Appendix-5 Hydrologic Study of Chira River Basin

International Cooperation
Agency Japan

PROJECT OF THE PROTECTION OF FLOOD PLAIN AND VULNERABLE RURAL POPULATION AGAINST FLOODS IN THE REPUBLIC OF PERU

HYDROLOGY OF MAXIMUM FLOODS IN CHIRA RIVER

Appendix-5

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HYDROLOGY OF MAXIMUM FLOODS IN CHIRA RIVER

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1 INTRODUCTION

In the last two extraordinary events (El Niño) occurred in 1983 and 1998, rainfall was very intense in the study area, which resulted in the activation of a number of rivers and streams adjacent to the Chira River, causing severe damage in populated areas, irrigation and drainage infrastructure, agricultural lands, likewise, floods with catastrophic damage in the areas of Sullana, Ignacio Escudero, Marcavelica, Querecotillo, Salitral, Amopate, Colan, La Huaca and Tamarindo.

El Niño is defined as the presence of abnormally warmer waters in the west coast of South America for a period longer than 4 consecutive months, and has its origin in the Central Equatorial Pacific. The phenomenon is associated with abnormal conditions of the atmospheric circulation in the Equatorial Pacific region. Abnormal conditions are considered when the equatorial circulation scheme takes the following three possibilities: may intensify, weaken or change direction.

This study contains a diagnosis of the problem, in order to explain the causes of the event and guide the actions to be implemented to provide greater security to the population, irrigation infrastructure, agricultural areas, etc. The report contains the hydrologic analysis to allow the characterization of the event in technical terms. With these analyses it has been possible to outline alternative structural solutions and no structural measures.

2 GENERAL ASPECTS

2.1 Location

2.1.1 Political Location

The study area is located in the province of Sullana and Paita in the department of Piura.

2.1.2 Geographic Location

The study area is located approximately at coordinates UTM at 482,480 y 708,883 in East Coordinates, and 9’421,040 y 9’492,030 in North Coordinates (Zone 17).

2.2 Background

As part of the project: “Protection of Rural Areas and Valleys and Flood Vulnerable”, it requires a supporting technical document of the maximum flooding of the Chira River, to define planning proposals hydrologic and hydraulic Chira River system.

The occurrence of extreme events such as El Niño in the northern and southern coast of Peru has resulted in the presence of heavy rains, rising rivers and streams activation of contributors to the main course, such as occurred in the last two events of 1983 and 1998. The Chira River overflowed causing flooding of extensive crop areas and cities such as Sullana, Ignacio Escudero, Marcavelica, Querecotillo, Salitral, Amopate, Colan, La Huaca y Tamarindo, and resulting in damage to agriculture, road infrastructure, housing, irrigation infrastructure and drainage. Currently there are vulnerable areas in river sections that require the application of structural measures for flood mitigation.

An assessment of maximum floods has been made based on data from the hydrometric station Ardillas and Puente Sullana. With the results obtained, the hydraulic box of the will be size base to the return period chosen in specific areas and also the design of protective structures.

2.3 Justification of the Project

Chira River allows drainage of floods from rainfalls and inflows from the watershed.

The presence of normal hydrological events causes some damage in agricultural areas, irrigation and drainage infrastructure, service roads and towns, therefore it requires structural measures that allow the mitigation of extreme events up to some degree magnitude.

2.4 Objectives of the Study

The objective of the study is to determine the maximum Chira River floods for different return periods, to allow an appropriate measurement of the hydraulic section of river channelization and the design of protection works, mitigating the potential damage from extreme hydrological events.

3 PROJECT DESCRIPTION

3.1 Hydrographic System of Chira River

3.1.1 General Description of the Basin

The basin of this river is geographically located between latitude 03º40'28 "and 05º07'06" of south latitude and the meridians 80º46'11 "and 79º07'52"W.

Bordered on the North River Basin Puyango, on the south by the river basins and Huancabamba Piura, on the east by the basin and Chinchipe Zamora (Ecuador) and on the west by the Pacific Ocean.

The Chira is an international river and its basin has a drainage area of 19.095 km2 surface until it empties into the sea, of which 7.162 km^2 are within Ecuadorian territory and 11.933 km^2 within Peruvian territory. Its watershed is approximately 9.500 km^2

The river rises in the Cordillera Occidental of the Andes more than 3,000 m with the name of Catamayo, and after traveling 150 km joins the river Macara hence the name of Chira River, runs 50 km. serving as the boundary between Peru and Ecuador to meet the continuing Alamor River in south-west direction in Peruvian territory until it empties into the sea after having traveled 300 km.

Its main tributaries are the rivers left bank Macara, Quiroz and Chipillico and the right bank of the Alamor river and several streams as Hawaii, Venados and Saman.

Figure 3.1 shows the location and area of the Chira River Basin.

Figure Nº 3.1. Location Map of the Chira River Basin

3.1.2 Hydrography of the Chira River Basin

The Andes Mountains catchment areas to the country divided into two main branches that drain their waters into the Pacific and Atlantic Oceans, respectively, thus forming the continental divide of the waters. There is also a third strand in the south-east of the country, consisting of a high inter-Andean basin whose waters drain into Lake Titicaca

The basin of the Pacific or Western has an approximate area of 290.000 km², equivalent to 22% of the total area of the country. As a result of rainfall and melting snow and glaciers in the upper part, 52 rivers, in some importance, run to the Pacific Ocean predominantly towards the southwest. Chira River is one of them, being located in the central region of this side.

The Chira river, river system belongs to the Pacific, has its source in the Republic of Ecuador, its waterways feeding primarily to seasonal rainfall that occur in their upper reaches. The International Basin covers an area of 19.095 km ², of which 7.162 km ² (37.51%) is in Ecuadorian territory and 11.933 km ² is located in Peruvian territory. Peruvian portion outlet of the provinces of Paita, Talara, Piura and Ayabaca, all located in the department of Piura

From its source and into Ecuadorian territory, the Chira River Catamayo adopts the name, a name that kept up the border to the confluence with the river Macara with a length of about 130 km, when entering Peruvian territory embracing the change of name of Chira River, relying on that section with a length of 170 km., after which empties into the Pacific Ocean, near the Old Bocana

The Chira river course, from its source to its mouth is sinuous, as in the first section, from its source to the height of the town of Sullana, running from northeast to southeast, then take a final direction from east to west to it flows into the Pacific Ocean

The main tributaries of the Chira River in Peruvian territory are on the right bank, Quebrada Honda , Peroles, La Tina, Poechos and Condor, on the left bank rivers and Chipillico Quiroz. They are also major tributaries, the river Pilares for its right bank and left bank Macara, which are counting on border lines of their drainage basins in Ecuador

3.2 Climatology

3.2.1 Rainfall

The rainfall in the Chira river basin can be classified into three types: the first, corresponds to the lower area between the contours of 0.0 and 80 meters. This stretch quite extensive, covering low rainfall of about 10-80 mm per year, concentrating on the period from January to April, and remain dry during the remaining months of the year. Rainfall in this area are very irregular, and appear to be closely related to the random occurrence of severe weather caused by El Niño, they do produce very intense rainfall, exceeding 20 times the normal values

The second type corresponds to the band located between 80 and 500 meters, where the rains are about 100 and 600 mm. Their period of occurrence is usually from December to May with variability characteristics less than the first group and being in the rest of the year significantly lower in some years even reaching zero

The third type corresponds to the band located from 500 meters to the line of water, the upper zone due to an Amazonian rainfall regime characterized by low variability of average annual rainfall ranging between 700 and 1.100

mm., the highest recorded rainfall in the months of January to May being the rest of the year of low intensity, but not reaching zero records. It can be seen in this area, the incidence of severe phenomena of El Niño (random occurrence) is almost zero.

The rainfall, as a main parameter of the runoff generation is analyzed considering the available information of the stations located in the interior of the Chira Basin, and in the neighboring basins.

Rainfall information is available from 13 pluviometric stations located in the Chira River Basin and surrounding basins. These stations are operated and maintained by the Peruvian National Service of Meteorology and Hydrology (SENAMHI by their initials in Spanish)

Table No. 3.1, shows the list of stations included in this study with their respective characteristics, such as code, name, and location. Historical records of monthly total rainfall and their histograms are presented in the Annexes. Figure Nº 3.2, shows the period and the length of the data available from meteorological stations and Figure No. 3.3 shows the locations in the Chira Basin and adjacent watersheds.

Table Nº 3.1. Period and longitude of the available information of the Rainfall stations

CODE	STATION	DEPARTAMENT	LONGITUDE	LATITUDE	ENTITY
152202	ARDILLA (SOLANA BAJA)	PIURA	80° 26'1	04° 31'1	SENAMHI
150003	EL CIRUELO	PIURA	80° 09'1	04° 18'1	SENAMHI
152108	FRIAS	PIURA	79° 51'1	04° 56'1	SENAMHI
230	LA ESPERANZA	PIURA	81° 04'4	04° 55'55	SENAMHI
152125	LAGUNA SECA	PIURA	79° 29'1	04° 53'1	SENAMHI
152104	LAS LOMAS 1	PIURA	80° 15'1	04° 38'1	SENAMHI
140	LAS LOMAS 2	PIURA	80° 15'1	04° 38'1	SENAMHI
208	MALLARES	PIURA	80° 44'44	04° 51'51	SENAMHI
152144	MONTERO	PIURA	79° 50'1	04° 38'1	SENAMHI
152101	PANANGA	PIURA	80° 53'53	04° 33'33	SENAMHI
152135	SAN JUAN DE LOS ALISOS	PIURA	79° 32'1	04° 58'1	SENAMHI
203	SALALA	PIURA	79° 27'27	05° 06'6	SENAMHI
152110	SANTO DOMINGO	PIURA	79° 53'1	05° 02'1	SENAMHI

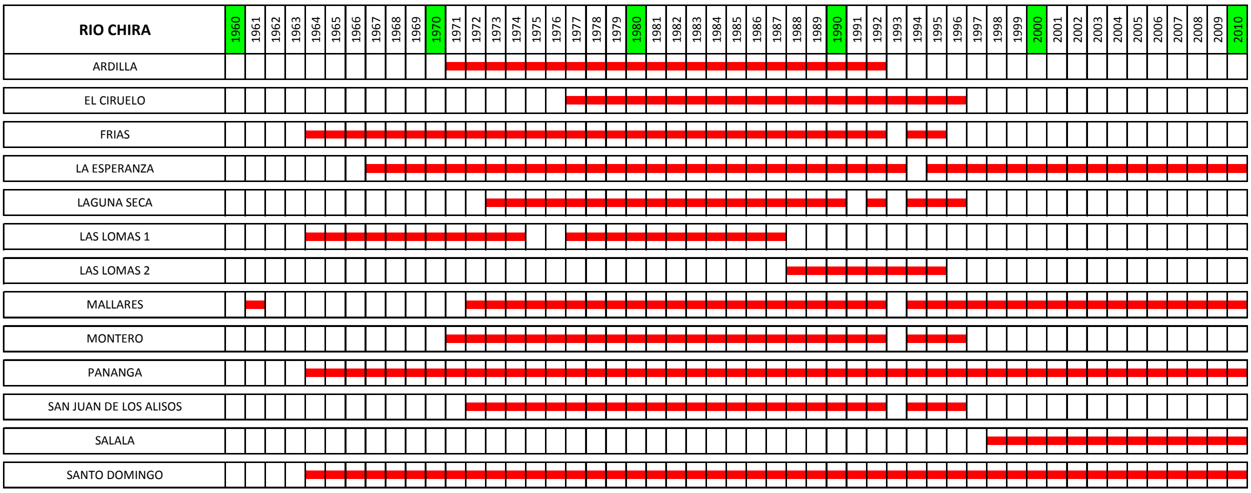


Figure Nº 3.2. Period and longitude of the available information of the rainfall stations

