CHAPTER 6 FLOOD

6.1 Creeks in Study Area

6.1.1 Tunjuelo River

All target creek catchments of Bogota are located in the Tunjuelo river basin. The Tunjuelo River, which is a tributary of the Bogota River, is located in the southern part of the Metropolitan District of Bogota. The target creeks are Chiguaza creek, Santa Librada creek, Yomasa creek and La Estrella Trompeta creek. (Figure 6-1).

The catchment area of the Tunjuelo River is 388.13 km^2, whose the highest point is 3,850 m and the lowest point is 2,536 m at the confluence to the Bogota river. The basin can be divided into the upper part, middle and lower part (Figure 6-2).

In the upper catchment there are the Chisaca river and the Curubital river. There is the La Regadera Dam at the confluence of those rivers. In the middle catchment, the Tunjuelo river is going down collecting other some tributaries to the Cantarrana Dam. The upper and middle part has the total area of 254 km^2 at Cantarrana Dam site.

The lower part can be defined for the reach from the Cantarrana to the Bogota river confluence. The lower catchment has eight (8) main tributaries such as Yomasa, Santa Librada, La Fiscala, Chiguaza (the right bank tributaries) and Botello, Trompeta, La Estrella and Limas (the left bank tributaries).

The annual rainfall in the upper part is 1,122 mm at Los Tunjos station and 1,002 mm at La Regadera station. The monthly rainfall distribution has mono-mode, in which there is a dry season between December and March whereas between April and November is wet season.

The annual rainfall in the lower part is less than that of the upper part. At Dona Juana station the annual rainfall is 644 mm having bi-mode, in which there are wet seasons between March and May, and October and November whereas between December – February and June – September are dry seasons.

Cantarrana Dam

The Cantarrana Dam is located at the most downstream point of the middle part of the basin. The dam (flood control purpose, return period 100 years and its storage volume is about 2,500,000 m^3) has been constructed since last year and April 2007 it was announced that the dam is completed by EAAB.

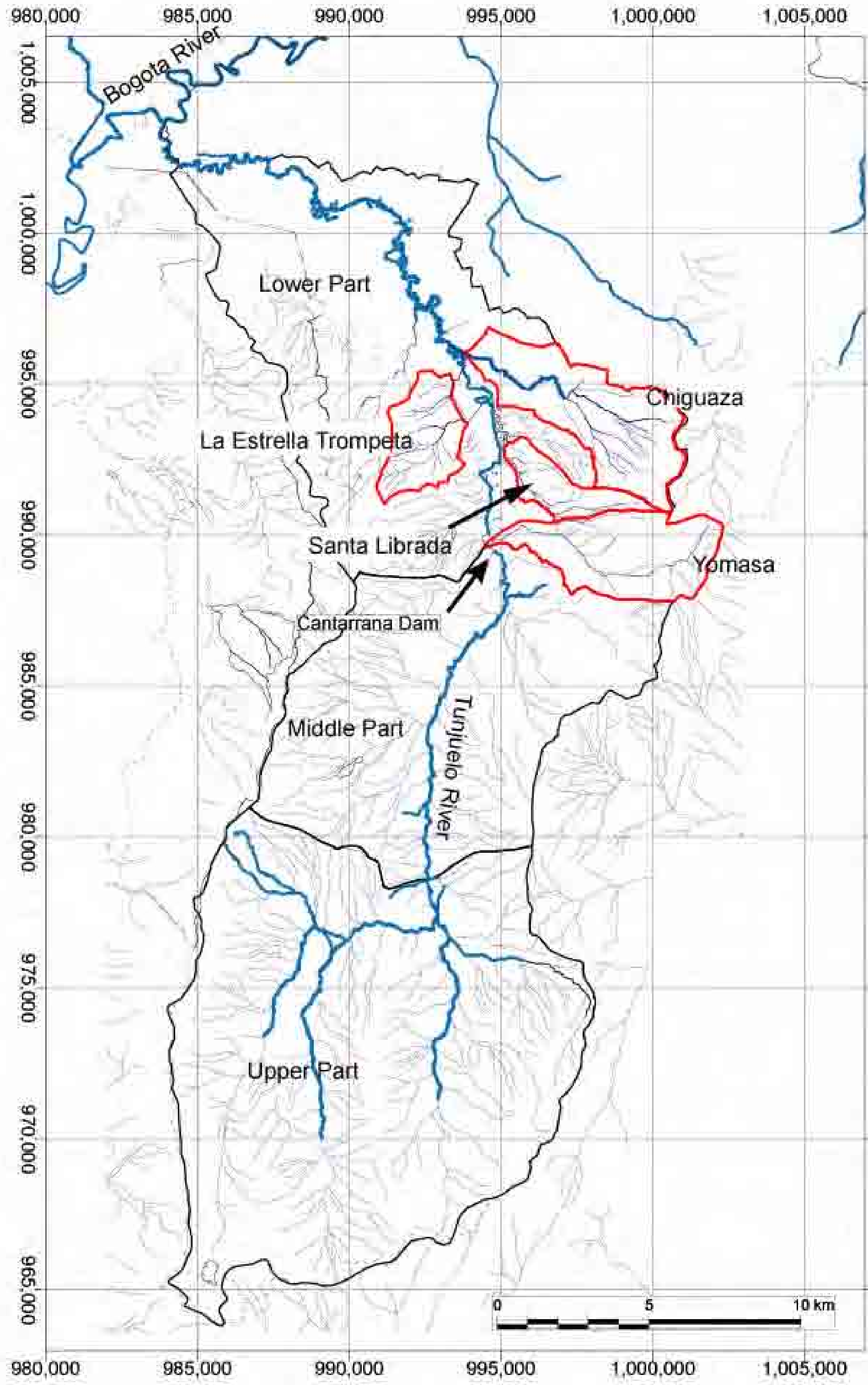


Figure 6-1 Catchment of Tunjuelo River

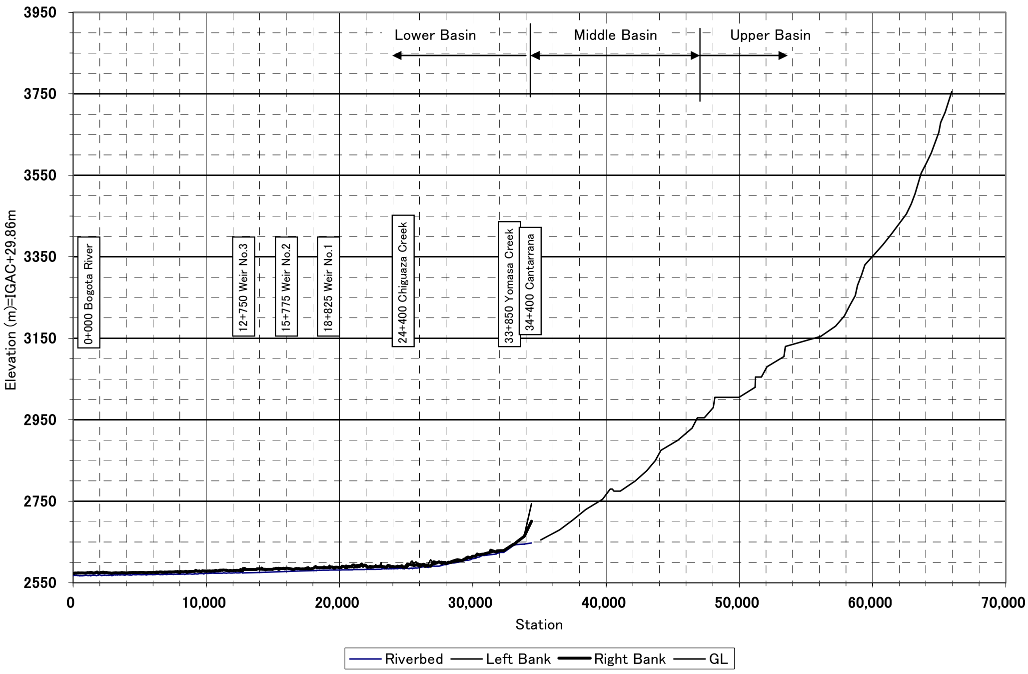


Figure 6-2 Longitudinal Profile of Tunjuelo River

Table 6-11 Localities in Each Stream Basin of the Study Area

River System	Stream Basin in the Study Area	Catchment Area	Locality
Tunjuelo River	Chiguaza	18.9 km^2	Usme, San Cristobal, Rafael Uribe Uribe, Tunjuelito
	Santa Librada	5.5 km^2	Usme
	Yomasa	15.4 km^2	Usme
	La Estrella	3.0 km^2	Ciudad Bolivar
	Trompeta(El Infierno)	5.3 km^2	Ciudad Bolivar

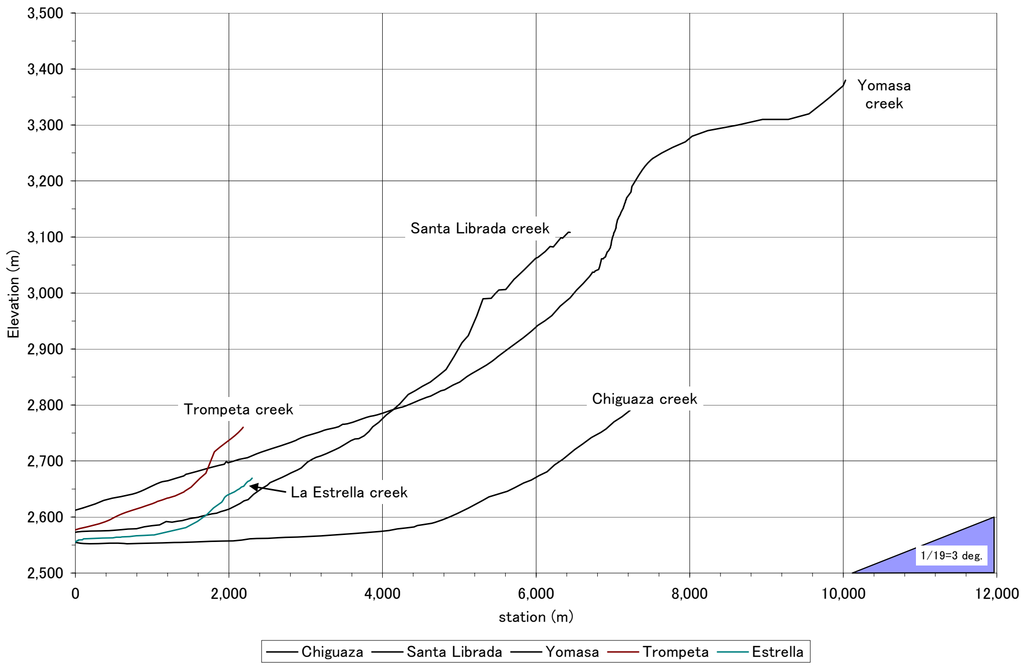


Figure 6-3 Longitudinal Profiles of Target Creeks in Bogota

6.1.2 Chiguaza Creek

There is a significant point in the catchment called "Los Puentes", which is a kind of narrow, neck point resulted from the break of fault. The Los Puentes upstream area can be regarded as an alluvial fan which has several tributaries of the Chiguaza. The main tributaries are Qda. Las Mercedes, Qda. Melo, Qda. Chorro Colorado, Qda. Seca, Qda. Nutria and Qda. Chiguaza as a tributary. These tributaries are joining until the Los Puentes to form the main Chiguaza stream toward to the Tunjuelo river.

In the Los Puentes upstream area, the creeks have been formed by degradation process, whose channels are confined by the positions of large rocks and bed rocks. The creek bed slope is steeper than 1/17.

In the Los Puentes downstream area, the section has milder slope like 1/50 to 1/500. This section has been improved (canalized) by EAAB. The are near the Tunjuelo river confluence used to be a part of floodplain of the Tunjuelo river, meandering creek courses, while the creek courses have been straightened with revetment.

The section between the Tunjuelo river confluence and Ave. Caracas has been improved by EAAB as of December 2007. Although the Study Team is requesting EAAB the basic creek design information in order to evaluate the channel capacity in the future, however, it is not confirmed yet.

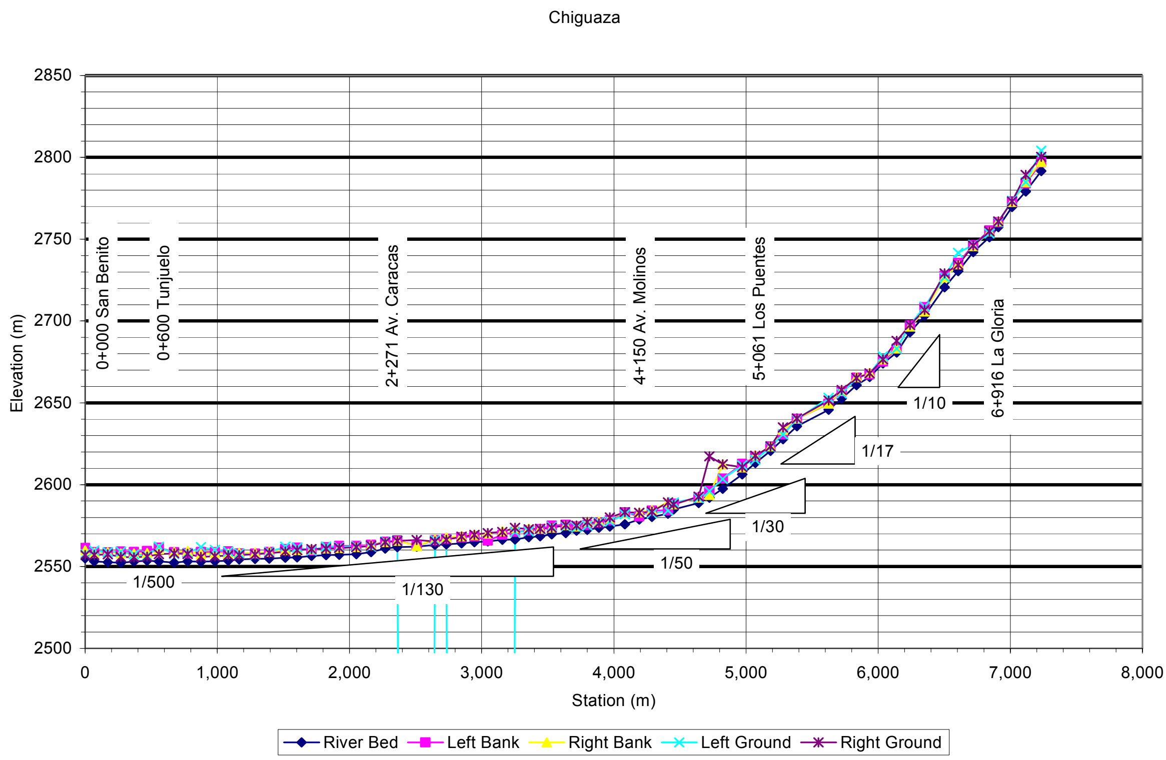


Figure 6- 4 Longitudinal Profile of Chiguaza Creek

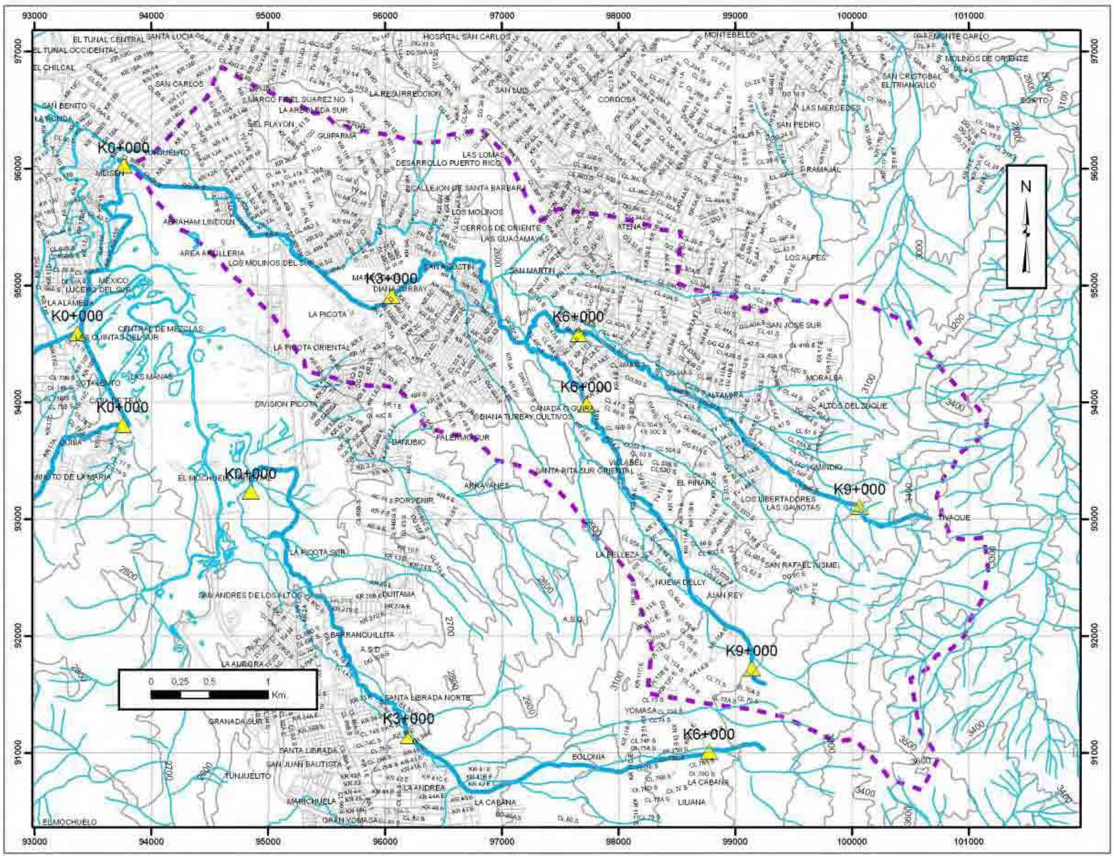


Figure 6- 5 Catchment of Subjective Creek (Chiguaza)

6.1.3 Santa Librada Creek

The Santa Librada creek is joining the Tunjuelo river inside the quarry site. From the Tunjuelo river confluence to 0+800 (a culvert crossing Ave. Caracas), the creek is located inside the quarry. From 1+330 (Calle 68 A Sur) to 3+800, the creek is confined by residential area and the creek bed slope is 1/12. In the residential area there are a lot of bridges crossing the Santa Librada creek, however, their capacity is quite small.

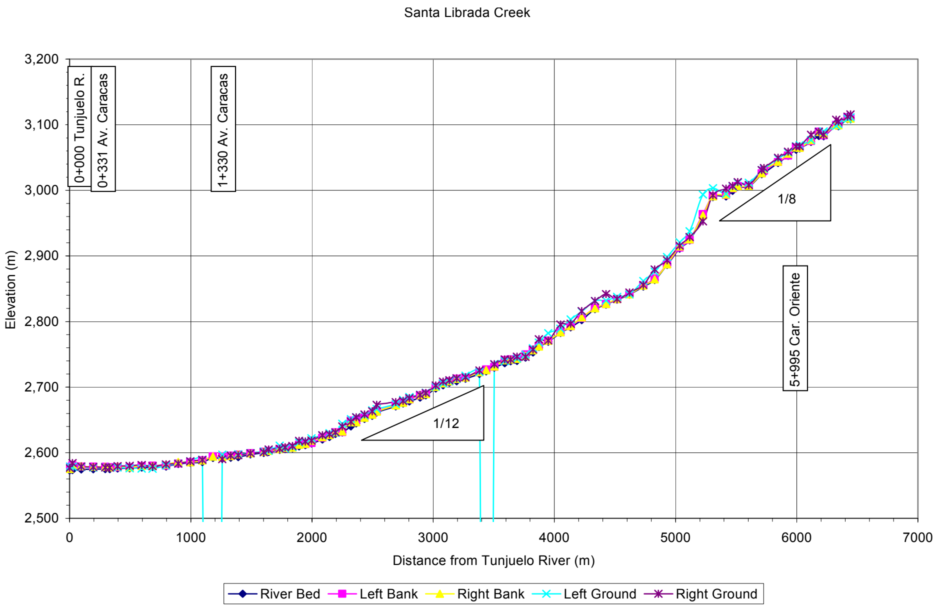


Figure 6- 6　Longitudinal Profile of Santa Librada Creek

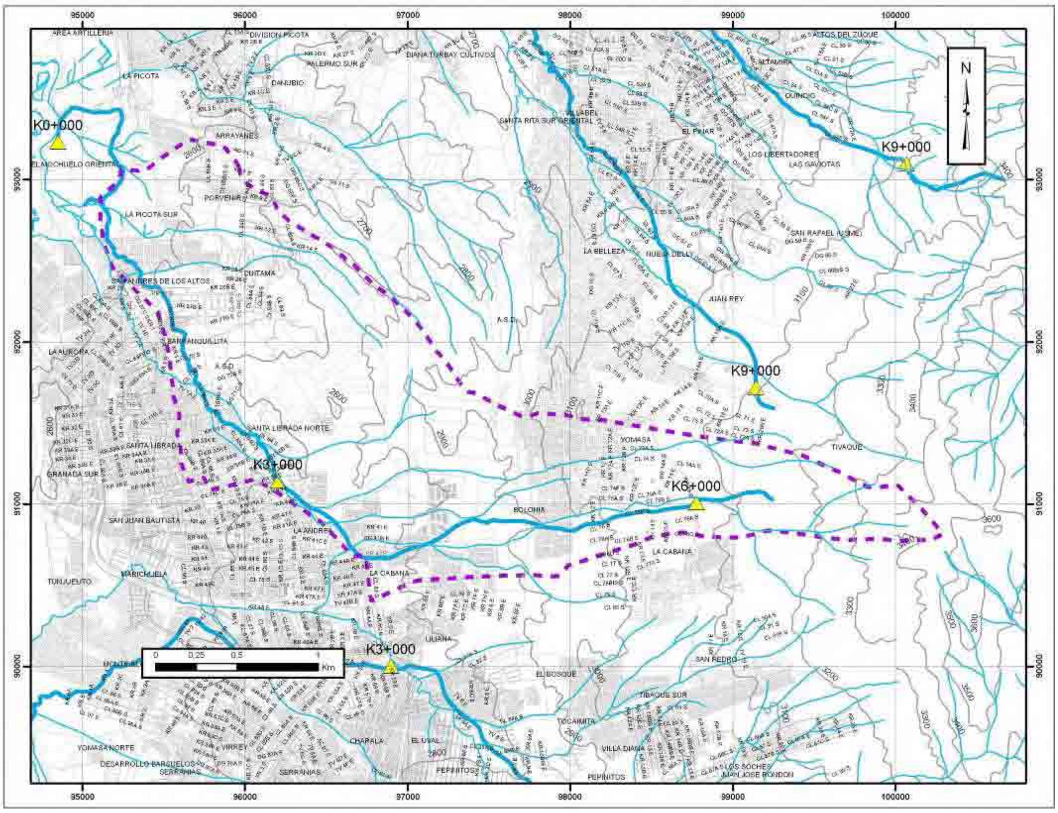


Figure 6- 7　Catchment of Subjective Creek (Santa Librada)

6.1.4　Yomasa Creek

The Yomasa creek is located at most upstream of the Tunjuelo River system among the target creeks in the Study Area. The confluence point to the Tunjuelo River is just downstream of the Cantaranna Dam site. Figure 6-8 is the longitudinal profile of the Yomasa main course. As it is shown in the figure, from the Tunjuelo river confluence to 4+000, the creek bed slope is constant, 1/25. Figure 6-3 is also showing the longitudinal profile of the Yomasa creek. As shown in this figure, in the upstream area there is a comparatively flat reach, whose downstream end is confined by a narrow neck point like as the Chiguaza.

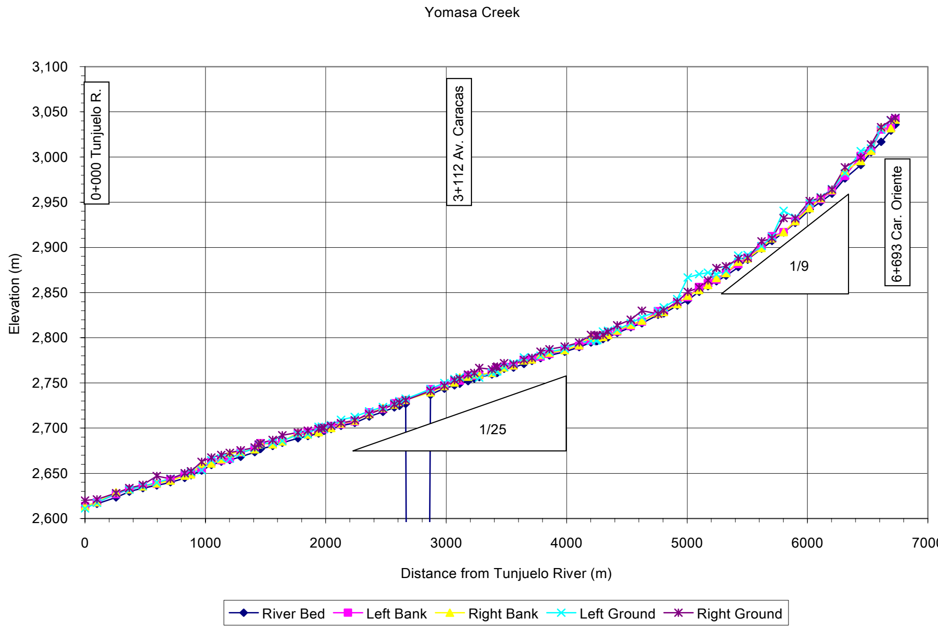


Figure 6-8 Longitudinal Profile of Yomasa Creek

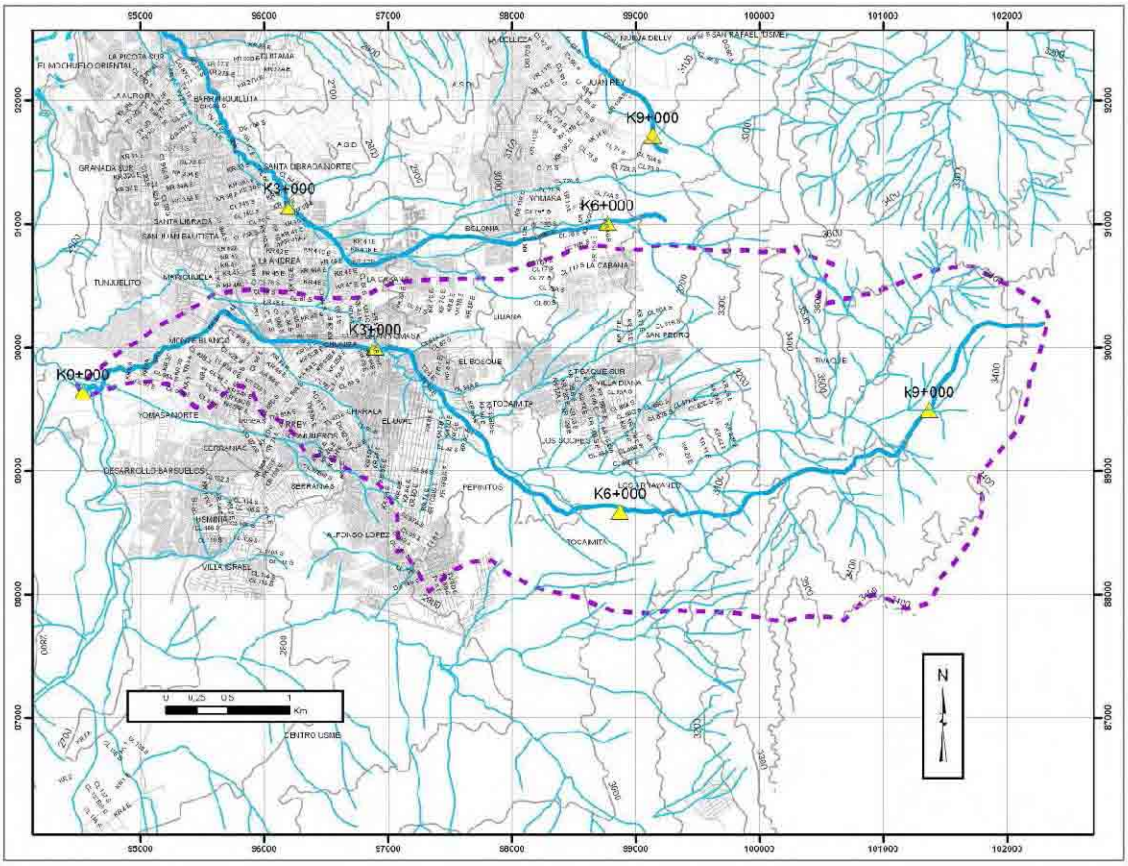


Figure 6-9 Catchment of Subjective Creek (Yomasa)

6.1.5 La Estrella and Trompeta Creek

The La Estrella and Trompeta creek is the left side tributary of the Tunjuelo River. The Scope of Works dated on September 1, 2005 was using the name of Infierno creek as a Study Area in Bogota, but the Infierno creek is a small tributary of the Trompeta creek system. In order to treat the Infierno and Trompeta as one catchment, the Study covers the both creeks.

