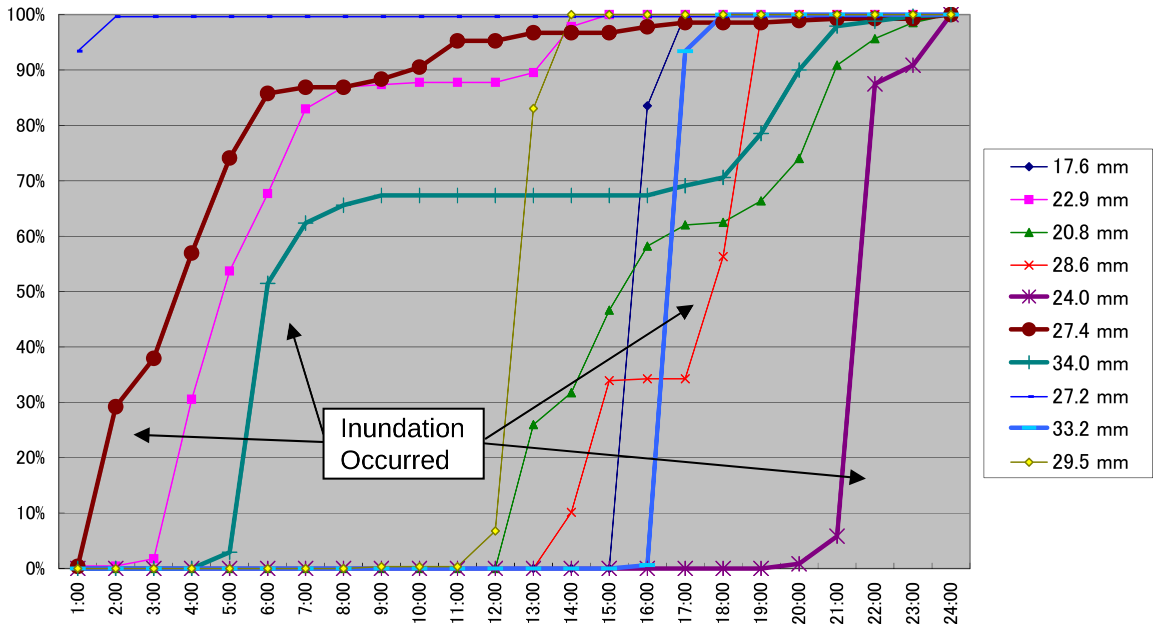


Figure S2-3-12 Rainfall Distribution in 1:00-24:00 in Tanque Quiba Station and Inundation in La Estrella Basin

(B) <u>Relation between Inundation Events and Rainfall</u>

Figure S2-3-13 to S2-3-17 show the daily rainfall in all the day when inundation occurred in each basin from 2001 to 2006.

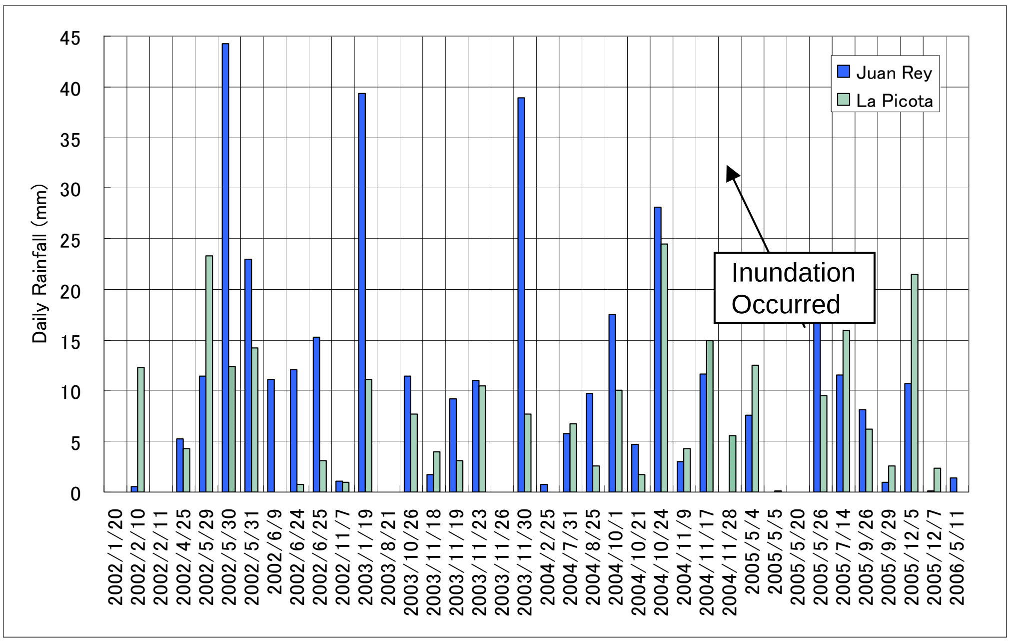


Figure S2-3-13 Relation between Inundation Events in Chiguaza Basin and Daily Rainfall in Juan Rey (EAAB) and La Picota (CAR) Stations

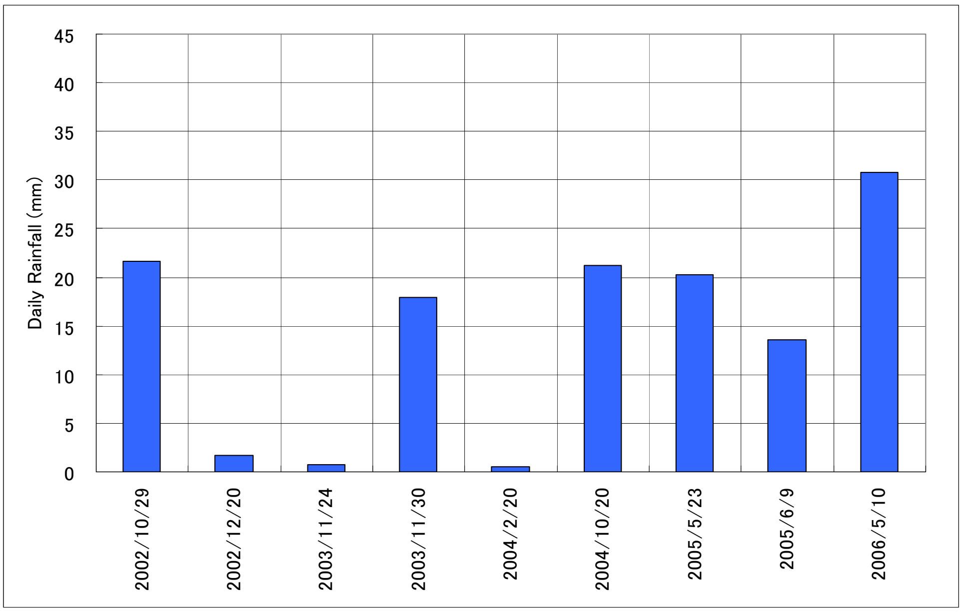


Figure S2-3-14 Relation between Inundation Events in Yomasa Basin and Daily Rainfall in Micaela (DPAE) Station

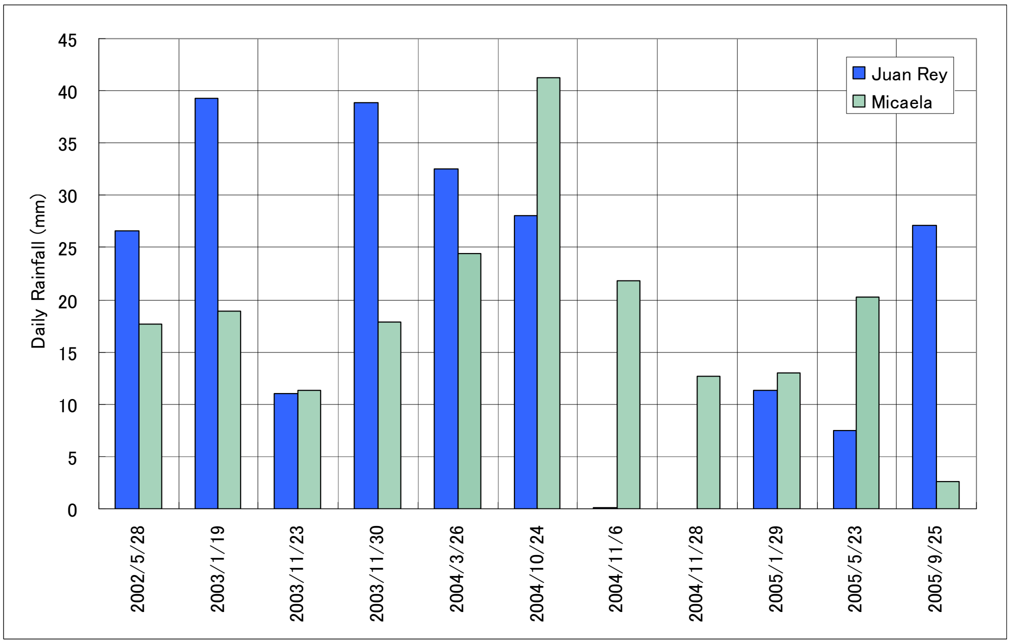


Figure S2-3-15 Relation between Inundation Events in Santa Librada Basin and Daily Rainfall in Juan Rey (EAAB) and Micaela (DPAE) Stations

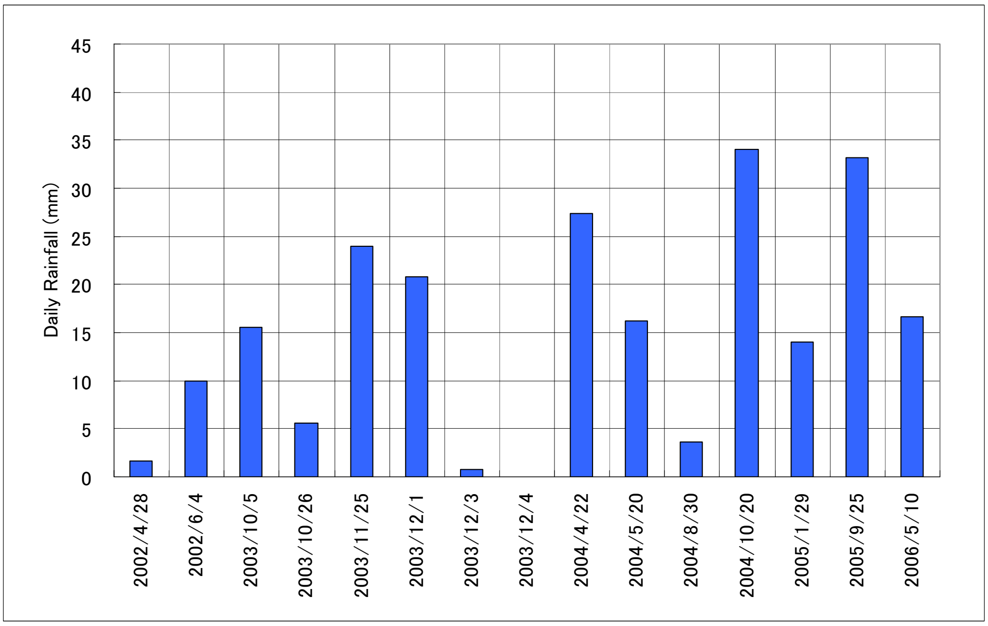


Figure S2-3-16 Relation between Inundation Events in La Estrella Basin and Daily Rainfall in Tanque Quiba (DPAE) Station

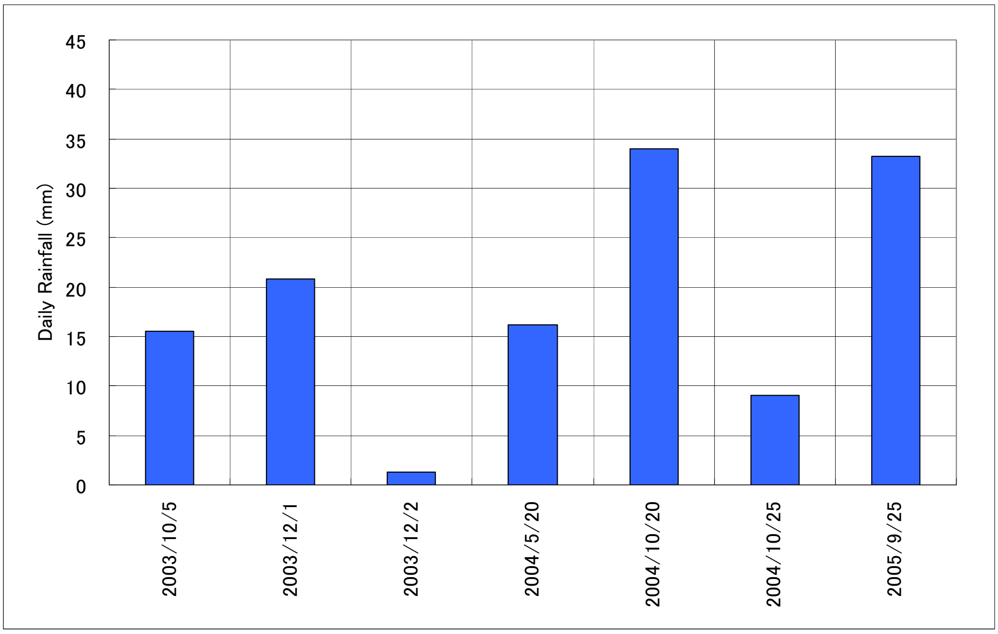


Figure S2-3-17 Relation between Inundation Events in Trompeta Basin and Daily Rainfall in Tanque Quiba Station (DPAE)

In the above figures, inundation occasionally occurred when rainfall amount is very small or in no rainfall. The following reasons or possibilities can be considered:

- Accuracy of rainfall data and inundation records
- Time lag between the occurrence time in the records and the actual occurrence time.
  For example, in case that inundation occurred at midnight, the occurrence date may have been recorded in the following day of actual inundation occurrence. Then, rainfall that caused inundation and rainfall used for the analysis are mismatched. In case of 2003/11/24 and 2004/2/20 in Yomasa basin, daily rainfall amounts of the previous day are more than 10 mm.
- Distance of rainfall station and actual rainfall area (local rainfall).
  In other words, it is the case that covered area of specified rainfall station could not include the

rainfall area/inundated area in the basin. For example, in case of 2002/12/20 in Yomasa basin, daily rainfall amount of Micaela station is quite small; however, rainfall amount of Tanque Quiba station is about 30 mm.