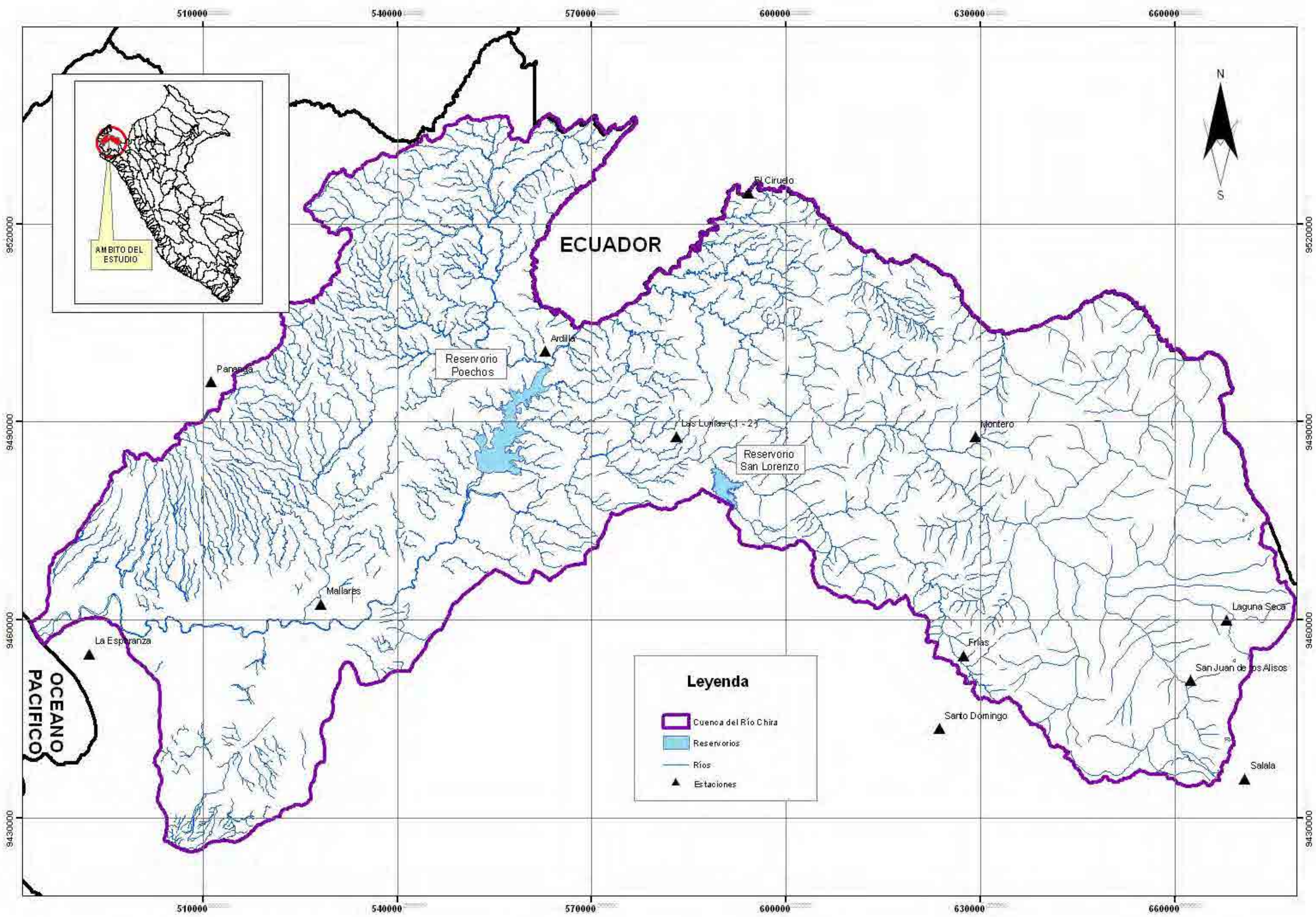


Figure Nº 3.3. Location of the rainfall stations in Chira River basin and adjacent basins

Table N° 3.2 shows mean monthly values for the stations that have been taken into account in the study, and Figure N° 3.4 shows the mean monthly variation for rainfall in each station; the Annex shows the historical series for each station, as well as the monthly and annual variation graphs for each station.

Table Nº 3.2. Characteristics of Rainfall Stations in the Chira River Basin and Surrounding Basins

ESTACION	Mes												Total
	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic	
ARDILLA	58.0	114.2	184.1	92.4	26.8	21.5	0.0	0.4	0.1	2.6	1.5	6.9	594.1
EL CIRUELO	102.2	161.0	231.1	141.0	22.1	8.1	1.3	0.2	0.6	2.6	4.4	30.3	680.3
FRIAS	180.3	251.8	308.4	155.7	54.1	12.6	4.0	5.3	10.3	19.2	19.2	74.1	1145.9
LA ESPERANZA	14.7	17.7	28.1	17.3	12.8	7.2	0.1	0.1	0.2	0.4	0.3	3.1	100.8
LAGUNA SECA	240.2	278.2	261.0	236.0	124.1	45.0	39.7	33.8	33.8	104.7	99.2	195.5	1584.1
LAS LOMAS 1	36.8	59.7	136.9	70.6	48.9	11.0	0.1	0.1	0.5	2.5	1.5	10.1	380.0
LAS LOMAS 2	8.3	86.9	123.0	53.0	5.7	0.6	0.1	0.1	0.0	0.2	2.2	5.9	287.6
MALLARES	30.2	46.3	69.6	37.5	15.0	0.4	0.2	0.2	0.3	1.0	0.9	8.2	221.5
MONTERO	123.7	181.2	296.1	191.1	79.9	29.3	5.5	5.8	7.8	17.6	15.1	45.7	987.4
PANANGA	39.3	59.9	95.2	43.8	14.3	3.9	0.1	0.0	0.2	0.8	0.9	11.4	272.5
SAN JUAN DE LOS ALISOS	186.7	222.7	229.5	184.7	68.9	33.9	18.3	18.8	22.1	67.2	72.7	145.4	1291.0
SALALA	104.4	138.9	128.0	114.7	82.4	58.4	51.4	27.1	33.3	81.1	84.0	104.0	1029.3
SANTO DOMINGO	169.0	263.7	370.6	217.4	74.5	12.7	2.8	4.3	10.7	16.6	28.6	76.7	1233.1

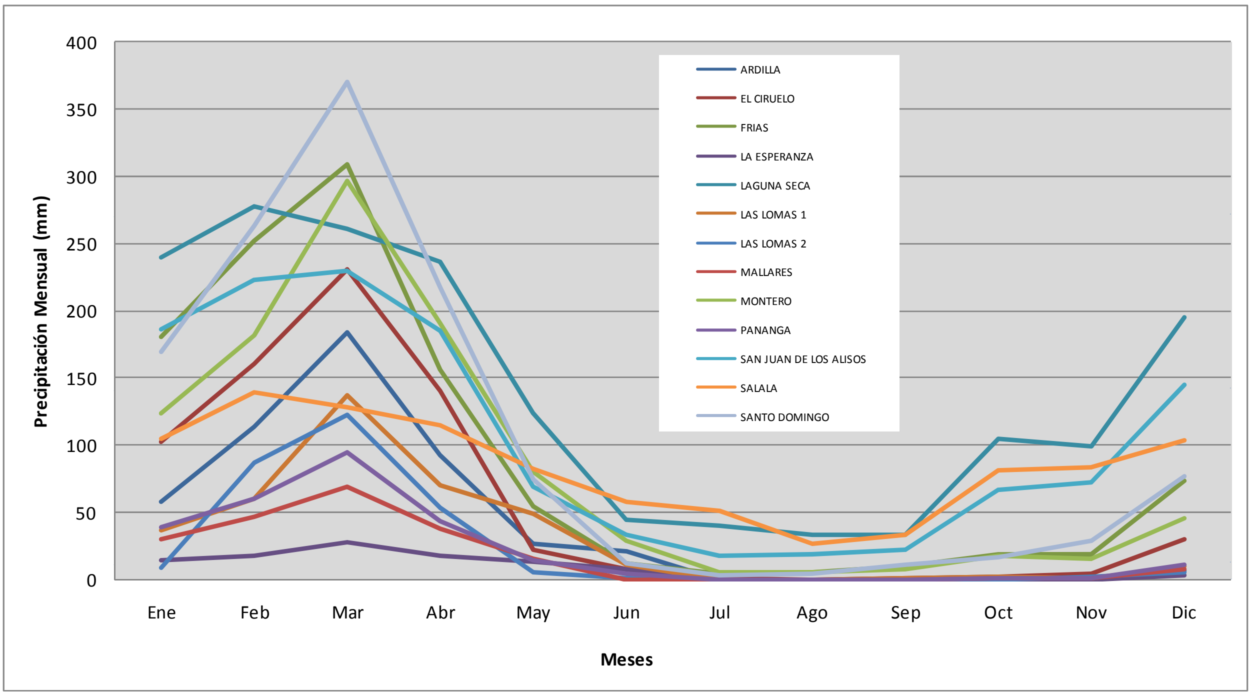


Figure Nº 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope

Table N° 3.2 and Figure N° 3.4 show that heaviest rainfalls are from October to April, and east rainfalls are from May to September. In addition, annual rainfall in the Chira River Basin is noted to vary from 1,584 mm (Laguna Seca) Station) to 100 mm (La Esperanza Station).

Figure N° 3.5 shows total annual rainfall variation for the stations included in this study, with their relevant trends. Taking into account only stations Panga and Santo Domingo which are the station with mayor quantity of information , we established a linear equation: P = mt + b, where P is annual rainfall and t is time in years, m and b are the variables that provide the best fit in a linear equation. The results are presented in Table 3.3, giving the following values of the trends:

Table Nº 3.3.Results of the linear fit equation of Montero, Pananga and Santo Domingo Stations

Estación	m	b	R^2
Montero	-20.42	1256	0.072
Pananga	7.25	93.39	0.035
Santo Domingo	21.75	710.4	0.142

The value of the regression coefficients (R^2) is very low. For Montero Station would be a seasonally downward trend and for Pananga and Santo Domingo Stations a vseasonally upward trend. $\mathbf{R^2}$ values indicate that the trends are not significant and can be said that even in these stations with maximum numbers of data there is no clear trend to increase or decrease regarding the rainfall.