The creek system of La Estrella and Trompeta creek is affected by Ave. Boyaca which is running in the most downstream of the creek. La Estrella creek is connecting the canal which is located in the central reservation of the Boyaca Ave. The canal is crossing the avenue at 0+487 by culvert and is receiving the water from Trompeta at 0+400, and joining the Tunjuelo River.

The Trompeta creek is connecting the canal which is constructed by CEMEX and HOLCIM (cement factories) after crossing the Boyaca Ave. The canal is located in the area of CEMEX and HOLCIM between the Tunjuelo river and Boyaca Avenue. In the HOLCIM area, there is a sediment trap reservoir at the outlet of the Trompeta creek. Usually the discharge of the Trompeta creek is guided toward the Estrella creek confluence, however, when more discharge comes from the outlet, some of the discharge is diverted to floodway channel in order to drain the water to quarry site.

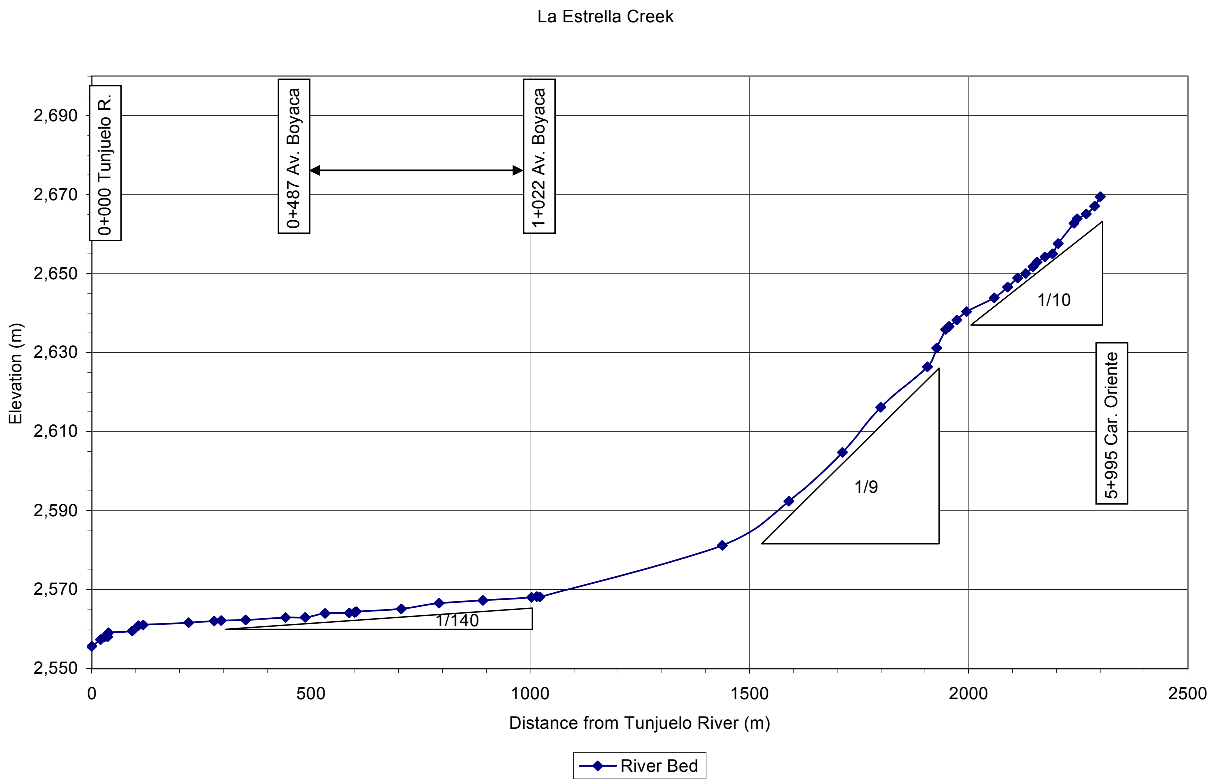


Figure 6-10 Longitudinal Profile of La Estrella Creek

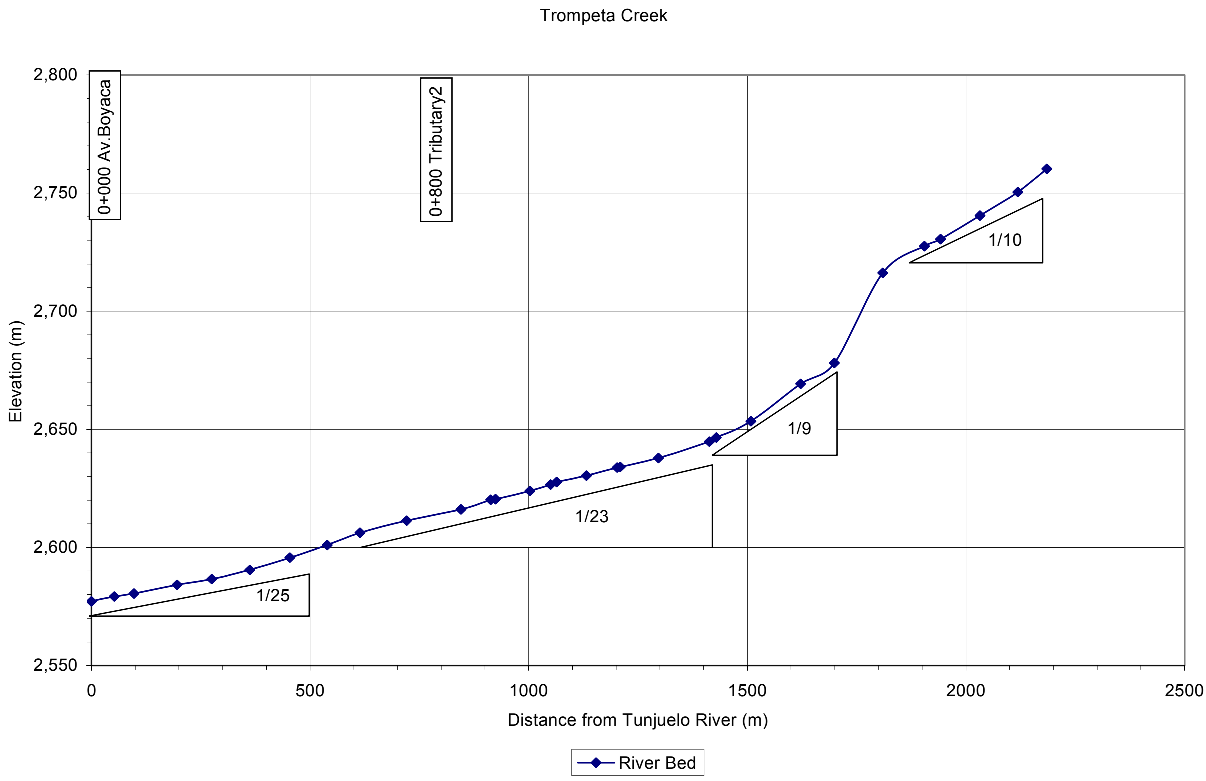


Figure 6-11 Longitudinal Profile of Trompeta Creek

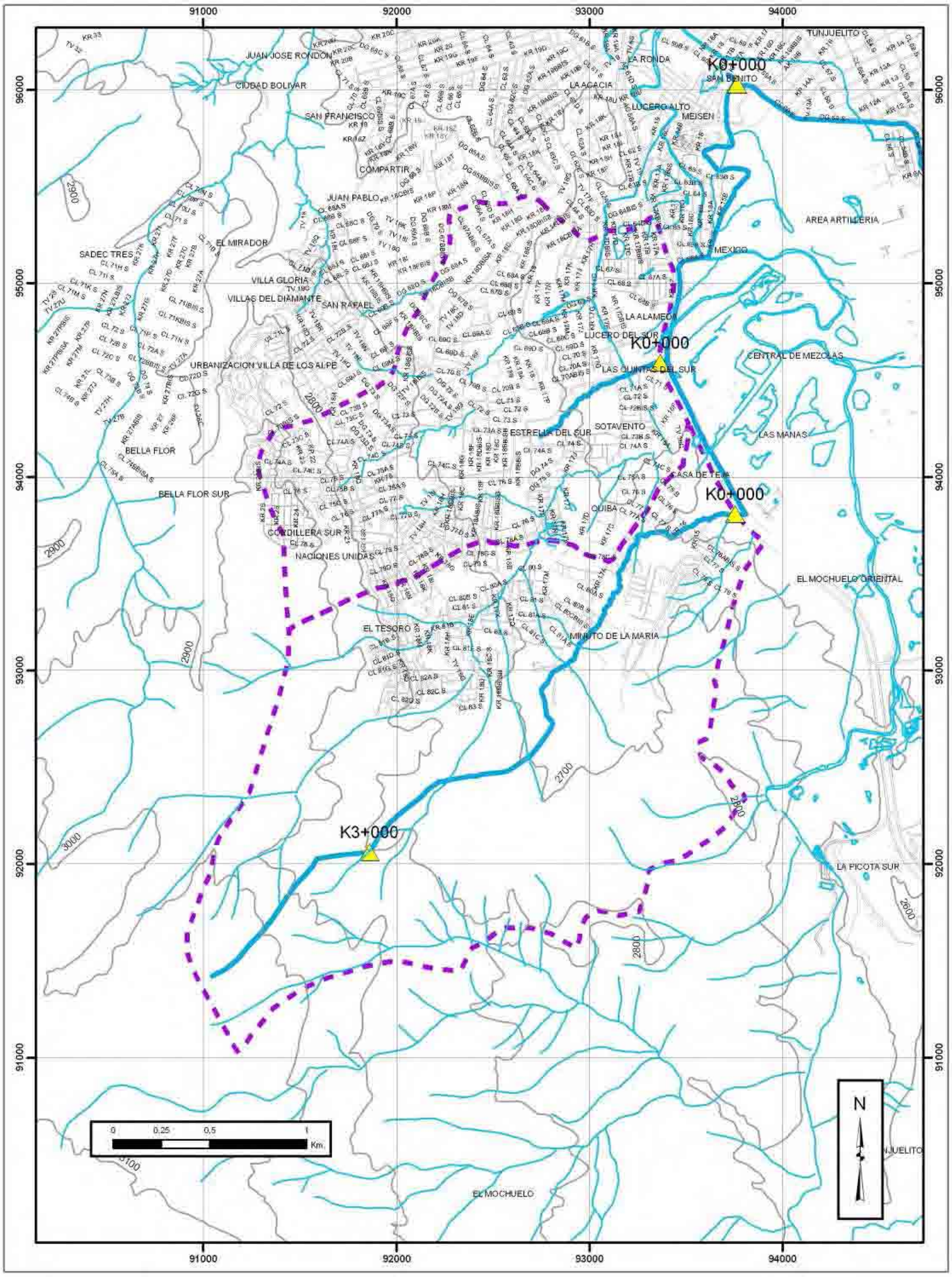


Figure 6-12 Catchment of Subjective Creek (La Estrella-Trompeta)

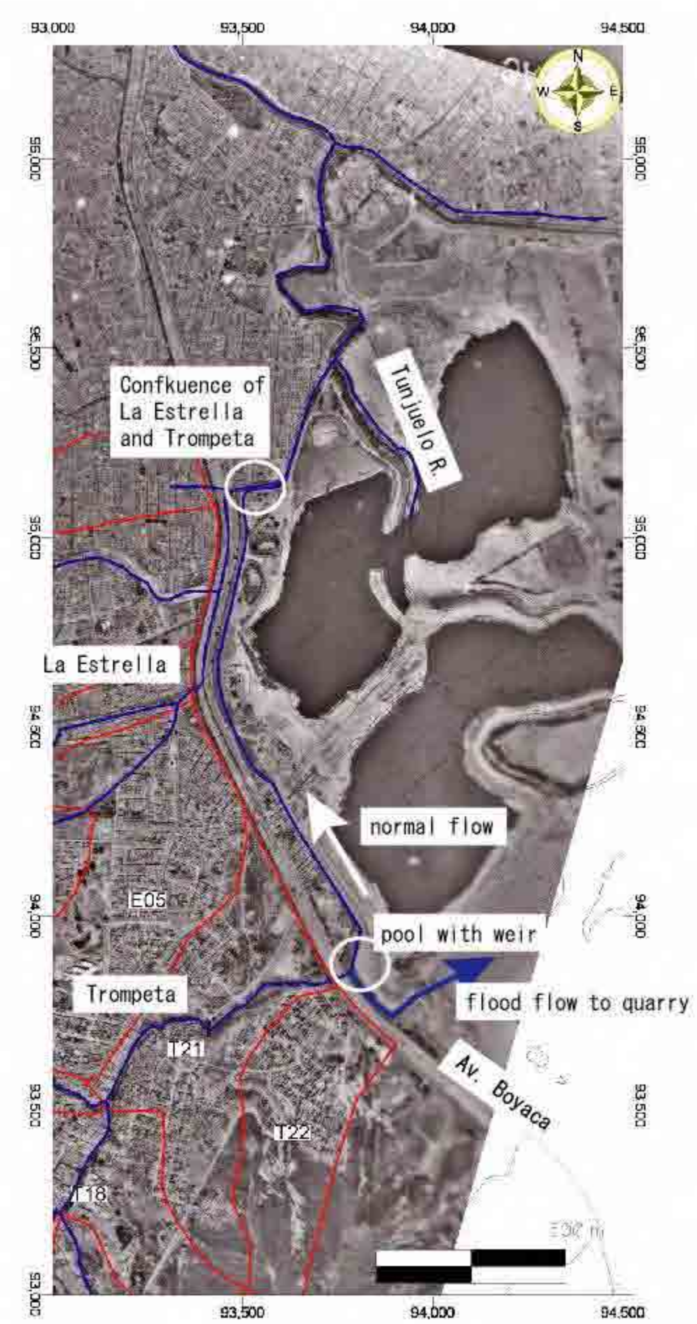


Figure 6-13 Connection Condition of La Estrella and Trompeta Creek

6.2 Past Floods

6.2.1 General

The Study Team analyzed the DPAE disaster inventory data (2000-2006) for flood and conducted interview survey for the people in previous affected area and community leaders.

DPAE has recorded disaster events in Bogota in Database. The fields of the database are EVENTO, EMERGENCIA, FECHA INICIO, TIPO, LOCALIDAD, UPZ, BARRIO, DIRECCION, INTERSECCION, BIT_RADIO_OPERADOR, UBICACION, ASISTEN and

BIT_OBSERVACIONES. The “TIPO” means the type of disaster such as inundation, landslide. This data is based on the operation record by DPAE such as urgently informed information from the disaster area and the responding activity by DPAE and other related organizations.

In the 2nd field survey in Colombia, the Study Team undertook an interview survey for flood in the Study Area. According to the results obtained, the following flood phenomenon ca be observed in the study area.

- Prolonged inundation by high water in the Tunjuelo River
- Overflow of main creek (with debris or without debris)
- Overflow of local drainage system and backwater through sewerage

The prolonged inundation by high water in the Tunjuelo River is regarded to be mitigated by the completion of the Cantarrana Dam (EAAB).

The overflow of local drainage or backwater through sewerage is a local phenomenon and the damage is limited. They are mainly caused by garbage deposit and a small capacity of ditch. This inundation is not concerned by the Study.

The remaining flood problem concerns the overflow from main creek in the Study Area. This type of flood has frequently occurred in the middle and upper part of the Chiguaza creek. The Study Team visited the Chiguaza on November 2006 and interviewed an old man living in the Barrio La Gloria. According to him, the area suffered from flood damage 5 (five) years ago. The flood depth was about 50 cm and was the most serious one during 35 (thirty five) years in the area. Also he pointed out to the Study Team that the area was not occupied by houses before, but recently the riverine area is occupied by houses resulting into high potential of flood damage.

In other creeks, the study results of the interview survey did not show any significant damage in the 2nd field survey in Colombia.

6.2.2 Flood on May 19, 1994

(1) Flood Conditions

The study team undertook an interview survey in Bogota in September 2006, visiting community leaders as well as local people. In the Chiguaza creek basin, at an interview in Quindio (Barrio) it was said that a kind of flash flood happened in the past in the neighborhood. This said phenomenon is regarded as that in Qda. Zuque. According to the interview, the flash flood was 30 m width and lasted 3 hours.

In January 2007 the study team conducted the interview survey focusing on the 1994 flash flood in the Chiguaza creek in order to identify the affected area and its magnitude such as flood depth. Also to find some flood marks which were specified by the people who experienced the 1994 event, the elevations of those flood marks were surveyed by the study team.

The most significant phenomenon in the 1994 event was the diversion from the bridge on *old highway to “Villavicencio”.* The resultant flash flood went to barrios Altamira, running on the streets among the blocks.

Photo 6-1　Affected Barrio Altamira (left: after May 19, 1994 source El Tiempo, right: Feb. 2007)

The area downstream of barrio Altamira suffered from the debris flow damage only in the creek and the limited riverine.

The Local Newspaper “El Tiempo” article dated on May 23, 1994 wrote that 4 people died, 15 people missing and 830 people were affected. The dead 4 people were 2 years old, 7 months baby, 22 years old pregnant ladies and 17 years old girl.

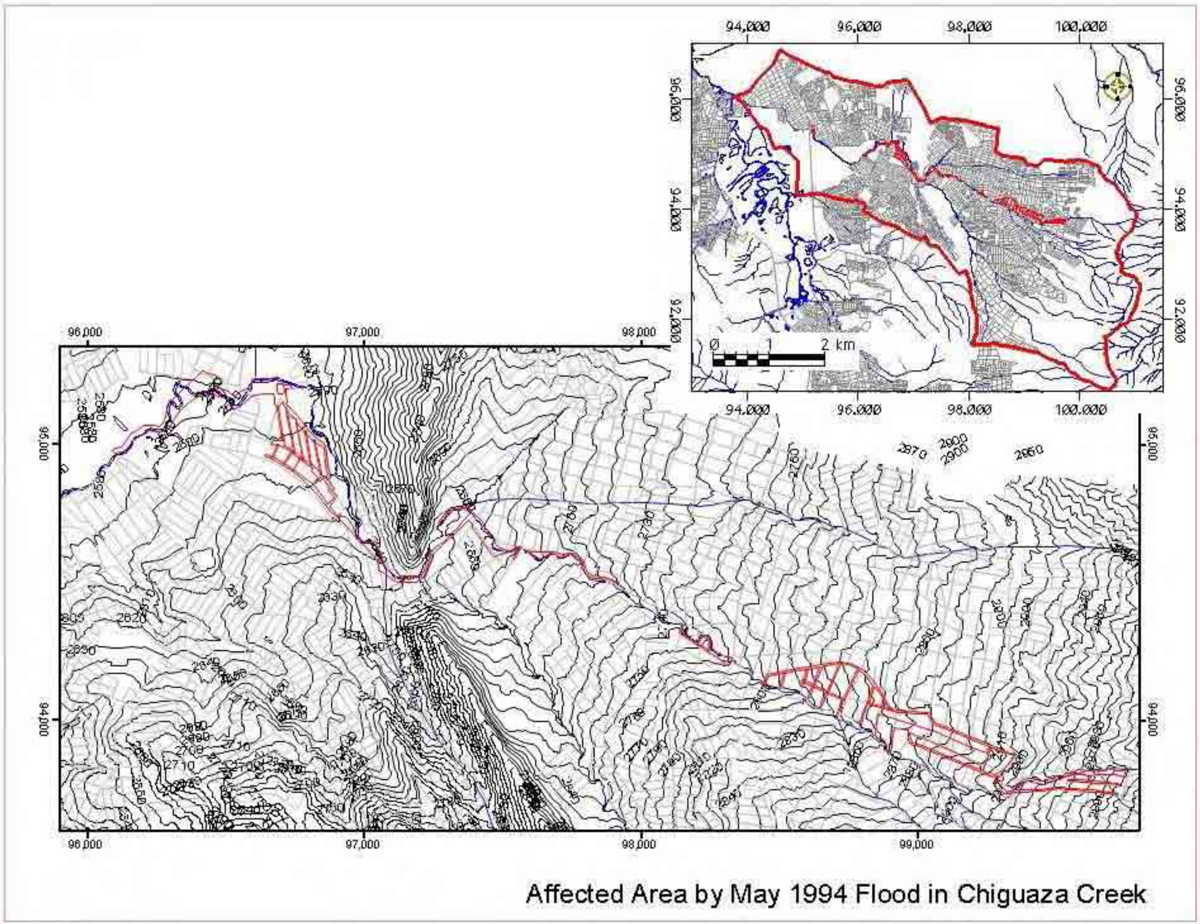


Figure 6-14　Affected Area by May 19, 1994 Flood in Chiguaza Creek

(2) Hydrological Conditions

According to the newspaper and the interview survey, the occurrence time of the debris flow is summarized as follows,

Description by Source	Source
At 4:30 PM the cloudburst began and 4:45 PM the overflow from the Belleza creek happened.	The article “El Tiempo “dated on May 20, 1994
At 4PM, there were three (3) times of debris flow.	People at 46A 33S (the house along the Zuque creek)
From 3:30PM to 9PM, the flow continued.	People at Tras 17 Este 47-44 Sur

Because they are people’s memories about 13 years ago and it is difficult to confirm the accuracy of the newspaper article at present, it can be regarded that about 4 PM the debris flow occurred.

The following figures show the daily rainfall on May 1994 of the stations near Qda. Zuque. In Juan Rey (EAAB) and Dona Juana (CAR), around 20 mm a day was observed on May 19, 1994. Especially Juan Rey station (EAAB) which is the nearest to the Qda. Zuque had 22.9 mm on May 19 after it experienced the almost same amount of rainfall on May 14.

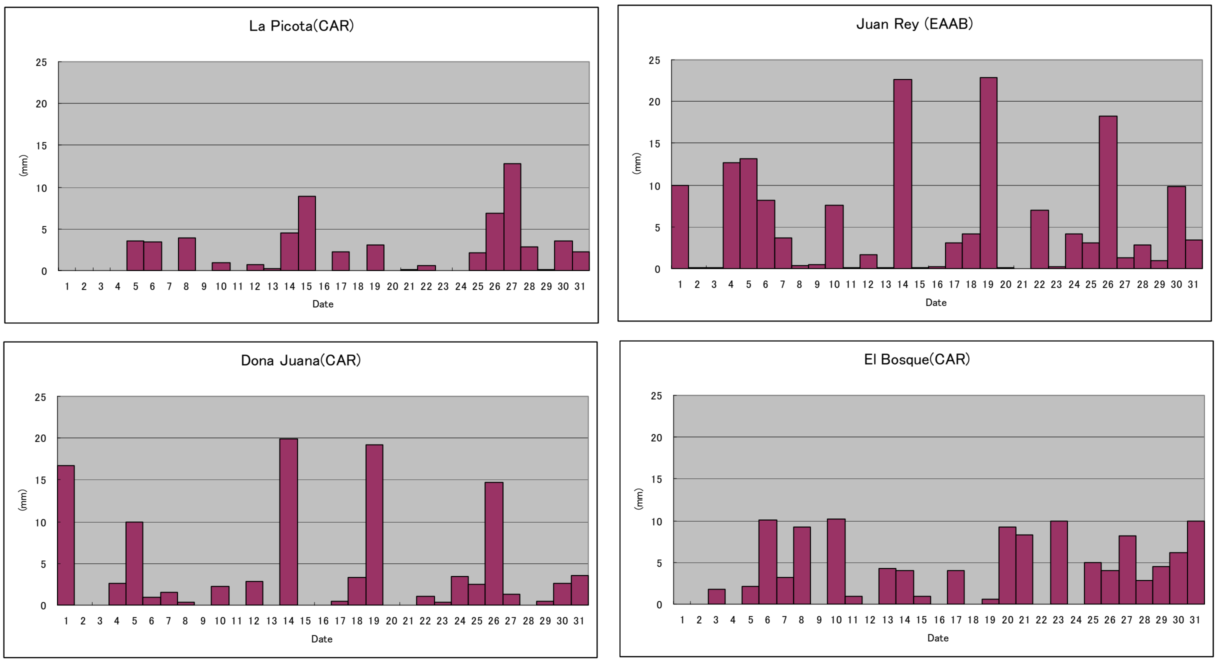


Figure 6-15 Daily Rainfall during 1 to 31 on May 1994

The hourly rainfall distribution of Juan Rey station (EAAB) was not available in EAAB database. The original recording sheets were collected in the Bogota Archives (see Table 6-2) are checked by the Team.