- Influence of other factors.
  Inundation in the Study Area may have occurred due to not only rainfall but also the influence of human activities or some surrounding environmental problems

In addition to the above possibilities, antecedent rainfall may influence the occurrence of inundation. Figure S2-3-18 to S2-3-20 show the antecedent rainfall when inundation occurred. From the figures, influence of antecedent rainfall to the inundation is not clear.

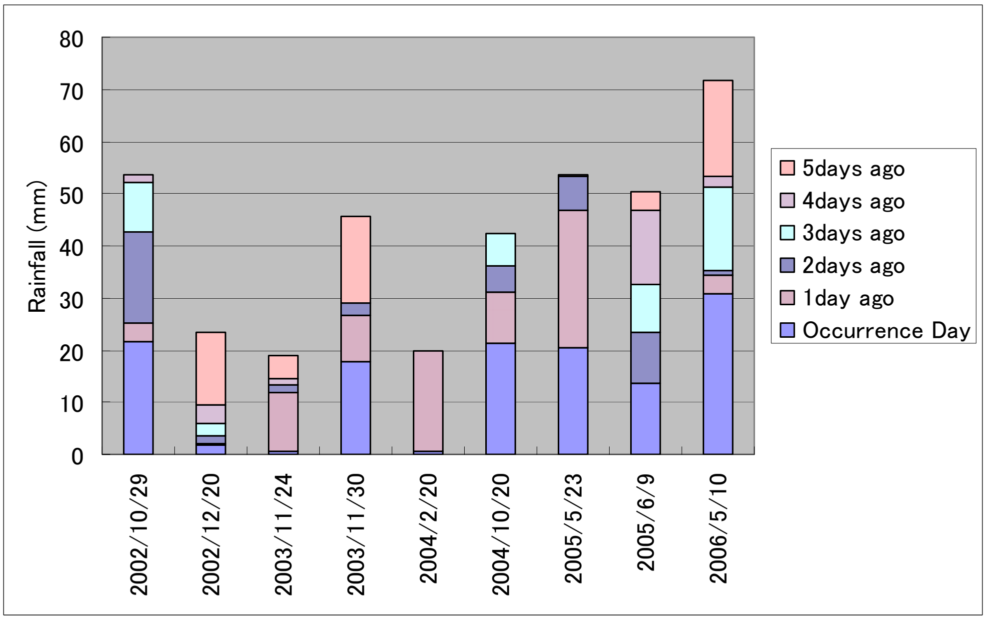


Figure S2-3-18 Antecedent Rainfall in Micaela Station (EAAB) when Inundation Occurred in Yomasa Basin

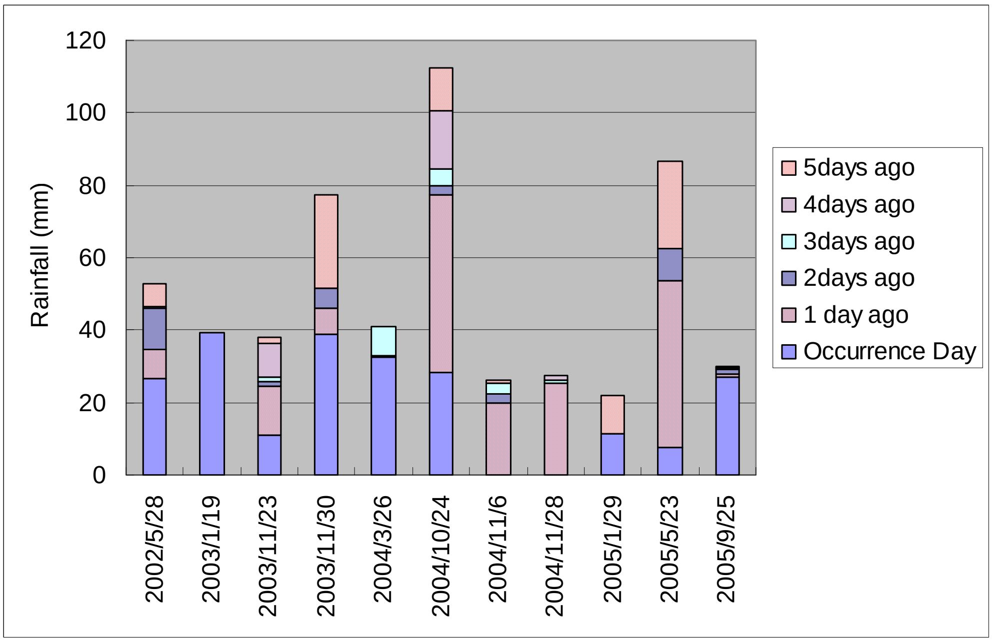
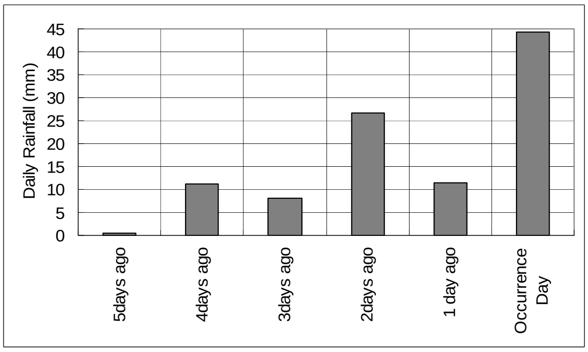
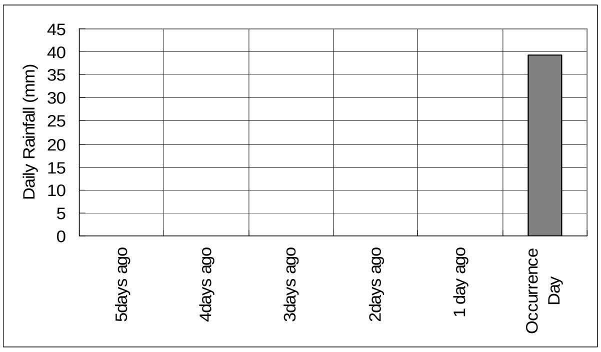


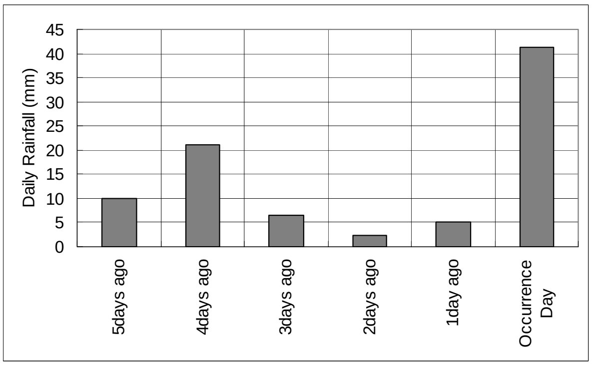
Figure S2-3-19 Antecedent Rainfall in Juan Rey Station (EAAB) when Inundation Occurred in Santa Librada Basin



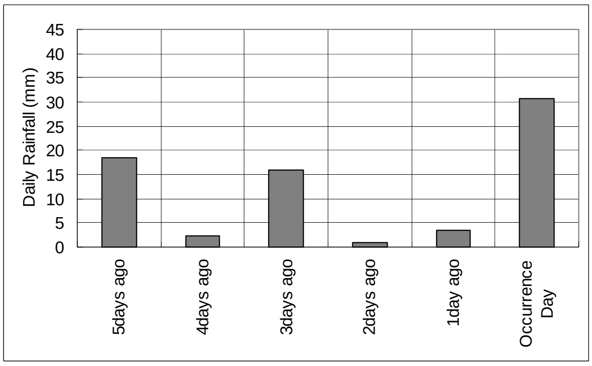
2002/5/30 in Juan Rey Station (EAAB)



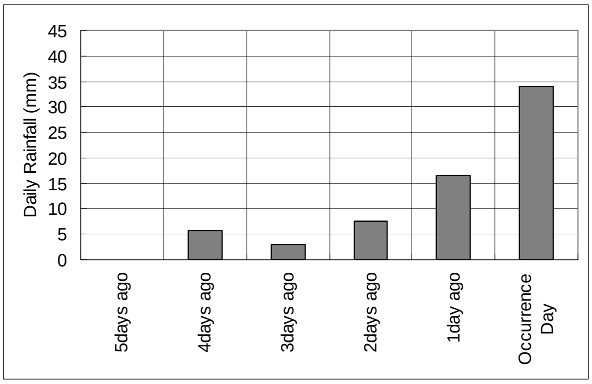
2003/1/19 in Juan Rey Station (EAAB)



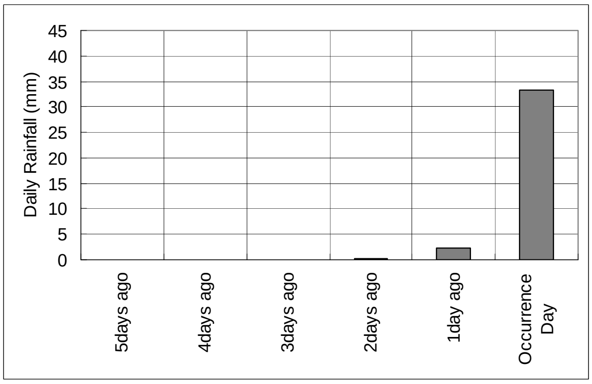
2004/10/24 in Micaela Station (DPAE)



2006/5/10 in Micaela Station (DPAE)



200410/20 in Tanque Quiba Station (DPAE)



2005/9/25 in Tanque Quiba Station (DPAE)

Figure S2-3-20 Antecedent Rainfall when Inundation Occurred

From the above analyses, inundation in the Study Area may happen by the influence of the some factors other than rainfall and may be difficult to explain from only rainfall. In addition, rainfall station and rainfall data in the Study Area are limited, few water level data exist in limited basin, and relation of rainfall and water level is impossible to know. Although the conditions are quite hard as described above, the determination of threshold is attempted by using only rainfall.

Daily rainfall amounts in past inundations are summarized in Table S2-3-6.

Table S2-3-6 Summary of Relation between Inundation Events and Daily Rainfall

Basin/Station	*No. of Days when Inundation Occurred from 2001 to 2006*	Daily Rainfall (mm)								
		< 5	<10	<15	<20	<25	<30	<35	<40	40=<
Chiguaza La Picota (CAR) or Juan Rey (EAAB)	*38*	14	20	26	31	34	35	35	37	38
	100%	37%	53%	68%	82%	89%	92%	92%	97%	100%
Yomasa Micaela (DPAE)	*9*	3	3	4	5	8	8	9	9	9
	100%	33%	33%	44%	56%	89%	89%	100%	100%	100%
Santa Librada Juan Rey (EAAB) or Micaela (DPAE)	*11*	0	0	3	3	5	7	8	10	11
	100%	0%	0%	27%	27%	45%	64%	73%	91%	100%
La Estrella Tanque Quiba (DPAE)	*15*	4	5	7	10	12	13	15	15	15
	100%	27%	33%	47%	67%	80%	87%	100%	100%	100%
Trompeta Tanque Quiba (DPAE)	*7*	1	2	2	4	5	5	7	7	7
	100%	14%	29%	29%	57%	71%	71%	100%	100%	100%

Table S2-3-7 shows the threshold of daily rainfall amount in each target basins, which is set using the rate of occurrence of past inundations as shown in the above table. The thresholds are classified into three. Since inundation record doesn't include the scale of the inundation and the damage, the relation between rainfall amount and the scale of inundation is not obvious, and it cannot be said that inundation with low rate of occurrence is severe inundation. However, in general, severe inundation occurs in heavy rainfall and the rate of occurrence of severe inundation is low. Based on the above assumption, thresholds were classified using rainfall amount. "Probable Annual Frequency" in the table means "how many times per year the relevant rainfall amount will be observed".

These thresholds are for daily rainfall. According to the former analysis, rainfall tends to concentrate in a short time when inundation occurs; therefore these thresholds are regarded to serve as a reference for determining the threshold of hourly rainfall.

Table S2-3-7 Thresholds of Daily Rainfall for Inundation

Criteria / Basin/Station	Inundation Occurrence probability More than 70%	Inundation Occurrence probability Less than 50%	Inundation Occurrence probability Less than 30%
Chiguaza Basin			
La Picota (CAR)	5 mm	10 mm	20 mm
Probable Annual Frequency	37 days	15 days	3 days
Juan Rey (EAAB)	5 mm	10 mm	20 mm
Probable Annual Frequency	85 days	41 days	11 days
Yomasa Basin			
Micaela (DPAE)	5 mm	20 mm	25 mm
Probable Annual Frequency	81 days	9 days	3 days
Santa Librada Basin			
Juan Rey (EAAB)	20 mm	30 mm	35 mm
Probable Annual Frequency	11 days	3 days	1 day
Micaela (DPAE)	20 mm	30 mm	35 mm
Probable Annual Frequency	9 days	2 days	1 day
La Estrella Basin			
Tanque Quiba (DPAE)	5 mm	20 mm	25 mm
Probable Annual Frequency	36 days	2 days	1 day
Trompeta Basin			
Tanque Quiba (DPAE)	15 mm	20 mm	25 mm
Probable Annual Frequency	7 days	2 days	1 day

For the reference, values to have converted frequency of rainfall into the number of the days during a year (365 days) in each station are shown in Table 2-3-8. For example, daily rainfall of more than 10mm may occur 14 times per year in Tanque Quiba (DPAE) station.

Table S2-3-8 Average Number of Days of Daily Rainfall Amount per Year

Unit: Number of days

Station	Daily Rainfall (mm)								
	0≦	5≦	10≦	15≦	20≦	25≦	30≦	35≦	40≦
La Picota (CAR)	365	37	15	8	3	1	1	0	0
Juan Rey (EAAB)	365	85	41	21	11	5	3	1	1
Micaela (DPAE)	365	81	40	21	9	3	2	1	1
Tanque Quiba (DPAE)	365	36	14	7	2	1	0	0	0

Remarks: Data Period is 2001-2006

(3) Analyses for Landslide

Table S2-3-9 summarized the daily rainfall amount in the day when a number of landslides occurred in each basin on the same date.