Information shown in Table N° 3.2 and support from ArcGIS software have allowed for generating monthly isohyet maps (from January to December) and annual isohyets maps , as shown in Figures N° 3.6 – N° 3.17, and N° 3.18, respectively.

Isohyets show that heaviest rainfalls in the basin are in March, and they vary between 50 mm and 300 mm. The least rainfalls are in August, and they vary between 5mm and 25 mm.

Total annual rainfall in the Chira River Basin varies between 1,400 mm and 200 mm, as shown in Figure N° 3.18.

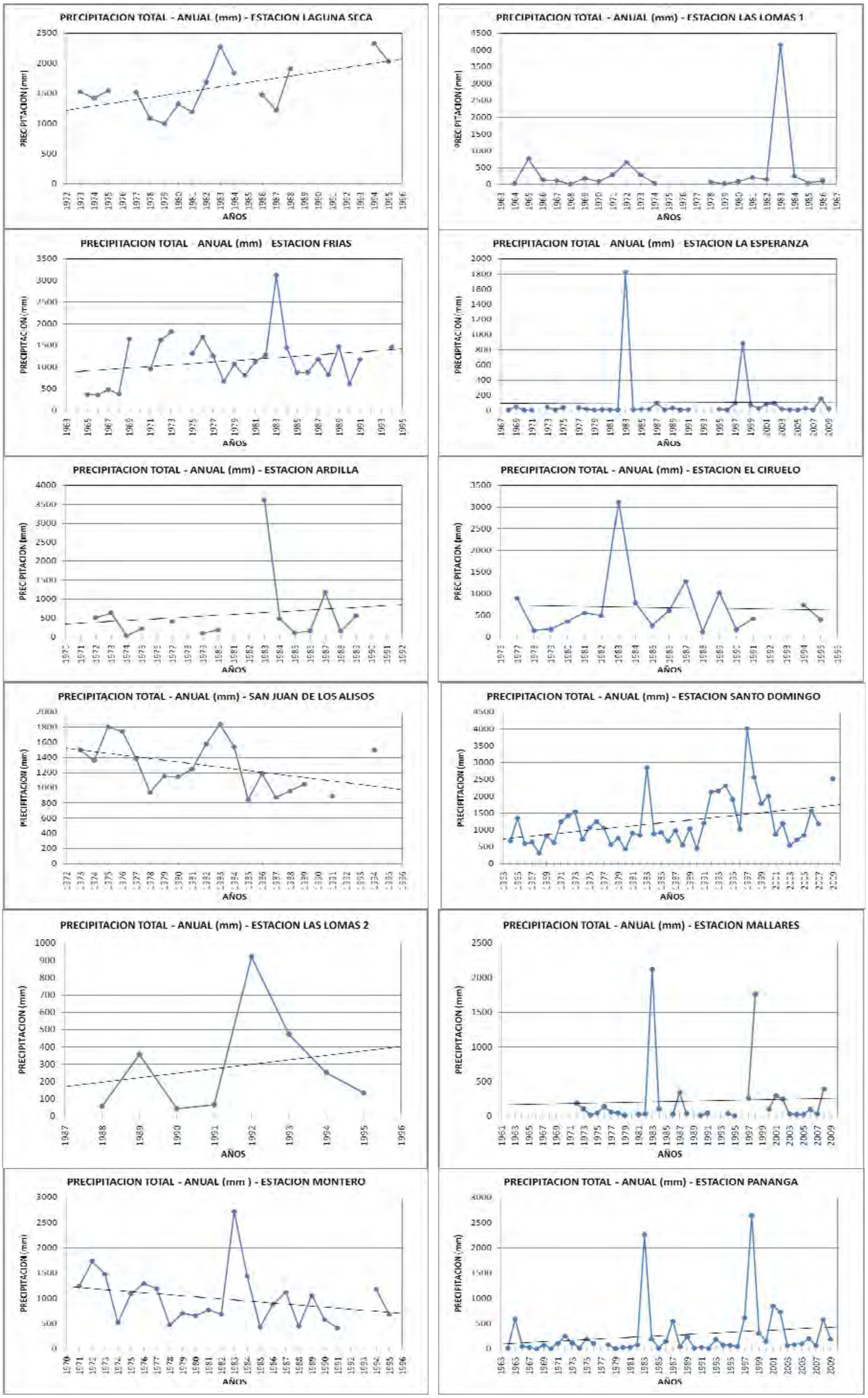


Figure Nº 3.5. Annual Rainfall Trends at the Stations considered within the Study Scop

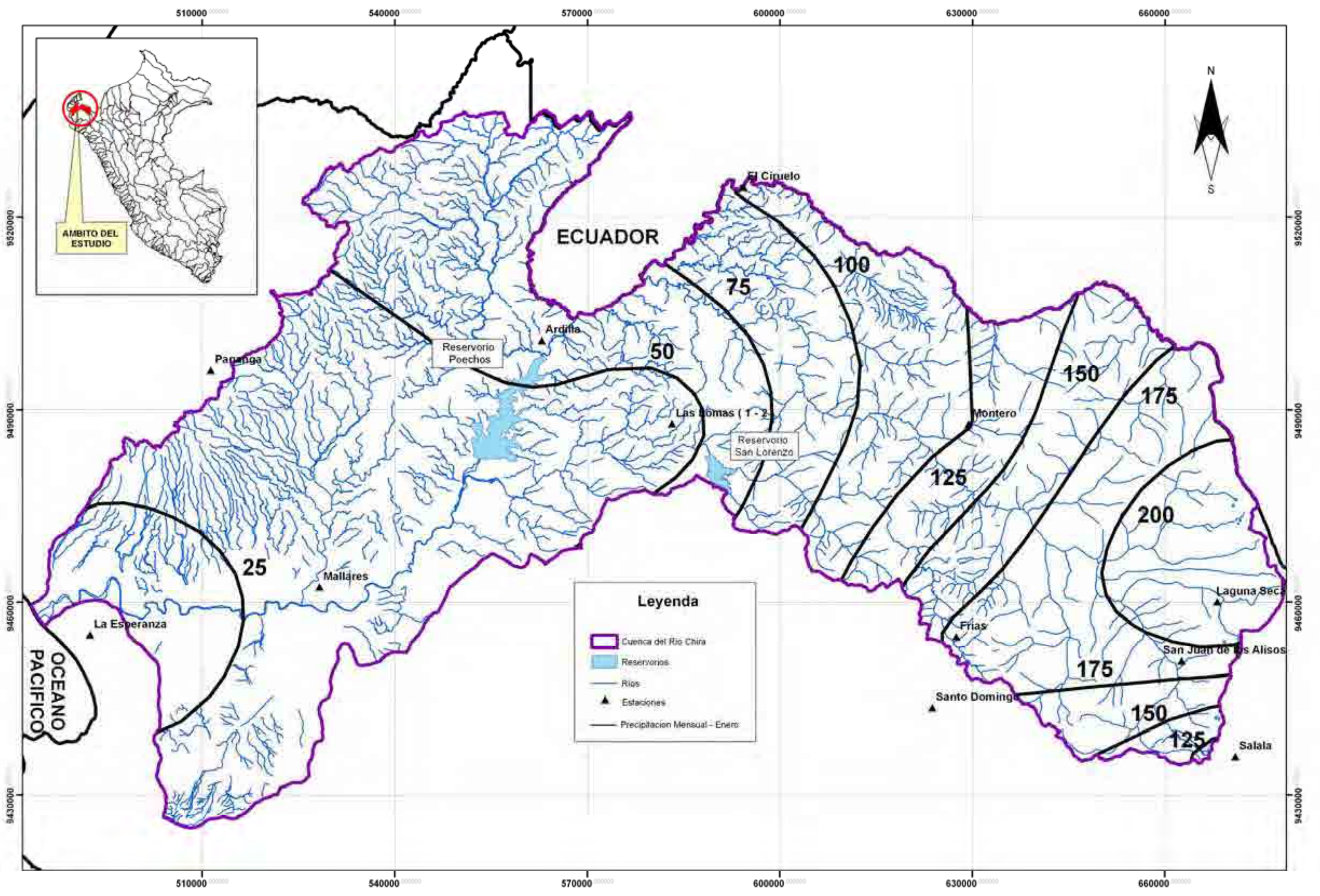


Figure Nº 3.6. Isohyets for Mean Monthly Rainfall in the Chira Basin, in January

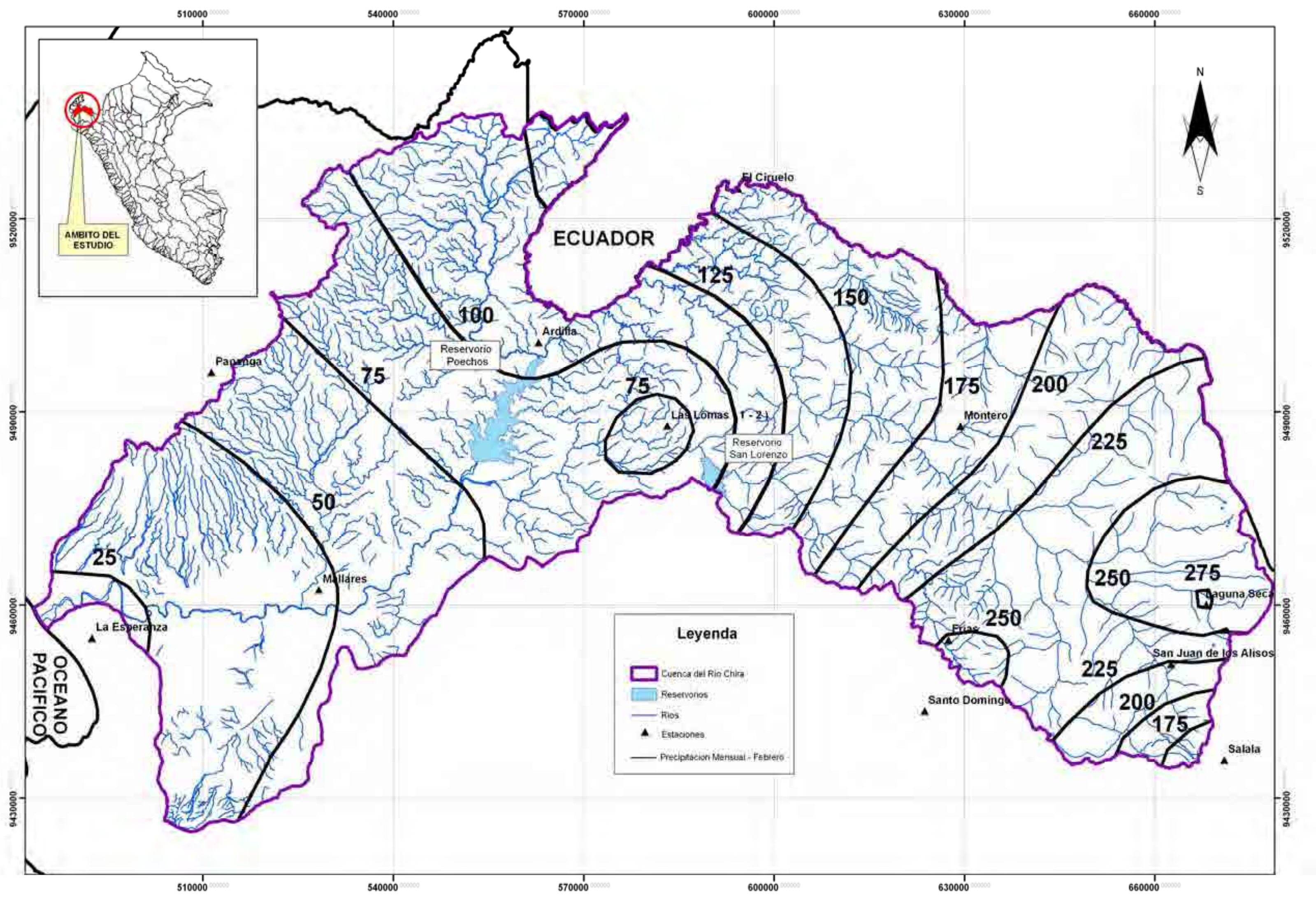


Figure Nº 3.7. Isohyets for Mean Monthly Rainfall in the Chira Basin, in February