Table 6-2 Hourly Rainfall Distribution at Juan Rey in May 19, 1994

Date	Time	Hourly Rainfall	Remarks
May 19	15:00-16:00	0 mm	
	16:00-17:00	5.1 mm	From 16:45 to 17:15 , the amount was 9.5 mm.
	17:00-18:00	6.3 mm	
	18:00-19:00	1.8 mm	
	19:00-20:00	2.2 mm	
	20:00-21:00	0.1 mm	
	21:00-22:00	0.0 mm	
	22:00-23:00	0.9 mm	
	23:00-24:00	3.7 mm	
May 20	24:00-1:00	2.5 mm	
	1:00-2:00	0.0 mm	
	2:00-3:00	0.1 mm	
	3:00-4:00	0.2 mm	
	Total	22.9 mm	

It was found that 9.5 mm was observed during 16:45 to 17:15 PM, which corresponding to 19 mm per hour as intensity.

6.2.3 Flood on May 31, 2002

(1) Flood Conditions

The inundation in the Chiguaza creek in May 2002 can be considered as one of the main flood disasters in recent years. The area near the Tunjuelo river confluence was seriously affected by flood water. As shown in Figure 6-16, it has been reported that the high water of the Tunjuelo river itself was the main cause of the inundation.

Figure 6-16 Presentation Material on May 2002 Flood by DPAE

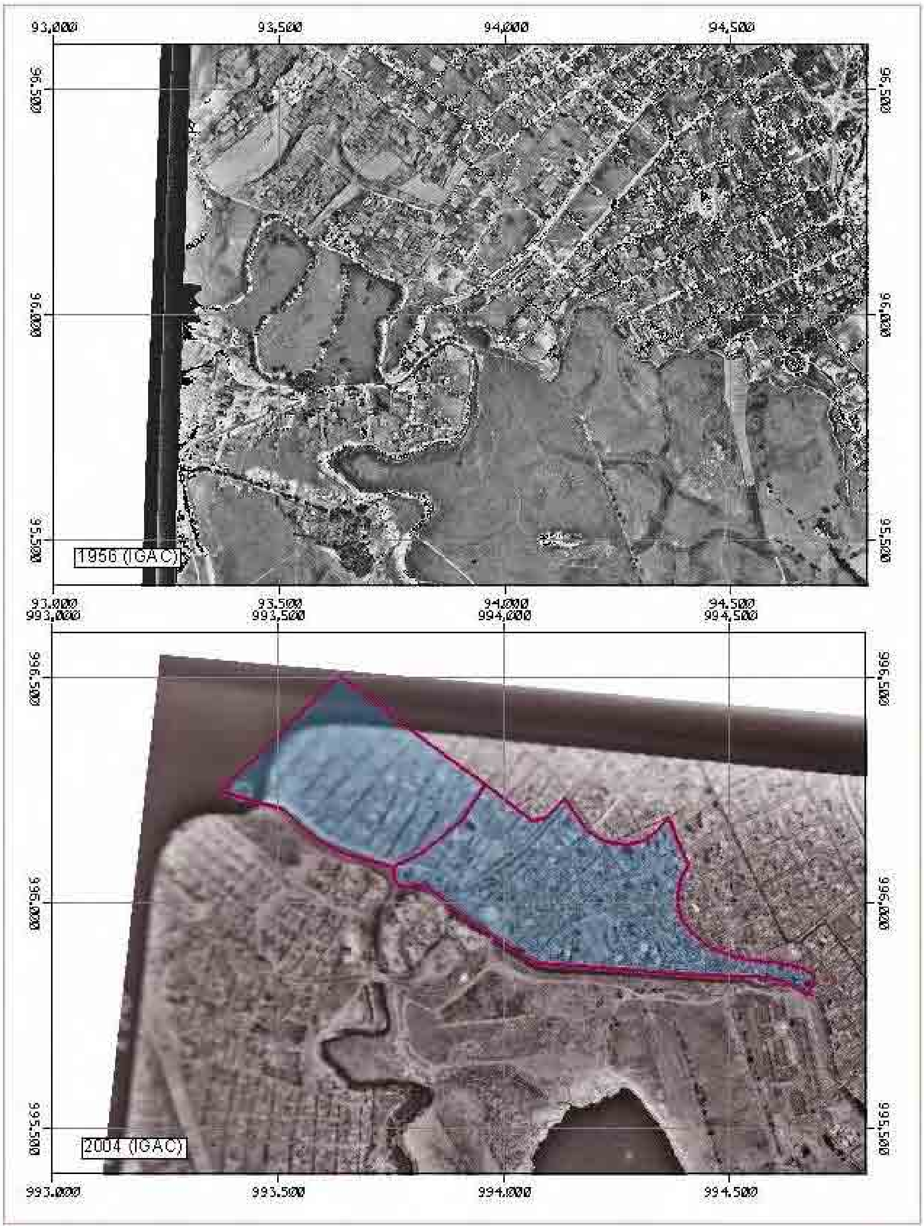


Figure 6-17 Affected Area by May 2002 Flood comparing with 1955 Aerial Photo

The Study Team conducted interview survey in Chiguaza in September 2006 and identified the affected area by the May 2002 flood as shown in Figure 6-17.

(2) Hydrological Conditions

1) Rainfall Condition in Juan Rey (EAAB)

In May 2002, the only available rainfall station in the Chiguaza upstream was Juan Rey (EAAB). The Study Team visited the Bogota Archive Center in order to check the rainfall of the end of May 2002. According to the recording chart, 15.4 m between 11AM and 12AM (22.4 mm for only 15 minutes) was recorded on May 30, 2002. Generally the flooding date was said May 31, 2002, however, the maximum rainfall for hour was recorded in May 30,2002.

Table 6-3 Hourly Rainfall at Juan Rey on May 30, 2002

Date	Time	Hourly Rainfall (mm)	remarks
May 30	7:00	0	
	8:00	0	
	9:00	0	
	10:00	0	
	11:00	8.4	
	12:00	15.4	22.4mm for 15 min.
	13:00	0.2	
	14:00	0.9	
	15:00	7.2	
	16:00	3.4	
	17:00	1.5	
	18:00	0.5	
	19:00	0	
	20:00	0	

2) Waterlevel Condition in Tunjuelo River Confluence near San Benito

EAAB had a waterlevel station at San Benito in May 2002. It was a staff gauge monitored by people. Figure 6-18 shows the reported waterlevel to EAAB at 6AM and 6PM from May 23 to June 6, 2002. This station is in the Tunjuelo river main course after the Chiguaza creek confluence. The waterlevel on May 30, 6PM was increased 1 meter compared with May 29. This can be regarded as effect of the discharge from Chiguaza due to the rainfall at Juan Rey. The highest waterlevel was recorded in May 31, 18PM, 2,562.9m.

Figure 6-19 shows the flood elevations along the Chiguaza and Tunjuelo River together with the longitudinal profile of the Chiguaza creek and the Tunjuelo River, according to the interview survey by the Study Team. The flood elevations were assumed as the ground elevation of the 2 m contour line plus interviewed inundation depth. The inundation depths are larger than 2 m in some points above ground elevation of the right bank.

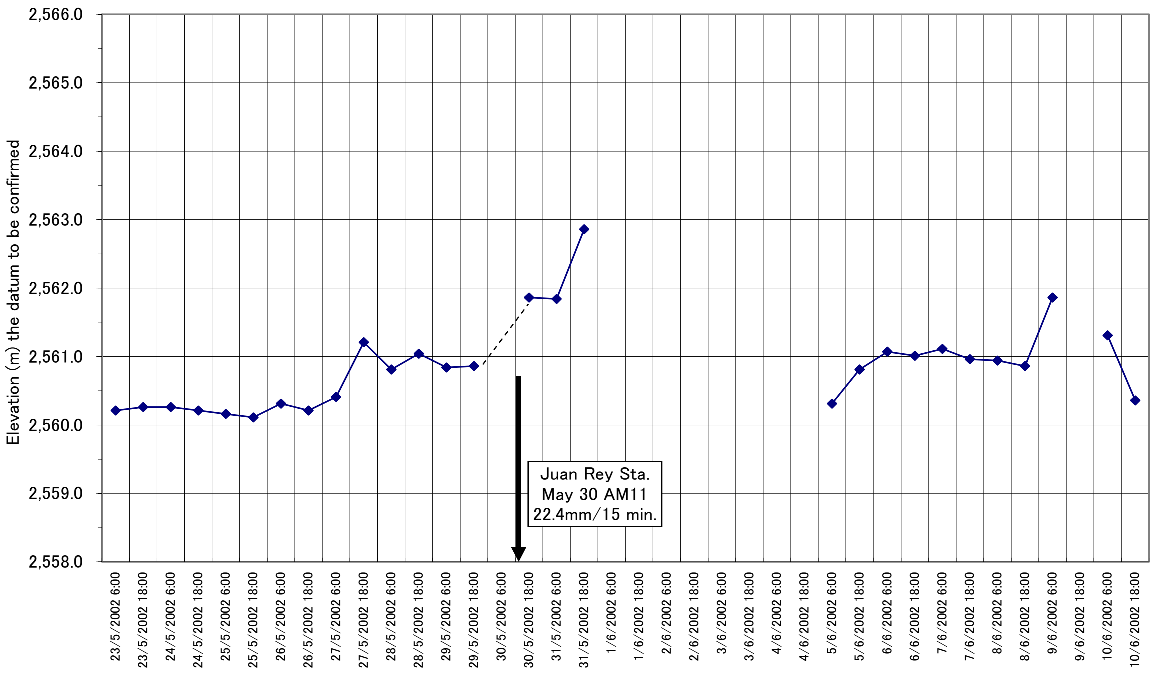


Figure 6-18 Observed Waterlevel from May 23 to June 6, 2002 at San Benito[1] (EAAB)

[1] The datum elevation of San Benito 2,559.809 m according to DPAE information dated on August 2, 2006.

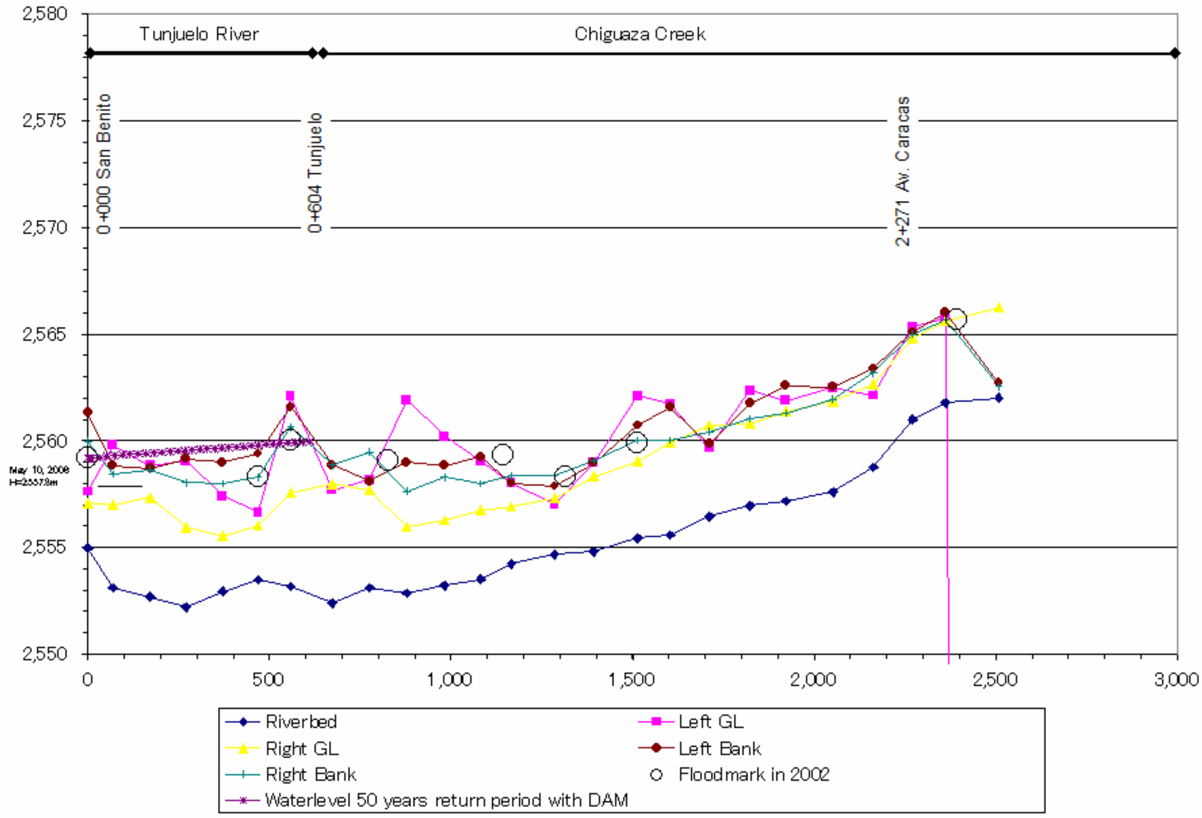


Figure 6-19 Flood Elevation in May 2002 Flood in Chiguaza and Tunjuelo River

(3) Effect of the Cantaranna Dam

After the May 2002 flood, the Tunjuelo river's flood is controlled by the Cantarrana Dam. According to the EAAB information, the Cantaranna Dam could cut 88 m^3/s for 100 years return period. The Study Team tried to explain the effect of the Dam at the point of San Benito.

Figure 6-20 shows the waterlevel and discharge curve at San Benito (0+068). The curve was made using uniform flow formula assuming the waterlevel slope 1/800 and Manning coefficient 0.04. According to the curve, the discharge of 88 m^3/s corresponds to the waterlevel of 1.7 m reduction. The flood mark in May 2002 was 2,559.2m at San Benito. If at present the same flood occurs in the Tunjuelo river, the waterlevel at San Benito is 2,557.5 m, which is lower than the existing right bank elevation.

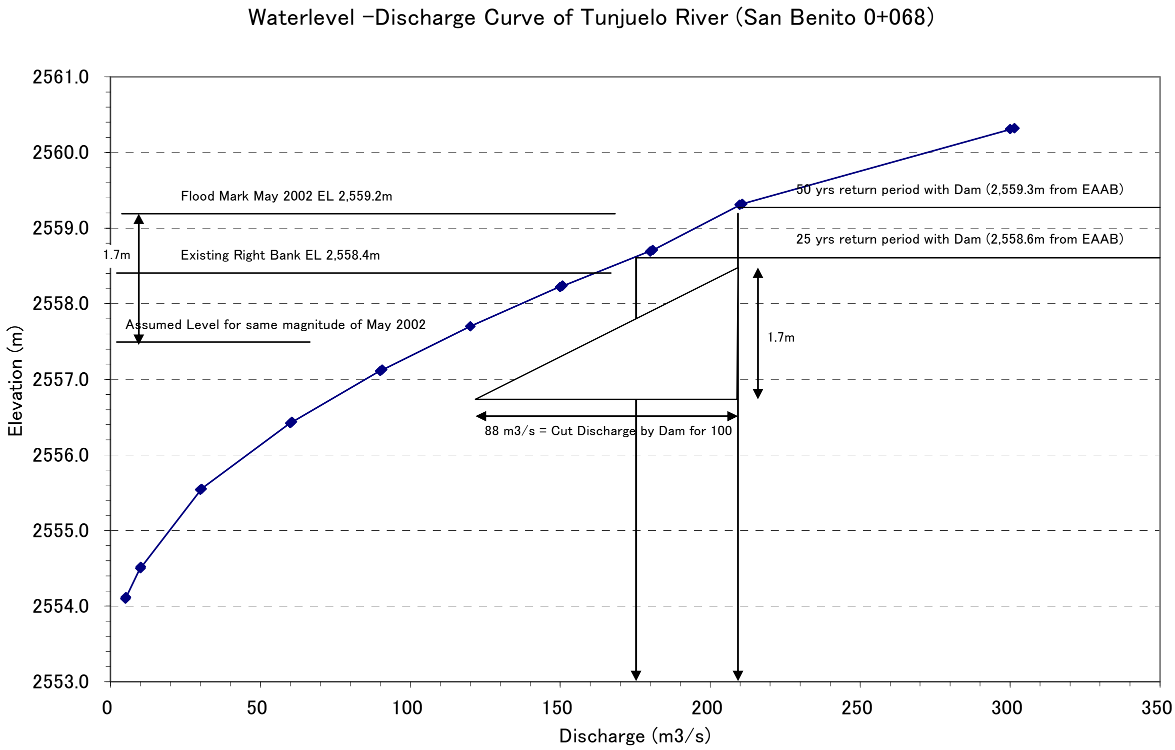


Figure 6-20 Waterlevel and Discharge Curve of Tunjuelo River (0+068)

6.3 Existing Monitoring System

6.3.1 Monitoring System of DPAE

(1) Automatic Station

In the Tunjuelo River basin, DPAE has already established a flood monitoring system as well as an early warning system using a combination of telemeter system and manual monitoring system. Figure 6-21 shows the DPAE web site of the Tunjuelo River Monitoring System, on which the Study Area boundary and scale were added by the Study Team as reference. In and around the Study Area of Bogota there are one (1) waterlevel station and four (4) rainfall stations as follows,

Table 6- 4 Automatic Monitoring Station in and around the Target Creeks

Monitoring	Name	Elev.	Remarks
Rainfall	San Benito	2590	San Benito rainfall station is located within the EAAB pumping station.
	Tanque Quiba	3078	Tanque Quiba rainfall station is located on the edge of La Estrella creek watershed with Limas creek watershed.
	Juan Rey	3160	Juan Rey rainfall station is located on the edge of Santa Librada and Chiguaza creek watershed. At the time of August 2006, when the Study started, the station was not operated because some equipment was stolen. The station was restarted by DPAE on February 2007.
	Santa María Micaela	2900	Santa Maria Micaela rainfall station is located within the middle part of the Yomasa creek watershed.
Waterlevel	San Benito	2590	San Benito waterlevel station is located at the bridge of Boyaca Avenue crossing the Tunjuelo River, just downstream of confluence of Chiguaza creek. The sensor is an ultrasonic type and other accessories such as data logger are located within the EAAB pumping station.

The above all stations have data transfer platform which can send the data to DPAE office via radio (UHF). The monitored data are displayed and updated for hourly in the DPAE web site under authorization access control.

Figure 6-21 Existing Monitoring System by DPAE

(2) Manual Monitoring Station

Other than the above monitoring stations, DPAE has already established monitoring points by staff gauge as follows,

Table 6-5 DPAE Monitoring Point (Mannual)

No.	Creek name and location	address
09	Q. YOMASA	AV. USME-Q. YOMASA
10	DIANA TURBAY - LOS PUENTES (Q. Chiguaza)	AV. GUACAMAYAS KR 1G
11	PICOTA (Q. Chiguaza)	CARRERA 5R CON CALLE 51 SUR
12	PUENTE EL HOYO (Q. Chiguaza)	CARRERA 16 B CON CALLE 60 SUR


Photo 6-2　DPAE Monitoring Point 9 “Yomasa Creek”

Photo 6-3　DPAE Monitoring Point 10“DIANA TURBAY - LOS PUENTES”


Photo 6-4　DPAE Monitoring Point 11“PICOTA”

Photo 6-5　DPAE Monitoring Point 12”PUENTE EL HOYO (Q. Chiguaza)”

In normal time DPAE does not do any monitoring activity for these points, however, in critical time, they are supposed to be monitored by Civil Defense or Firefighter based on the DPAE instruction.

6.3.2 Monitoring Stations of Other Organizations

Figure 6-22 shows the location of rainfall and waterlevel stations in and around the Study Area of DPAE, IDEAM, CAR and EAAB. The purpose of each organization regarding the hydrological monitoring is different. IDEAM stations are provided for climate monitoring on the national level viewpoint. CAR stations are provided for environmental monitoring, and EAAB stations concern the water supply potential and drainage planning. Regarding the flood early warning purpose, only DPAE has hydrological stations targeting the Tunjuelo river basin.

The data of the monitoring stations other than DPAE were used for hydrological evaluation in the Study. Only the DPAE stations were considered in the monitoring and early warning planning in the Study Area.

The present system by DPAE presented previously is established for the Tunjuelo River main course as the target area. For the flood-prone area in the Study Area, more monitoring points should be established considering the local flood phenomenon within the Study Area.

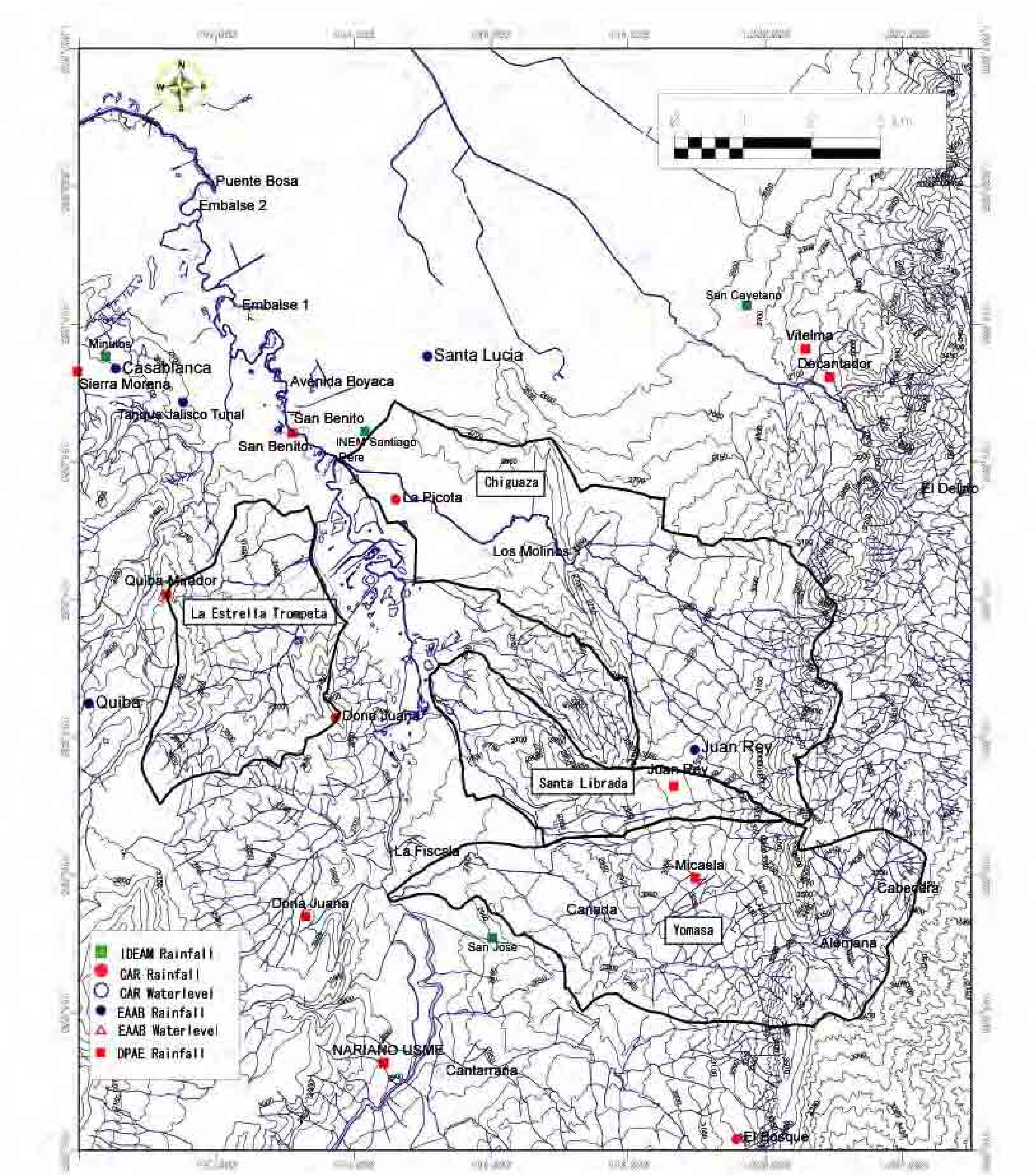


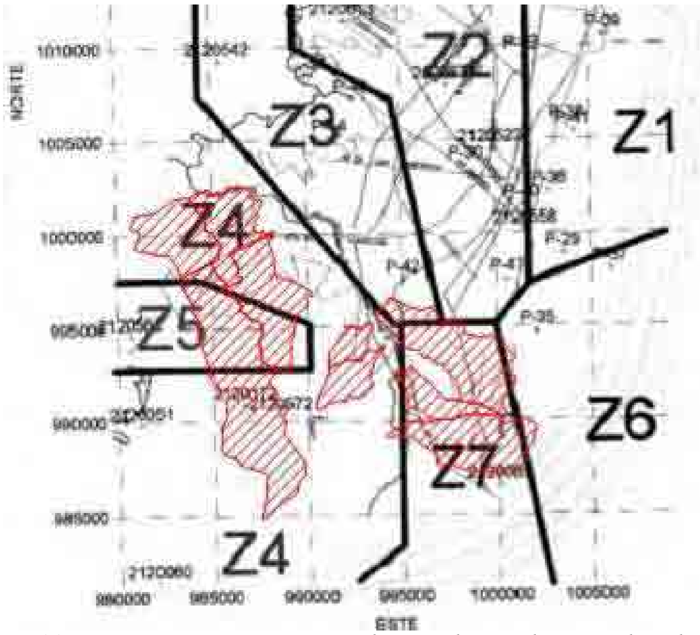
Figure 6-22 Existing Monitoring System in and around the Study Area (Bogota)

6.4 Flood Analysis and Mapping

6.4.1 Hydrological Modeling

(1) Rainfall Duration Intensity Curve

EAAB has defined a group of IDF(Intensity-Duration-Frequency) curve in and around the Study Area. Figure 6-23 shows the zones by EAAB on which the Study Areas are overlapped. In Bogota, the Chiguaza, Santa Librada and Yomasa creek catchment belong to Zone 7, while La Estrella and Tromepeta catchments belong to Zone 4.



(Source: EAAB-IRH Ingenieria y Recursos Hidricos Ltda, Estudio para el analisis y caracterizacion de tormentas en la sabana de bogota volumen 1 Informe General,1995)

Figure 6-23 Defined Zones for IDF curve by EAAB

Figure 6-24 is the IDF curves of Zone 4 and Zone 7. The 60 minutes rainfall for 100 years return period of Zone 4 and Zone 7 are only 42.0 mm and 38.3 mm, respectively.