Table S2-3-9 Daily Rainfall of the Day of Landslides Occurrence

Basin/Station	No. of Days when a Number of Landslides Occurred from 2002 to 2006	Daily Rainfall (mm)				
		< 5	< 10	< 15	< 20	< 25
Chiguaza Basin (Juan Rey (EAAB))	18 100%	8 44%	14 78%	17 94%	17 94%	18 100%
Yomasa Basin (Micaela (DPAE))	2 100%	0 0%	0 0%	1 50%	2 100%	2 100%
Santa Librada	0	-	-	-	-	-
La Estrella Basin (Tanque Quiba (DPAE))	8 100%	5 63%	6 75%	6 75%	8 100%	8 100%
Trompeta Basin (Tanque Quiba (DPAE))	3 100%	3 100%	3 100%	3 100%	3 100%	3 100%
Total	31 100%	16 52%	23 74%	27 87%	30 97%	31 100%

More than 50% of Landslides occurred less than 5 mm of daily rainfall. It is considered to be difficult to grasp the characteristic of rainfall in landslides occurrence using only daily rainfall of the day of the landslides occurrence. Thus, antecedent rainfall is investigated for the analysis. Figure S2-3-21 shows the various type of rainfall amount of Juan Rey (EAAB) station in landslides occurrence in Chiguaza basin and average values in Juan Rey (EAAB) station for comparison. Upper values with box in each category are the rainfall amount in landslides occurrence. Accumulative rainfall is a total rainfall amount up until the calculated day (the day of landslides occurrence), which was calculated adding the entire daily rainfall amount after the day when the daily rainfall was zero (0) previously. For example, when the daily rainfall was zero (0) before 2 days of the calculated day, accumulative rainfall is total rainfall amount of the previous day and the calculated day.

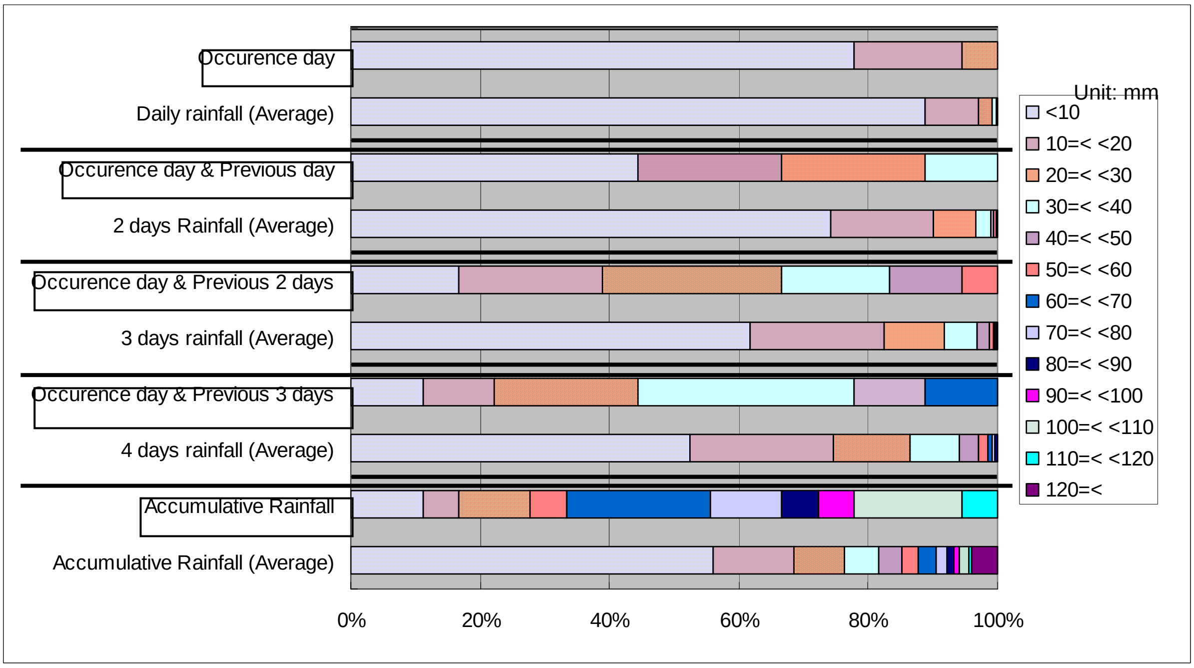


Figure S2-3-21 Various Rainfall Amount in Landslides Occurrence and Average Values in Juan Rey Station (EAAB)

From the above figure, the obvious differences of the tendency are not seen in the cases of occurrence day and daily rainfall (average), and occurrence day & previous day and 2 days rainfall (average). On the other hand, differences can be clearly found in case of accumulative rainfall, and can be recognized in 3 days and 4 days rainfall. DPAE already sets and uses the 3 days rainfall for the criteria in the current monitoring system. Therefore, analyses are conducted using accumulative rainfall and 3 days rainfall (rainfall of occurrence day and previous 2 days).

Figure S2-3-22 to S2-3-25 show the correlation of three (3) days rainfall and accumulative rainfall when landslides occurred in each basin. Figure S2-3-26 to S2-3-28 show the distribution of three (3) days rainfall and accumulative rainfall in the period of 2001-2006 in each station and the data in landslides occurrence. Relation between landslide events and three (3) days or accumulative rainfall is summarized in Table S2-3-10. In the table, the percentage of "Landslide" rows is the rate of the number of days with the designated rainfall amount when landslides occurred, and the percentage of "Average" rows is the rate of the number of days with the designated rainfall amount in the period of 2001-2006.

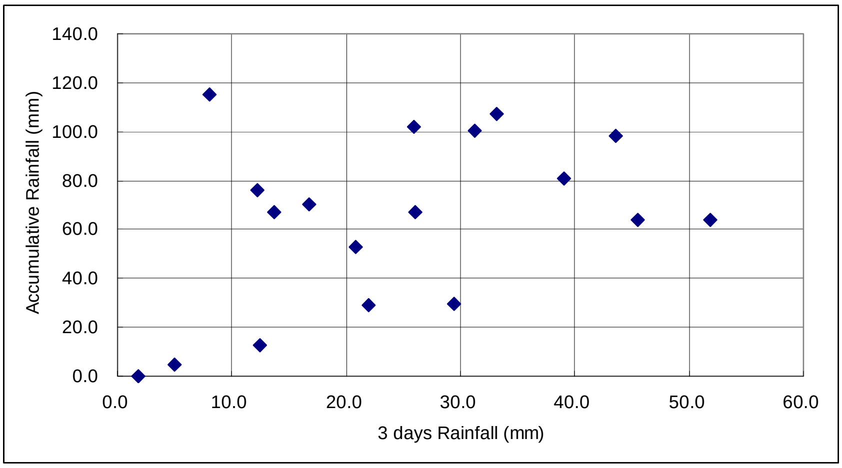


Figure S2-3-22 Correlation of 3 days Rainfall and Accumulative Rainfall in Chiguaza Basin

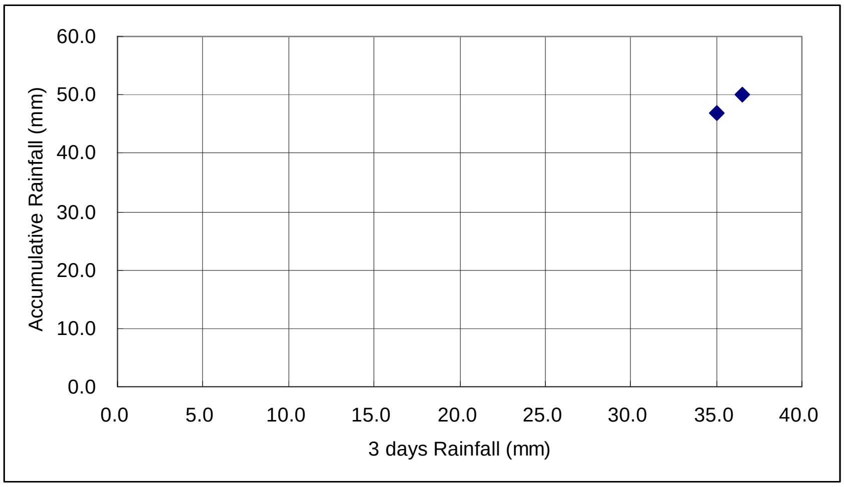


Figure S2-3-23 Correlation of 3 days Rainfall and Accumulative Rainfall in Yomasa Basin

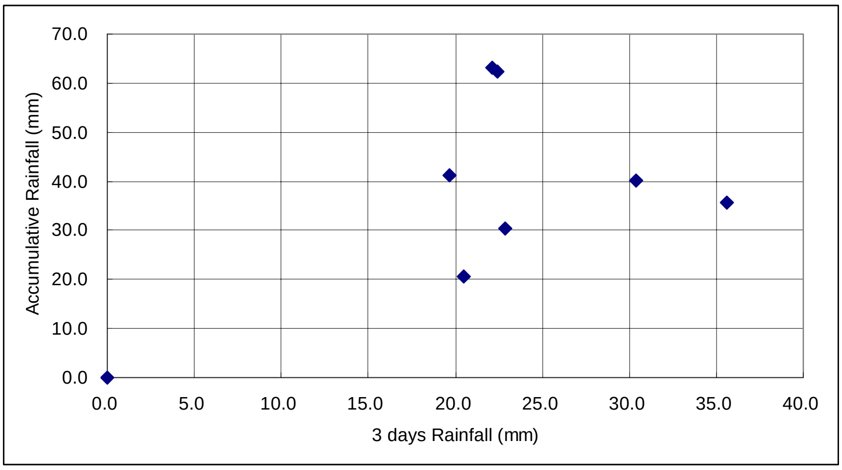


Figure S2-3-24 Correlation of 3 days Rainfall and Accumulative Rainfall in La Estrella Basin

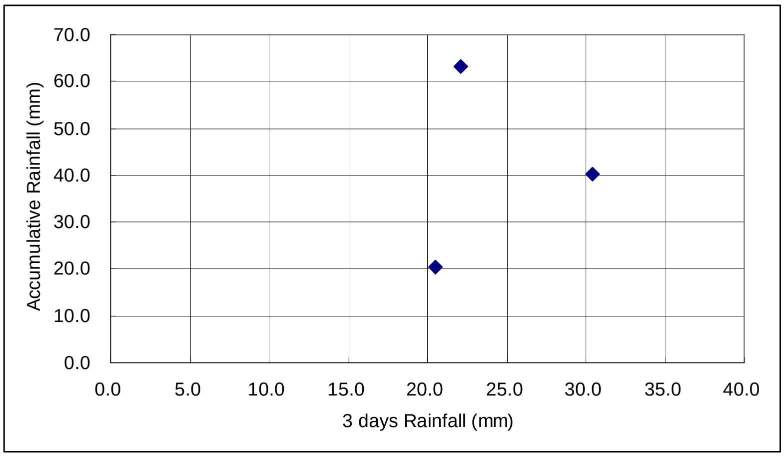


Figure S2-3-25 Correlation of 3 days Rainfall and Accumulative Rainfall in Trompeta Basin

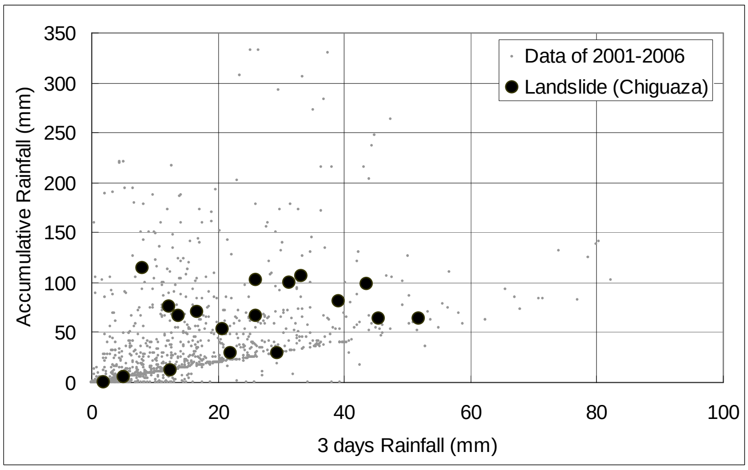


Figure S2-3-26 Distribution of 3 days Rainfall and Accumulative Rainfall in Juan Rey Station

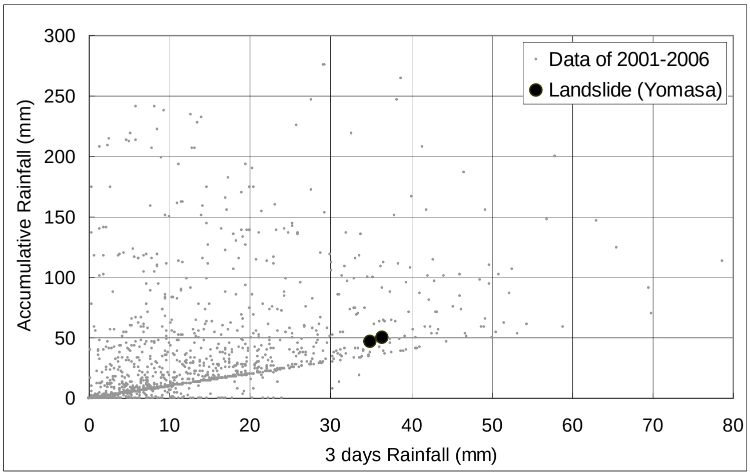


Figure S2-3-27 Distribution of 3 days Rainfall and Accumulative Rainfall in Micaela Station

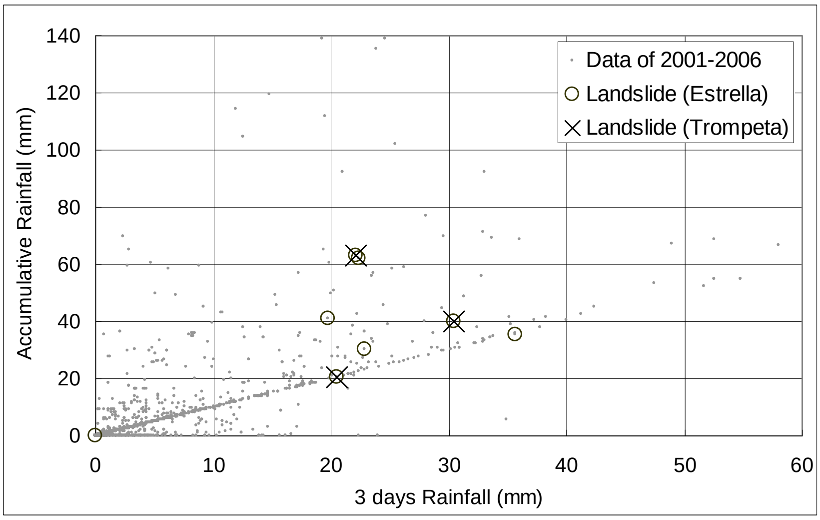


Figure S2-3-28 Distribution of 3 days Rainfall and Accumulative Rainfall in Tanque Quiba Station