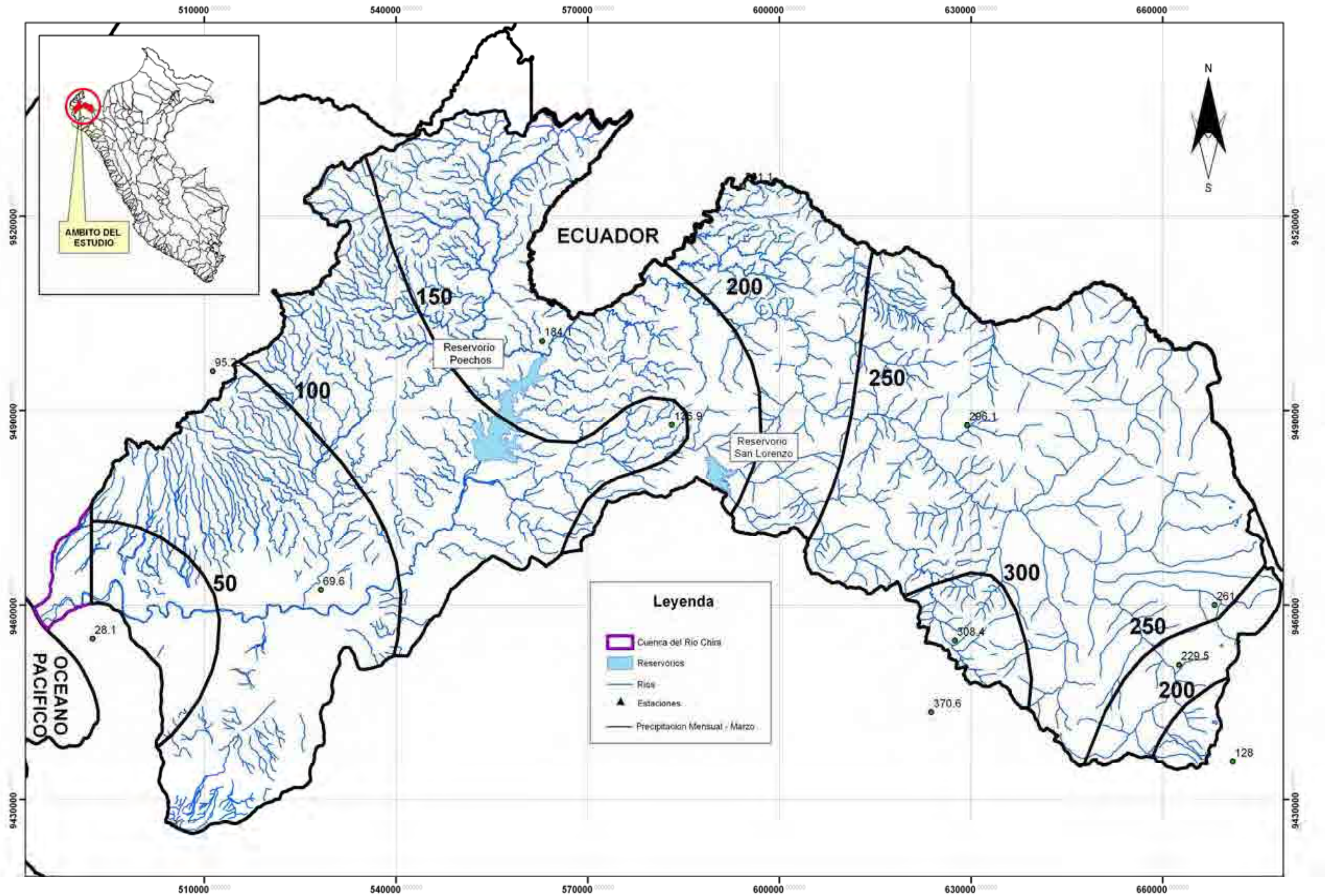


Figure Nº 3.8. Isohyets Mean Monthly Rainfall in the Chira Basin, in March

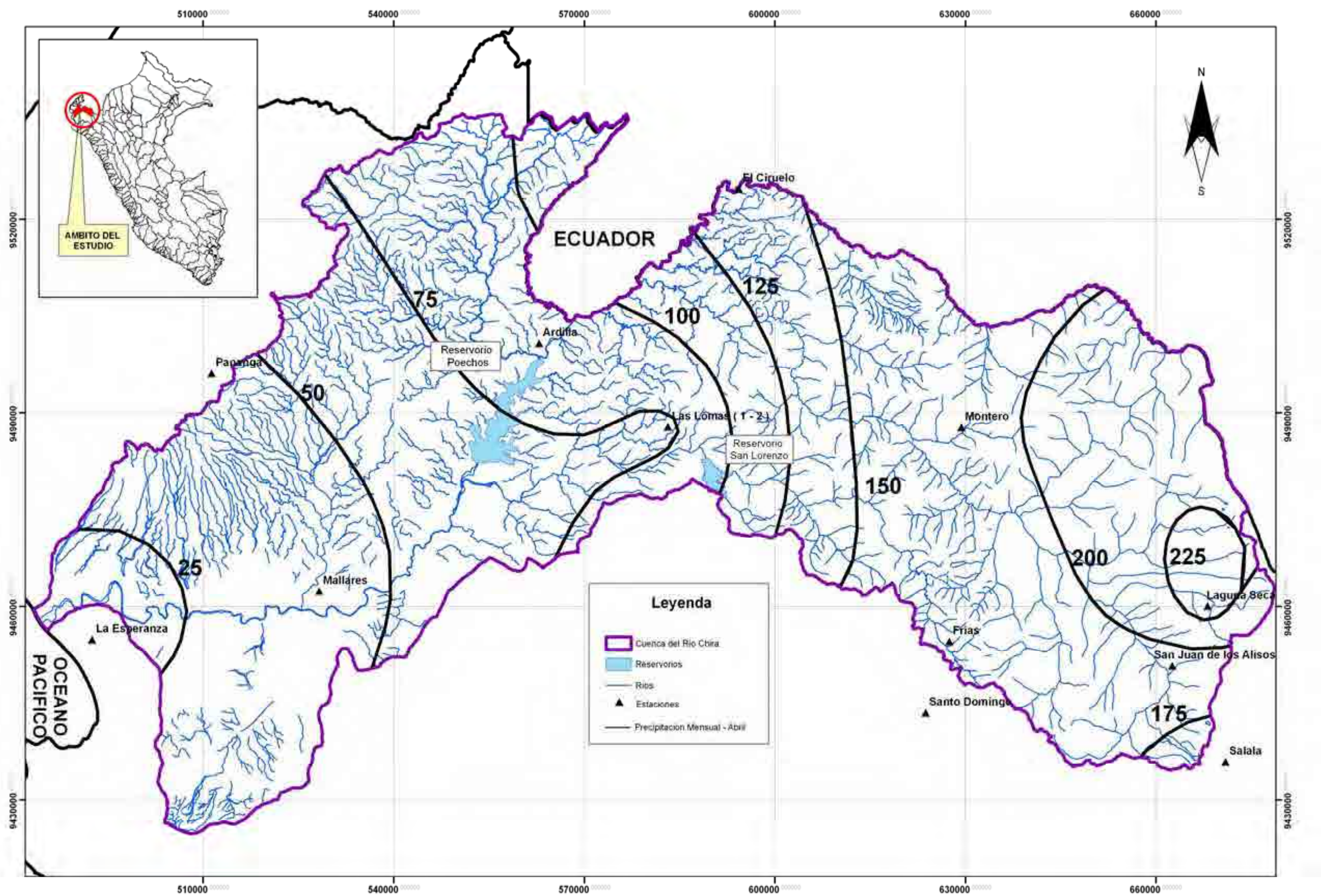


Figure Nº 3.9. Isohyets Mean Monthly Rainfall in the Chira Basin, in April

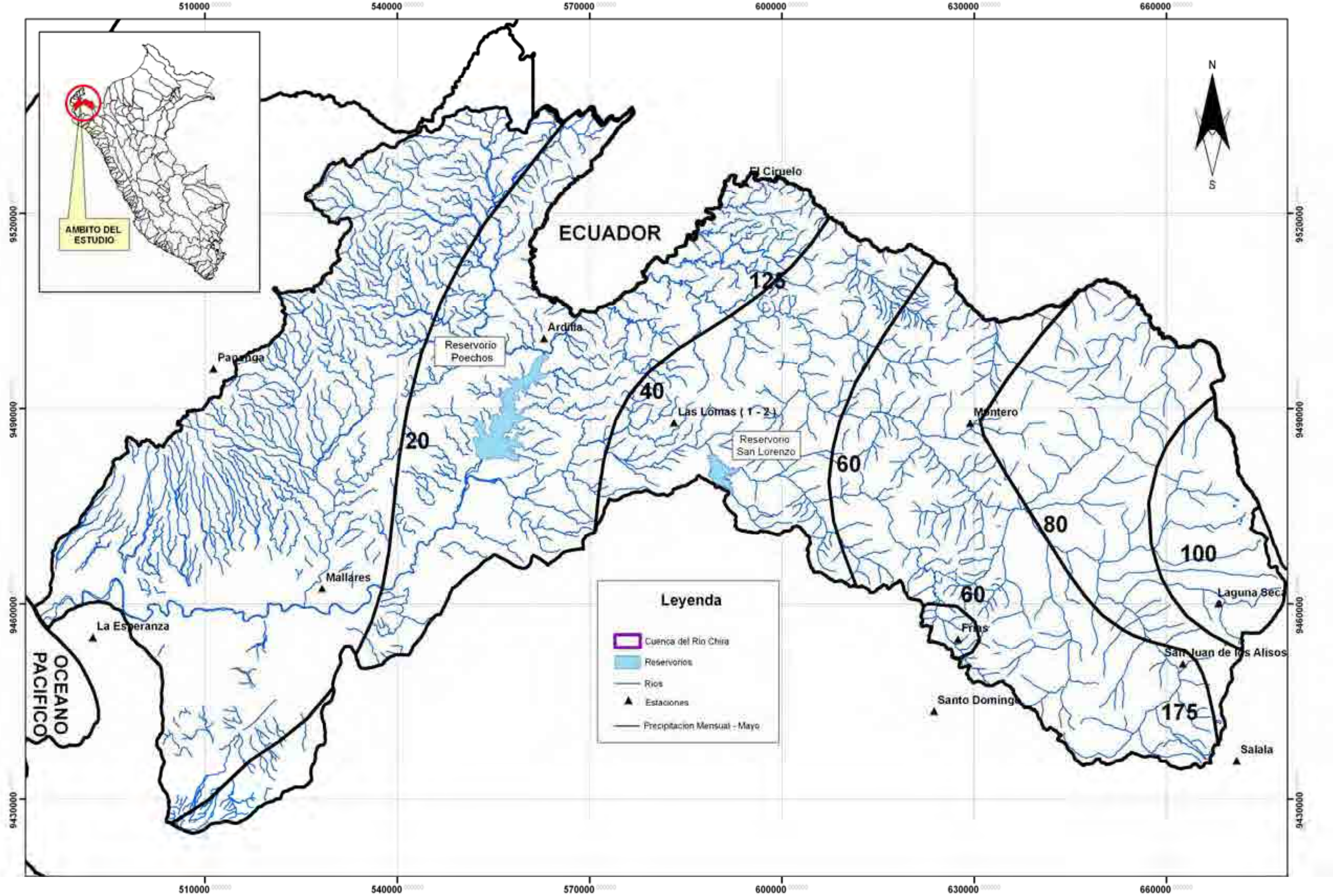


Figure Nº 3.10. Isohyets Mean Monthly Rainfall in the Chira Basin, in May

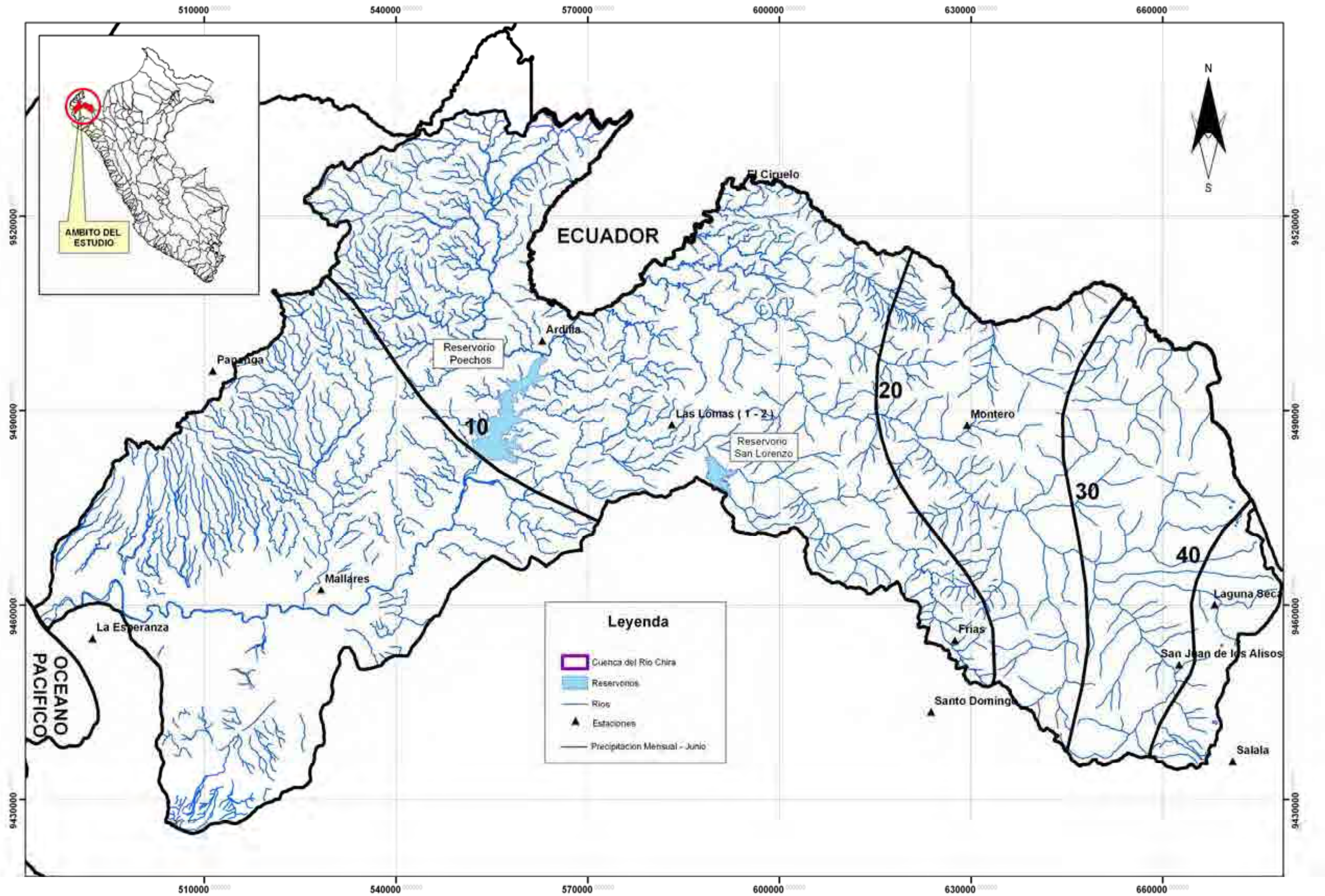