Zone 4 La Estrella, Trompeta

PERIODO DE RETORNO (AÑOS)	C1	Xo	C2
3	1413.4	19.0	-0.9539
5	1708.8	18.5	-0.9668
10	1716.3	15.5	-0.9424
25	1979.3	14.5	-0.94
50	2117.9	13.5	-0.9345
100	2301.0	13.0	-0.9331

Duration (minutes)							
5	10	15	30	60	120	180	240
68.2	56.9	48.9	34.5	21.9	12.8	9.1	7.1
80.8	67.0	57.3	40.1	25.2	14.5	10.3	7.9
99.6	81.1	68.5	47.0	29.2	16.8	11.9	9.2
121.3	97.9	82.2	55.9	34.4	19.7	14.0	10.8
138.6	110.8	92.5	62.3	38.2	21.9	15.5	12.0
155.1	123.4	102.7	68.8	42.0	24.0	17.0	13.2

Zone 7 Chiguaza, Yomasa, Santa Librada

PERIODO DE RETORNO (AÑOS)	C1	Xo	C2
3	259.2	0.0	-0.6586
5	320	0.0	-0.6639
10	343.7	-2.0	-0.6422
25	525.7	1.0	-0.6837
50	387.4	-5.0	-0.6054
100	435.4	-5.0	-0.6068

Duration (minutes)							
5	10	15	30	60	120	180	240
89.8	56.9	43.6	27.6	17.5	11.1	8.5	7.0
109.9	69.4	53.0	33.5	21.1	13.3	10.2	8.4
169.7	90.4	66.2	40.4	25.3	16.1	12.3	10.2
154.4	102.0	79.0	50.2	31.6	19.8	15.0	12.4
	146.2	96.1	55.2	34.2	21.9	17.0	14.2
	164.0	107.7	61.7	38.3	24.5	19.0	15.9

(Source: EAAB-IRH Ingenieria y Recursos Hidricos Ltda, Estudio para el analisis y caracterizacion de tormentas en la sabana de bogota volumen 1 Informe General,1995)

Figure 6-24 EAAB IDF data in Study Area in Bogota

(2) Rainfall and Runoff Model

There are several types of rainfall and runoff model, for example, rational method, unit hydrograph, storage function model, etc. Since in the Study Area in Bogota, the size of creek catchment is small and the creek bed slope is very steep (without storage function), and also some previous studies by EAAB have used a rational method, which is the most appropriate method for the four (4) creek catchment.

Rational Method

$$Q = \frac{1}{3.6} C \times I \times A$$

Where Q: peak discharge (m^3/s), C: runoff coefficient, I: rainfall intensity (mm/hr) during the concentration time, A: catchment area (km^2).

$$I = C_1 \times (d + X_0)^{C_2}$$

Where I: rainfall intensity (mm/h), d: duration (minutes).

Figure 6-25 is subcatchment of the Chiguaza creek defined in this Study. Figure 6-26 is the schematic tree of the Chiguaza hydrological model. The models of other 3 creeks are shown in Supporting Report S6.

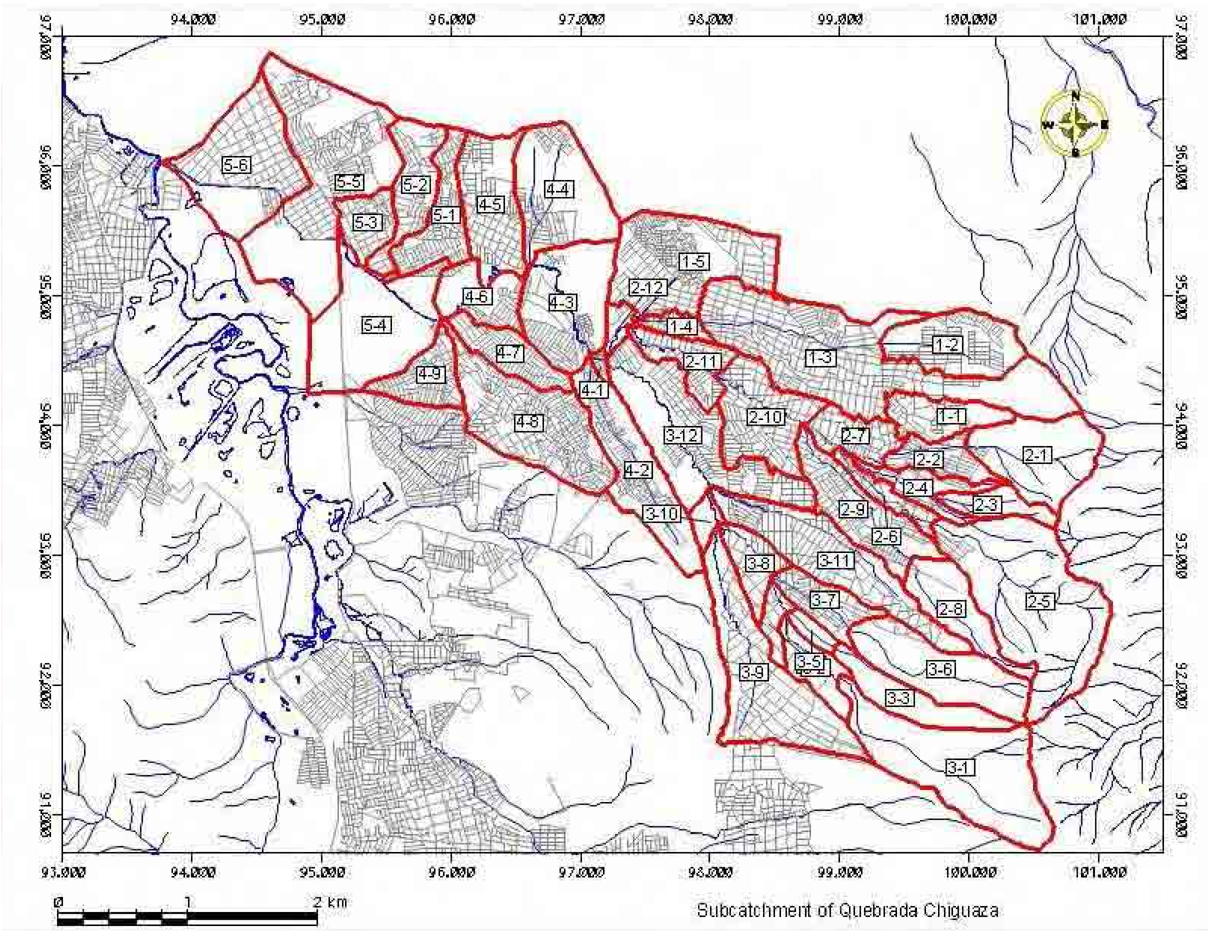


Figure 6-25 Subcatchment of Chiguaza Creek

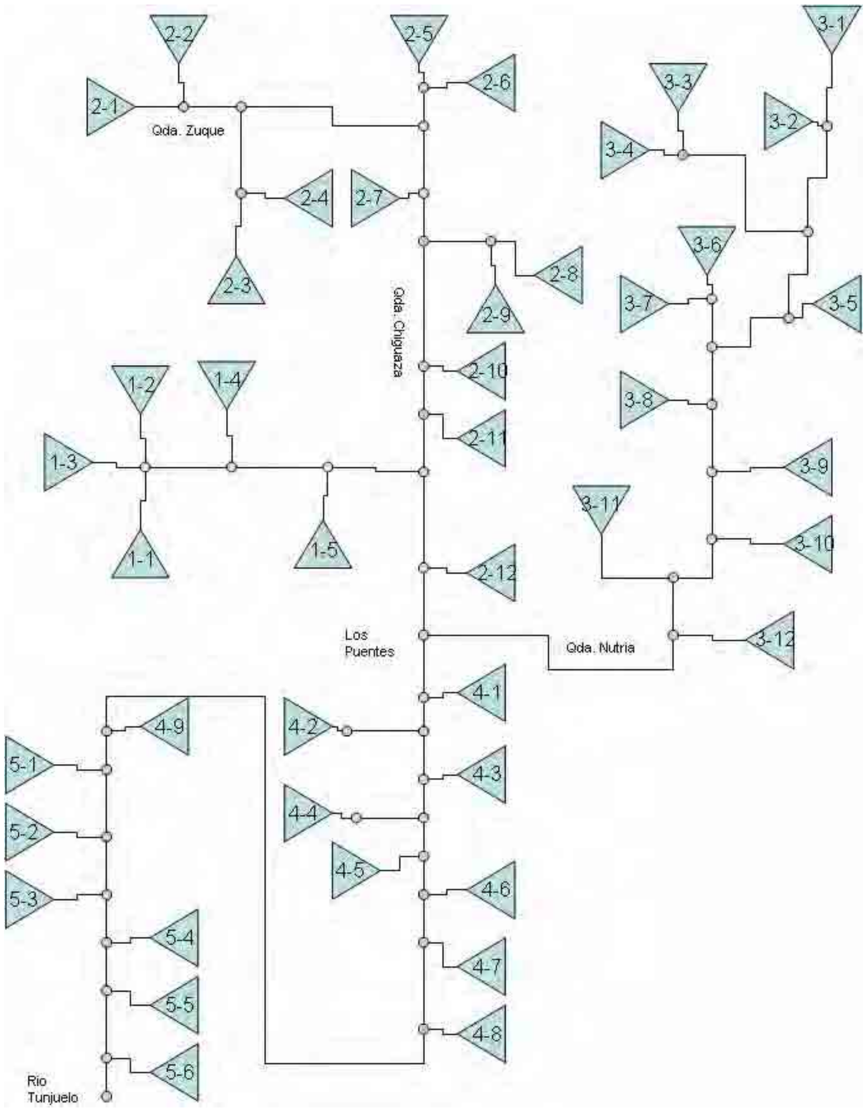


Figure 6-26 Schematic Tree for Hydrological Model of Chiguaza Creek

(3) Landuse (Runoff Coefficient) for Rational Method

Landuse of each sub-catchment was simply categorized as urban area, industrial and rural area based on GIS attribute. The source of the GIS data is Cadastre office in Bogota. In order to calculate composite runoff coefficient, the runoff coefficient for urban area, industrial and rural area were assumed to be 0.8, 0.5 and 0.3, respectively.

Table 6-6 and Table 6-7 shows the area of urban, industrial and rural area for each creek catchment, and resulting composite runoff coefficient. Table 6-8 shows the discharge calculation by return period in the Chiguaza creek.

Table 6-6 Landuse and Runoff Coefficient of Chiguaza and Santa Librada Catchment

Landuse of Chiguaza Creek Catchment

Main subcatchment	Subcatchment name	Urban Area C=0.8	Industrial Park C=0.5	Rural Area C=0.3	Composite Runoff Coeffcient
up	1-1	211,929	0	25,359	0.75
up	1-2	-	0	420,988	0.30
up	1-3	1,092,020	0	264,609	0.70
up	1-4	77,113	0	6,203	0.76
up	1-5	539,039	0	220,048	0.66
up	2-1	23,189	0	487,905	0.32
up	2-2	128,158	0	64,000	0.63
up	2-3	31,730	0	119,796	0.40
up	2-4	120,513	0	63,765	0.63
up	2-5	285	0	1,150,097	0.30
up	2-6	50,625	0	72,821	0.51
up	2-7	169,743	0	44,640	0.70
up	2-8	-	0	320,205	0.30
up	2-9	270,115	0	172,679	0.61
up	2-10	420,361	0	55,327	0.74
up	2-11	174,799	0	53,001	0.68
up	2-12	40,132	0	23,341	0.62
up	3-1	-	0	919,023	0.30
up	3-2	59,628	0	128,135	0.46
up	3-3	-	0	289,880	0.30
up	3-4	3,834	0	57,196	0.33
up	3-5	68,893	0	21,712	0.68
up	3-6	29,744	0	509,142	0.33
up	3-7	171,905	0	48,324	0.69
up	3-8	142,407	0	45,901	0.68
up	3-9	560,181	0	222,792	0.66
up	3-10	3,430	0	65,892	0.32
up	3-11	417,238	0	226,193	0.62
up	3-12	481,183	0	315,092	0.60
middle	4-1	10,256	0	13,213	0.52
middle	4-2	93,145	0	454,733	0.39
middle	4-3	296,558	0	281,262	0.56
middle	4-4	210,502	0	378,233	0.48
middle	4-5	440,273	0	24,199	0.77
middle	4-6	215,223	0	42,898	0.72
middle	4-7	234,944	0	3,645	0.79
middle	4-8	632,276	0	95,419	0.73
middle	4-9	232,528	0	2,322	0.80
down	5-1	312,583	0	5,520	0.79
down	5-2	313,512	0	1,815	0.80
down	5-3	179,454	0	3,224	0.79
down	5-4	105,455	0	673,743	0.37
down	5-5	810,805	0	388,429	0.64
down	5-6	463,999	0	250,888	0.62
		9,839,709	0	9,033,607	

Landuse of Santa Librada Creek Catchment

Main subcatchment	Subcatchment name	Urban Area	Industrial Park	Rural Area	Runoff Coeffcient
	01	1,801	0	507,496	0.30
	02	352,062	0	198,023	0.62
	03	3,465	0	411,417	0.30
	04	125,180	0	191,899	0.50
	05	97,963	0	59,929	0.61
	06	124,033	0	517,418	0.40
	07	255,904	0	37,070	0.74
	08	527,769	0	6,693	0.79
	09	456,941	0	309,238	0.60
	10	87,941	0	38,339	0.65
	11	166,595	0	237,934	0.51
	12	6,055	0	121,307	0.32
	13	271,539	0	281,768	0.55
		2,477,249	-	2,918,530	

Table 6-7 Landuse and Runoff Coefficient of Yomasa and La Estrella Trompeta Catchment

Landuse of Yomasa Creek Catchment

Main subcatchment	Subcatchment name	Urban Area	Industrial Park	Rural Area	Runoff Coeffcient
	01	-	0	3,933,717	0.30
	02	-	0	847,675	0.30
	03	-	0	104,285	0.30
	04	12,923	0	498,633	0.31
	05	143,936	0	643,365	0.39
	06	181,319	0	135,784	0.59
	07	-	0	355,020	0.30
	08	-	0	700,586	0.30
	09	25,400	0	389,529	0.33
	10	29,288	0	242,573	0.35
	11	221,632	0	845,854	0.40
	12	210,858	0	303,281	0.51
	13	546,190	0	350,769	0.60
	14	550,068	0	1,464,097	0.44
	15	450,601	0	137,208	0.68
	16	839,799	0	42,907	0.78
	17	1,034,324	0	187,695	0.72
		4,246,336	-	11,182,980	

Landuse of La Estrella Trompeta Creek Catchment

Main subcatchment	Subcatchment name	Urban Area	Industrial Park	Rural Area	Runoff Coeffcient
Estrella	E01	236,260	0	25,763	0.75
Estrella	E02	45,634	0	44,075	0.55
Estrella	E03	216,001	0	30,338	0.74
Estrella	E04	438,944	107,022	77,230	0.69
Estrella	E05	303,644	0	112,916	0.66
Estrella	E06	99,007	0	36,231	0.67
Estrella	E07	807,972	0	28,122	0.78
Estrella	E08	337,624	0	-0	0.80
Trompeta	T01	-	239,646	0	0.50
Trompeta	T02	-	166,422	0	0.50
Trompeta	T03	-	138,826	-0	0.50
Trompeta	T04	-	286,632	0	0.50
Trompeta	T05	-	126,361	-0	0.50
Trompeta	T06	-	196,553	-0	0.50
Trompeta	T07	-	437,407	0	0.50
Trompeta	T08	-	579,952	0	0.50
Trompeta	T09	-	92,364	5,528	0.49
Trompeta	T10	15,123	250,886	288	0.52
Trompeta	T11	25,383	99,839	5,920	0.55
Trompeta	T12	2,518	13,834	111,186	0.33
Trompeta	T13	34,906	4,215	6,277	0.70
Trompeta	T14	2,155	8,719	19,352	0.39
Trompeta	T15	-	352,742	3,871	0.50
Trompeta	T16	131,936	1,577	35,949	0.69
Trompeta	T17	-	492,085	9,719	0.50
Trompeta	T18	92,124	61,170	42,050	0.60
Trompeta	T19	132,277	104,582	52,589	0.60
Trompeta	T20	147,444	0	41,349	0.69
Trompeta	T21	146,551	20,210	125,029	0.56
Trompeta	T22	104,578	14,397	82,185	0.57
		3,320,081	3,795,441	895,966	

Table 6-8 Discharge calculation of Chiguaza Creek

Subcatchment 1

Sub Area	Creek Name	Subcatchment	Area			Runoff Coef.		Subcatchment				Channel in Subcatchment				Tc	Travel Time		Accumulated	Location	Area	C	Tc	Intensity						Discharge					
		Number	(m2)	(km2)	(km2)			EL(Min)	EL(Max)	Length	Slope	EL(Min)	EL(Max)	Length	Slope	(min)	(min)	(min)	(min)	Name	(km2)	(-)	(min)	3	5	10	25	50	100	3	5	10	25	50	100
up	Chorro Colorado	1-1	237,288	0.24		0.75		2910	3130	1027	0.214					7.35																			
up	Los Toches	1-2	420,988	0.42		0.30		2875	3140	1170	0.226					7.95																			
up		1-3	1,356,629	1.36		0.70		2710	3440	3080	0.237					16.46																			
																				[1]	2.01	0.62	16.46	41.0	49.8	61.8	74.4	88.5	99.1	14.3	17.4	21.6	26.0	30.9	34.6
up		1-4	83,316	0.08		0.76		2650	2735	690	0.123	2650	2710	530	0.113	6.69	1.63		18.09																
																				[2]	2.10	0.63	18.09	38.5	46.8	57.7	70.0	81.6	91.4	14.1	17.2	21.2	25.7	29.9	33.5
up		1-5	759,087	0.76		0.66		2650	2760	1320	0.083					12.82																			
																				[3]	2.86	0.64	18.09	38.5	46.8	57.7	70.0	81.6	91.4	19.4	23.6	29.1	35.3	41.2	46.2

Subcatchment 2 (Chiguaza Main Creek)

Sub Area	Creek Name	Subcatchment	Area			Runoff Coef.		Subcatchment				Channel in Subcatchment				Tc	Travel Time		Accumulated	Location	Area	C	Tc	Intensity(mm/h)						Discharge(m3/s)					
		Number	(m2)	(km2)	(km2)			EL(Min)	EL(Max)	Length	Slope	EL(Min)	EL(Max)	Length	Slope	(min)	(min)	(min)	(min)	Name	(km2)	(-)	(min)	3	5	10	25	50	100	3	5	10	25	50	100
up	Zuque	2-1	511,094	0.51	4.06	0.32	0.48	3030	3450	1090	0.385					6.13																			
up	Zuque	2-2	192,158	0.19		0.63		2930	3150	1000	0.220	2930	3030	650	0.154	7.12	1.67																		
																				[4]	0.70	0.41	7.80	67.0	81.8	111.1	118.8	207.7	233.1	5.3	6.5	8.9	9.5	16.5	18.6
up	Chorro Silverio	2-3	151,526	0.15		0.40		3010	3440	980	0.439					5.38																			
up	Chorro Silverio	2-4	184,278	0.18		0.63		2890	3100	1250	0.168	2890	3010	710	0.169	9.38	1.72																		
																				[5]	0.34	0.53	7.10	71.3	87.1	120.8	125.8	247.5	277.9	3.5	4.3	5.9	6.2	12.2	13.7
																				[6]=[4]+[5]	1.04	0.45	7.80	67.0	81.8	111.1	118.8	207.7	233.1	8.6	10.5	14.3	15.3	26.7	30.0
up	Chiguaza	2-5	1,150,382	1.15		0.30		3010	3570	2560	0.219					14.72		14.72																	
up	Chiguaza	2-6	123,446	0.12		0.51		2870	3060	1120	0.170	2870	3010	980	0.143	8.59	2.62	2.62	17.35																
																				[7]	1.27	0.32	17.35	39.6	48.1	59.5	71.9	84.6	94.7	4.5	5.4	6.7	8.1	9.6	10.7
																				[8]=[6]+[7]	2.31	0.38	17.35	39.6	48.1	59.5	71.9	84.6	94.7	9.6	11.6	14.4	17.4	20.5	22.9
up	Chiguaza	2-7	214,383	0.21		0.70		2810	2950	830	0.169	2810	2920	740	0.149	6.84	1.94	1.94	19.28																
																				[9]	2.53	0.40	19.28	36.9	44.9	55.1	67.2	77.5	86.7	10.5	12.7	15.6	19.0	22.0	24.6
up	Seca	2-8	320,205	0.32		0.30		3000	3530	1400	0.379					7.49																			
up	Seca	2-9	442,794	0.44		0.61		2810	3100	1720	0.169	2810	3000	1400	0.136	11.98	3.87																		
																				[10]	0.76	0.48	11.36	52.3	63.8	81.8	94.2	126.4	141.7	5.3	6.4	8.3	9.5	12.8	14.3
																				[11]=[9]+[10]	3.29	0.42	19.28	36.9	44.9	55.1	67.2	77.5	86.7	14.2	17.3	21.2	25.8	29.8	33.3
up	Qda. Chiguaza	2-10	475,688	0.48		0.74		2730	2910	1080	0.167	2730	2810	855	0.094	8.41	2.95	2.95	22.24																
																				[12]	3.77	0.46	22.24	33.6	40.8	49.8	61.2	69.1	77.4	16.2	19.7	24.0	29.5	33.4	37.3
up	Qda. Chiguaza	2-11	227,800	0.23		0.68		2650	2755	1030	0.102	2650	2730	860	0.093	9.80	2.98	2.98	25.21																
																				[13]	3.99	0.47	25.21	30.9	37.5	45.6	56.3	62.8	70.2	16.3	19.7	24.0	29.6	33.0	36.9
up	Qda. Chiguaza	2-12	63,473	0.06		0.62		2635	2740	480	0.219	2635	2650	380	0.039	4.06	2.20	2.20	27.42																
																				[14]	4.06	0.48	27.42	29.3	35.5	43.0	53.3	59.0	66.0	15.7	19.1	23.1	28.6	31.6	35.4

Subcatchment 3 (Nutria Creek)

Sub Area	Creek Name	Subcatchment	Area			Runoff Coef.		Subcatchment				Channel in Subcatchment				Tc	Travel Time		Accumulated	Location	Area	C	Tc	Intensity(mm/h)						Discharge(m3/s)					
		Number	(m2)	(km2)	(km2)			EL(Min)	EL(Max)	Length	Slope	EL(Min)	EL(Max)	Length	Slope	(min)	(min)	(min)	(min)	Name	(km2)	(-)	(min)	3	5	10	25	50	100	3	5	10	25	50	100
up	Nutria	3-1	919,023	0.92	4.79	0.30	0.50	3040	3630	2180	0.271					11.99																			
up	Nutria	3-2	187,763	0.19		0.46		2940	3090	990	0.152	2940	3040	700	0.143	8.16	1.87																		
																				[15]	1.11	0.33	13.86	45.9	55.9	70.2	83.1	103.4	115.9	4.6	5.6	7.1	8.3	10.4	11.6
up	Nutria	3-3	289,880	0.29		0.30		3020	3570	1630	0.337					8.80																			
up	Nutria	3-4	61,030	0.06		0.33		2940	3020	460	0.174	2940	3020	460	0.174	4.29	1.09																		
																				[16]	0.35	0.31	9.90	57.3	69.9	91.2	102.7	148.1	166.1	1.7	2.1	2.7	3.1	4.4	4.9
up	Nutria	3-5	90,605	0.09		0.68		2900	2990	740	0.122	2900	2940	300	0.133	7.10	0.84																		
																				[17]	1.55	0.34	14.70	44.1	53.7	67.2	80.0	97.9	109.7	6.5	7.9	9.9	11.8	14.4	16.2
up	Nueva Delhi	3-6	538,886	0.54		0.33		3010	3580	1640	0.348					8.74																			
up	Nueva Delhi	3-7	220,229	0.22		0.69		2900	3060	950	0.168	2900	3010	730	0.151	7.59	1.89																		
																				[18]	0.76	0.43	10.64	54.6	66.6	86.1	98.2	136.0	152.5	5.0	6.1	7.9	9.0	12.4	13.9
up	Nutria	3-8	188,308	0.19		0.68		2810	2950	865	0.162	2810	2900	600	0.150	7.17	1.56																		
																				[19]	2.50	0.40	16.26	41.3	50.2	62.4	75.0	89.5	100.2	11.3	13.8	17.1	20.6	24.5	27.5
up	Nutria	3-9	782,973	0.78		0.66		2810	3170	2340	0.154					15.73																			
																				[20]	3.28	0.46	16.26	41.3	50.2	62.4	75.0	89.5	100.2	17.2	21.0	26.0	31.3	37.3	41.8
up	Nutria	3-10	69,322	0.07		0.32		2770	2915	520	0.279	2770	2810	300	0.133	3.93	0.84																		
up	Marales	3-11	643,431	0.64		0.62		2770	3260	2460	0.199					14.80																			
																				[21]	3.99	0.48	17.10	40.0	48.6	60.1	72.6	85.6	95.9	21.4	26.0	32.2	38.8	45.8	51.3
up	Verejones	3-12	796,275	0.80		0.60		2635	2935	2140	0.140	2635	2770	1380	0.098	15.22	4.64																		
																				[22]	4.79	0.50	21.74	34.1	41.4	50.6	62.1	70.4	78.8	22.8	27.7	33.8	41.5	47.0	52.6

Subcatchment 4 (Middle and Downstream)

Sub Area	Creek Name	Subcatchment	Area			Runoff Coef.		Subcatchment				Channel in Subcatchment				Tc	Travel Time		Accumulated	Location	Area	C	Tc	Intensity(mm/h)						Discharge(m3/s)					
		Number	(m2)	(km2)	(km2)			EL(Min)	EL(Max)	Length	Slope	EL(Min)	EL(Max)	Length	Slope	(min)	(min)	(min)	(min)	Name	(km2)	(-)	(min)	3	5	10	25	50	100	3	5	10	25	50	100
																				[23]	11.70	0.53	27.42	29.3	35.5	43.0	53.3	59.0	66.0	50.1	60.7	73.6	91.2	100.8	112.8
middle	Qda. Chiguaza	4-1	23,469	0.02	3.66	0.52	0.62	2620	2720	300	0.333	2620	2635	140	0.107	2.40	0.45	0.45	0.45	Los Puentes															
middle	Qda. Chiguaza	4-2	547,878	0.55		0.39		2620	2940	1910	0.168					13.02																			
																				[24]	12.27	0.52	27.86	29.0	35.1	42.6	52.8	58.3	65.2	51.3	62.3	75.4	93.5	103.2	115.5
middle	Qda. Chiguaza	4-3	577,820	0.58		0.56		2585	2780	750	0.260	2585	2620	990	0.035	5.35	6.13	6.13	6.57																
middle	Qda. Chiguaza	4-4	588,735	0.59		0.48		2585	2710	1160	0.108					10.51																			
middle	Qda. Chiguaza	4-5	464,472	0.46		0.77		2580	2670	1420	0.063	2580	2585	430	0.012	15.07	5.19	5.19	11.76																
																				[25]	13.90	0.53	39.18	23.1	28.0	33.7	42.1	45.7	51.1	47.2	57.1	68.7	85.8	93.1	104.1
middle	Qda. Chiguaza	4-6	258,121	0.26		0.72		2570	2620	800	0.063	2570	2580	440	0.023	9.74	3.55	3.55	15.31	Molinos															
middle	Qda. Chiguaza	4-7	238,589	0.24		0.79		2570	2670	1120	0.089					11.00																			
middle	Qda. Chiguaza	4-8	727,695	0.73		0.73		2570	2840	1930	0.140					14.07																			
middle	Qda. Chiguaza	4-9	234,850	0.23		0.80		2570	2650	800	0.100					8.13																			
																				[26]	15.36	0.55	42.73	21.9	26.5	31.8	39.7	43.0	48.1	51.2	62.0	74.5	93.1	100.8	112.7
down	Qda. Chiguaza	5-1	318,103	0.32	3.51	0.79	0.61	2570	2690	1380	0.087					13.05																			
down	Qda. Chiguaza	5-2	315,327	0.32		0.80		2568	2720	1280	0.119					10.92																			
down	Qda. Chiguaza	5-3	182,678	0.18		0.79		2566	2600	660	0.052					9.05																			
down	Qda. Chiguaza	5-4	779,198	0.78		0.37		2565	2580	1070	0.014	2565	2570	1070	0.005	21.66	22.31	22.31	37.62																
																				[27]	16.96	0.55	65.04	16.6	20.0	24.0	30.0	32.5	36.3	43.1	52.1	62.5	78.0	84.5	94.4
down	Qda. Chiguaza	5-5	1,199,234	1.20		0.64		2563	2700	1390	0.099	2563	2565	600	0.003	12.50	15.32	15.32	52.94																
																				[28]	18.16	0.56	80.36	14.4	17.4	20.9	26.0	28.3	31.6	40.6	49.0	58.8	73.1	79.7	89.0
down	Qda. Chiguaza	5-6	714,887	0.71		0.62		2560	2568	1550	0.005	2560	2563	1050	0.003	42.33	29.41	29.41	82.35	Rio Tunjuelo															
																				[29]	18.87	0.56	109.76	11.7	14.1	17.0	21.0	23.2	25.9	34.5	41.6	50.0	61.8	68.1	76.1

6.4.2 Channel Flow Capacity

(1) Methodology

The flow capacity of river cross section is defined by passable water discharge within both banks at the bank elevation. Usually the elevations of left and right banks are different, so the flow capacity was evaluated for each bank elevation.