Table S2-3-10 Summary of Relation between Landslide Events and Rainfall

Basin	Rainfall		Rainfall (mm)												
			<10	<20	<30	<40	<50	<60	<70	<80	<90	<100	<110	<120	120=<
Chiguaza (Juan Rey)	3 days Rainfall	Landslide	17%	39%	67%	83%	94%	100%	100%	100%	100%	100%	100%	100%	100%
		Average	62%	83%	92%	97%	99%	99%	100%	100%	100%	100%	100%	100%	100%
	Accum. Rainfall	Landslide	11%	17%	28%	28%	28%	33%	56%	67%	72%	78%	94%	100%	100%
		Average	56%	68%	76%	82%	85%	88%	91%	92%	93%	94%	96%	96%	100%
Yomasa (Micaela)	3 days Rainfall	Landslide	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		Average	63%	83%	93%	97%	99%	100%	100%	100%	100%	100%	100%	100%	100%
	Accum. Rainfall	Landslide	0%	0%	0%	0%	50%	100%	100%	100%	100%	100%	100%	100%	100%
		Average	54%	66%	75%	80%	84%	88%	89%	91%	92%	93%	94%	95%	100%
La Estrella (Tanque Quiba)	3 days Rainfall	Landslide	13%	25%	75%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		Average	86%	95%	98%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Accum. Rainfall	Landslide	13%	13%	25%	50%	75%	75%	100%	100%	100%	100%	100%	100%	100%
		Average	84%	91%	95%	97%	98%	99%	99%	100%	100%	100%	100%	100%	100%
Trompeta (Tanque Quiba)	3 days Rainfall	Landslide	0%	0%	67%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		Average	86%	95%	98%	99%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Accum. Rainfall	Landslide	0%	0%	33%	33%	67%	67%	100%	100%	100%	100%	100%	100%	100%
		Average	84%	91%	95%	97%	98%	99%	99%	100%	100%	100%	100%	100%	100%

Either of three (3) days rainfall and accumulative rainfall is considered to be able to use as the threshold for general warning. However, for those relevant days are quite frequent using them independently, investigation of their combination is attempted.

The classification of thresholds is set to three and is determined using the rate of occurrence of past landslides. Since there are a lot of pattern of the combination of three (3) days rainfall and accumulative rainfall, which satisfy a certain rate of occurrence, three (3) days rainfall and accumulative rainfall are combined by the following way: 1) three (3) days rainfall is temporarily fixed as a base, and 2) combination pattern is adjusted by accumulative rainfall. This is because three (3) days rainfall is regarded to be easy to handle in actual operation than accumulative rainfall that needs the longer time for data collection.

Table S2-3-11 shows the example of the combination of three (3) days rainfall and accumulative rainfall as a threshold, and probable annual frequency. This is nothing but the example. On the occasion that actual threshold is going to be determined, more detailed and careful investigation should be conducted. For example, it should be carefully investigated whether two (2) kinds of rainfall amounts shall be used independently or in combination. Whatever, grasping and recording the exact phenomena and conditions of disasters are absolutely necessary.

Table S2-3-11 Example of Thresholds for General Warning of Landslide

Criteria / Basin/Station	Occurrence probability More than 70%	Occurrence probability Less than 50%	Occurrence probability Less than 30%
Chiguaza Basin Juan Rey (EAAB)	3days Rain > 10mm & Accum. Rain > 20 mm	3days Rain > 20mm & Accum. Rain > 50 mm	3days Rain > 30mm & Accum. Rain > 70 mm
Probable Annual Frequency (days)	94	28	12
Yomasa Basin Micaela (DPAE)	3days Rain > 30mm & Accum. Rain > 40 mm	3days Rain > 30mm & Accum. Rain > 50 mm	3days Rain > 40mm & Accum. Rain > 50 mm
Probable Annual Frequency (days)	21	17	9
La Estrella Basin Tanque Quiba (DPAE)	3days Rain > 20mm & Accum. Rain > 20 mm	3days Rain > 20mm & Accum. Rain > 40 mm	3days Rain > 20mm & Accum. Rain > 50 mm
Probable Annual Frequency (days)	18	6	4
Trompeta Basin Tanque Quiba (DPAE)	3days Rain > 20mm & Accum. Rain > 20 mm	3days Rain > 20mm & Accum. Rain > 50 mm	3days Rain > 30mm & Accum. Rain > 50 mm
Probable Annual Frequency (days)	18	4	2

3.2 Analyses for Soacha

3.2.1 Disaster Events for the Analyses in Soacha

For the analyses of relation between hydrological conditions, mainly rainfall, and disasters in Soacha, disaster records by the fire station (Bomberos) from May 1996 to April of 2006 for inundation and from May 1998 to June 2006 except 2004 for landslide are used. The disaster records by the fire station don't include the enough information to grasp the magnitude of disaster, such as inundation depth, inundated area and the damage to the people and houses; therefore it is able to analyze only the relation between hydrological conditions and occurrence of disasters.

Figure S2-3-29 shows the number of inundation events in each barrio in Soacha urban area, and Table S2-3-12 shows the list of inundation events in Soacha urban area. Figure S2-3-30 shows the number of landslide events in each barrio, and Table S2-3-13 and S2-3-14 show the list of all landslide events and the list of selected landslide events for analysis, respectively. The landslide events for the analysis are selected in the same way as the landslide analysis of Bogota.