Figure Nº 3.11. Isohyets Mean Monthly Rainfall in the Chira Basin, in June

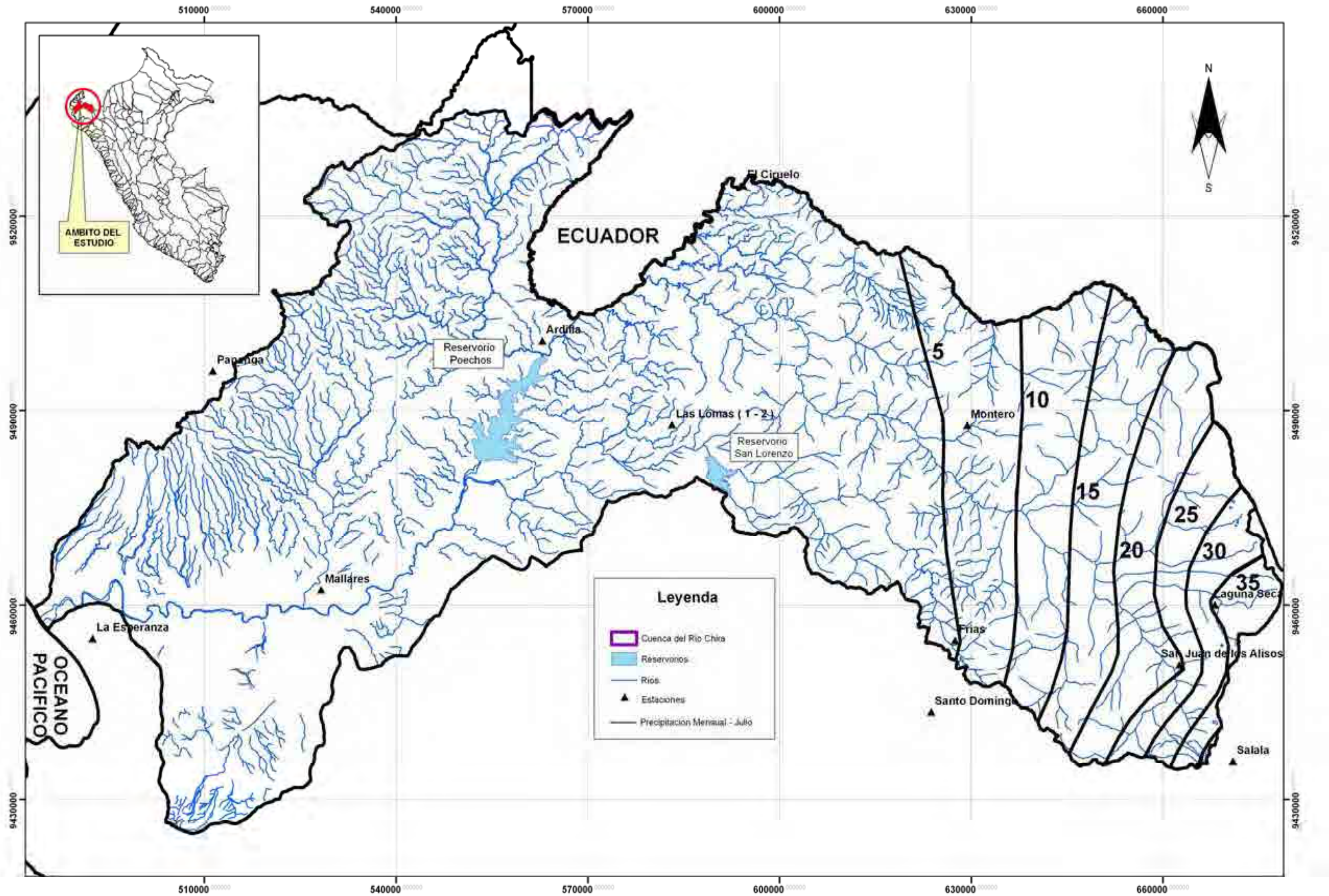


Figure Nº 3.12. Isohyets Mean Monthly Rainfall in the Chira Basin, in July

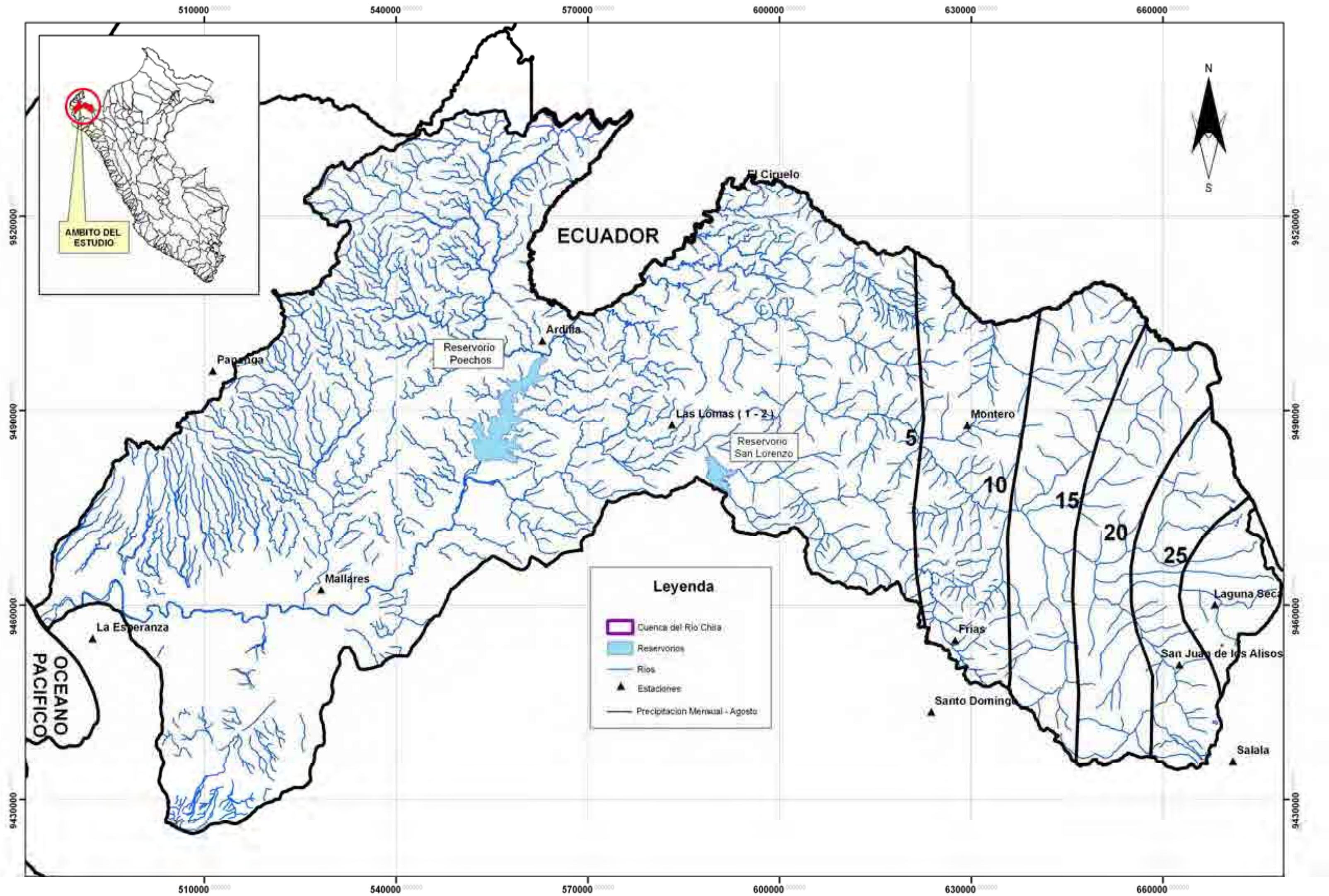


Figure Nº 3.13. Isohyets Mean Monthly Rainfall in the Chira Basin, in August

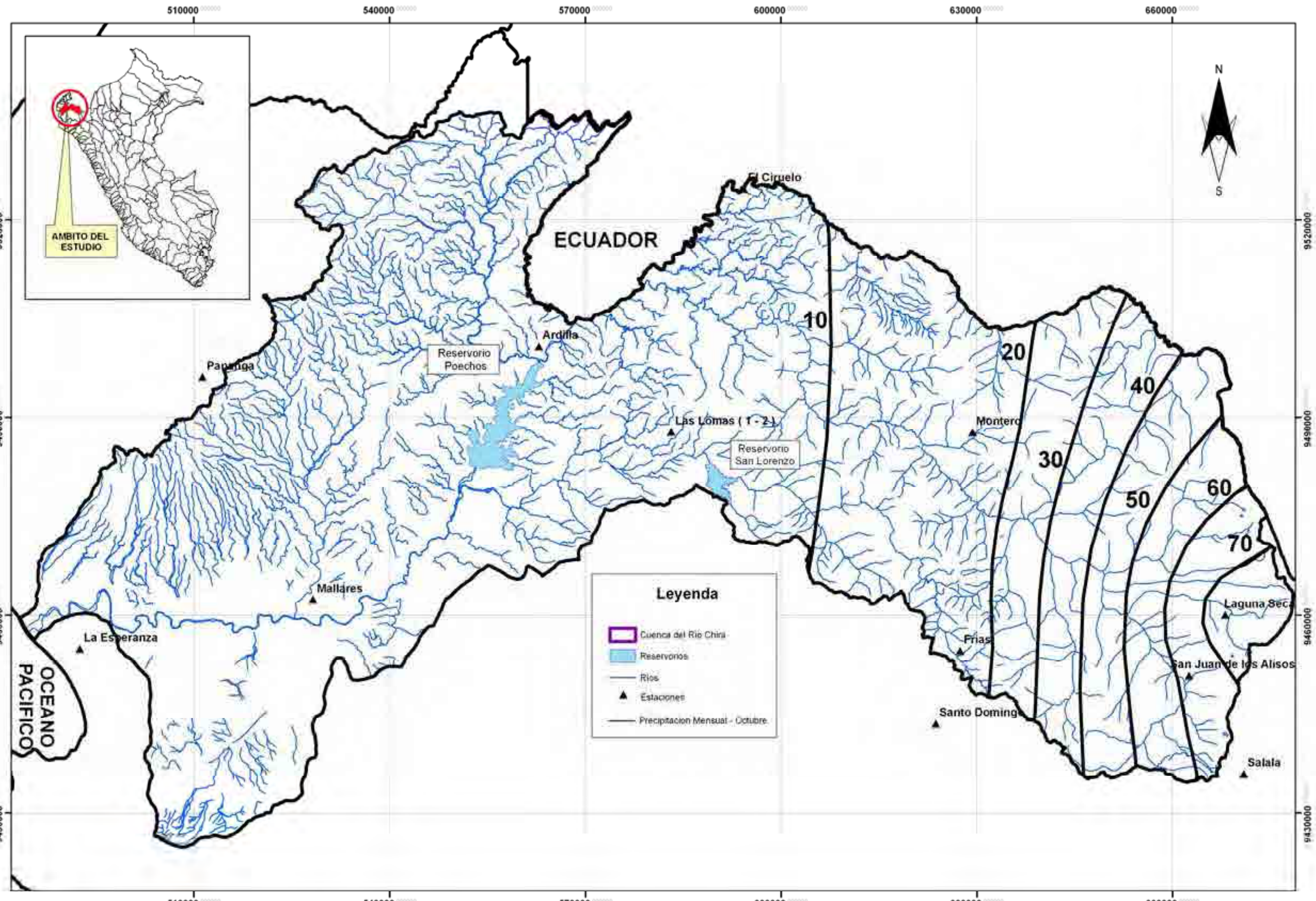


Figure Nº 3.14. Isohyets Mean Monthly Rainfall in the Chira Basin, in September