There are several ways to calculate the flow capacity of river cross section. The famous hydraulic software called HECRAS version 4 was used for this analysis. HECRAS has been used widely in the world because of the comprehensive features on hydraulics, easy to use, and was developed by Corps of Engineers of the United States of America. Usually HEC-RAS is used for non-uniform flow analysis as well as unstable flow computation.

HECRAS has been used in DPAE and EAAB for some creeks in Bogota. It is beneficial to make hydraulic model by this software for future usage by DPAE.

Here the HEC-RAS was used in order to calculate the flow conveyance at specific elevations of left and right bank.

If the river bed slope is given, the flow capacity can be calculated as follows,

$$Q_c = K \times \sqrt{S}$$

K : conveyance (m3/s)

S : River bed slope for flow capacity calculation

Qc : Flow capacity in m3/s

Bridge/Culvert

In the Study Area there are three (3) types of structure crossing the creeks. They are bridge, box culvert and pipe culvert. For bridge, Manning formula (uniform flow) is applied. The Manning coefficient was set 0.03 to 0.02 depending on the concrete condition. For culvert of box and pipe, orifice concept was applied. The following is the equation of orifice concept.

$$Q_c = C_d A \sqrt{2g(HW - b/2)}$$

C_d : orifice discharge coefficient(= 0.6)

b : culvert height(m)

HW - b/2 : head on culvert measured from barrel centerline

Qc : Flow capacity in m3/s

(2) Chiguaza

Figure 6-27 shows the profile of creek capacity (left and right banks) comparing with probable discharge distribution. Through this figure, we can see the critical points along the creek. Fortunately the Chiguaza creek has a high flow capacity, because the section of Los Puentes downstream has at least 20 years return period capacity.

The creek has crossing structures such as bridge and culvert. Figure 6-27 also indicates the capacity of main crossing structure assuming without sedimentation. These structures have a sufficient capacity, however, the clogging due to sedimentation and garbage is easily to happen. In this sense, the critical points are selected as shown in Table 6-9.

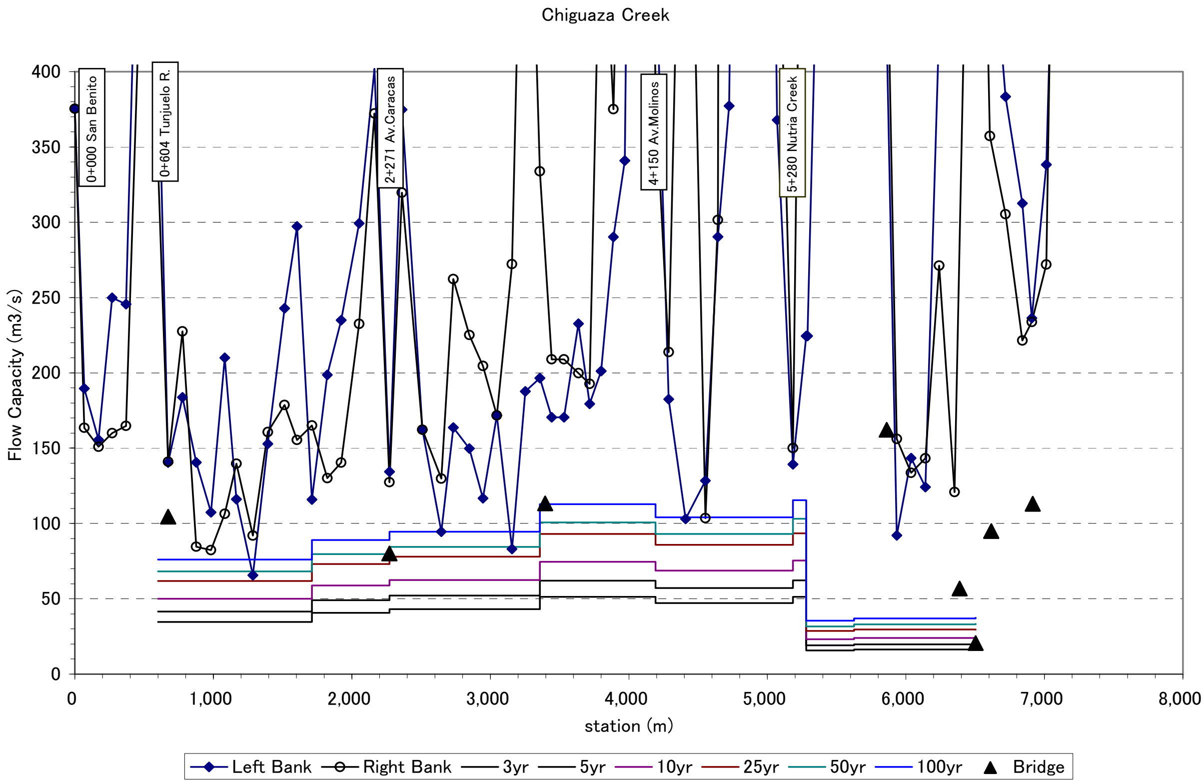


Figure 6-27 Channel Capacity and Probable Discharge of Chiguaza Creek

Table 6-9 Critical Point in Chiguaza Creek

Area Name	Station	Anticipated phenomenon	Remarks
Caracas Avenue	2+271	When sedimentation proceeds at upstream side, overflow could happen toward the surrounding.	Removal of sediment of the Bridge upstream should be done.
Molinos II (Residential Complex)	4+723	Fan apex topography. The overflow due to the obstacle could spread toward left bank.	
Los Puentes (Nutria confluence upstream)	5+450	In terms of the creek alignment, the flow from the Chiguaza upstream could hit the right bank side.	
CRA3 Este	6+388	When sedimentation proceeds at upstream side, the overflow could happen toward left bank side.	Maintenance of bridge upstream side
(CRA 3B Este)	6+504	Small pipe culvert, overflow could happen toward the surrounding.	Maintenance of bridge upstream side
La Gloria (CRA 6A Este)	6+916	When sedimentation proceeds at upstream side, the overflow could happen toward left bank side.	Maintenance of bridge upstream side
Avenue Villaviciencia	0+109 (Zuque)	When sedimentation proceeds at upstream side, the overflow could happen toward left bank side.	Maintenance of bridge upstream side

(3) Santa Librada

Figure 6-28 shows the profile of creek capacity (left and right banks) comparing with probable discharge distribution of Santa Librada creek. The downstream section of Caracas Avenue is inside quarry site. The area around Calle 69 Sur is low capacity area regarding not only bridge and culvert but also the creek size itself.

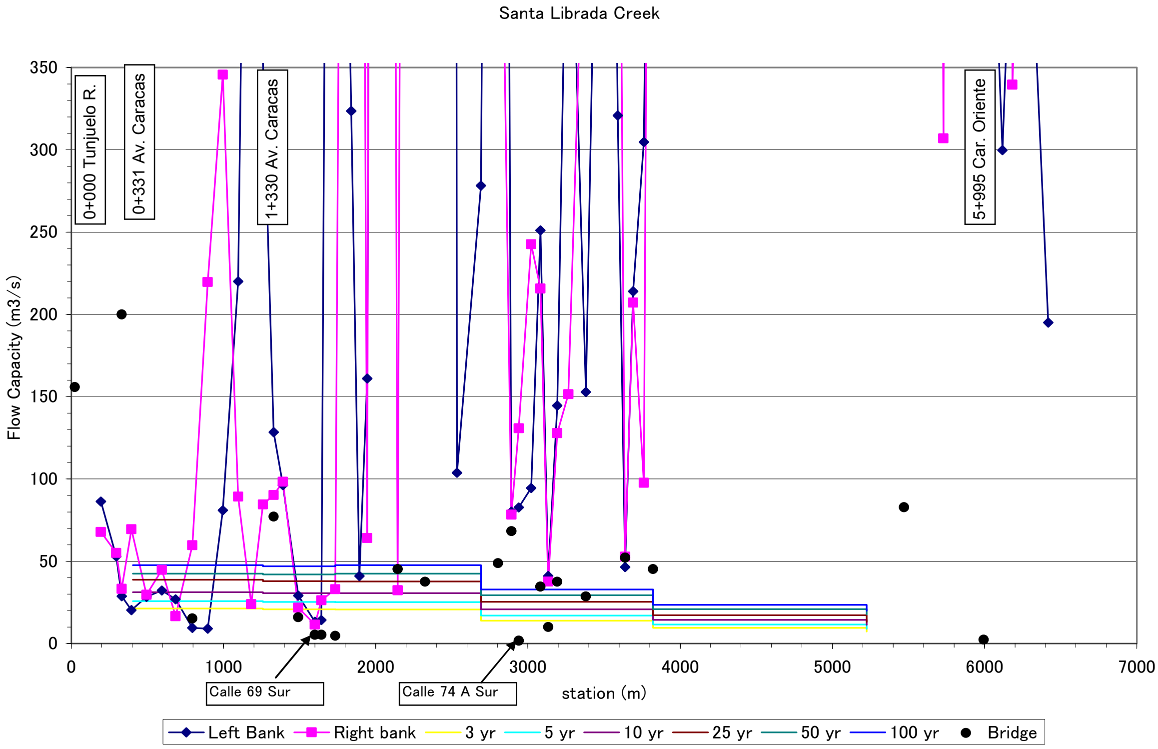


Figure 6-28 Channel Capacity and Probable Discharge of Santa Librada Creek

(4) Yomasa

Figure 6-29 shows the profile of creek capacity (left and right banks) comparing with probable discharge distribution of Yomasa creek. Fortunately the Yomasa creek has high flow capacity basically. Also the number of bridge and culvert which could become critical is very few.

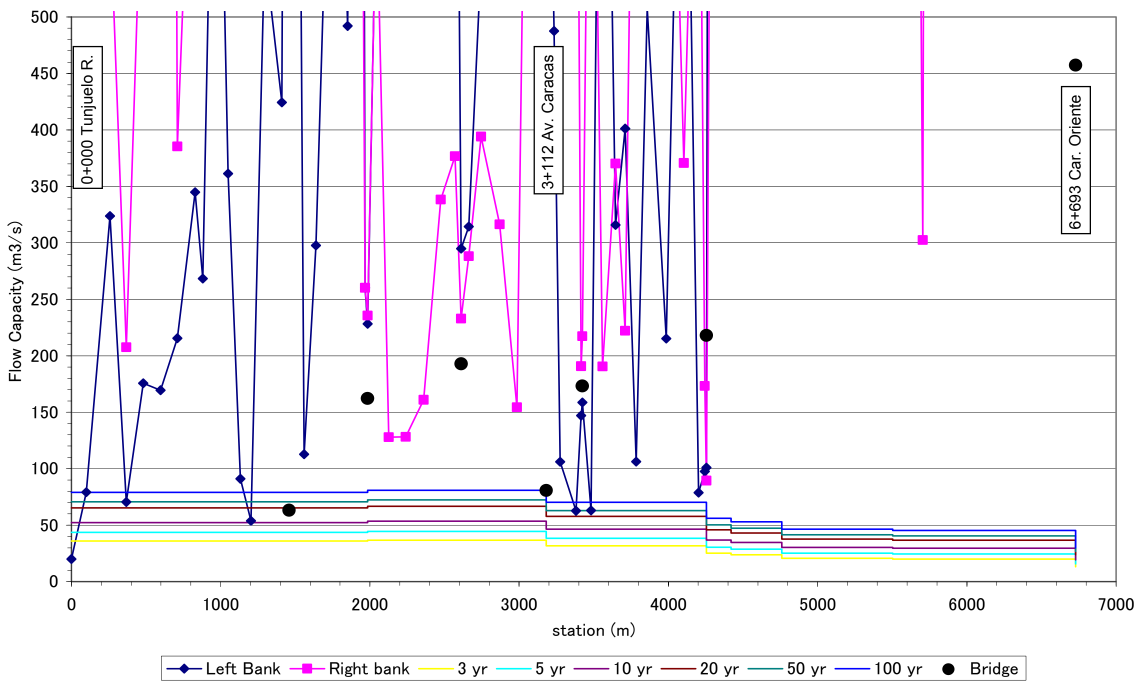


Figure 6-29 Channel Capacity and Probable Discharge of Yomasa Creek

(5) La Estrella and Trompeta

Figure 6-30 and Figure 6-31 show the profile of creek capacity (left and right banks) comparing with probable discharge distribution of La Estrella creek and Trompeta creek, respectively.

In the La Estrella, the central reservation creek in Boyaca Avenue has small capacity, the return period is less than three (3) years.

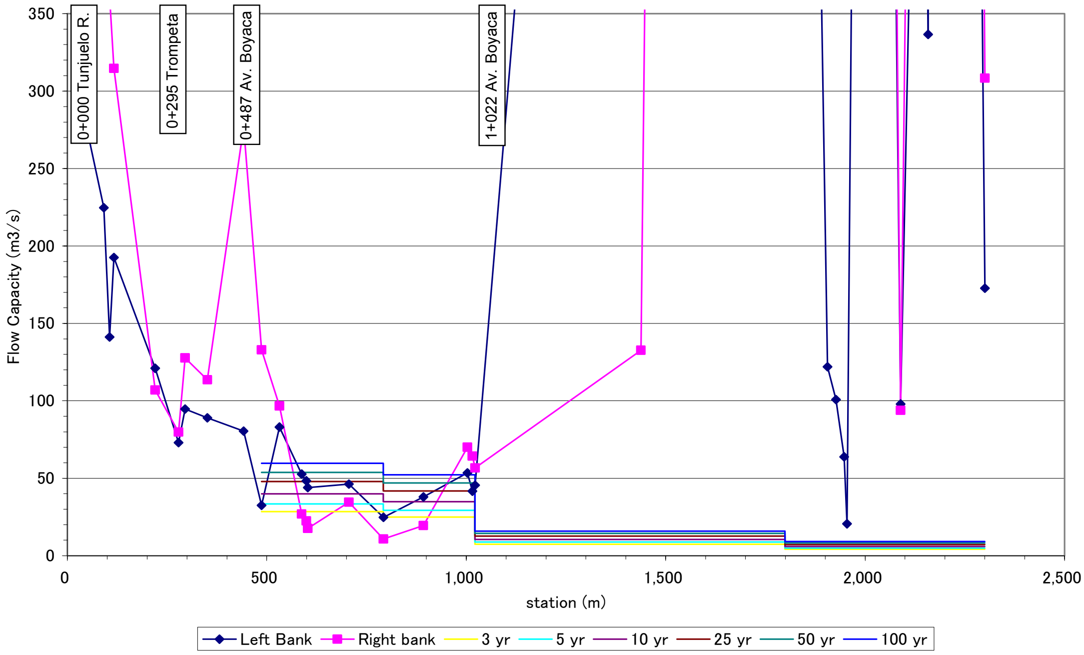


Figure 6-30 Channel Capacity and Probable Discharge of La Estrella Creek

In the Trompeta, the section upstream of the Infierno creek has comparatively small capacity, the return period is less than three (3) years.

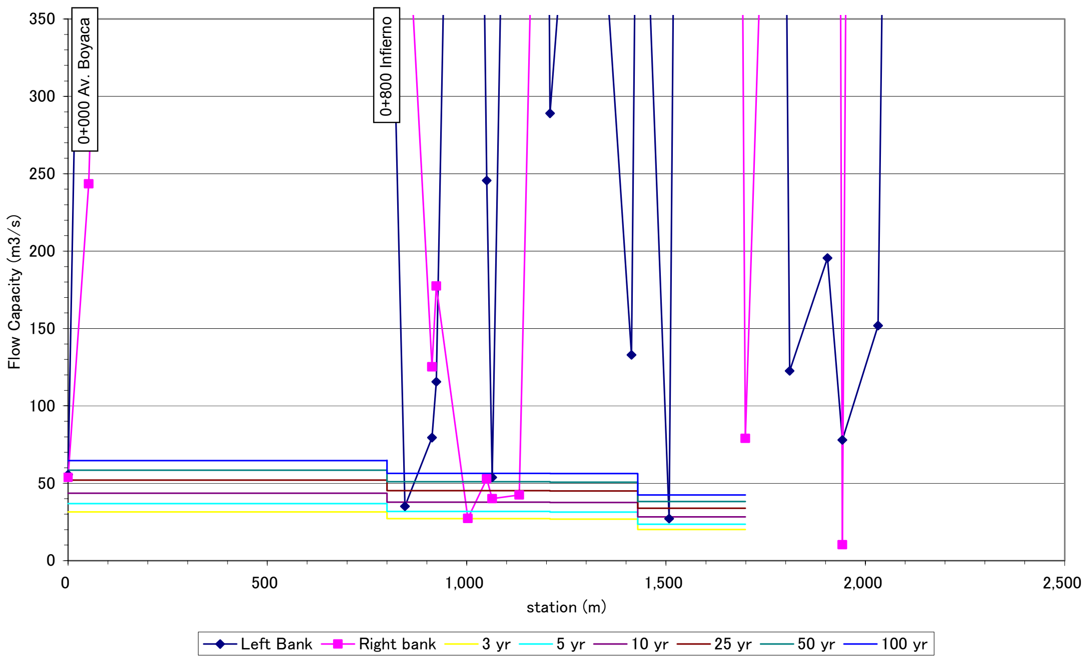


Figure 6-31 Channel Capacity and Probable Discharge of Trompeta Creek

6.4.3 Flood Mapping

(1) Methodology

In the target creeks in Bogota as well as the Study area in Soacha, the creek / river bed slope is quite steep and the topography is represented by V-shape contour lines, the flood flow is quite one dimensional. Since the energy slope is quite high, the uniform flow concept is appropriate. In the creek flow capacity evaluation (Supporting Report S6 Chapter 1), conveyance calculation was already applied based on Manning's equation.

For one (1) dimensional water surface profile calculation, HEC-RAS was used in the Study considering the usefulness, world-wide popularity, freeware and the existing studies related with the Study area.
Manning's roughness coefficient is the most dominant parameter in one dimensional hydraulic calculation. Considering the steep slope (creek bed), gravel and boulder on the river bed and grass on banks, the Manning's roughness was set 0.040.

(2) Chiguaza

For Chiguaza creek, middle reach to downstream reach, one dimensional hydraulic calculation was made using HEC-RAS model in order to check the flood area.

The model outline is as follows,

Modeled Reach: San Benito to Los Puentes

Cross Section: River cross section survey (January 2007) supplemented by 2 m contour line of Bogota for floodplain

Discharge: Discharge by rational method at Los Puentes (25 years return period, refer to Supporting Report S6 Chapter 3).

The flood map by this calculation is shown in Figure of next page and Data Book 1 GIS Map as Monitoring Plan Map.

The reason why 25 years return period was selected is as follows, the return period of the channel capacity of the downstream reach is between 10 to 25 years if the peak discharge of Los Puentes is applied. The waterlevel at warning at Molinos station is also corresponding to the overflow discharge at downstream reach. Therefore the magnitude of the flood map is better to same magnitude because people living there feel the magnitude at hand.

According to the rational method discharge calculation, the peak discharge is decreasing from Los Puentes to the downstream reach because the flood concentration time is becoming longer while the catchment area is not increase so much. This kind of theoretical issue should be confirmed by actual monitoring data at Molinos and El Hoyo after the Study.

6.4.4 Flash Flood Mapping

In the target creeks catchment substantial flash flood such as called debris flow has not taken place on record. In this study, aerial photo interpretation and creek condition survey, and site visit were frequently conducted. Regarding the susceptibility of flash flood occurrence, recent slope failure and creek condition such as sediment deposition on the creek and vegetation on banks, and downstream creek condition regarding the flash flood occurrence (experience) are important factors and studied. It is concluded that the Yomasa (downstream end of sub-catchment No.2) should be regarded as a basic point for the considering of flash flood susceptibility. The upstream reach of the basic point of the Yomasa creek is assumed unstable sediment remains together with drift woods. Also in the upper catchment (sub-catchment No.1) many new slope failures are recognized.

The yellow zone of the Yomasa creek is shown in Data Book 1 GIS map. The zone is not affected by houses or building in this case.

The sediment runoff volume was tentatively estimated as shown in Supporting Report S6 Chapter 4 with description of the detailed methodology. The purpose of the evaluation of sediment runoff volume is, in Japan, by laws, to design sediment control structure if it is feasible, and to make detailed zoning map for the relocation from dangerous zone.

In the Yomasa creek, since there is no record on substantial flash flood in the past, the estimated sediment volume should be supported by future sediment balance studies in other creeks for sediment control planning and detailed zoning. The recommendation of the sediment balance study was described in the Supporting Report S6 Chapter 4. The methodology is quite primitive and needs steady site investigation, however, the Yomasa creek should have own efforts. Without this kind of steady efforts, any other mathematical simulation is meaningless.

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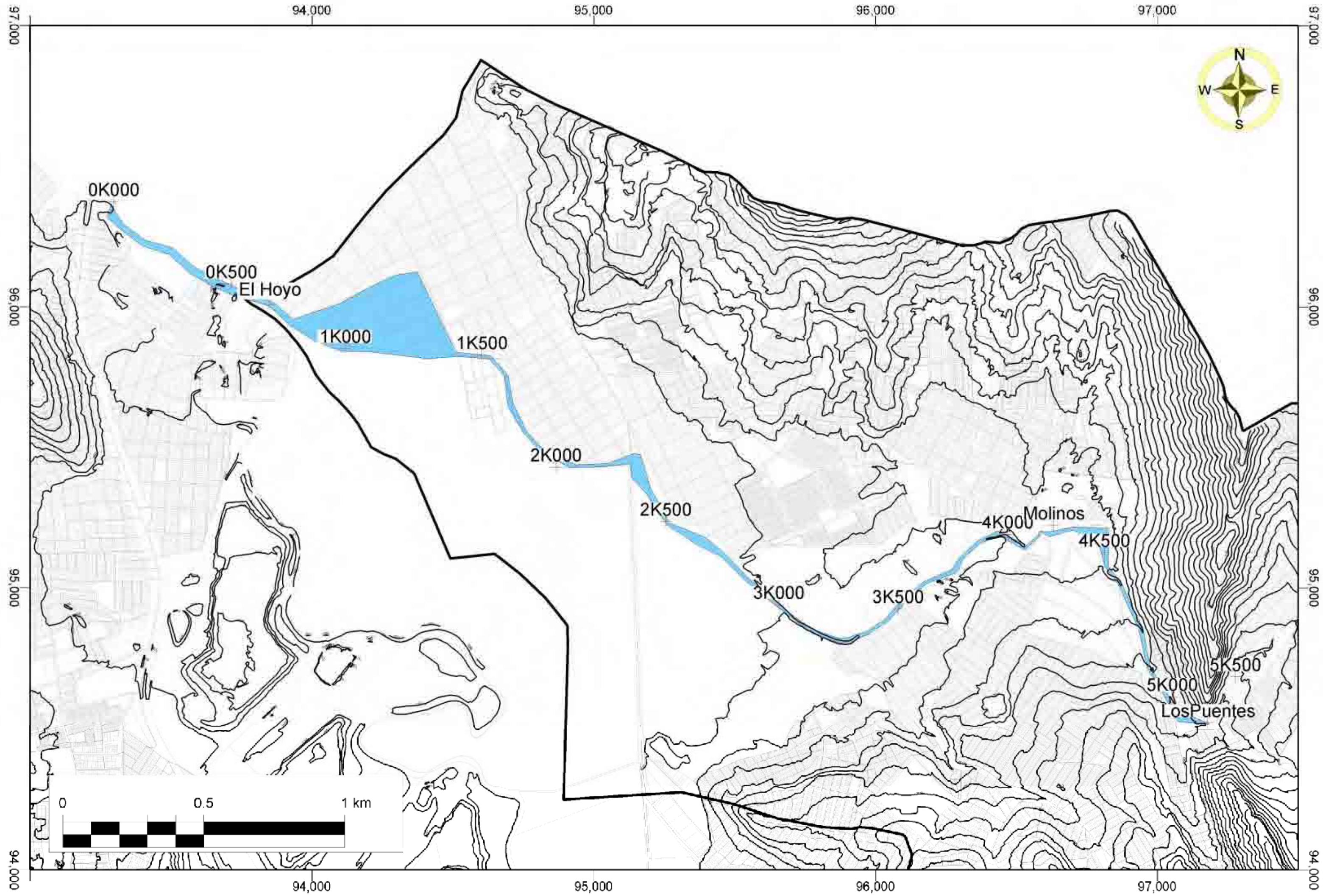

Figure 6-32 Flood Area for 25 Year Return Period in Chiguaza

6.5 Monitoring and Early Warning Plan

6.5.1 Introduction

The target creeks in Bogota in the Study are in four (4) tributaries catchment of the Tunjuelo River for flood disaster. They are the Chiguaza, Santa Librada, Yomasa and La Estrella- Trompeta (including Infierno). These creeks have steep bed slope such as five (5) to seven (7) degrees, which could result into occurrence of flash flood associated with sediment-laden flow as well as frequent flooding in riverine area.

One of the significant features in the study area in terms of the disaster prevention is that structure measures and non-structure measures have been implemented by the related organizations in and around the study area. For example, EAAB has been conducting river improvement and flood control project along the Tunjuelo River. Also EAAB has been conducting flood area delineation studies almost all the creeks in the study area in order to identify the environmental management zone along the creeks.

DPAE is carrying out hydro-meteorological monitoring and early warning in the Tunjuelo river basin based on their own monitoring system in order to issue flood warning in the basin and to execute emergency response with coordination with other related organizations such as locality government, firefighter department, civil defense, etc. DPAE is only organization who is in charge of flood monitoring and early warning system in the Study area.