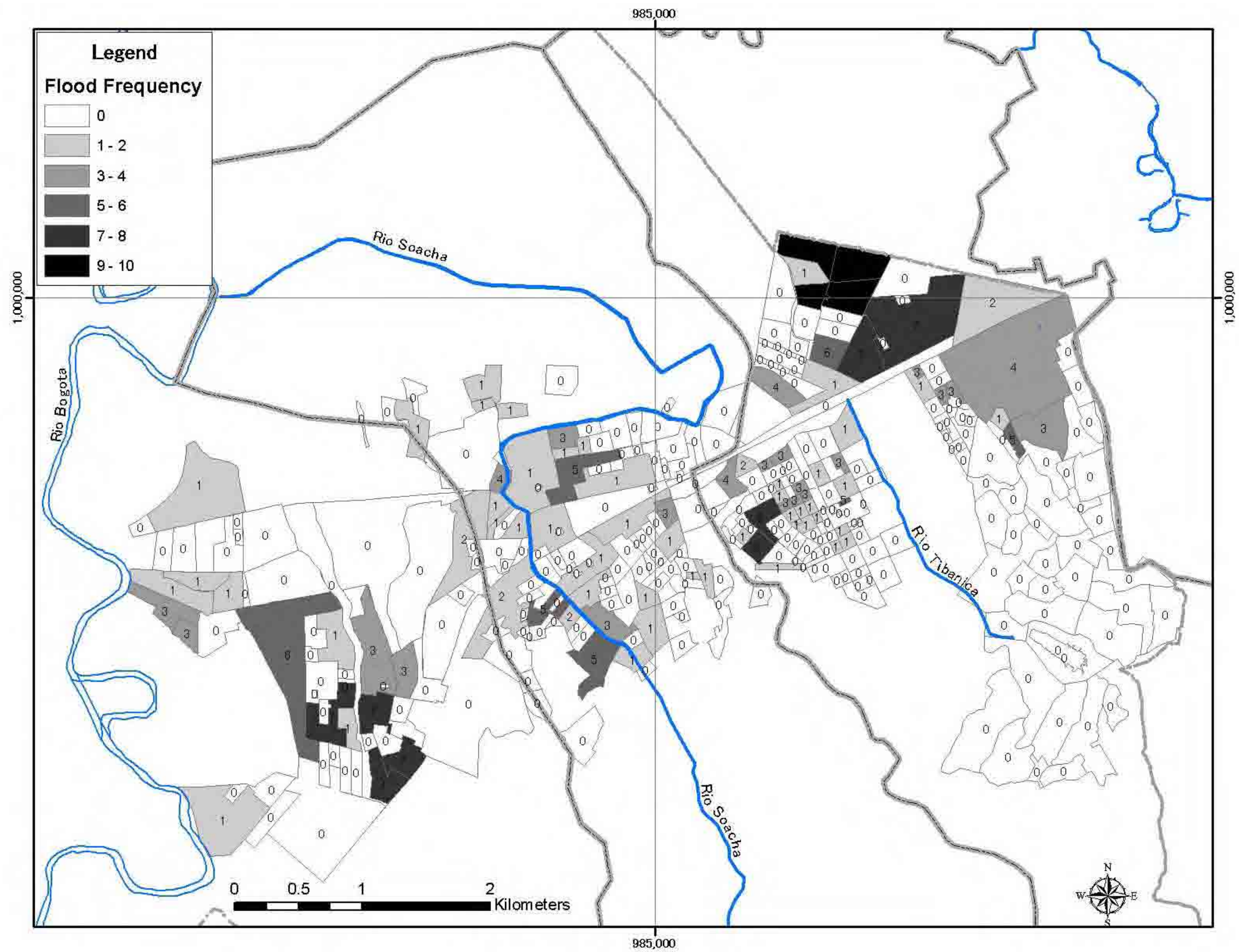


Figure S2-3-29 Number of Inundation Events in Barrio in Soacha Urban Area

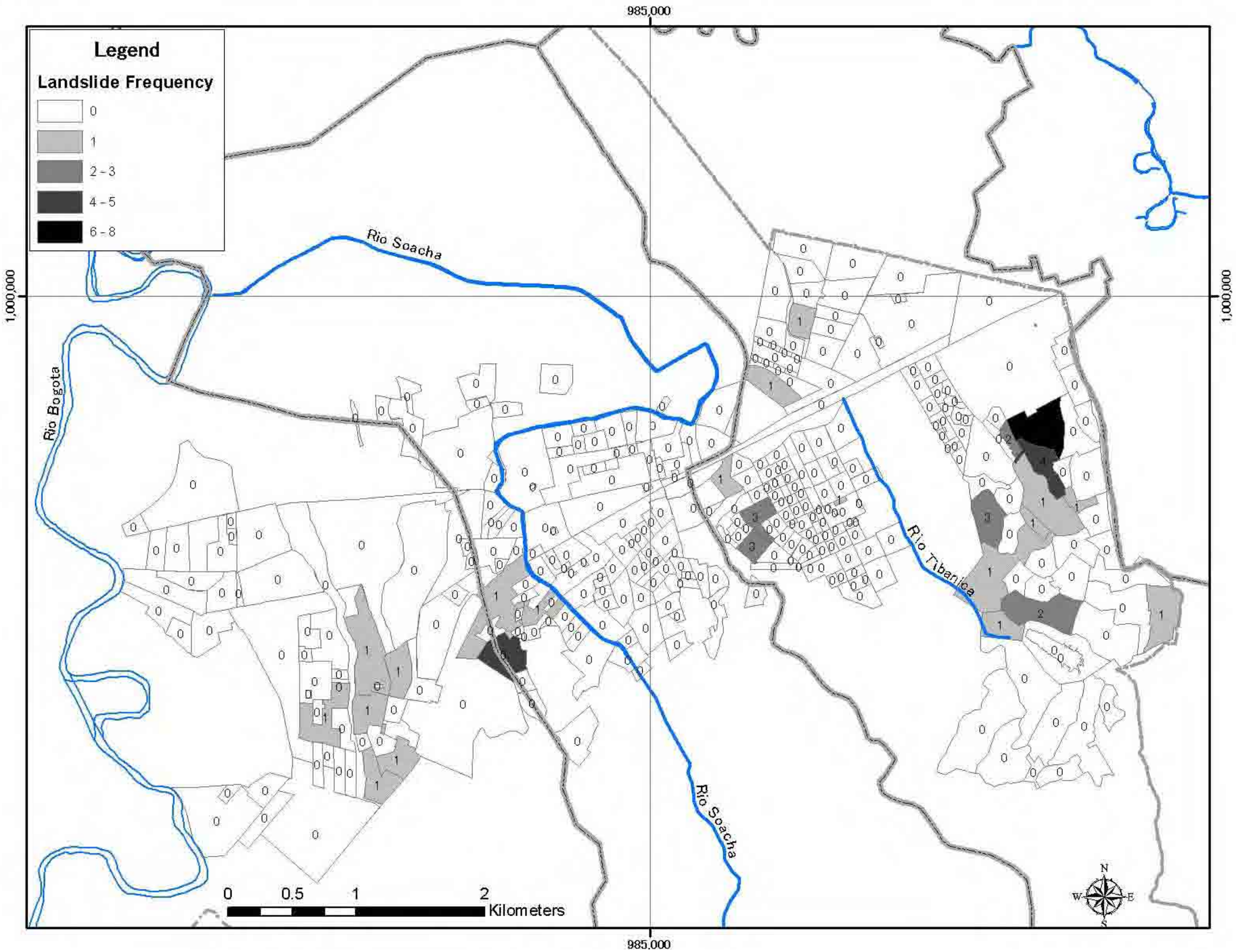


Figure S2-3-30 Number of Landslide Events in Barrio in Soacha Urban Area

Table S2-3-12 Inundation Records in Soacha Urban Area

Date	Barrio Name	No. of Wounded	No. of Dead
1996/5/17	C. Latina	0	0
1996/5/20	Satelite	0	
1996/5/23	OLIVOS	0	0
1996/6/29	S MARCOS	0	0
1997/6/4	El Sol, Cazuca Ind.	0	0
1997/11/4	Linconl	0	0
1997/11/11	Portalegre	0	0
1997/12/2	Casa linda	0	0
1998/4/3	El Praiso	0	0
1998/4/30	Cumbres S.M.	0	0
1998/5/2	Rincon Santafe, Cra.7-14 Soacha	0	0
1998/5/3	El Praiso	0	0
1998/5/4	Cazuca Ind	0	0
1998/5/5	Olivos	0	0
1998/5/8	Cien Familias, El paraiso	0	0
1998/9/16	Cazuca	0	0
1998/10/16	Cazuca	0	0
1998/10/17	S. Mateo iglesia	0	0
1999/1/2	Comercial Tequendama	0	0
1999/1/3	Leon 13	0	0
1999/2/23	12 de octubre	0	0
1999/3/17	La despensa	0	0
1999/3/10	San mateo	0	0
1999/3/28	La capilla	0	0
1999/4/5	Cien Familias, La florida	0	0
1999/4/12	San mateo	0	0
1999/6/17	Santana Tropiabastos	0	0
1999/7/23	Capilla de cazuca	0	0
1999/10/30	Quintas de Santana, Compartir	0	0
1999/11/1	La huerta (Indumil), Quintas de la Laguna, Quintas de Santana	0	0
1999/11/2	La Capilla	0	0
2000/3/24	OLIVOS	0	0
2000/4/23	Centro	0	0
2000/11/7	Santa Maria del rincon, Nuevo Colon		
2000/11/21	SANTA ANA	0	0
2000/11/26	COMPARTIR	0	0
2001/3/19	SAN NICOLAS	0	0
2001/5/9	VEREDITA	0	0
2001/5/10	EL ROSAL	0	0
2001/5/31	BOSATAMA	0	0
2001/6/2	FLORIDA	0	0
2001/6/6	SANTILLANA, RICAURTE, Leon 13, CIUDADELA SUCRE, LA UNION, ACACIAS, QUINTANARES	0	0
2001/7/7	COMPARTIR	0	0
2001/11/2	RICAURTE	0	0
2001/11/3	EL SOL	0	0
2001/12/2	DUCALES, Mirador de S.Ignacio	0	0
2001/12/24	Mirador de S.Ignacio, EL CHICO	0	0
2002/5/14	SAN CARLOS	0	0
2002/5/24	COMPARTIR	0	0
2002/5/31	BOSATAMA	0	0
2002/6/7	LLANO GRANDE, EUGENIO DIAZ	0	0
2002/8/11	Mirador de S.Ignacio	0	0
2002/11/7	OLIVOS, Leon 13	0	0
2002/11/9	OLIVOS, QUINTANARES, Altico, 12 DE MARZO, Ricaurte, Sta Ma. Rincon, SAN MATEO	0	0
2002/11/10	Portalegre	0	0
2002/11/13	Santa Elena	0	0
2002/11/16	Altico	0	0
2002/11/24	SANTA ANA	0	0
2002/12/5	SANTA ANA	0	0
2002/12/17	LOS CRISTALES	0	0
2003/1/3	OLIVOS, QUINYANARES, UBATE, Portalegre, ACACIAS, Ducales, Leon 13	0	0
2003/1/20	OLIVOS	0	0
2003/3/21	Compartir	0	0
2003/4/3	CODEC	0	0
2003/4/16	SANTA ANA, Leon 13, Terragrande, San Mateo	0	0
2004/10/19	CIUDADELA SUCRE	0	0
2004/10/20	LA MARIA	0	0
2004/10/25	FANALCA S.A	0	0
2004/10/27	ECOOPSOS	0	0
2004/10/30	EL SILO	0	0
2004/10/31	ALMACEN FRACUA,	0	0
2004/11/3	UNISUR	0	0
2004/11/9	UNISUR	0	0
2004/11/14	TROPIABASTOS	0	0
2004/11/16	EL SILO	0	0
2004/11/18	EL SILO	0	0
2004/11/24	SANTA ANA	0	0
2004/11/28	DUCALES	0	0
2005/1/5	EL SOL	0	0
2005/2/12	EL SILO Y SAN IGNACIO, FLORIDA, R.SANTA M.	0	0
2005/4/23	OLIVOS, Leon 13	0	0
2005/5/2	EL DORADO, DANUBIO	0	0
2005/5/15	CENTRO, SAN CARLOS, CAZUCA IND.	0	0
2005/5/17	S.MATEO	0	0
2005/5/18	CENTRO	0	0
2005/5/22	QUINTAS DE LA LAGUNA	0	0
2005/5/23	CAZUCA	0	0
2005/5/25	OLIVOS 1	0	0
2005/5/29	CIUDADELA SUCRE	0	0
2005/8/3	LAS VEGAS	0	0
2005/8/22	CENTRO	0	0
2005/10/21	DESPENSA, CAZUCA, OLIVOS, VILLA SOFIA	0	0
2005/10/23	SANTA ANA, SANTA MARIA DEL RIN.	0	0
2005/11/10	SAN MATEO	1	0
2005/11/23	CAZUCA, CAZUCA IND	0	0
2006/1/10	ALMACEN ALCALDIA	0	0
2006/3/8	TABACAL	0	0
2006/3/26	FLORIDA	0	0
2006/4/6	CENTRO	0	0
2006/4/12	SAN MATEO	0	0
2006/4/13	CIUDADELA SUCRE	0	0

Table S2-3-13 Landslide Records in Soacha Urban Area

Date	Barrio Name	No. of Wounded	No. of Dead
1998/5/6	Divino Nino	0	0
1998/7/19	S. Mateo	0	0
1998/9/15	S. Mateo	0	0
1998/12/17	Km 12 via mesitas	0	0
1999/3/17	La capilla	0	0
1999/5/17	La florida	0	0
1999/6/1	La capilla	0	0
1999/11/1		0	0
2000/2/10	Villa Esperanza Barreno	0	0
2000/2/29	Divino nino	0	0
2000/11/1	LOMA LINDA	0	0
2000/11/8	LOMA LINDA, LA CAPILLA	0	0
2000/11/9	LOMA LINDA	0	0
2002/4/27	OSAS SAN MATEO	0	0
2002/4/30	LA CAPILLA	0	0
2002/5/30	VILLA ESPERANZA	0	0
2002/6/3	LA CAPILLA	0	0
2002/6/2	EL ARROYO	0	0
2002/6/6	LA CAPILLA, TERRANIOVA, DIVINO NINO, LA CAPILLA, VILLA SANDRA	0	0
2002/6/7	DIVINO NINO	0	0
2003/1/19	2003	0	0
2003/4/15	2003	0	0
2005/10/31	CAZUCA	0	0
2005/11/1	CIUDADELA SUCRE	0	0
2005/11/11	V. MERCEDES	0	0
2005/11/24	CAZUCA	0	0
2005/11/28	V . SANDRA	0	0
2005/12/20	V. SANDRA	0	0
2006/1/9	CAPILLA	0	0
2006/6/24	EL PROGRESO	0	0
2006/4/10	EL PROGRESO	0	0
2006/5/5	LOMA LINDA, SANTA ANA, Divino nino	0	0
2006/5/21	SANTA MARIA	0	0
2006/6/10	V. ESPERANZA	0	0
2006/6/11	OLIVARES, DUCALES	0	0
2006/6/15	EL BARRENO	0	0
2006/6/24	LOS ROBLES	0	0

Table S2-3-14 Selected Landslide Events for Analysis in Soacha

Date	Barrio Name	No. of Wounded	No. of Dead
2000/11/8	LOMA LINDA, LA CAPILLA	0	0
2002/6/6	LA CAPILLA, TERRANIOVA, DIVINO NINO, LA CAPILLA, VILLA SANDRA	0	0
2006/5/5	LOMA LINDA, SANTA ANA, DIVINO NINO	0	0
2006/6/11	OLIVARES, DUCALES	0	0

3.2.2 Analysis for Relation between Hydrological Conditions and Selected Disaster Events

(1) Hydrological Stations for Analysis

The relation between hydrological conditions, mainly rainfall, and disasters in Soacha is analyzed using collected daily rainfall data, water level data and disaster records.

The stations using the rainfall data for the analyses are Las Huertas station (EAAB), Bosa Barreno No.2 station (EAAB), Sierra Morena station (DPAE), and San Jorge station (IDEAM). And the stations using the water level data are Las Huertas station (EAAB) and Independencia station (DPAE). The selected stations for the analyses are shown in Figure S2-3-31.

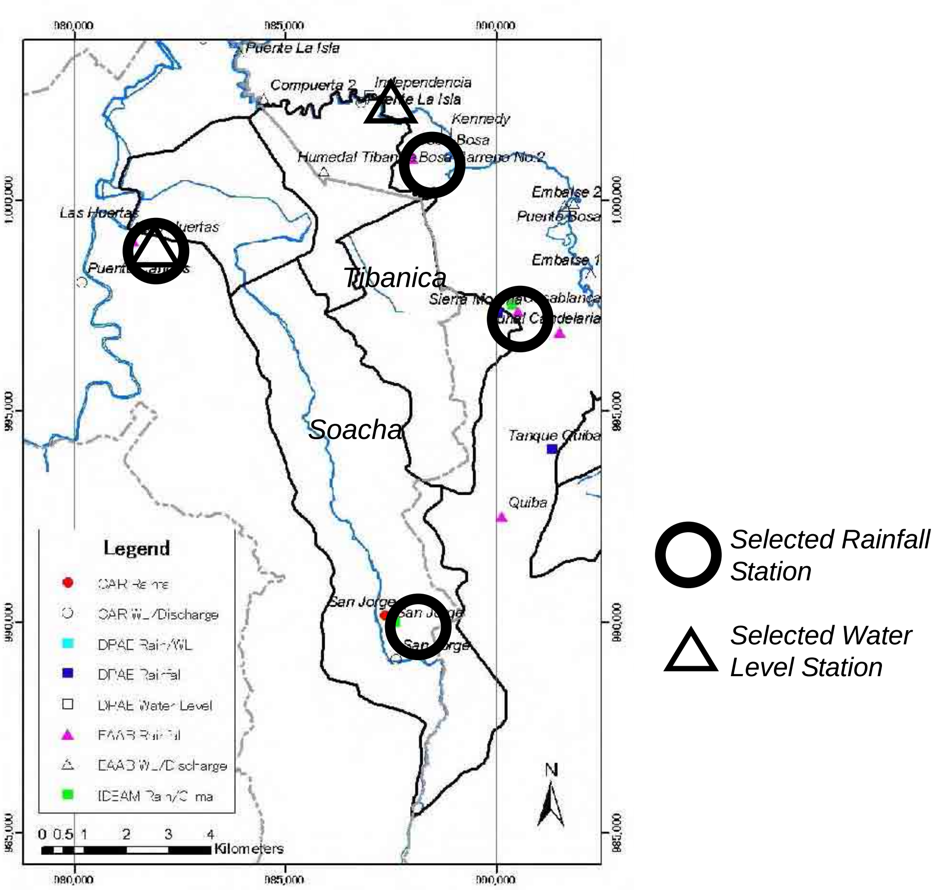


Figure S2-3-31 Selected Stations for Analyses

(2) Analysis for Inundation

Figure S2-3-32 and Table S2-3-15 show the daily rainfall amount of selected four (4) stations in all the days when inundation occurred (101 days, 150 inundation events) from May 1996 to April of 2006. And Table S2-3-16 show the water level in Las Huertas (EAAB) and Independencia (DPAE) stations when inundation occurred in Soacha. More than 50% of inundation events occurred when daily rainfall amount was less than 10mm and difference of water level for average value was lower than 0.2 m.

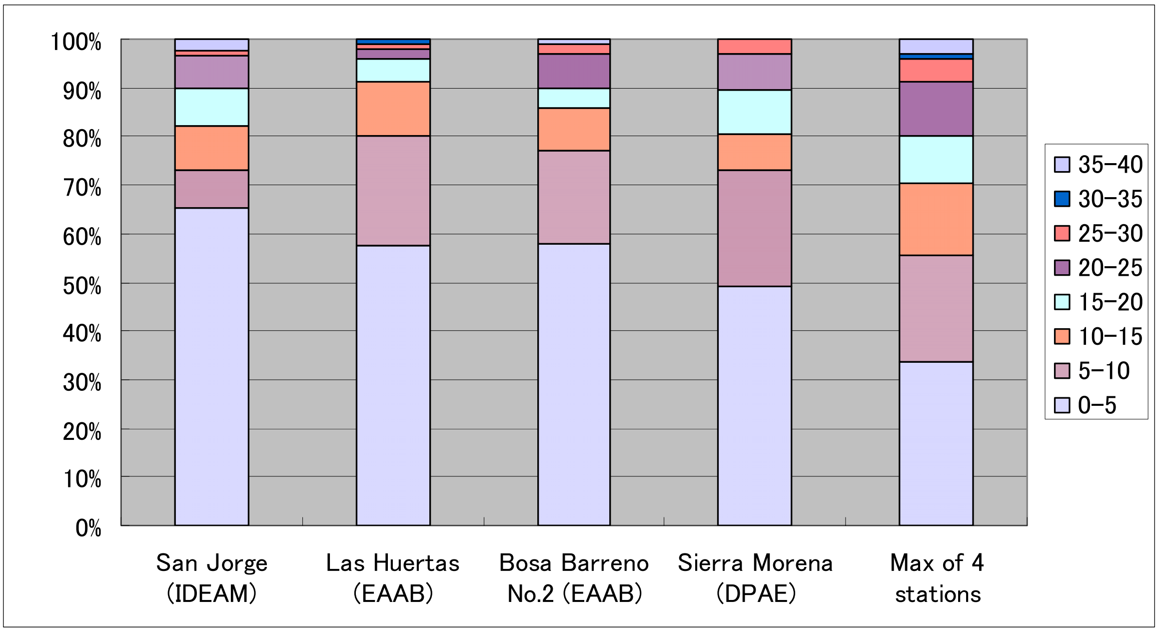


Figure S2-3-32 Relation between Inundation Events and Daily Rainfall

Table S2-3-15 Summary of Relation between Inundation Events and Daily Rainfall

Daily Rainfall (mm)	San Jorge (IDEAM)	Las Huertas (EAAB)	Bosa Barreno No.2 (EAAB)	Sierra Morena (DPAE)	Max of 4 stations
0-5	65%	57%	58%	49%	34%
5-10	8%	23%	19%	24%	22%
10-15	9%	11%	9%	7%	15%
15-20	8%	5%	4%	9%	10%
20-25	7%	2%	7%	7%	11%
25-30	1%	1%	2%	3%	5%
30-35	0%	1%	0%	0%	1%
35-40	2%	0%	1%	0%	3%

Table S2-3-16 Differences between Average Water Level and Water Levels in Inundations

Unit of differences: m

WL Station	<-0.4	<-0.2	<0	<0.2	<0.4	<0.6	<0.8	<1.0	<1.2	<1.4	<1.6
Las Huertas (EAAB)	1%	9%	30%	54%	71%	85%	91%	96%	100%	100%	100%
Independencia (DPAE)	3%	18%	32%	53%	62%	76%	91%	91%	94%	97%	100%

Soacha urban area is divided into six (6) comunas as shown in Figure S2-3-33. The relation between inundation events in each comuna and daily rainfall in four (4) stations are shown in Figure S2-3-34.