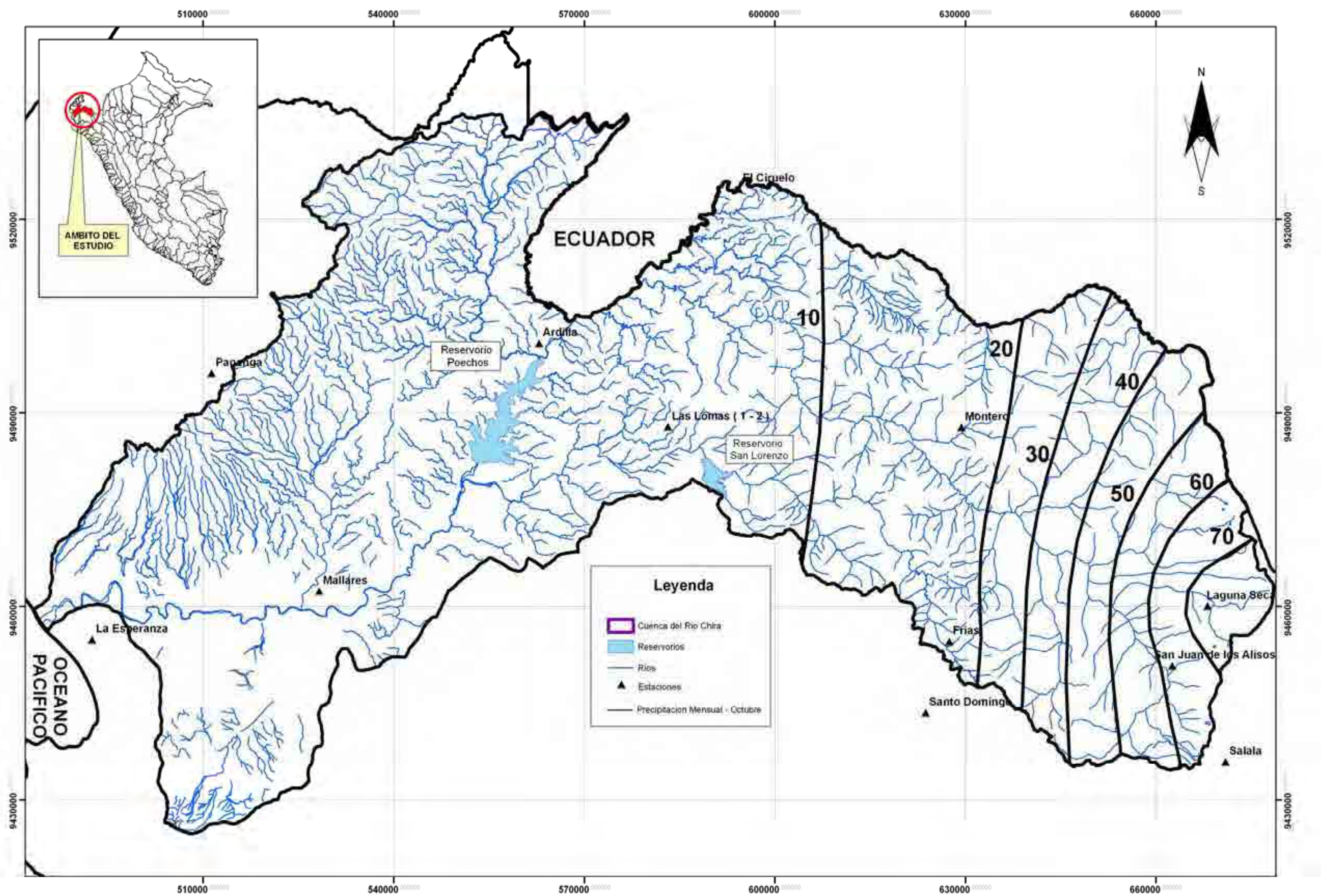


Figure Nº 3.15. Isohyets Mean Monthly Rainfall in the Chira Basin, in October

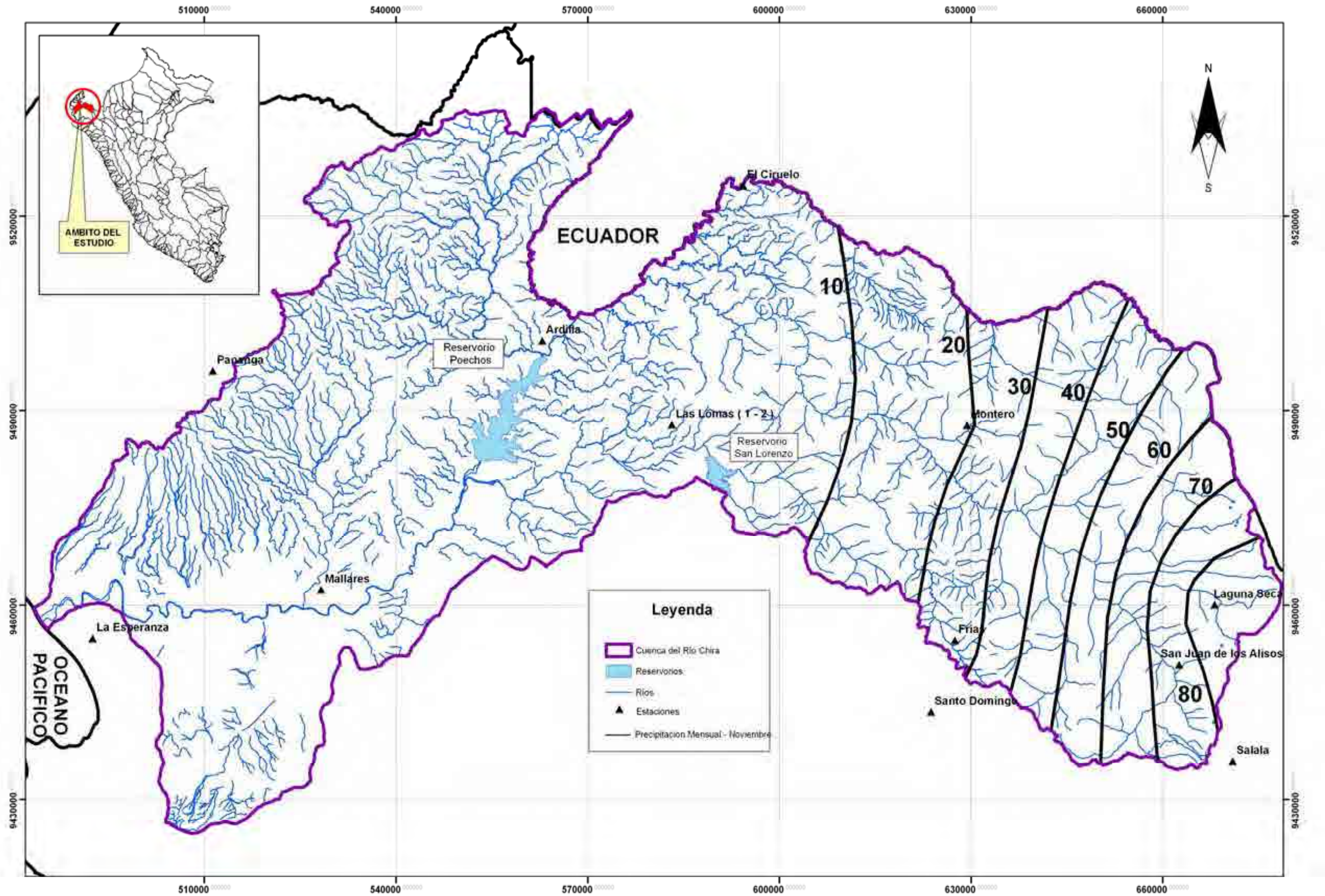


Figure Nº 3.16. Isohyets Mean Monthly Rainfall in the Chira Basin, in November

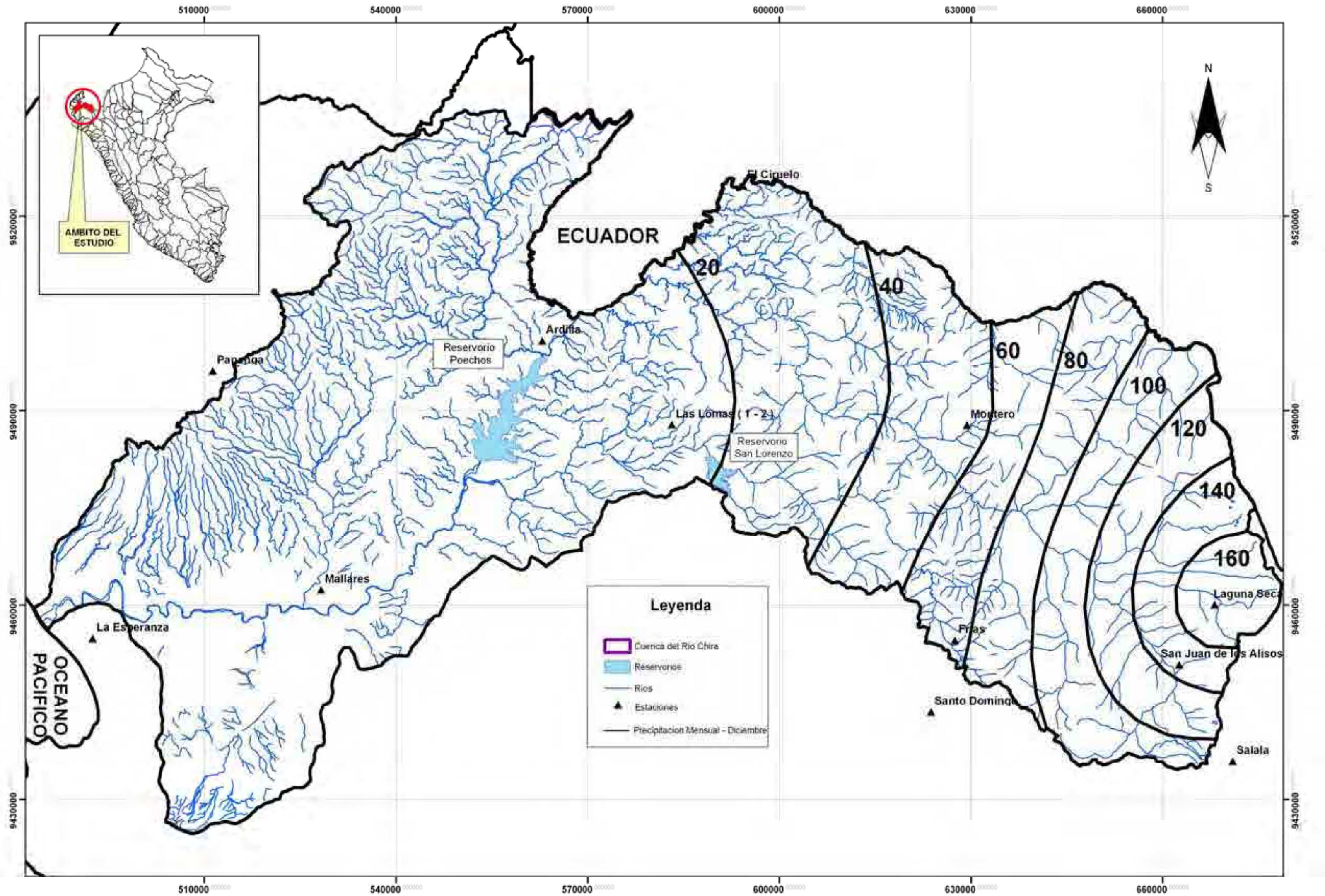


Figure Nº 3.17. Isohyets Mean Monthly Rainfall in the Chira Basin, in December