In the study area, responsibilities on flood management are shared among DPAE, EAAB and SDA as shown in the following figure.

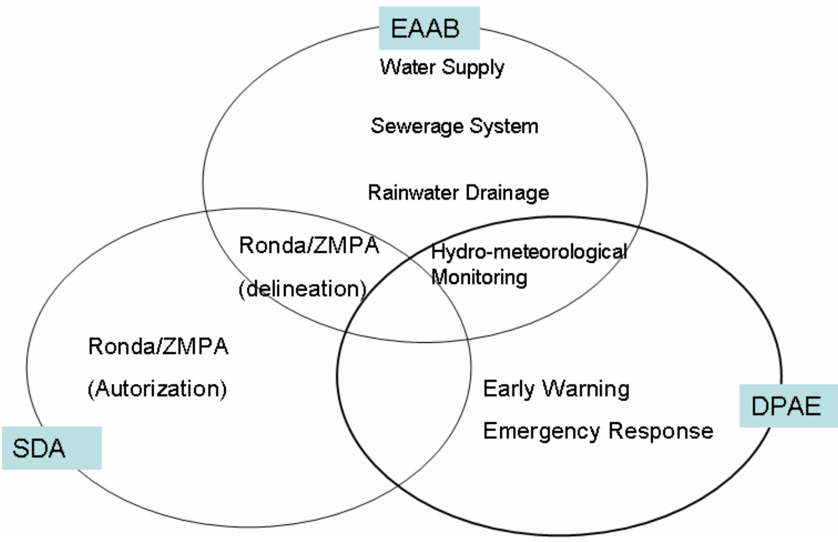

Figure 6-33 Responsibility Diagram on Flood Management in Bogota

The monitoring and early warning plan in the Study should be those to enhance and extend DPAE's activity into the Study Area.

6.5.2 Planning Principle

(1) Objective of Monitoring and Early Warning System

The plan of monitoring and early warning system (MEWS) is prepared for DPAE. The scope of the monitoring and the early warning must be limited to the design of the monitoring and the early warning system for short, middle and long term for each study area.

The objectives, which are tried to achieve in the plan, are;

- Saving of people's life in the study area in Bogota
- Enhancement of capacity on disaster prevention in DPAE

(2) Basic Conditions

The above-mentioned plan was prepared with short, middle and long term plans. The definition of short, middle and long is shown in Table 6-10. The target year of the plan is set up in 2020, assuming that the implementation of the plan starts in 2007 and fourteen (14) years would be required for the completion. The reason for starting the said plan in 2007 is that the pilot project(s) in this Study will be undertaken as a part of the proposed plan.

The target area of the plan is the study area in Bogota including the Chiguaza creek catchment, Santa Librada creek catchment, Yomasa creek catchment and the La Estrella Trompeta creek catchment.

Table 6-10 Definition of Short, Middle and Long Term Plan

Plan	Year	Definition
Short	2007-2008	It is urgently required and should be implemented as pilot projects which will become the basis of middle and long plan.
Middle	2008-2012	This is an extension for a short term plan in order to secure the target creeks more.
Long	2013-2020	This is a fully advanced system based on the experience of short and middle plans.

(3) Planning Principle

In order to achieve the above objectives, the Study Team proposed the following basic principles for the planning.

- The purpose of the proposed plan is to prevent the people in the previously affected area from the same flood damage in near future, or mitigate the future damage by the plan.
- Thus, as a tool for the above, monitoring of hydro-meteorological conditions by equipment and preparation of early warning system based on the monitored data are required.
- Therefore, it should be pointed out that the people who should evacuate in an event of flood understand the meaning of the early warning system and they take necessary actions are quite important. In this sense, unless the people understand the importance of the system and can make use of the system actually, any expensive equipment for the monitoring and early warning is meaningless.
- In the above context, the Study Team has studied and discussed what to do at first in Bogota in order to achieve the study purposes believing that installation of monitoring equipment in the study area is just a tool.

In general, early warning system can be separated into the system based on real time monitoring and the system based on weather forecast as shown in Figure 6-34. It should be pointed out that the system based on real time monitoring is not always telemeter based system, but also people's monitoring using radio and telephone. The system based on weather forecast means that radar system, numerical weather analysis are made use of. In order to issue warning, ability and improvement of accuracy are required placing strong emphasis on the past floods. DPAE has been doing the early warning system based on real time monitoring via telemeter system and telephone. The Study also is placing emphasis on the system based on real time monitoring by the people.

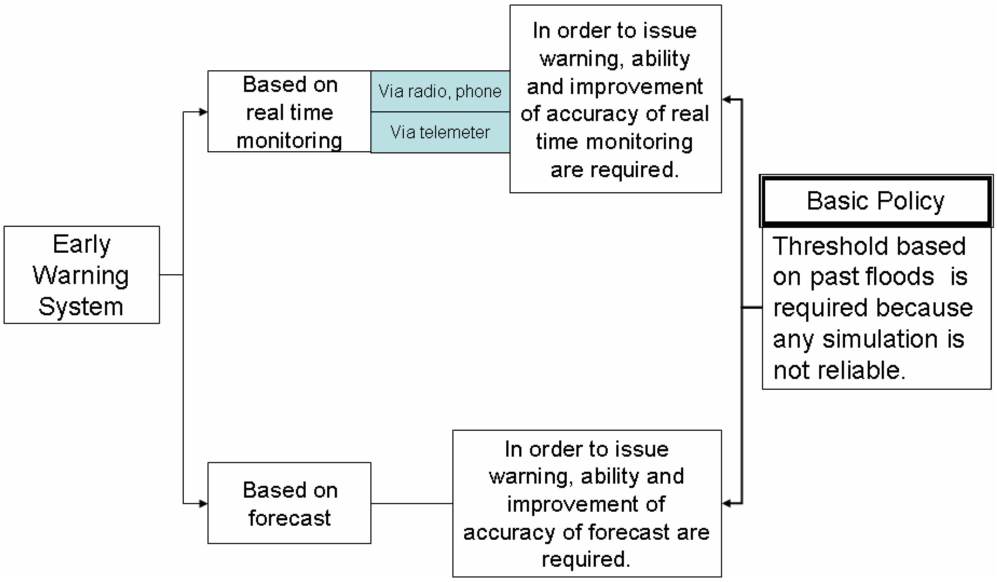

Figure 6-34   Early Warning System to be Considered in DPAE

The plan is a kind of extension and addition for the existing system regarding the monitoring system. The proposed plan has mainly three (3) supports; monitoring and data gathering system, data analysis and hazard assessment, and warning issuing.

It should be noticed to the Colombian side that the plan proposed in this report will be revised based on the monitoring activity which started in September 2007 and accumulated hydrological data under the DPAE leadership.

6.5.3   Monitoring and Data Gathering System

(1) Monitoring Plan

1) Considerations for Each Creek

The basic principle for the monitoring system is as follows,

- If there are existing stations (rainfall / waterlevel) which have a long time record in the past, the plan should consider the usage of the available data. If a station is suspended due to reasons such as lack of budget, stolen, at first it should be considered such station should restart as soon as possible.
- Advanced technology such as telemeter system should be installed after when the hydrological data is accumulated for the setting up of the early warning criteria. The primary purpose of the telemeter system is to issue early warning "timely" and "accurately" to the affected people, those who should evacuate upon the issued warning.
- The people who should evacuate upon the issued warning are those who have already understood the importance and real meaning of the hydrological data and issued warning such as critical waterlevel XX m and rainfall amount YY mm in 10 minutes.
- In order to let the people understand the importance and real meaning of the hydrological data, at first they should be trained to observe the hydrological data such as reading of staff gauge by themselves.
- It is clear that for setting up of an appropriate warning criterion, a set of hydrological data (rainfall and waterlevel/discharge) is necessary. To obtain such data, simple measurement equipment should be used for example self-recording rainfall gauge, self-recording waterlevel gauge and staff gauge.

- The Study Team would like to avoid installed expensive equipment being stolen.
- The telemeter system (equipment) should be installed when necessity is confirmed by hydrological study using measured data by manually and simple equipment as well as when the affected people understand the importance and real meaning of the hydrological data and issued warning and more timely and accurate warning is regarded as necessary.

2) Overall Monitoring Plan with Priority

Among the four (4) creeks as the Study Area, the flood disaster which caused victims happened in the Chiguaza basin in May 1994. According to newspaper articles on the May 1994 flood, four (4) people died for the flood. It is regarded as one of the most serious floods in the Study Area on record. In other creeks in the Study Area, such serious floods could not be confirmed by the Study Team. This is one of the main reasons why the Chiguaza creek catchment was selected as the pilot project area.

As the first step, this flood phenomenon shall be set to the basis of the early warning system planning.

The May 1994 flood in the Chiguaza basin can be characterized by the movement of deposited materials on the river bed in the Zuque creek which is located at the most upstream of the Chiguaza, overflow of sediment to the street along the right side of Chiguaza due to the small capacity of culvert crossing the Carrera Oriente. Also in the middle reach, overflow of water to the street along the left side of the Chiguaza took place.

In the case of Chiguaza, the flood phenomena can be classified into three (3) according to the river bed slope.

Table 6-11 Three (3) Types of Flood in the Chiguaza Creek and the Corresponding Early Warning System

River Reach	Tunjuelito	Molinos- Los Puentes	Los Puentes upstream
Phenomena	Inland flood by high water of the Tunjuelo River or Chiguaza creek itself	Overflow from critical points	Overflow from critical points
Early Warning	Warning for the lowland area based on San Benito waterlevel	Rainfall Monitoring at Maralba station and Juan Rey Station Warning to the middle reach overflow	Improvement of culvert

For the area Los Puentes upstream, first of all, rainfall measurement especially short duration amount of rainfall should be measured. In the upstream area , currently there is Juan Rey station (DPAE and EAAB) however it is far from the Zuque creek in which the May 1994 flood happened. In order to monitor the rainfall near the Zuque creek, another rainfall station is necessary. In this context, the area called Quindio was selected as candidate area.

As it was pointed out in 6.5.2 (3), the people who suffered from past floods should participate into the hydro-meteorological measurement so that those people should understand the importance and meaning of the monitoring equipment. Thus along the Chiguaza Creek some candidate locations for manual waterlevel monitoring were considered.

Also for more accurate early warning system in the Chiguaza, not only rainfall data but also waterlevel measurement is necessary to accumulate the continuous data set of rainfall and waterlevel. Since in the Chiguaza there is not automatic waterlevel station at this moment, some candidate locations for automatic waterlevel monitoring were considered as long as the location is not affected by the backwater of the Tunjuelo River.

Additionally, the security issue which assures the stable maintenance and the protection from robbery was considered

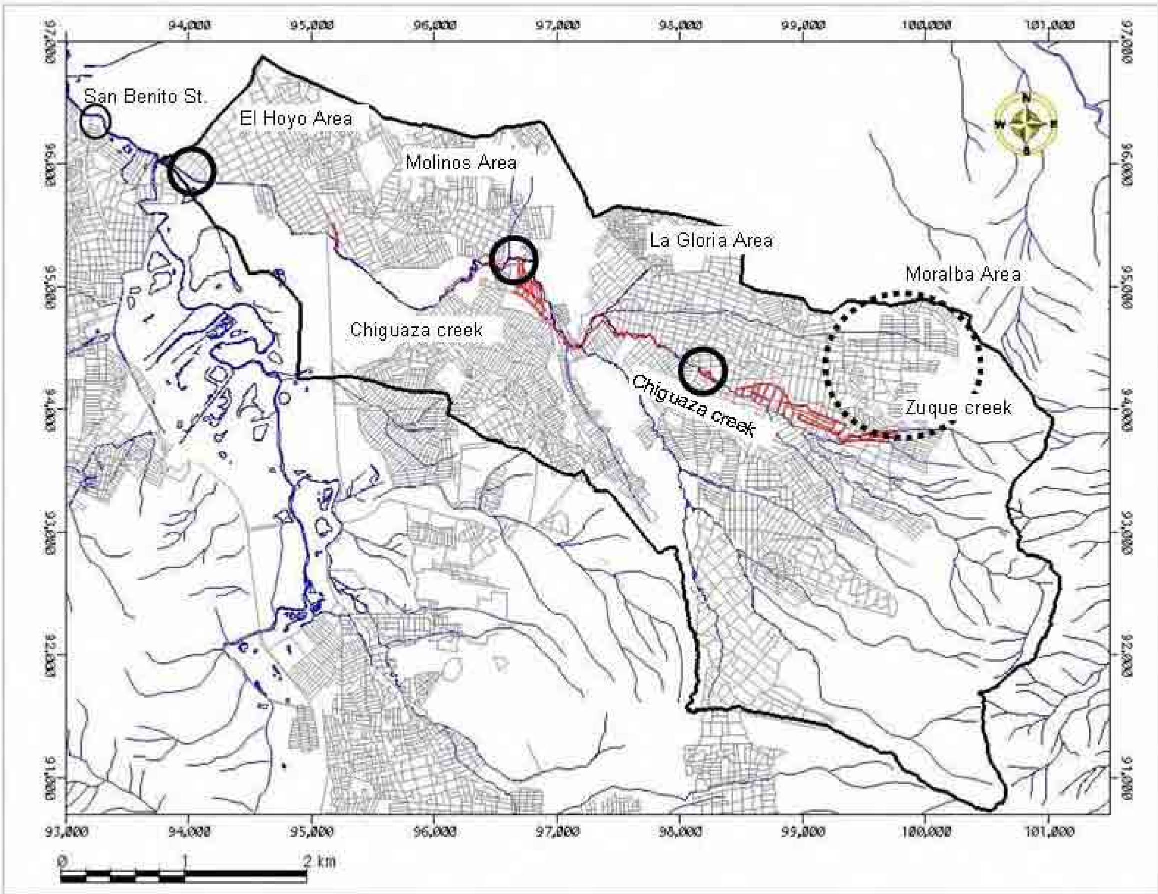

Figure 6-35 Location of Monitoring and Target Area

Figure 6-36 shows the relation between the target areas and the monitoring stations. For each target area, the necessity of monitoring is explained. First of all, manual monitoring of waterlevel at La Gloria and Molinos and El Hoyo should be started in the area in which the people were affected by past major flood. In May 1994, the upstream short duration rainfall caused the floods in downstream, so that the rainfall monitoring should be started in the upstream of affected area. Also hydrological purposes are considered in the location of Molinos, La Gloria and Moralba. The measurement at La Gloria is useful to study the flood concentration time and the measurement at Molinos by automatic recording equipment is providing the continuous waterlevel data. The Moralba automatic recording rainfall measurement will provide the short duration rainfall in the upper area. In Molinos, since it is located in the representative of the Chiguaza creek catchment, velocity measurement should be started to confirm the accuracy of flood peak discharge.

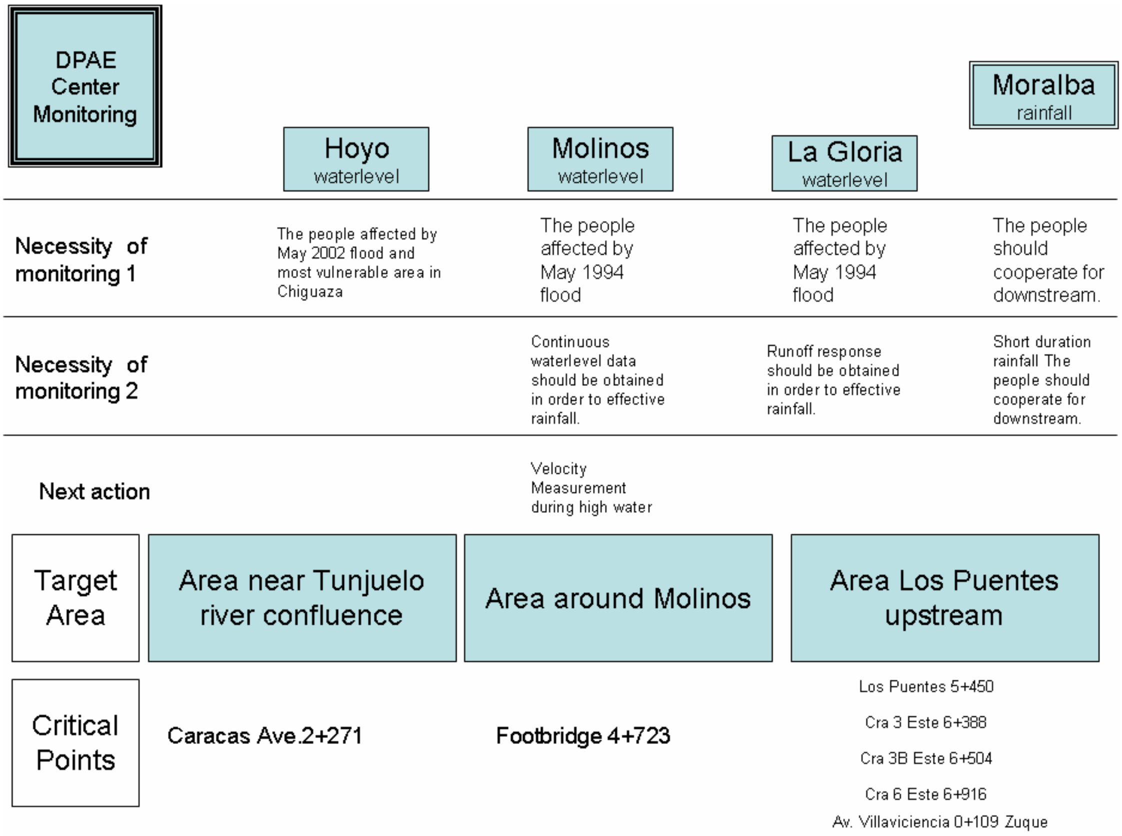

Figure 6-36 Necessity of Monitoring and Target Area

(2) Data Gathering System Planning

Proposed data gathering system can be separated into two (2) phases, namely, “data accumulating and people’s training phase” and “timely and accurate warning using advanced technology phase”.

1) Data Accumulating and People’s Training Phase (Short Term Data Gathering System)

Based on the above, the short-term monitoring system is as follows,

Table 6- 12 List of Stations to be Monitored for DPAE (Short Team)

Creek	Data	Monitoring Station	Existing or New	Purposes
Chiguaza	Rainfall	Juan Rey (DPAE telemeter)	Existing	Short duration rainfall is monitored by DPAE via telemeter system.
		Moralba in the upper part (self-recording type with small display monitor)	New	To supplement the data of Juan Rey station, self-recording type stations shall be installed in the upper part of the Chiguaza. In order to let people observe the data timely, the equipment should have a small display.
Chiguaza	Waterlevel	El Hoyo (DPAE station at bridge before the confluence of the Chiguaza to the Tunjuelo river)	Existing	To analysis the response for the discharge from the Chiguaza creek in the event of storm in the Chiguaza catchment.
		Mollinos at bridge of the Chiguaza downstream	New	To analysis the response for the discharge from the Chiguaza creek in the event of storm in the Chiguaza catchment. To prepare waterlevel and discharge relation curve, the rainfall and runoff relation will be studied as well as to issue a warning to the downstream based on the monitored waterlevel.
		La Gloria (affected area along the Chiguaza upstream)	New	To let the people understand the importance and real meaning of the hydrological data, at first they should be trained to observe the hydrological data such as reading of staff gauge by themselves.

Among the above stations, in Moralba and Molinos, automatic-recording type stations were proposed. The rainfall equipment is automatic type with display. Because in the proposed system it is necessary for observers to read the current data through display, other type of equipment, for example, recording chart type, is not suitable. The waterlevel equipment for automatic-recording type is ultrasonic type sensor. In the Study area, the creek course is fixed and the waterlevel change is very fast. Therefore the non-touch water stage sensor should be recommended. Also, from the viewpoints of economics, popularity in Colombia, the ultrasonic type sensor is regarded as best sensor.

The overall concept for new stations in short term is described in Table 6-13.

Table 6-13 Overall Concept for Chiguaza Creek Location of Monitoring Points

Station Name	Basic Point(Distance from Target Point)	Monitoring Item	Reason	Feature on Hydraulic or Catchment	Type of Equipment	Reason to select the equipment type	Security of Equipment	Person in charge of Maintenance	Capacity of person in charge of maintenance	Other remarks
Moralba Rainfall Station	Flood concentration time 65 minutes	10 minutes rainfall	Short period rainfall is very effective for the flood discharge in downstream, so such short duration rainfall should be monitored.	The rainfall is quite local and the location can be supplemental between Juan Rey and Vitelma.	Tipping bucket type with data logger having display	Since the short period rainfall is monitored, self-recording type and display were included.	The location is inside the school and the security guard is working 24 hours.	Security guard of school and students	DPAE is planning some education program for security guard and students.	The monitoring people will have cooperative policies for the downstream people.
La Gloria Waterlevel Station(Catchment Area 3.8 km2)	Flood concentration time 40 minutes	water level	The place is where the May 1994 flood-affected people are living.	The location is upstream of the Chiguaza, and the runoff response by upstream rainfall should be monitored.	Staff gauge and simple waterlevel detector	The location is steep slope reach, exposed by rocks. At least the runoff response should be recorded.	The local residents are well organized in order to watch the equipment by DPAE assistance.	Local residents(DPAE)	The location was affected by May 1994 flood , so the people's awareness for flood monitoring is very high.	Letting people to know the response time of flood by rainfall in upstream and the false alert can not be avoided.
Molinos Waterlevel Station (Catchment Area 13.9 km2)	Flood concentration time 25 minutes	water level	The place is where the May 1994 flood-affected people are living.	The place is downstream of the confluence of 3 upstream tributaries, so that its runoff reflecting the total runoff from the upstream. It is only location to foresee the inundation possibility in the downstream area.	Staff gauge	To establish people's involvement system with waterlevel monitoring	The local residents are well organized in order to watch the equipment by DPAE assistance.	Local residents for staff gauge(DPAE)	The location was affected by May 1994 flood, so the people's awareness for flood monitoring is very high.	Letting people to know the response time of flood by rainfall in upstream and the false alert can not be avoided.
		Water level(continuously)	The place is downstream of the confluence of 3 upstream tributaries, so that its runoff reflecting the total runoff from the upstream. In this sense it is necessary to record the continuous water level data in order to evaluate runoff mechanism such as effective rainfall.		Ultra sonic type waterlevel gauge with data logger having display	In order to evaluate the effective rainfall in future, the continuous waterlevel data shall be stored.	The location is inside the school and the security guard is working 24 hours.	Security guard of school and students	DPAE is planning some education program for security guard and students.	

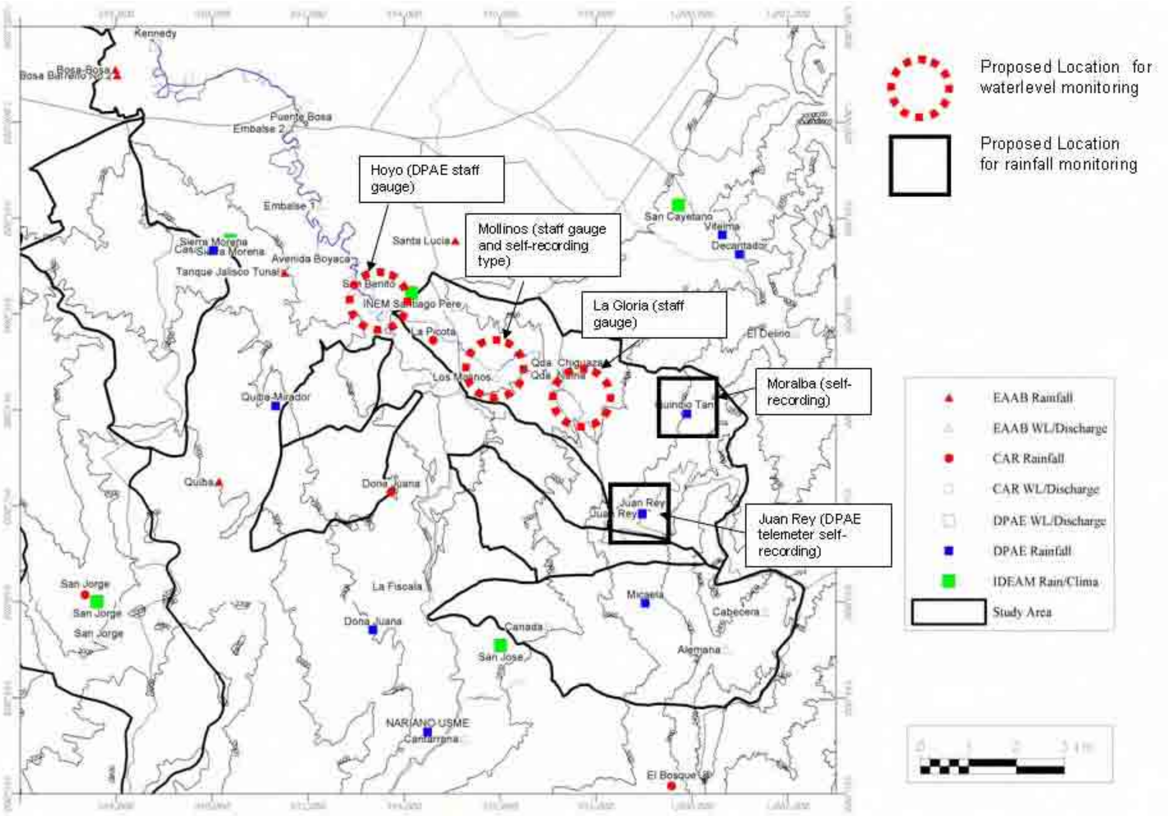

Figure 6- 37 Proposed Location to be Monitored for DPAE (Short Team)

In the case of Moralba, the correlation of 10 minutes rainfall in time with Juan Rey (DPAE) should be checked. If the 10 minutes rainfall for warning level is taking place simultaneously in Moralba and Juan Rey, the upgrading of Moralba is not recommended.

In the case of Molinos, the correlation of instant waterlevel with El Hoyo during non-flood time of the Tunjuelo river should be checked. The points to be checked are the waterlevel rising velocity at Molinos and El Hoyo and the flood concentration time at those stations.

Regarding the data gathering system for rainfall, since DPAE has already have the telemeter system the proposed new stations in the above is assuring the compatible system to the existing.

2) Timely and Accurate Warning Using Advanced Technology Phase (Middle and Long Term Data Gathering System)

In the middle-term, the installed automatic recording rainfall gauge at Moralba and the automatic recording type waterlevel gauge at Molinos should be telemeterized only when such upgrading is evaluated to be necessary.

In the Yomasa creek, in the upper part of the catchment (Alemana upstream) there is potential of debris flow because sediment depositions and recent slope failure are recognized. Therefore, rainfall measurement in upper part and waterlevel measurement in the downstream shall be started by simple equipment as they do in the Chiguaza creek.

In the long-term, in order to issue timely and accurate warning, the replacement of the existing automatic stations should be done only when such upgrading is evaluated to be necessary. Also if it is evaluated that more precise measurement of local rainfall in the Study Area is necessary, radar system should be considered in the Tunjuelo river basin.