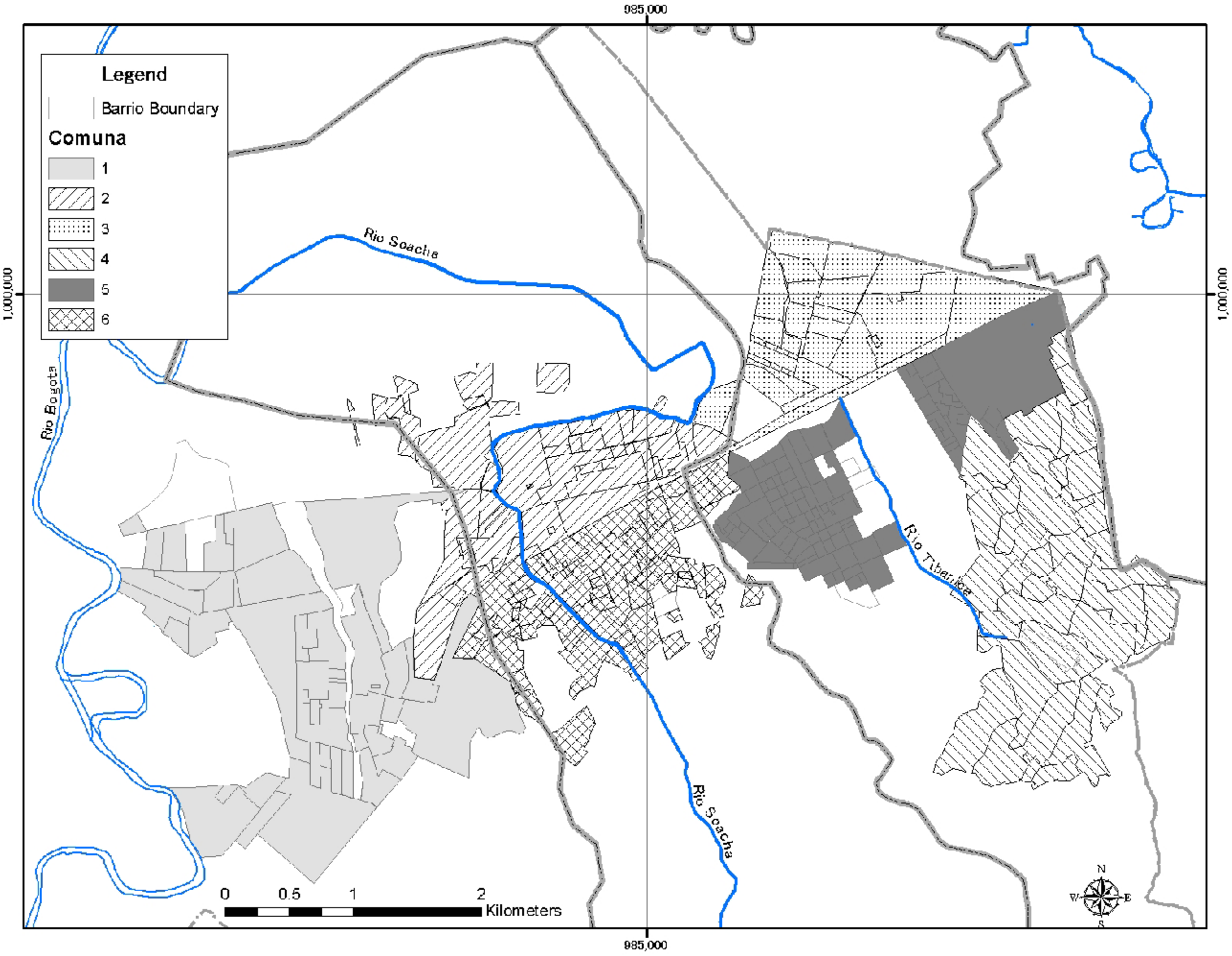
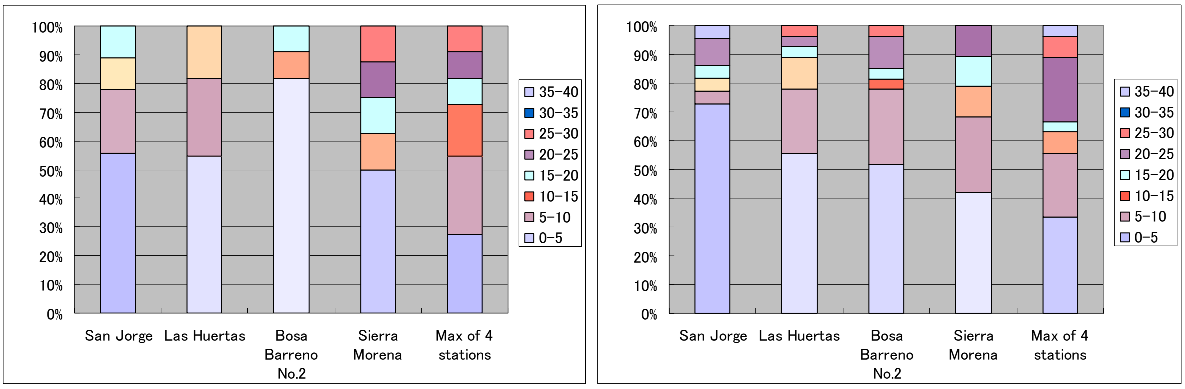


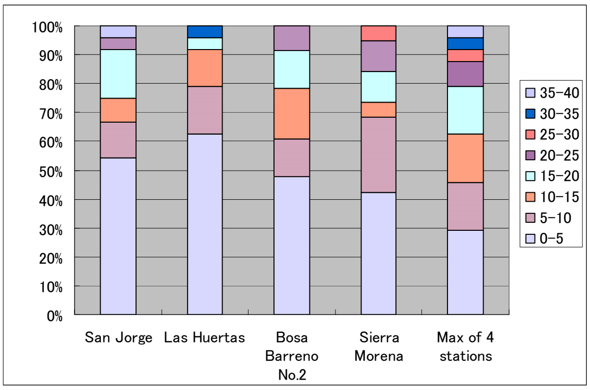
Figure S2-3-33 Comuna in Soacha



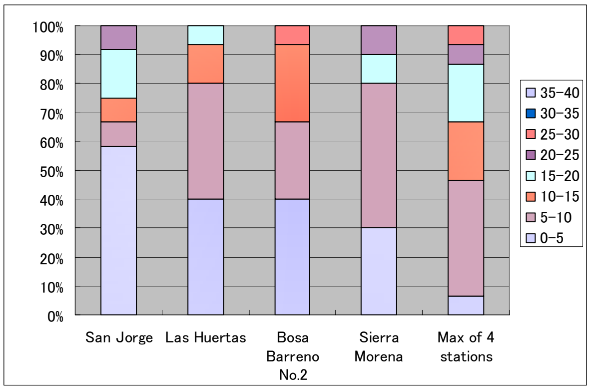
Comuna 1

Comuna 2

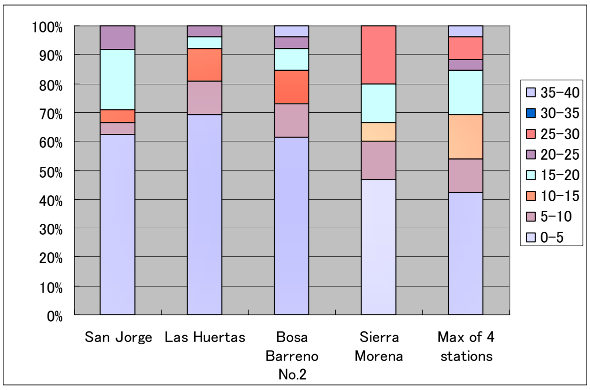
Figure S2-3-34 Daily Rainfall in Inundation Events in Each Comuna (1/2)



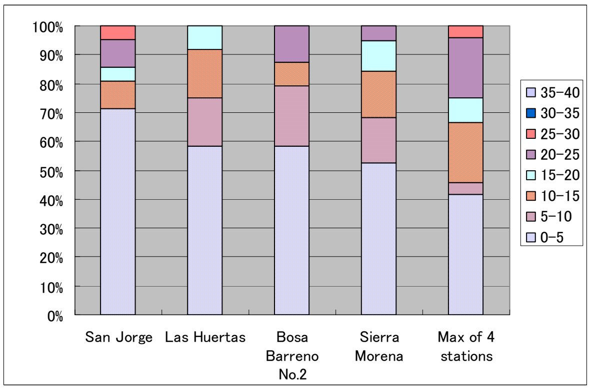
Comuna 3



Comuna 4



Comuna 5



Comuna 6

Figure S2-3-34 Daily Rainfall in Inundation Events in Each Comuna (2/2)

From the above figures, the strong correlation of comuna/area and rainfall of each station cannot be found. Therefore, investigation of threshold value in Soacha is conducted using the maximum among the selected four (4) stations.

Table S2-3-17 summarizes the relation between past inundation events and maximum value among the selected four (4) stations.

Table S2-3-17 Summary of Relation between Inundation Events and Daily Rainfall

Area/Station	No. of Days Inundation Occurred from 1996 to 2006	Daily Rainfall (mm)							
		< 5	< 10	< 15	< 20	< 25	< 30	< 35	< 40
Soacha Urban Area (Las Huertas (EAAB), Bosa Barreno No.2 (EAAB), Sierra Morena (DPAE) & San Jorge (IDEAM))	101 100%	34 34%	56 55%	71 70%	81 80%	92 91%	97 96%	98 97%	101 100 %

The thresholds for inundation in Soacha, which is investigated using the above results, are shown in Table S2-3-18. Values to have converted frequency of rainfall into the number of the days during a year (365 days) in each station are shown in Table S2-3-19.

Table S2-3-18 Thresholds for Inundation in Soacha

Criteria / Area/Station	Occurrence probability More than 70%	Occurrence probability Less than 50%	Occurrence probability Less than 30%
Soacha Urban Area Las Huertas (EAAB), Bosa Barreno No.2 (EAAB) & Sierra Morena (DPAE)	5 mm	10 mm	15 mm
Probable Annual Frequency (days)	81	40	20

Table S2-3-19 Average Number of Days of Daily Rainfall Amount per Year

Unit: Number of days

Station	Daily Rainfall (mm)								
	0≦	5≦	10≦	15≦	20≦	25≦	30≦	35≦	40≦
San Jorge (IDEAM)	365	52	26	12	6	3	1	1	0
Las Huertas (EAAB)	365	33	13	6	3	1	1	0	0
Bosa Barreno No.2 (EAAB)	365	38	16	8	4	2	1	0	0
Sierra Morena (DPAE)[1]	365	37	16	8	3	1	0	0	0
Max of 4 stations	365	81	40	20	10	4	2	1	0

Remarks: Data period is 2000 – 2006 except Sierra Morena (2000-2006)

(3) Analyses for Landslide

The same analysis as landslide in Bogota is conducted for selected landslide events as shown in Table S2-3-14. Rainfall amount using the analysis is the maximum value of three (3) stations of Las Huertas (EAAB), Bosa Barreno No.2 (EAAB) and Sierra Morena (DPAE).

Figure S2-3-35 shows the daily rainfall, 3 days rainfall and accumulative rainfall in the day when a number of landslides occurred on the same date. Each rainfall value is the maximum value of the three stations described above.

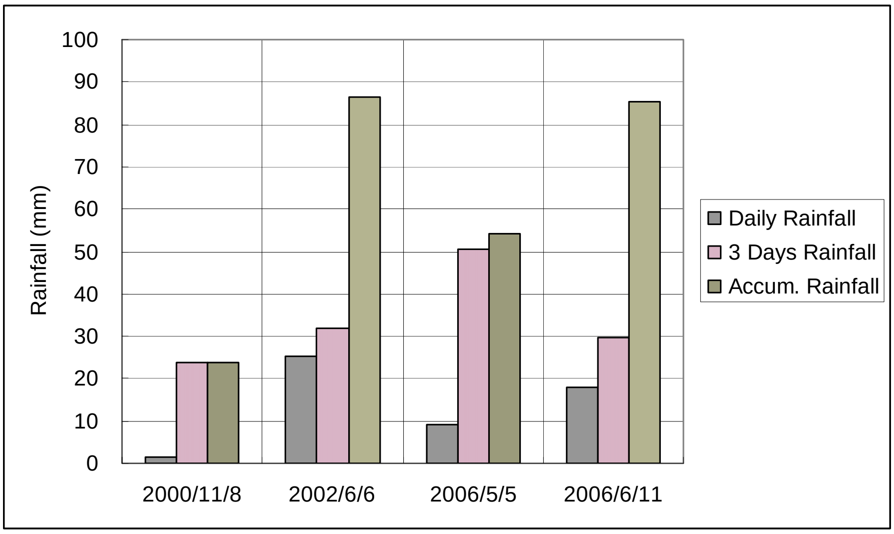


Figure S2-3-35 Daily, 3 days and Accumulative Rainfall when Landslides Occurred

Figure S2-3-36 and Figure S2-3-37 show the correlation of three (3) days rainfall and accumulative rainfall when landslide occurred in Soacha, and the distribution in the period of 1996-2006 of the maximum value of the three (3) stations, respectively.

The relation between landslide events and three (3) days or accumulative rainfall is summarized in Table S2-3-10. In the table, the percentage of “Landslide” rows is the rate of the number of days with the designated rainfall amount as landslide occurrence, and the percentage of “Average” rows is the rate of the number of days with the designated rainfall amount in the period of 1996-2006.