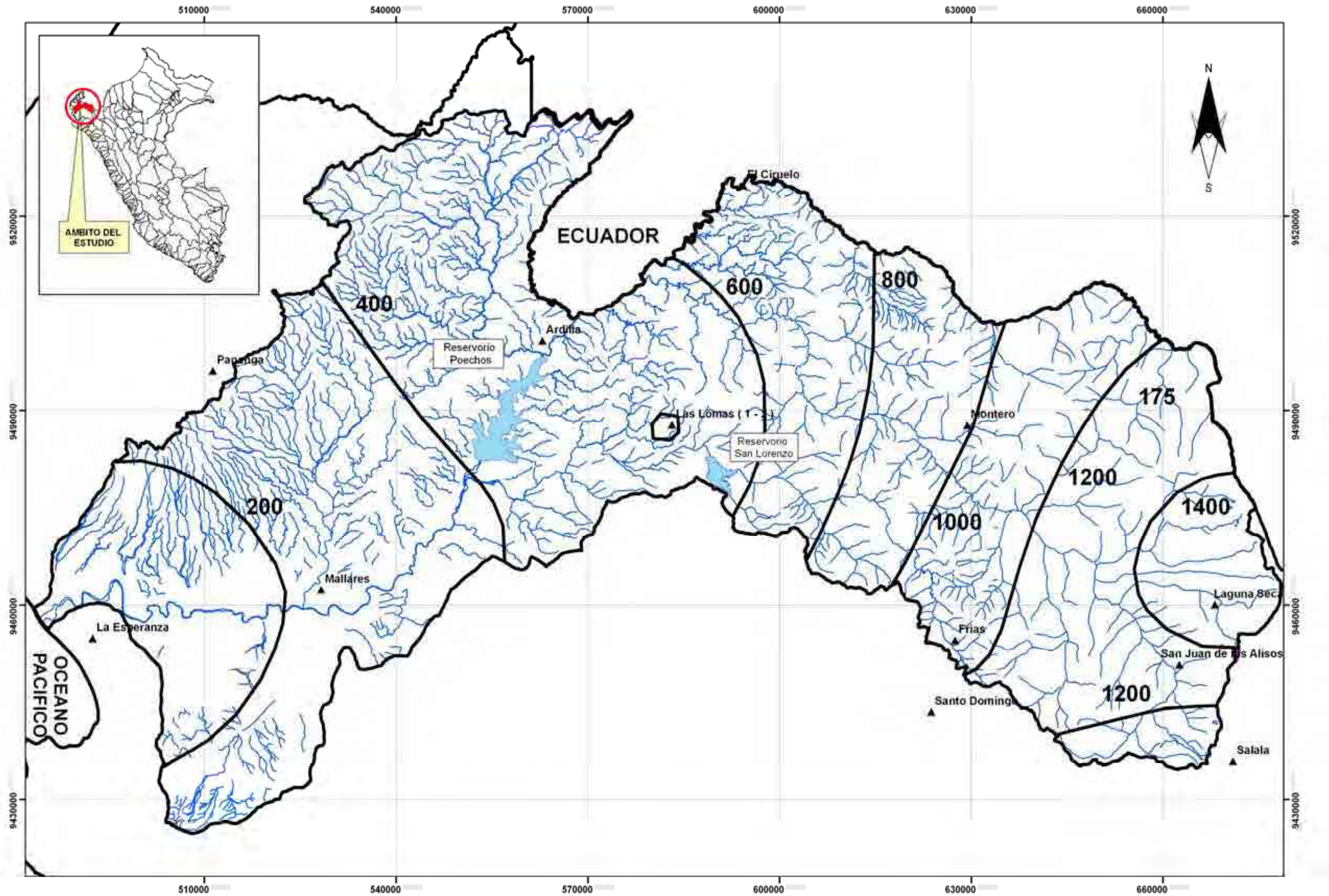


Figure Nº 3.18. Isohyets Annual Mean Monthly Rainfall in the Chira Basin

3.2.2 Temperature

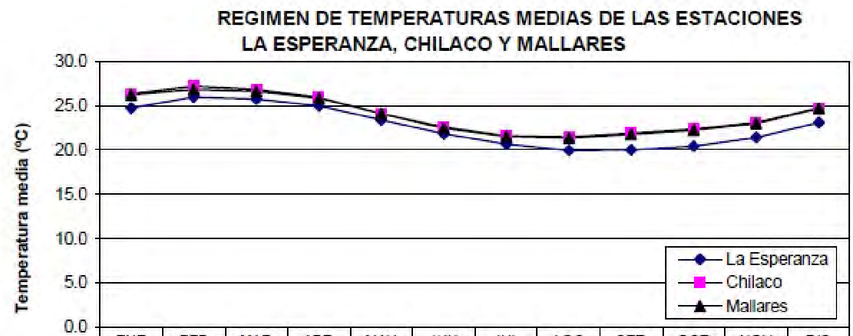
The temperature of air and its daily and seasonal variations are very important for development of plants, being one of the main factors that directly affect the growth rate, length of growing cycle and stages of development of perennial plants.