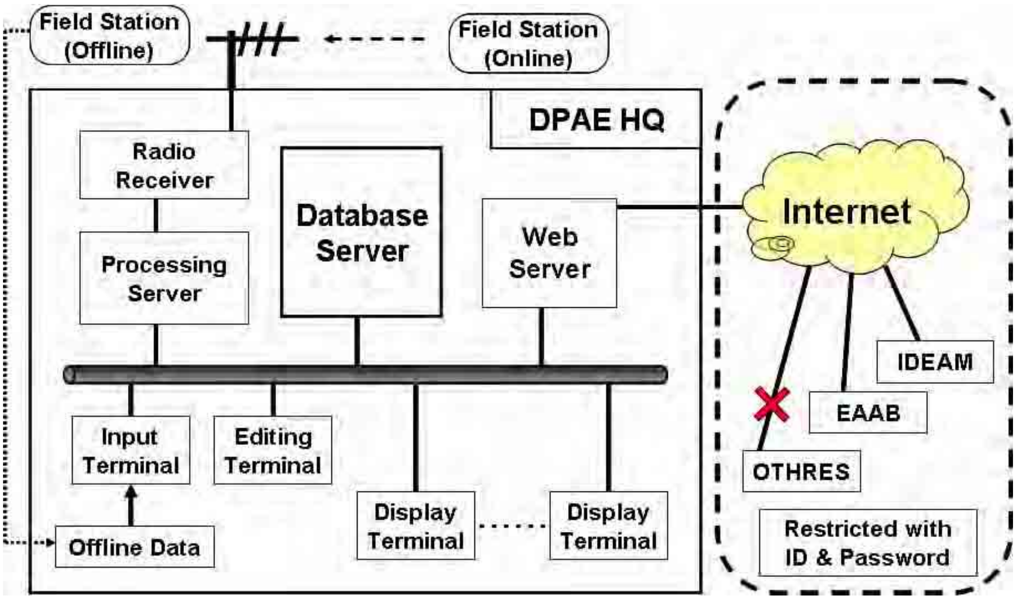

Figure 6-38 Existing Monitoring System of DPAE

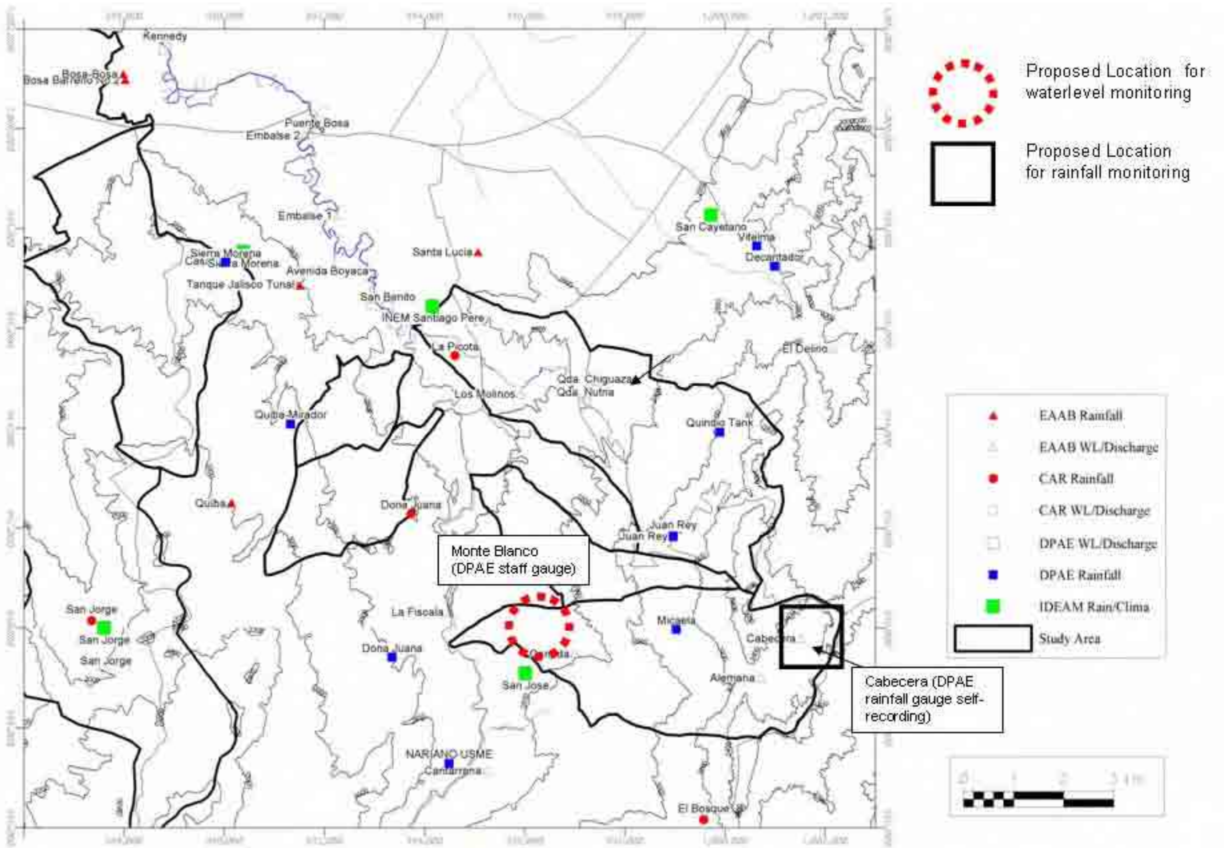

Figure 6-39 Proposed Additional Location to be Monitored for DPAE (Mid Team)

(3) Detailed Monitoring Plan for Chiguaza Creek

1) Data Accumulating and People’s Training Phase(Short Term Data Gathering System)

Regarding the rainfall data accumulating, DPAE’s Juan Rey station (telemeter) and Moralba station installed in the JICA Study can be valuable information covering the upper part of the Chiguaza catchment. The Moralba station has automatic recording equipment (Motorola RTU). The security guard at Moralba school will record the hourly rainfall data in the data sheet provided by DPAE by telephone. Also DPAE will download the 10 minutes interval rainfall from the data logger two (2) times a month.

Regarding the waterlevel data accumulating, La Gloria, Molinos and El Hoyo will be monitored by community three times a day in normal time and more frequently during high water.

Timing of the waterlevel monitoring at La Gloria, Molinos and El Hoyo should be same, for example, 6AM, 2PM and 10PM as communities can agree. By this monitoring timing, people can understand the waterlevel conditions simultaneously. For example, when the waterlevel at Molinos is almost at the bank height to overflow, if people in El Hoyo have been observing the waterlevel same time as the Molinos, they can understand the meaning of waterlevel at Molinos as a warning criteria.

Also when heavy rainfall is observed in Moralba or measured in Juan Rey station, if such information is transferred to the downstream points like Molinos, La Gloria and El Hoyo, they could know how much minutes is taken to arrive the flood water arrives at their points as their own experience.

Mutual collaboration between DPAE and communities including school is quite inevitable in order to establish the monitoring system.

The Study Team also would like to propose communication between stations, which means upstream observers can inform the monitored data to the downstream and the people in downstream can take action by their own decision because of the short flood concentration time. Also people's awareness for the early warning should be evaluated by DPAE before installation of new telemeter equipment. The criteria how people have awareness for the early warning system is how they can continue the daily monitoring activities and how they can take action such as evacuation training based on DPAE provided data and people's monitored data.

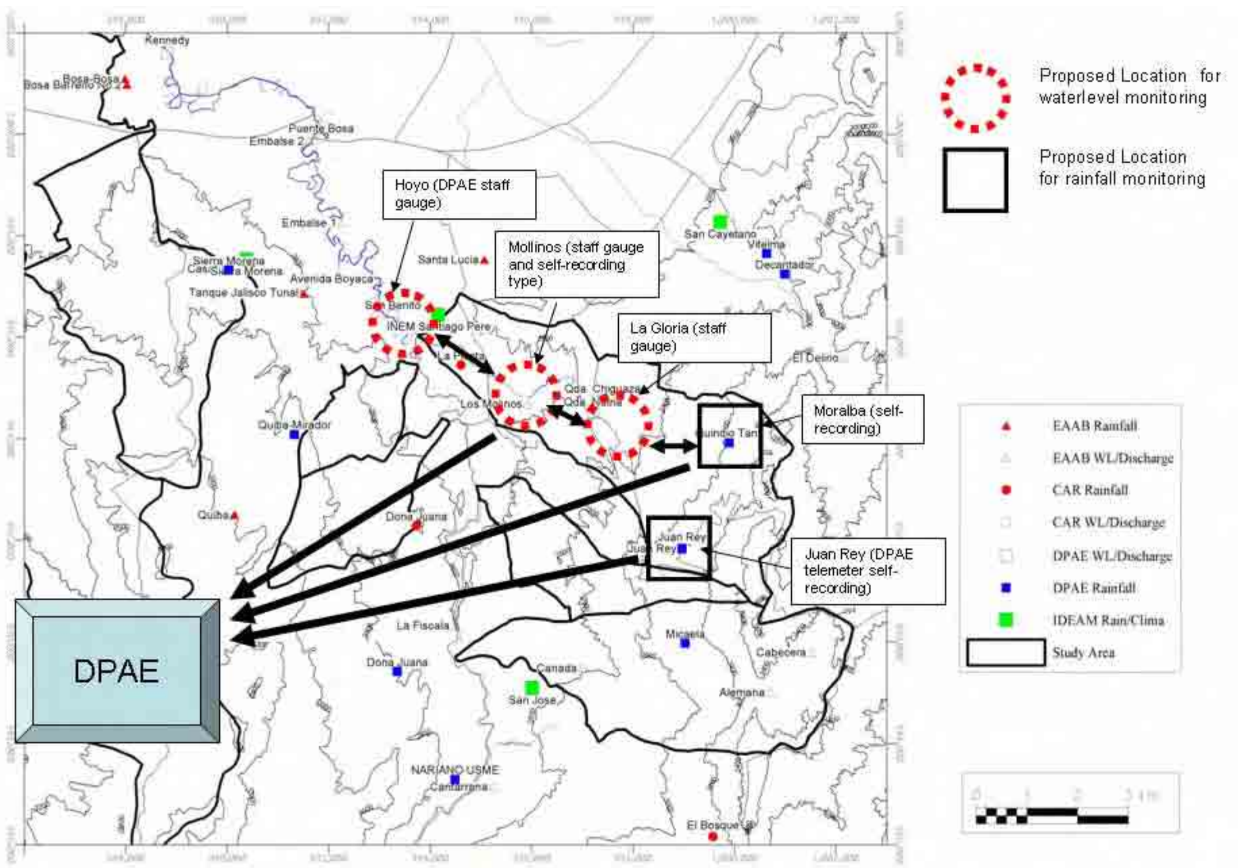

Figure 6-40 Data Gathering System (Mid and Long term)

2) Timely and Accurate Warning Using Advanced Technology Phase (Mid and Long Term Data Gathering System)

Figure 6-40 is proposed data gathering system in the mid term. The figure is assuming that Molinos (waterlevel) and Moralba (rainfall) station are on-line with DPAE system.

6.5.4 Warning criteria

(1) Hydrological Consideration for Warning Criteria

1) Runoff Mechanism

One of the hydrological features to be clarified in the study area is rainfall loss in the process of rainfall and runoff. Since there are few data sets of rainfall and discharge in the study area, obviously it is very difficult to calibrate the hydrological analysis. However, in order to issue a warning timely and properly, it is necessary to make efforts to measure the data sets of rainfall and discharge in the study area. By the measurement, especially the following should be clarified.

- Flood concentration time
- Rainfall loss(runoff coefficient)
- Effect of antecedent rainfall

Flood concentration time can be clarified by accumulating of rainfall hyetograph and waterlevel hydrograph. The hyetograph of Moralba and Juan Rey and waterlevel hydrograph at La Gloria, Molinos and El Hoyo should be accumulated by DPAE.

The evaluation method of rainfall loss is explained in Figure 6-41. The top figure is the rainfall hyetograph and discharge hydrograph. From the discharge hydrograph, the direct runoff is separated at the rising limb of the discharge hydrograph. Then the corresponding total rainfall depth and the runoff depth (this is effective rainfall depth), which is that the direct runoff volume is divided by the catchment area at the waterlevel station are plotted in X-Y graph. If we can plot several points in X-Y graph, some tendency that some points are positioned in upper and some are lower. Basically, the inclination of each point on the graph means the runoff coefficient.

It is expected that the runoff coefficient is varied by antecedent rainfall and base flow. In the Study area, it is better to focus on the base flow. If the base flow is reflected by antecedent rainfall in upstream, depending on the base flow (waterlevel before the storm), the corresponding runoff coefficient can be defined.

Figure 6-42 introduces the result of urban area according to some investigation in Japan, the ratio of effective rainfall to total rainfall is close to the ratio of impermeability of the catchment.

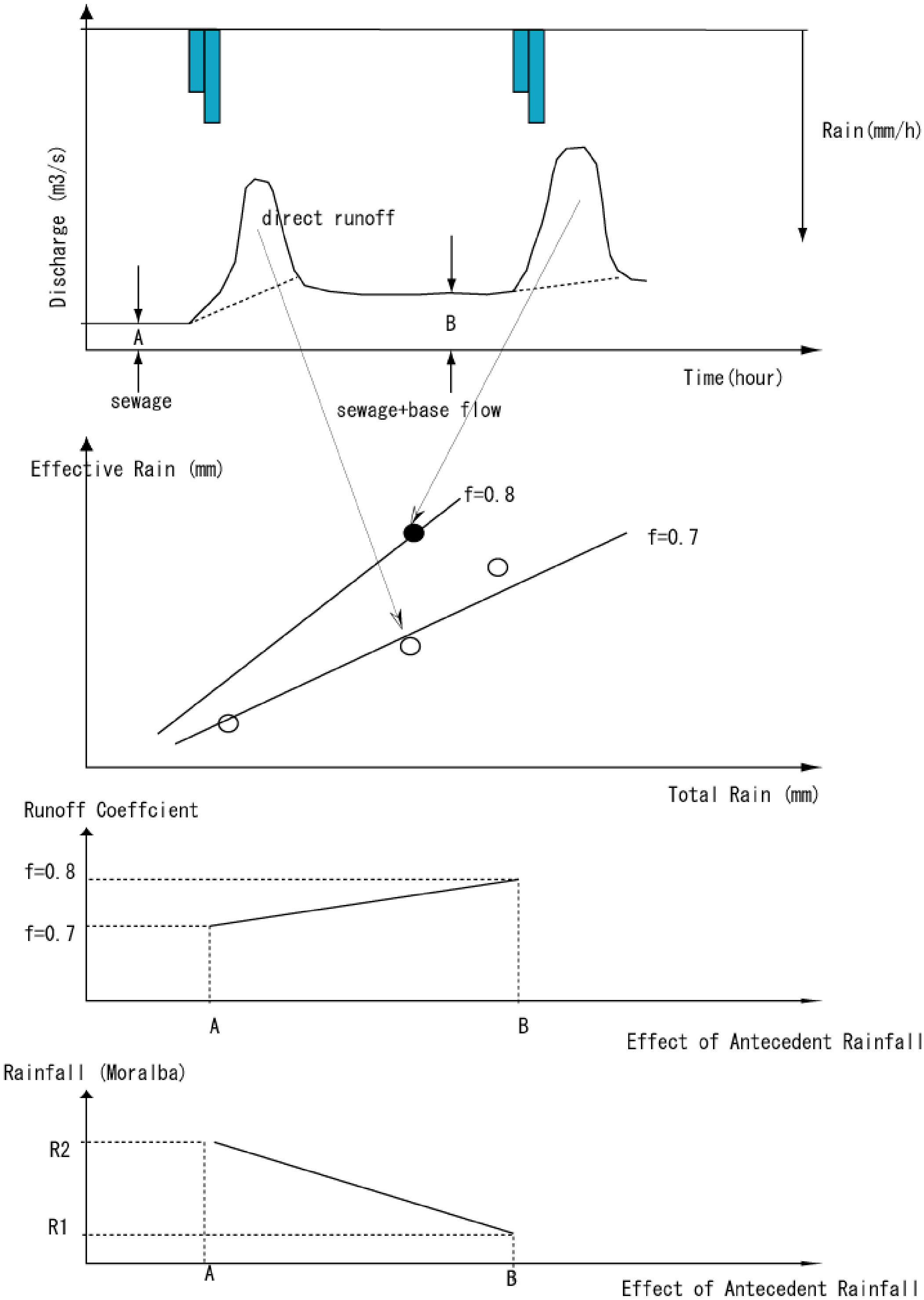

Figure 6-41 Basic Concept to Determine the Rainfall Criteria in Chiguaza Creek

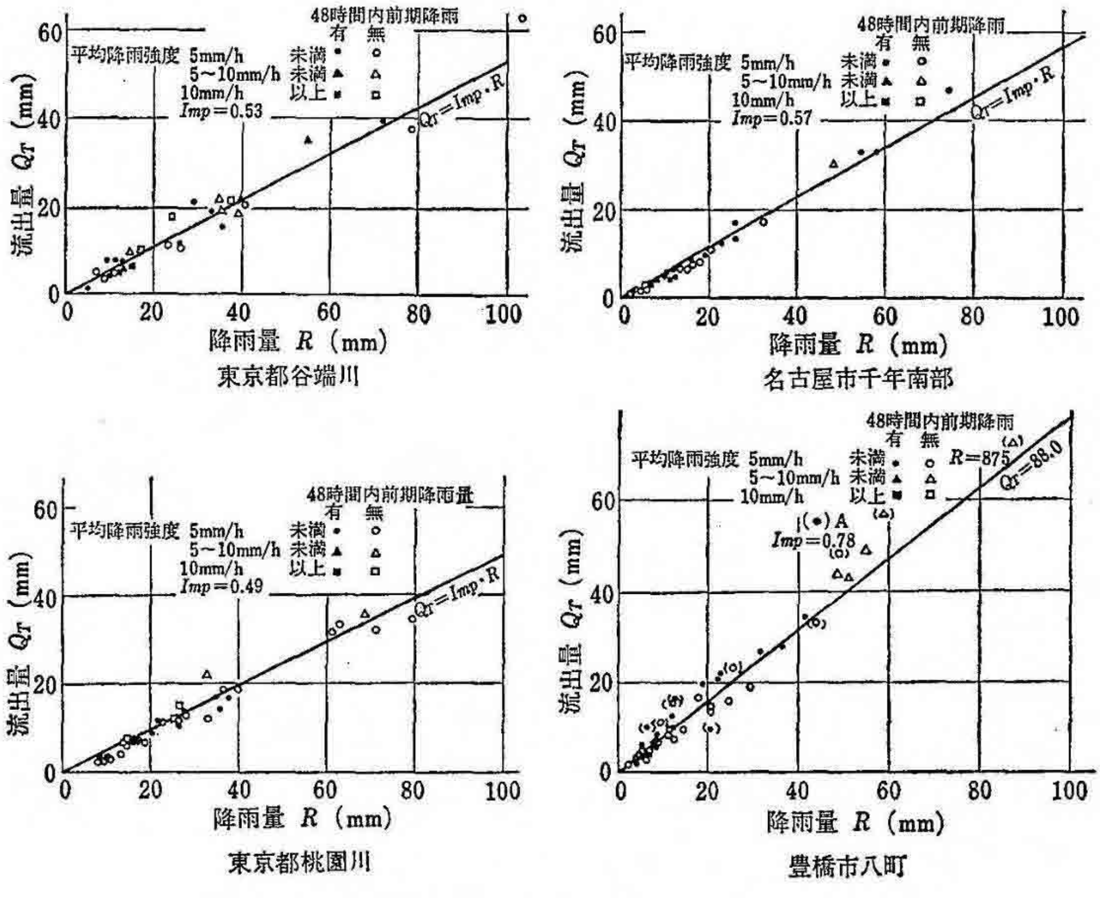

図 9・12 都市流域における雨量と直接流出量の関係[10]

(Source: Okamoto, Engineering Hydrology, Nikkan Kogyo Shinbunsha, 1982 (Japanese Book))

Figure 6-42 Relation between Total Rainfall and Effective Rainfall in Urban Area in Japan

2) Discharge (velocity) Measurement at Molinos Station

The Molinos Station which an ultrasonic type waterlevel sensor will measure the continuous waterlevel data.

The waterlevel and discharge relation at Molinos is necessary because the rainfall and runoff mechanism should be clarified to improve the accuracy of early warning criteria.

In Molinos Station, the discharge measurement can be done by velocity measurement during floods.

Method 1: Current meter

Method 2: Floating

In the Chiguaza (Molinos station) the floating method is recommended. Because

- The flood peak is very instant. There is no enough time to prepare the team of measurement by current meter
- In Molinos, there are two (2) bridges nearby which can make the usage of float easy.
- The people who participated with the waterlevel measurement during the JICA Study or the people in the Colombia Viva School are expected to be in charge of the float measurement.

3) Waterlevel and Discharge Relation at Molinos

The Study Team calculated the waterlevel and discharge relation curve at Molinos Station (4+217) by Manning formula. For this calculation, the hydraulic parameters such Manning coefficient and waterlevel slope are set 0.04 and 1:50, respectively. These parameters should be calibrated by the discharge measurements.

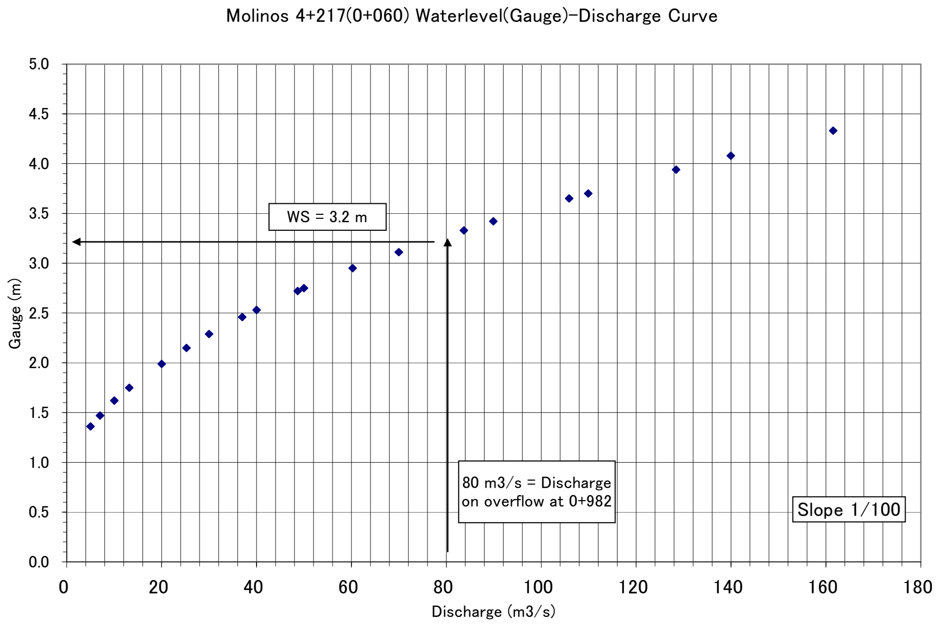

Figure 6-43 Waterlevel and Discharge Relation Curve at Molinos Station (4+217)(0+060)

Since the catchment size is small and the creek is steep, the flood concentration time is expected to very short. By clarifying of the flood concentration time and rainfall loss, the parameters of the hydrological analysis can be reviewed.

DPAE is going to have a hydraulic model for the downstream reach of the Cantaranna Dam for the early warning for the area along the Tunjuelo River main stream. The model should have discharge input from each tributary catchment; the Chiguaza, Yomasa, Santa Librada and La Estrella-El Infierno, and other residual ones.

(2) Susceptibility / Hazard Assessment

1) Flood

The flood map for 25 years return periods made by the Study Team is the basis of the early warning in the Study Area. The Chiguaza, the pilot project area was mapped in scale 1:2,000

EAAB has been implementing channel improvement work in Chiguaza, so DPAE should receive the latest report on such works periodically in order they have the latest information.

2) Flash Flood

There is a possibility of flash flood occurrence in the Yomasa creek according to the geological studies in the Study. In the study area, flash flood zoning map (yellow zone) was prepared by the Study Team. The methodology of the flash flood zoning was based on that used in Japan by law.

The Study Team prepares yellow zone based on the above method for the Yomasa working on the 1 m to 10 m contour lines as shown in Data Book 1. The methodology is quite deterministic, however, it is not supported by the historical debris flow events in the Study Area. In this sense, the yellow zone map should be treated as reference.

(3) Warning Criteria

1) General

In the course of the discussion between DPAE and the Study Team, DPAE has already wanted to monitor the established telemeter data in the central office (DPAE building) and make a decision to issue a warning to the related organizations parallel to the communities-based early warning system. This system has been established in the Tunjuelo River early warning system and has been sought in the Limas creek in Bogota.

However, considering the catchment size and the steep slope of the creeks in the study area, it is desired that community-based monitoring system is required, for example, at the upper part of a creek, waterlevel shall be monitored by a local person and if the waterlevel exceeds a certain level the person should inform the condition to the downstream community as well as DPAE headquarter. It could be said that this system is practical if the short flood concentration time is considered.

Actually the rainfall and runoff process is a quite complicated one even in a small catchment such as in the Study Area. Spatial and temporal rainfall distribution, antecedent rainfalls are significant factors affecting the process. Any warning criteria have uncertainty in terms of hydrological parameters. In the Study Area, at first using conventional methodology such as below shall be applied while measured data set is accumulated. As the measured data is accumulated, near future the improvement can be made to the warning criterion.

2) Waterlevel Criteria

In the Chiguaza, the most critical section is regarded as 0+982. The cross section of 0+982 is shown in Figure 6-44. At the right bank, when the waterlevel elevation is 2,558.3 m, the overflow will happen. At that time the discharge at this section can be assumed as 80 m^3/s according to the waterlevel and discharge relation curve (Figure 6-45).

As shown in Figure 6-43, at Molinos station the discharge 80 m^3/s is corresponding to the waterlevel 3.2 m on the staff gauge. It means the waterlevel 3.2 m in Molinos is critical condition at the downstream such as Station 0+982. Therefore the warning level is set 2.2 m on the Molinos staff gauge, tentatively.