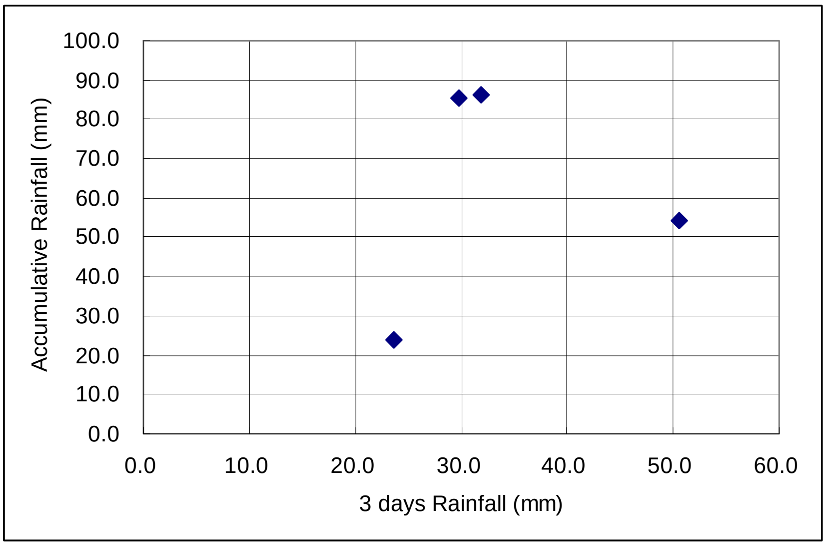


Figure S2-3-36 Correlation of 3 days and Accumulative Rainfall when Landslide Occurred

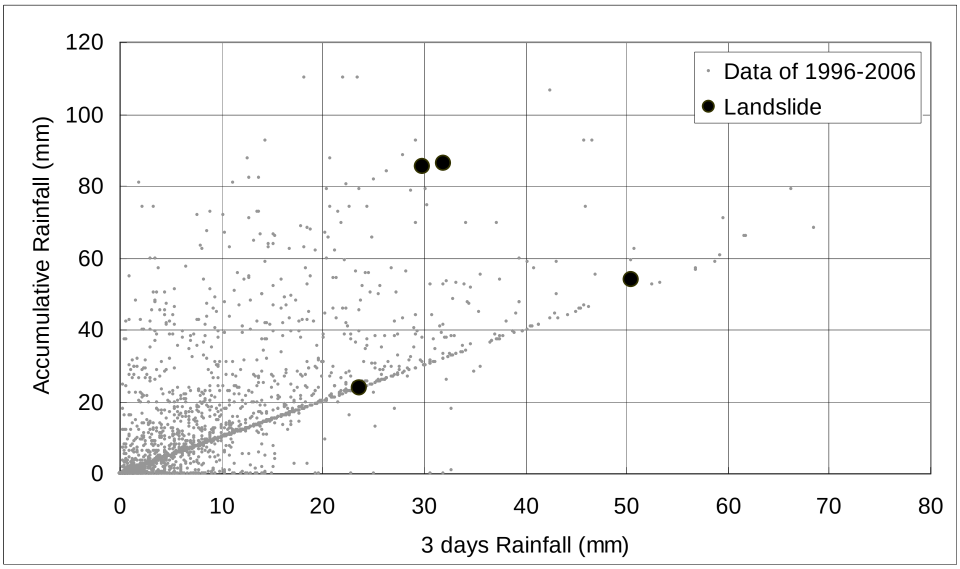


Figure S2-3-37 Distribution of 3 days Rainfall and Accumulative Rainfall

Table S2-3-20 Summary of Relation between Landslide Events and Rainfall

Area	Rainfall		Rainfall (mm)								
			<10	<20	<30	<40	<50	<60	<70	<80	<90
Soacha Urban Area	3 days Rainfall	Occurrence of Landslide	0%	0%	50%	75%	75%	100%	100%	100%	100%
		Average in 1996-2006	78%	92%	97%	99%	100%	100%	100%	100%	100%
	Accum. Rainfall	Occurrence of Landslide	0%	0%	25%	25%	25%	50%	50%	50%	100%
		Average in 1996-2006	71%	84%	91%	94%	97%	98%	99%	99%	100%

By the use of the above results, the combination of three (3) days rainfall and accumulative rainfall as an example of threshold is examined in the same way as the analysis for landslide in Bogota. The result is shown in Table S2-3-21. This is nothing but the example. More detailed and careful investigation and accumulation of exact disaster records are vitally important and necessary in order to determine the thresholds.

Table S2-3-21 Example of Threshold for General Warning of Landslide

Criteria / Area/Station	Occurrence probability More than 70%	Occurrence probability Less than 50%	Occurrence probability Less than 30%
Soacha Urban Area Las Huertas (EAAB), Bosa Barreno No.2 (EAAB) & Sierra Morena (DPAE)	3days Rain > 20mm & Accum. Rain > 50 mm	3days Rain > 30mm & Accum. Rain > 50 mm	3days Rain > 40mm & Accum. Rain > 50 mm
Probable Annual Frequency (days)	7	4	2

SUPPORTING REPORT

S3

AERIAL PHOTO INTERPRETATION AND CREEK CONDITIONS

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List of Photos

Photo S3-2-1 Chiguaza Creek (confluence point of Qda. Nutria) S3-2-12
Photo S3-2-2 Yomasa Creek (near Carrera Oriente).. S3-2-17

CHAPTER　1 AERIAL PHOTO INTERPRETATION

1.1 Aerial Photos Used

Aerial photographs in and around the Study Area were used in the Study for topographical investigation, land use check, geomorphologic investigation and presentation on community hazard map.

IGAC's 1997 and 1998 Aerial photos which were obtained at the time of previous JICA Study were used for the analysis of geomorphologic condition in the flood Study Area.

In addition, in this Study, DPAE purchased for the JICA Study' purpose IGAC's 2004 aerial photos and the Study Team borrowed them during the Study period and returned them to DPAE by the end of 2007. The 2004 photos were used mainly for the landslide study in altos de la Estancia and Soacha area.

The Cartographic section of Soacha Municipality provided the Study Team with 2005 aerial photo in color for the JICA study purpose. The color photos were prepared by Geovial Ltda in 2005 under the contract with Soacha Municipality. The Study Team made use of the color photos mainly for community hazard map in the Soacha river and the confirmation of the river conditions in Soacha.

1.2 Topography Map

The Study Team also collected the following IGAC topography maps.

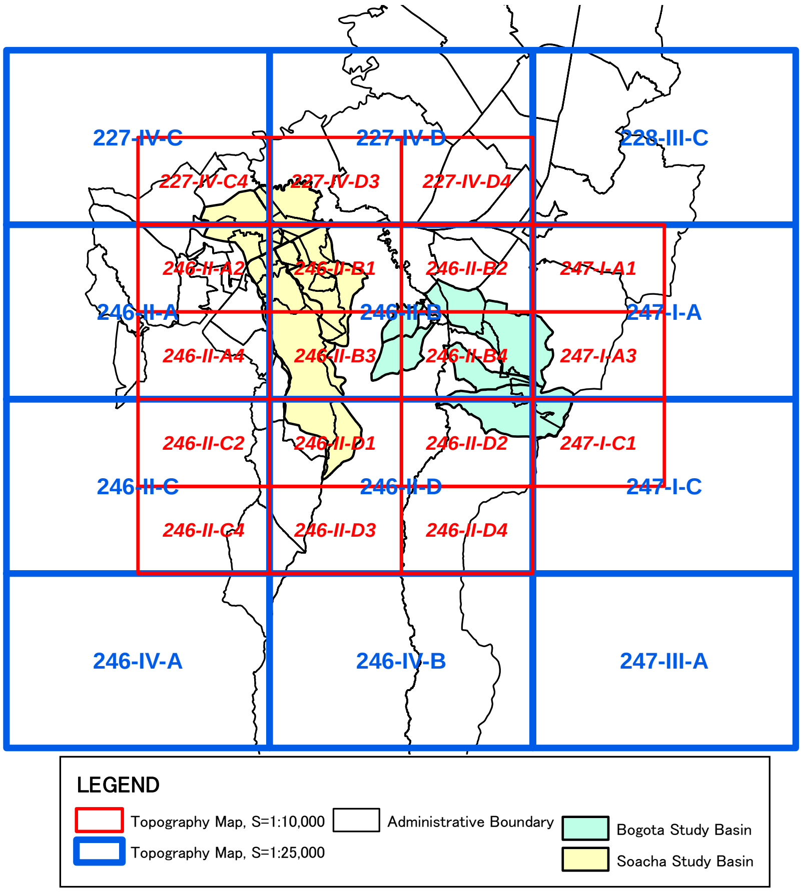

Figure S3-1-1 Index Map of obtained Topography Maps

1.3 Interpretation of Flood Study Area

1.3.1 Methodology

Using 1997 and 1998 IGAC aerial photos, the watershed conditions in the Study Area were interpreted. The purpose of the interpretation is to identify the past slope failure area related with debris flow occurrence.

There are three (3) types of area to be identified as follows,

a. Comparatively Recent slope failure
b. Comparatively old slope failure
c. Mass movement

The characteristics of the comparatively recent slope failure are thin vegetation, slope failure topographic features. This type of area is very important index for the assumption of the debris flow occurrence in the near future because they are regarded as unstable and frequently collapsed.

The characteristics of the comparatively old slope failure are slope topographic features but thick vegetation. This type of area has past experience of slope failure, but in the long time or less frequent slope failure resulting into the thick vegetation. In the consideration of debris flow occurrence, this area is not included in the analysis.

Mass movement area is topographically regarded as large scale movement area such as landslide. It is just as reference information for the debris flow occurrence analysis.

1.3.2 Results

(1) Overall Tendency

Figure 3-1-2 shows the absolute area of identified old and new slope failures in the Study Area. The Chiguaza and the Yomasa creek catchment have larger area of old and new slope failures compared with the other creeks. The Santa Librada creek has the smallest area of old and new slope failure. This is because the Santa Librada creek has smaller size of upper part catchment. Regarding only new slope failure area, the Yomasa has the largest area and the Chiguaza has the second.

Figure 3-1-3 shows the percentage of identified old and new slope failures to each catchment area of Bogota. The Chiguaza and the Estrella-Trompeta creek have larger percentage of old and new slope failures to the catchment area.

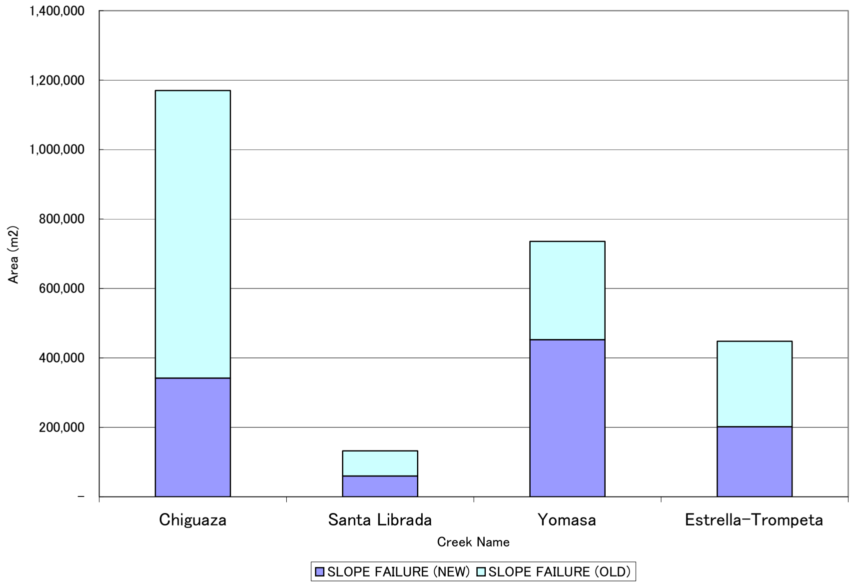

Figure 3-1-2 Identified Area in Each Creek Basin of Bogota

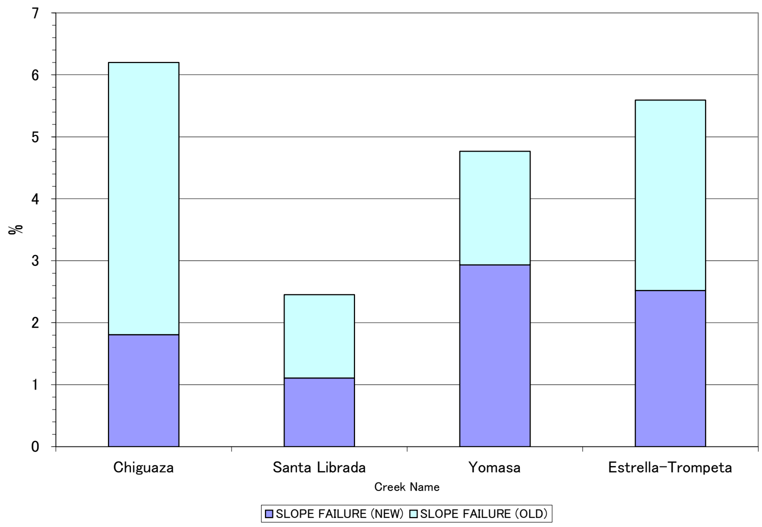

Figure 3-1-3 Percentage of Identified Area to Each Creek Basin of Bogota

Figure 3-1-4 shows the absolute area of identified old and new slope failures in the Soacha. Since the catchment area is larger than the creeks in Bogota, the area of old and new slope failures is almost same or larger than the Chiguaza and Yomasa.

Figure 3-1-5 shows the percentage of identified old and new slope failures to each catchment area of Soacha. The both rivers have less than 1 % of the catchment area.

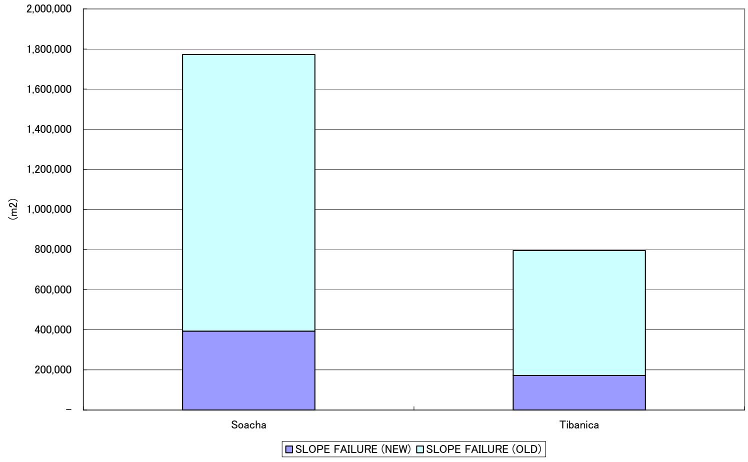

Figure 3-1-4 Identified Area in River Basin of Soacha

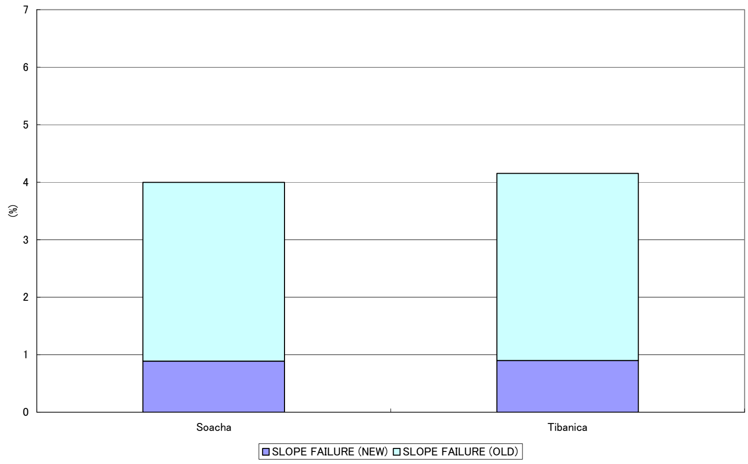

Figure 3-1-5 Percentage of Identified Area to Each River Basin of Soacha

Figure 3-1-6 shows the location of new and old slope failure in the target creeks of Bogota. The most of the new slope failure are located in the upper part of the Chiguaza catchment, the Yomasa catchment and the Trompeta catchment. The upper part of the Chiguaza catchment is composed of Zuque creek, Silverio creek, Nueva Dehli creek and Verejones creek, etc.

In Bogota target creeks, the Yomasa upstream area has larger area of new slope failures. The upstream area is the upstream reach of Villaviciencia street. It is expected that sediment deposit on the creek of the Yomasa upsteam reach is outstanding due to the slope failure.

Figure 3-1-7 shows the location of new and old slope failure in the target creeks of Soacha. In the Soacha and Tibanica river basins, the size of slope failure is small compared with those of the target creeks in Bogota. Since there is a variation regarding when each slope failure took place, it is expected that in the Soacha and Tibanica rivers, the sediment deposition on the river bed should be quite small.

Figure 3-1-8 shows the geological map of the Study Area. It can be said that the new and old slope failure are distributed on the Guadalupe layer (Ksg “Geological Age Cretaceous”). The abbreviations of geology such as Ksg are explained in Table S3-1-1.

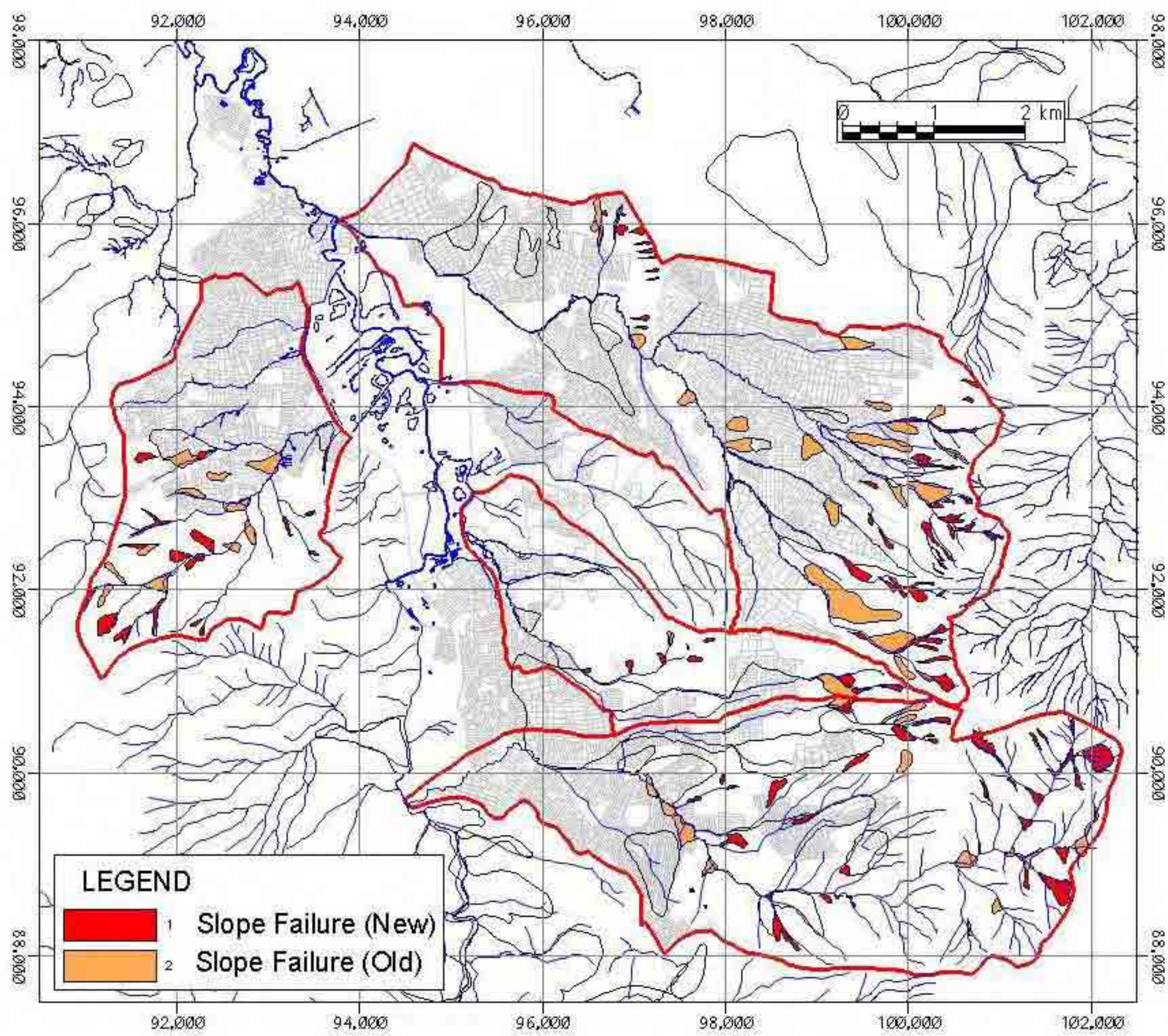

Figure 3-1-6 Location of New and Old slope failure in Bogota

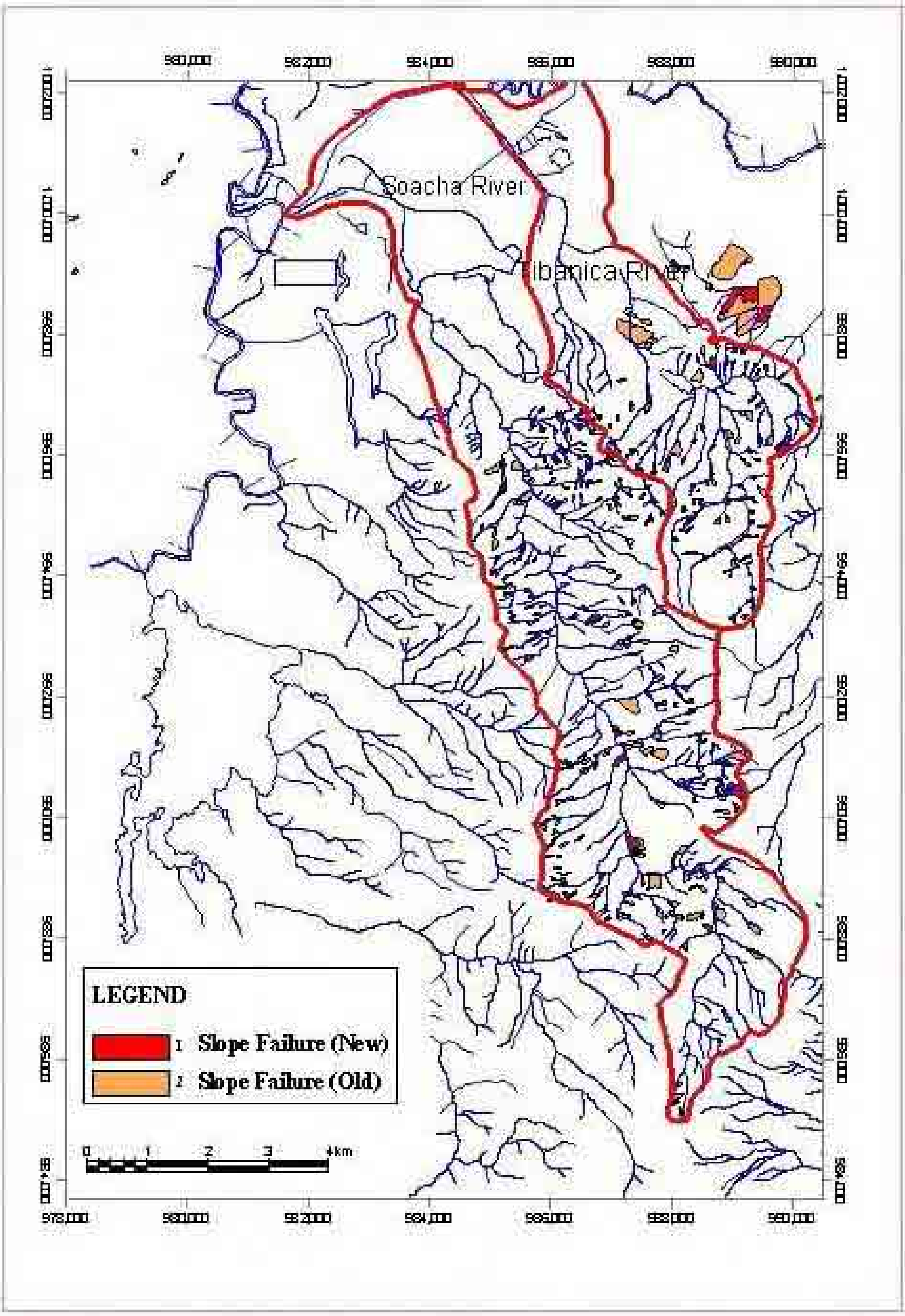

Figure 3-1-7 Location of New and Old slope failure in Soacha

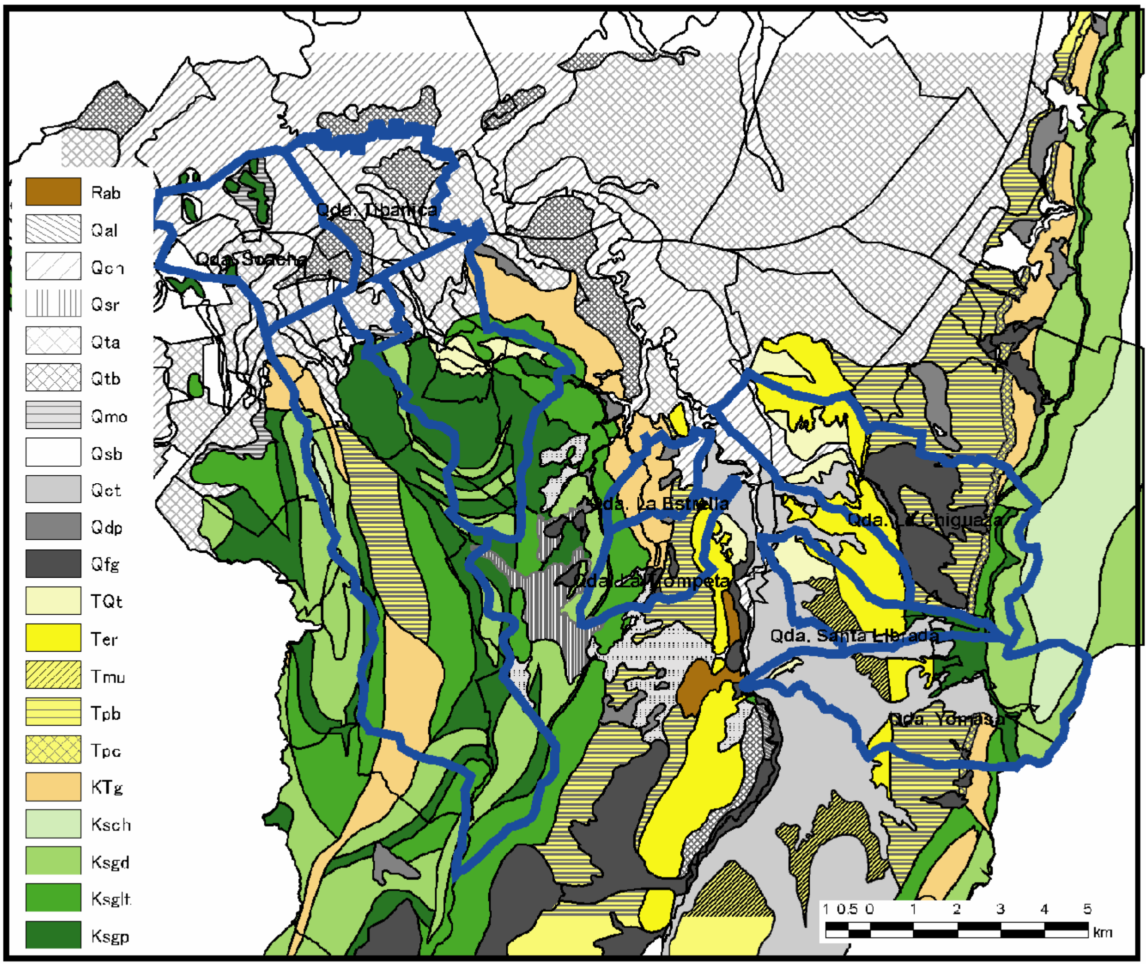

Figure 3-1-8 Geological map

Table S3-1-1 Geological Stratigraphy and Geology Distribution

GEOLOGICAL AGE		GEOLOGICAL UNIT	LEGEND	LITHOLOGICAL DESCRIPTION
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.
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