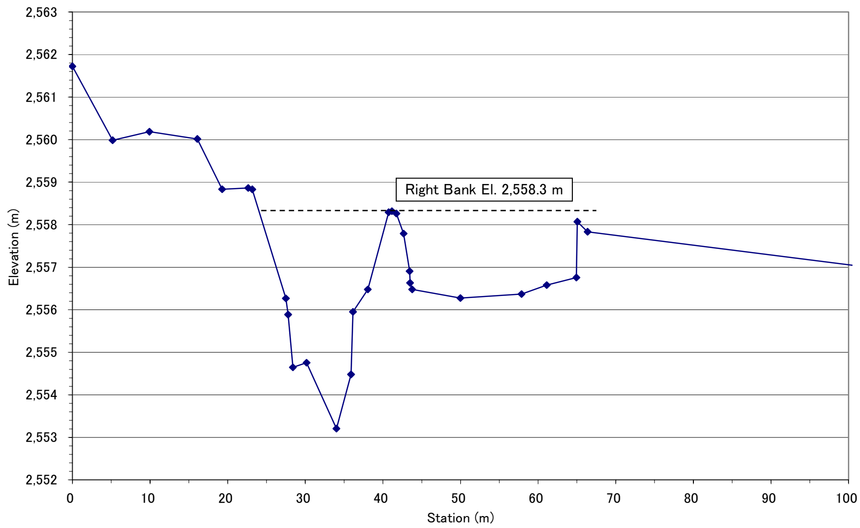

Figure 6-44 Cross Section and Overflow Level of Critical Section (0+982)

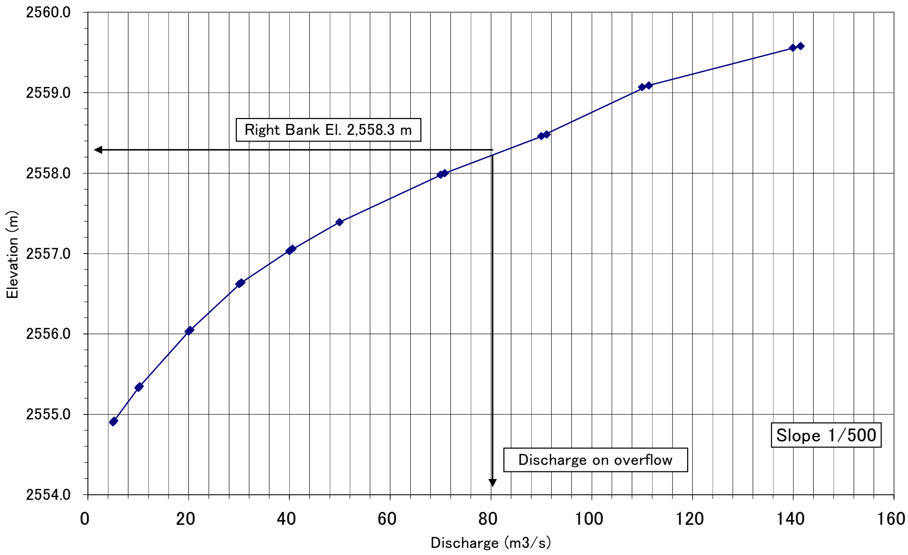

Figure 6-45 Waterlevel and Discharge Curve (0+982)

3) Rainfall Criteria

a. General Alert

Chapter 4 of this main report shows that in Chiguaza, 53 % of the "flood" incidents occurred at the time when rainfall (La Picota or Juan Rey) exceeds 10 mm (daily). In other creeks, the daily rainfall corresponding to the above criteria is larger than 10 mm. As tentatively the following criteria shall be set for the Study Area.

General Alert	Daily Rainfall 10 mm for the four (4) creeks

b. Chiguaza Middle Stream

According to runoff analysis in the Chiguaza, the flow capacity of the critical point in Molinos reach is corresponding to ten (10) years return period. At Los Puentes, the 10 years return period is 43 mm/h for 27 minutes, which means the rainfall amount 19.4 mm for 30 minutes. Tentatively, the following criterion is set for the Chiguaza middle stream.

Alert	10 minutes rainfall 6 mm
Warning	30 minutes rainfall 20 mm

Figure 6-46 shows the timing of issuing alert and warning during 30 minutes. The timing of alert is proposed 6 mm for 10 minutes, however, the rainfall distribution after 10 minutes can not be forecasted at the time when the 6 mm was observed in the first 10 minutes. Anyhow the warning should be issued when the accumulated rainfall reaches 20 mm within 30 minutes. Therefore after the alert is issued, the rainfall should be monitored continuously.

For reference, the frequency of 6 mm per 10 minutes at Juan Rey (DPAE) in Feb.2 to October 10 in 2007 is as follows,

Date and Time	10 minutes rainfall	30 minutes rainfall
2007/2/14 17:00	7 mm	13.2 mm
2007/4/7 4:00	9 mm	13.8 mm
2007/4/21 22:00	6.2 mm	15.2 mm
2007/7/16 21:00	9 mm	11.7 mm
2007/10/7 21:00	8 mm	13.1 mm

In the above period, the 20 mm per 30 minutes did not occur.

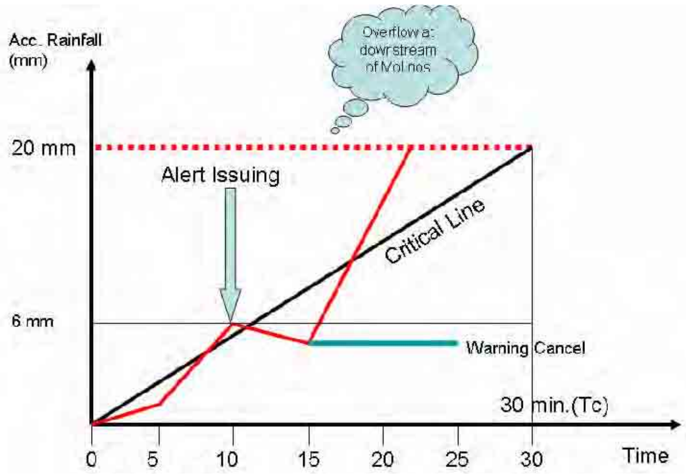

Figure 6-46 Timing of Issuing of Alert and Warning

c. Chiguaza Upstream

In Chiguaza upstream, at present there is not possible for substantial flash flood (associated with movement of unstable sediment on creek bed). However, from now on, if the sediment deposit on creek becomes outstanding, it is necessary to watch if the similar phenomenon with the May 19, 1994 in Zuque creek likely to happen in the Chiguaza.

In short term it is recommended as follows,

- Monitor the creek condition to check if there is new sediment deposit on the creek
- Check the creek-crossing structure to be clogged by debris , garbage (Table 6-9)
- When the above condition becomes worse, the debris and garbage should be taken out by Chiguaza creek related entities.
- The rainfall condition in May 1994 like below should be set as watch level. At the watch level, the runoff phenomenon should be checked by Chiguaza creek related entities together with upstream conditions.

Warch	15 days rainfall 80 mm and the daily rainfall 23 mm in Juan Rey or Moralba stations.

6.6 Implementation Program

Implementation program between 2007 and 2020 is shown in Figure 6-47. The cost is also estimated in US$.

Year 2007 is the year of pilot project in the JICA Study. So the cost of monitoring station is that subcontracting amount in the Study for DPAE.

Telemeter system equipment will be replaced within ten (10) years.

Rainfall radar system shall be conducted by IDEAM. In this sense, the cost for them is not indicated in the figure.

For Data Analysis and Processing System and Set Appropriate Warning Criteria, only remuneration of engineers or researchers are considered in the cost.

Community-based disaster management activity such as hydrological measurement and drill shall be conducted by DPAE's ordinary activity. In this sense, the cost for them is not indicated in the figure.

The total cost until 2020 is about US$171,000.

unit: US$

Actions	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
	Short Term		Middle Term				Long Term								
Monitoring and Early Waning System Establishment															
Monitoring and Data Gathering System															
Installation of Monitoring Equipment for Pilot Project															
1 Rain Gauge at Moralba School(Chiguaza creek)	10,000				2,500	(telemeter)				10,000	(replace)				
2 Waterlevel Gauge at Mollinos(Chiguaza creek)	13,000				2,500	(telemeter)				13,000	(replace)				
3 Water Level Gauge at La Gloria(Chiguaza creek)	5,000														
Installation of Monitoring Equipment for Future Stage															
1 Yomasa upstream Rainfall Station (Yomasa creek)			10,000			2,500	(telemeter)				10,000	(replace)			
2 Yomasa downstream Water Level Gauge (Yomasa creek)			5,000			2,500	(telemeter)				5,000	(replace)			
3 Radar System for IDEAM						-	by IDEAM								
Warning Criteria															
Hydrological Consideration															
Analysis of Flood Concentration Time (Pilot Project)	6,000														
Development of Entire Catchment Model						6,000	6,000						6,000	6,000	(upgrade)
Mapping of Susceptibility															
Susceptibility of Flood and Flash Flood	6,000														
Updating of Maps depending on the flood occurrence						6,000	6,000						6,000	6,000	(upgrade)
Set Appropriate Warning Criteria															
Setting of Tentative Warning Criteria															
Hydrological Analysis using Data during the Pilot Project Period	10,000														
Modification of Warning Criteria				2,500			2,500			2,500			2,500		
Community Based Disaster Management (CBDM) Activities by DPAE															
Training on Hydro-meteorological Observation	-														
Information Transfer Simulation and Drill		-													
Evacuation Drill		-													
Community Based Hydro-meteorological Observation															
Total	50,000	0	15,000	2,500	5,000	17,000	14,500	0	0	25,500	15,000	0	14,500	12,000	171,000

Figure 6-47 Implementation Schedule for DPAE

6.7 Pilot Project

6.7.1 General

The pilot project for DPAE in the Study area is that of implementation of the proposed short term projects in Section 6.6. They are installation / operation of monitoring equipment and monitoring / maintenance activity by DPAE-supported community, hydrology and hydraulic analysis, and study of tentative early warning criteria.

6.7.2 Outline of Pilot Project

(1) Installation / Operation of Monitoring Equipment

1) Rainfall Station in Moralba

The rainfall station was set up inside of Moralba school in Ciudad Bolivar, in Bogota City. In order to measure the short duration rainfall, tipping bucket type sensor was selected. The sensor was installed on the roof of the school class building and the data logger, solar panel were installed in the security house in front of the school entrance. Also in order to enable an observer to see the real time rainfall amount, a display was installed to the logger, which shows the current date and time, the latest 10 minutes, 1 hour and 24 hours rainfall in millimeter.

In addition, the Study Team is going to install by January 2008 a sound alarm device to the data logger which will beep sound for the security guard when the accumulated 30 minutes rainfall exceeds a threshold.

Table 6-14 shows the specification of Moralba rainfall station.

Table 6-14 Specification of Moralba Rainfall Station

Element of Observation	Type	Specification
Rainfall	Tipping-bucket	Rain gauge : Texas Electronics TR-525 Rainfall Sensor Resolution : 0.1 mm Metric Accuracy : 1.0% up to 50 mm/hour Collector diameter : 245 mm Logger : MOTOROLA MOSCAD-L Remote Terminal Unit Solar panel : SUNTECH STP080S-12/Bb Battery : VISION 6FM55 DC12V 55Ah Regulator : Sun Saver 10
		Sound alarm device for configured rainfall threshold

Since the rainfall data must be monitored by people, the Study Team proposed the school and DPAE that the security guard hired by Moralba school would monitor the display and record the hourly data on data sheet. The school and DPAE agreed with this proposal and the security guard started the monitoring in the beginning of October 2007. DPAE prepared the data sheet for the security guard and was collecting them periodically. In heavy rainfall situation, by the sound alarm device of the data logger, the security guard can notice the current rainfall is exceeding the threshold and should inform the situation to DPAE and other downstream communities.

The data logger can store the 10 minutes rainfall continually. Data download from the data logger to notebook computer is possible by Microsoft Excel macro program.

The maintenance of the station was conducted by the Study Team periodically.

2) Waterlevel Station in La Gloria

The waterlevel station was set up in La Gloria in Ciudad Bolivar, in Bogota City. The station is composed of waterlevel staff gauge and simple waterlevel detector device. The Study Team proposed DPAE that the communities should monitor the waterlevel staff gauge and record the data every day and DPAE agreed with this proposal.

In order to measure the instant waterlevel rising, simple waterlevel detector device was introduced in La Gloria because the flood concentration time is quite short in the site. The main unit of the alarm device was installed in a house of an observer located in the right bank of the Chiguaza creek. The observer usually monitor the waterlevel of the staff gauge three (3) times a day, however, when the alarm rings, the observer can notice the waterlevel rising and measure the instant waterlevel.

Table 6-15 shows the specification of La Gloria waterlevel station.

Table 6-15 Specification of La Gloria Rainfall Station

Element of Observation	Type	Specification
Water Level	Staff gauge	Water level gauge : APCYTEL staff gauge Resolution : 1 cm Metric Gauge rod : steel Self standing and stuck on the river wall
Water Level	Electrode	Water level gauge : APCYTEL simplified water level gauge Resolution : 20 cm Metric 15 sensors Alarm : Preset the level optionally Gauge device : PVC tubes and telephone cable Stuck on the river wall

The maintenance of the station was conducted by the Study Team periodically.

3) Waterlevel Station in Molinos

The waterlevel station was set up in Molinos in Ciudad Bolivar, in Bogota City. The station is composed of waterlevel staff gauge and non-touch stage sensor (ultrasonic waterlevel sensor). The ultrasonic sensor was installed under the foot bridge. The data logger and solar panel were installed in Colombia Viva school located on the right side of the Chiguaza creek. The Study Team proposed DPAE that the communities should monitor the waterlevel staff gauge and record the data every day and DPAE agreed with this proposal.

The data logger can store the waterlevel continually. Data download from the data logger to notebook computer is possible by Microsoft Excel macro program.

Table 6-16 shows the specification of Molinos waterlevel station.

Table 6-16 Specification of Molinos Waterlevel Station

Element of Observation	Type	Specification
Water Level	Staff gauge	Water level gauge : APCYTEL staff gauge Resolution : 1 cm Metric Gauge rod : steel Self standing and stuck on the river wall
Water Level	Ultrasonic	Water level gauge : Sonder Ultrasonic Level Meter Measuring range : 0.5m – 12m Resolution : 0.35% of measured range Beam angle : 8deg. at -3dB Logger : MOTOROLA MOSCAD-L Remote Terminal Unit Solar panel : SUNTECH STP080S-12/Bb Battery : VISION 6FM55 DC12V 55Ah Regulator : Sun Saver 10

The maintenance of the station was conducted by the Study Team periodically.

(2) Hydrology and Hydraulic Analysis, and Study of Tentative Early Warning Criteria

1) Flood Concentration Time

The monitored data at Moralba (10 minutes interval rainfall) and the downstream waterlevel data at La Gloria were compared to confirm the flood concentration time.

2) Creek Flow Capacity Evaluation

The creek flow capacity was evaluated in the target creeks based on the river cross section survey done for the pilot project. The flow capacity was compared with probable peak discharge.

3) Tentative Early Warning Criteria

Based on the hydrological analysis and creek flow capacity evaluation, the tentative early warning criteria were studied.

6.7.3 Lesson Learned from the Pilot Project

(1) Installation / Operation of Monitoring Equipment

1) Maintenance of Staff Gauge

In the pilot project, one staff gauge at La Gloria was damaged by boulder hit during high water in October 2007. Also the staff gauge at Molinos which was installed in the creek bed was covered by garbage flowing from upstream. The La Gloria staff gauge was reinstalled in front of the concrete base of the left bank in order to avoid further boulder hit. Basically the staff gauge of lower position at La Gloria and Molinos are easy to be affected by boulders and garbage. The observers of these stations should be advised if they notice some boulder or garbage around the staff gauge to inform DPAE or maintain them by themselves if possible.

2) Maintenance of Automatic Monitoring Equipment

The rainfall gauge at Moralba and the solar panel for the data logger/sensor of Molinos station are installed on the roof of school building. During the pilot project the Study Team felt difficulty to access to the roof because it was difficult to find a ladder. Most of the school teachers of Moralba and Molinos are not sure where the ladder is. It is necessary for the schools to confirm the location of the ladder in order to make the access easy when DPAE officials want to access them.

(2) Hydrology and Hydraulic Analysis, and Study of Tentative Early Warning Criteria

1) Flood Concentration Time

Figure 6-48 shows the observed waterlevel at Molinos and La Gloria during the pilot project phase in this Study. The frequency of the monitoring is basically three (3) times a day, however, the community has been recording the high water level as much as possible. In October 2007, La Gloria recorded three (3) high water events at October 13 and October 14 and October 18.

The flood concentration time at La Gloria can be assumed about 22 minutes (until sub-catchment 2-11) according to Kirpich formula.

Figure 6-49 shows the observed rainfall at Moralba which is picked up at the time of high water in La Gloria in order to see the concentration time. In the case of October 14, at 2PM the waterlevel was 2.2 m at La Gloria while the Moralba rainfall was started 1:38-1:48PM. The time of waterlevel was recorded by people, so there might be some range of time. October 13 and October 18 cases are 42 minutes and 22 minutes, respectively. Such data should be accumulated more, however, the assumed flood concentration time can be regarded within the actual range or safety side according to the data obtained in the pilot project.

The monitoring at La Gloria does not directly contribute to the early warning issue for the downstream area, however, as we can see in the below, the data of La Gloria is very valuable for the calibration of hydrological parameter.

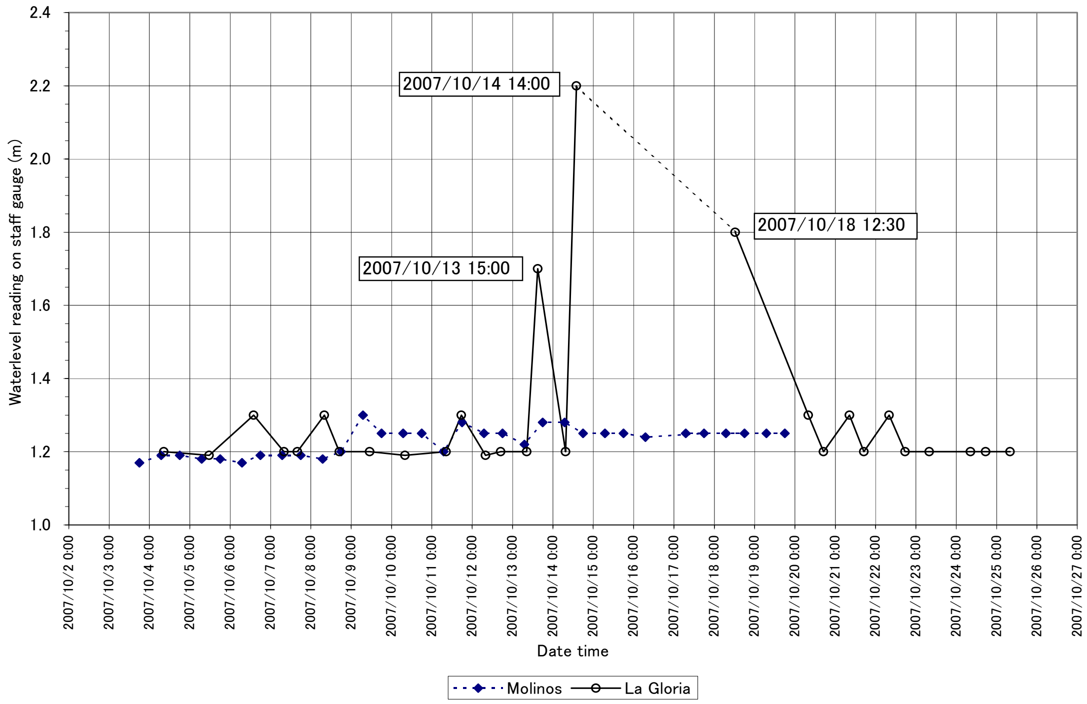

Figure 6-48 Observed Waterlevel at La Gloria and Molinos Stations

Moralba		La Gloria	
Date Time	10 minutes Rainfall	Date Time	Waterlevel
2007/10/18 5:9	0		
2007/10/18 5:18	0		
2007/10/18 5:28	0		
2007/10/18 5:39	0		
2007/10/18 5:48	0		
2007/10/18 5:58	0		
2007/10/18 11:48	0		
2007/10/18 11:59	0.2		
2007/10/18 12:8	4.6		
2007/10/18 12:18	3.9		
2007/10/18 12:29	0.8		
		2007/10/18 12:30	1.8 m
2007/10/18 12:38	0		
2007/10/18 12:48	0		
2007/10/18 12:59	0		

22 minutes

Moralba		La Gloria	
Date Time	10 minutes Rainfall	Date Time	Waterlevel
2007/10/13 13:8	0		
2007/10/13 13:18	1.1		
2007/10/13 13:29	1.6		
2007/10/13 13:38	0.6		
2007/10/13 13:48	0.3		
2007/10/13 13:59	0		
2007/10/13 14:8	0.1		
2007/10/13 14:18	3.2		
2007/10/13 14:29	0.7		
2007/10/13 14:38	0.3		
2007/10/13 14:48	0.1		
2007/10/13 14:59	0.1		
		2007/10/13 15:00	1.7 m
2007/10/13 15:8	0		
2007/10/13 15:18	0		
2007/10/13 15:29	0.1		

42 minutes

Moralba		La Gloria	
Date Time	10 minutes Rainfall	Date Time	Waterlevel
2007/10/14 12:48	0		
2007/10/14 12:59	0		
2007/10/14 13:8	0.4		
2007/10/14 13:18	0		
2007/10/14 13:29	0		
2007/10/14 13:38	0		
2007/10/14 13:48	3.3		
2007/10/14 13:59	5.6		
		2007/10/14 14:00	2.2 m
2007/10/14 14:8	9.7		
2007/10/14 14:18	0.2		
2007/10/14 14:29	0		
2007/10/14 14:38	0		
2007/10/14 14:48	0		
2007/10/14 14:59	0.1		

12 minutes

Figure 6-49 Observed Rainfall at Moralba at the Time of High Water in La Gloria

CHAPTER 7 RECOMMENDATIONS FOR DPAE

7.1 Common

One of the significant features in the Study area for flood is the small creek catchment and short flood concentration time. For this type of area, the early warning system needs the timely and accurate information from local level, and also the gathered information should be transferred to others timely and accurately. Also in the landslide area, to know any local phenomenon which may indicate the change of landslide conditions is very important for monitoring system. Considering these necessity in local level, it is regarded that community participant in the monitoring and early warning system is inevitable because they are the first respondents in the case of flood and significant change of landslide area.

For the sustainable monitoring and early warning system, the integration of institutional resources and community participants should be emphasized as it was discussed in a series of technical transfer seminar in the Study. DPAE has already recognized the necessity of technical training for community who can participate in hydrological monitoring and information transfer as the first respondent in order to establish the monitoring and early warning system based on the cooperation with communities. Since DPAE has already started to work with communities in Bogota, DPAE should continue further to develop the collaboration activities with communities in flood ad landslide prone areas.

7.2 Landslide

7.2.1 Stabilization Works in Altos de Estancia

The most effectiveness measure to be taken for Altos de Estancia is a relocation from the danger area, and DPAE developed a relocation program for families toward immitigable high risk area, and most of inhabitants of Phase I area and Phase II area have been relocated. Therefore, an emergency measure is not required for the Landslide. DPAE is planning the stabilization works in the Landslide; however, the details are not confirmed yet. The stabilization works are classified into two major categories, namely works for reduction of driving forces and works for increase in resistance force. In a large scale landslide such as the Landslide in Altos de Estancia, a method for reduction of driving forces should be adopted as a priority, since cost effectiveness for a large scale landslide is normally better than a method for increase in resistance force.

A noticeable situation occurred in Altos de Estancia: the surface water coming from an inadequate drainage system in Phase III area flows all over the front part of the Landslide and this creates many channels and pools in the Landslide itself. It is easily understood that the water inflow affects greatly the stability of the Landslide. What is most important and effective for the stabilization of the Landslide is to reduce the groundwater level, and prevent the water penetration into the ground, especially from sewer and rainwater.

7.2.2 Monitoring in Altos de Estancia

The DPAE engineers and the communities must check the ground conditions through regular patrol. A visual observation of the Landslide and its adjacent areas must be undertaken periodically as for the conditions of the ground, and, if necessary, the site must be measured to determine whether or not any deformation of the ground occurs. As soon as possible, a periodic inspection of the landslide prevention facilities, if any, must be made to detect abnormalities. If cracks or other ground abnormalities on the face of a slope or abnormalities of landslide prevention facilities are found, the changing conditions of such abnormalities should be monitored, followed by a survey so as to allow preparing the emergency mitigation or stabilization works. This observation survey will allow examining the extent, direction of movement, and mechanism of landslides in details when any sign of landslide motion such as slide scarps or cracks are found or when there will be a possibility of occurrence of landslides.

The instrumentation and monitoring could be applicable to following conditions in this Landslide.

a) Safety of the residential area; this will confirm whether the Landslide activity is not approaching the residential areas. This monitoring should be continued as far as the people are living there along the rim of the Landslide.

b) Monitoring on specific cracks and deformation on structures and the ground; this concerns the monitoring works on cracks or deformations on the ground or structures when they are found. This monitoring should be applied every time when cracks or deformation are found on the ground and structure.

c) Safety of construction works; this concerns the monitoring works to prevent accidents under construction that may occur on both workers and residents surroundings. This monitoring should be applied on every construction works as long as the works continue.

d) Verification of effectiveness of stabilization works; it is necessary to confirm the effect of stabilization woks at completion of the construction works.

7.3 Flood

1) The early warning criteria are tentatively proposed by the Study Team for only estimations, since the conditions come from scarcity of registers. Such rainfall criteria and water level should be updated to specify their reliability through the use of registered information by the community even after the Study; therefore, those tentative criteria are not definitive values.

2) After the Study, DPAE should conduct the following activities,

(a) Continuous monitoring

The integration of the community monitoring and the telemeter monitoring systems in Bogota are related to the policy of DPAE. One of the important strategies for risk management of floods for DPAE is to give a high priority in proceeding with the community monitoring in the catchment of Chiguaza. The recommendation for monitoring in the catchment made by the Study Team will constitute the starting point for the system. With more information such as monitored data or information from executed by other district entities, DPAE will review and revise the location of the monitoring.

Based on the above-mentioned principles, DPAE should start the following activity recommended by the Study Team.

- Continuation of community people’s water level monitoring of staff gauge at Molinos and La Gloria
- Starting and continuation of community people’s water level monitoring of El Hoyo bridge with coordination of the related communities

In Molinos water level station and Moralba rainfall station, automatic recording equipments were installed in the Study. The data logger for the sensor includes the display to indicate the current monitored data. Even if the automatic-recording type observation equipment is installed, a manual observation by the community people should be continued.

(b) Studies for early warning criteria using the monitored data

The early warning criteria proposed in this report are only estimated values based on assumption, and they should be modified as early as possible using the observation results, for which DPAE will integrate this data into the existing city flood alert system, including the constant revision to calibrate and adjust the alert criteria.

Since the early warning criteria can be modified only using observed water level relationship, the relation between the water level in the past flooded area and the upstream should be monitored continuously.

(c) Establishment of more reliable early warning plan,

The proposed flood early warning plan would operate properly under the condition that there will be no significant clogging, one of the cause of past serious flood events. The flooding, such as the one of May 1994 that took place through clogging of the structures in the zone, cannot be mitigated by any early warning system.

The creek conditions in the study area have been constantly changing because of channel improvement works as well as sedimentation and garbage. The hydraulic parameters associated with the flow capacity should be monitored and evaluated periodically in order to take into account the revision of the early warning criteria.

(d) Divulgation of the plan to the communities.

Installed equipment may be stolen in certain circumstances or may be damaged depending on the natural conditions. In order to ensure the sustainability for the monitoring system, DPAE should coordinate with the community to watch the equipment on a daily basis.