The average annual temperature in the basin to the lower and middle areas have similar values of 24 ° C, then decreases in the upper records up to 13 º C.

The maximum point values are between 13 and 15 hours, reaching 38 º C in the lowlands (February or March) and 27 º C in the high zone.

Minima occur in the months of June through August, reaching 15 º C on the coast, down to 8 º C during the months of June to September on top.

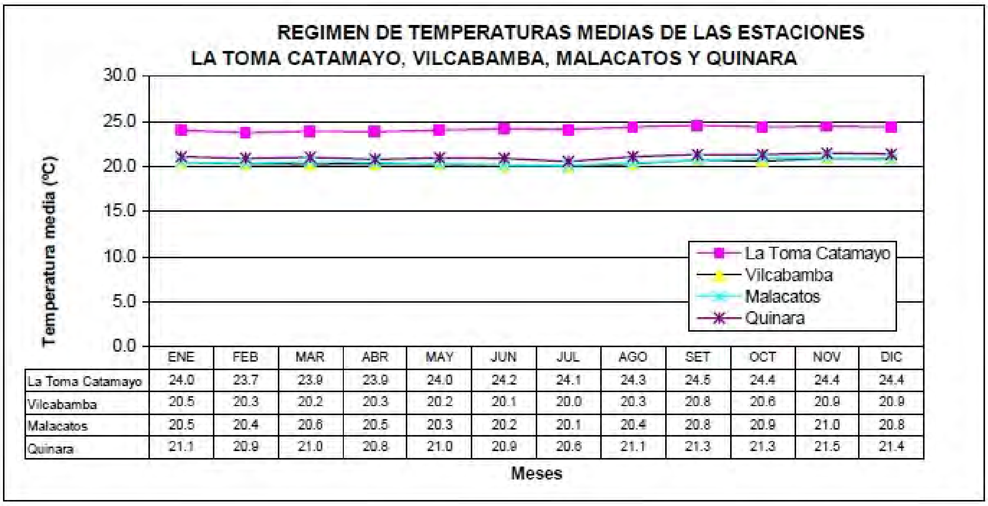
Figures 3.19 to 3.21 present the average monthly temperature charts for stations in Ecuador side.



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DIC
La Esperanza	24.8	26.0	25.8	25.0	23.4	21.8	20.7	19.9	20.0	20.4	21.4	23.1
Chilaco	26.4	27.2	26.9	25.9	24.1	22.6	21.6	21.5	21.9	22.3	23.1	24.7
Mallares	26.2	26.9	26.6	25.9	24.1	22.5	21.5	21.4	21.7	22.2	23.0	24.7

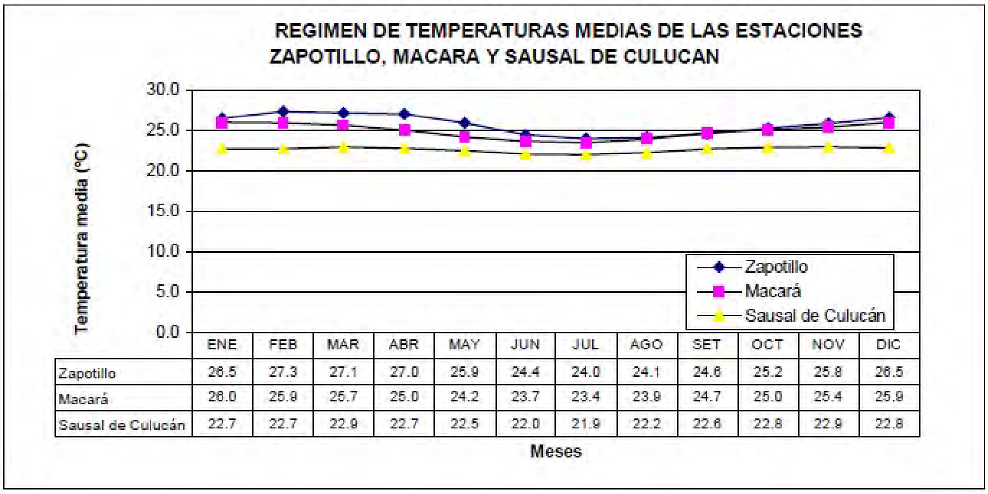
Meses

Figura Nº 3.19. Average monthly temperature for La Esperanza, Chilaco and Mallares Stations
Fuente: Proyecto Binacional Catamayo - Chira



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DIC
La Toma Catamayo	24.0	23.7	23.9	23.9	24.0	24.2	24.1	24.3	24.5	24.4	24.4	24.4
Vilcabamba	20.5	20.3	20.2	20.3	20.2	20.1	20.0	20.3	20.8	20.6	20.9	20.9
Malacatos	20.5	20.4	20.6	20.5	20.3	20.2	20.1	20.4	20.8	20.9	21.0	20.8
Quinara	21.1	20.9	21.0	20.8	21.0	20.9	20.6	21.1	21.3	21.3	21.5	21.4

Figura Nº 3.20. Average monthly temperature for La Toma Catamayo, Vilcabamba, Malacatos and Quinara Stations
Fuente: Proyecto Binacional Catamayo – Chira



	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DIC
Zapotillo	26.5	27.3	27.1	27.0	25.9	24.4	24.0	24.1	24.6	25.2	25.8	26.5
Macará	26.0	25.9	25.7	25.0	24.2	23.7	23.4	23.9	24.7	25.0	25.4	25.9
Sausal de Culucán	22.7	22.7	22.9	22.7	22.5	22.0	21.9	22.2	22.6	22.8	22.9	22.8

Figura Nº 3.21. Average monthly temperature for Zapoltillo, Macara and Sausal de Culucan Statios
Fuente: Proyecto Binacional Catamayo – Chira

3.3 Hydrometry

There are 25 hydrometric stations located along the River Chira catchment and surrounding basins. These stations are operated and maintained by the Peruvian National Service of Meteorology and Hydrology (SENAMHI by their initials in Spanish)

Table No. 3.4, shows the list of stations included in this study with their respective characteristics, such as code, name, and location. Historical records of monthly total rainfall and their histograms are presented in the Annex.

Table Nº 3.4. Characteristics of Hydrometric Stations in the Chira River Basin and Surrounding Basins

CODE	STATION NAME	CATEGORY*	CATCHMENT	DEPARTAMENT	PROVINCE	DISTRICT	LONGITUDE	LATITUDE	ELEVATION	CONDITION	WORKING PERIOD	
											START	END
200302	SOLANA BAJA	HLM	CHIRA	PIURA	SULLANA	LANCONES	80° 25'1	04° 31'1	112	Closed	1969-01	1975-12
200303	ZAMBA	HLM	CHIRA	PIURA	AYABACA	PAIMAS	79° 54'1	04° 40'1	761	Closed	Not Available	
200304	LAGARTERA	HLM	CHIRA	PIURA	AYABACA	SAPILLICA	80° 04'1	04° 44'1	472	Closed	Not Available	
200305	PUENTE SULLANA	HLM	CHIRA	PIURA	SULLANA	SALITRAL	80° 41'1	04° 53'1	25	Paralyzed	1938-09	1984-12
200306	PARDO DE ZELA	HLM	CHIRA	PIURA	PIURA	LAS LOMAS	80° 14'1	04° 40'1	233	Closed	1966-01	1975-02
200307	ROSITA	HLM	CHIRA	PIURA	SULLANA	LANCONES	80° 30'1	04° 36'1	102	Closed	Not Available	
200308	CANAL MIGUEL CHECA	HLM	CHIRA	PIURA	SULLANA	SULLANA	80° 31'1	04° 41'1	68	Paralyzed	1991-03	1995-07
200309	ENTRADA ARDILLA R. POECHOS	HLM	CHIRA	PIURA	SULLANA	LANCONES	80° 26'1	04° 31'1	120	Paralyzed	1991-03	1997-08
200310	PUENTE INTERNACIONAL MACARA	HLM	CHIRA	PIURA	AYABACA	SUYO	79° 57'1	04° 24'1	415	Paralyzed	1991-03	1997-08
200311	CANAL CHIPILLICO	HLM	CHIRA	PIURA	PIURA	LAS LOMAS	80° 10'1	04° 44'1	300	Closed	1969-09	2009-11
200312	PARAJE GRANDE QUIROZ	HLM	CHIRA	PIURA	AYABACA	MONTERO	79° 54'1	04° 37'1	1060	Paralyzed	1935-08	1995-07
200313	EL CIRUELO	HLM	CHIRA	PIURA	AYABACA	SUYO	80° 09'1	04° 18'1	300	Paralyzed	1992-04	1992-04
200314	LOS ENCUENTROS	HLM	CHIRA	PIURA	SULLANA	LANCONES	80° 17'1	04° 26'1	150	Closed	1975-11	2009-12
200316	CANAL PELADOS	HLM	CHIRA	PIURA	SULLANA	SULLANA	80° 30'1	04° 41'1	100	Closed	Not Available	
200318	SOLANA BAJA	HLM	CHIRA	PIURA	SULLANA	LANCONES	80° 25'1	04° 31'1	112	Paralyzed	Not Available	
200319	PUENTE SULLANA	HLM	CHIRA	PIURA	SULLANA	SALITRAL	80° 41'1	04° 53'1	25	Paralyzed	1991-03	1998-01
200320	LAGARTERA	HLM	CHIRA	PIURA	AYABACA	SAPILLICA	80° 04'1	04° 44'1	472	Paralyzed	Not Available	
200321	AYABACA	HLM	CHIRA	PIURA	AYABACA	AYABACA	79° 45'1	04° 40'1	2663	Paralyzed	Not Available	
200322	RESERV POECHOS(VOL)	HLM	CHIRA	PIURA	SULLANA	MARCAVELICA	80° 41'1	04° 31'1	333	Paralyzed	Not Available	
200323	RESERVORIO SAN LORENZO	HLM	CHIRA	PIURA	PIURA	LAS LOMAS	80° 12'1	04° 40'1	230	Paralyzed	Not Available	
200324	ALAMOR	HLM	CHIRA	PIURA	SULLANA	LANCONES	80° 23'56.9	04° 28'48.41	133	Operating	1997-09	2005-01
200418	CANAL YUSCAY	HLM	CHIRA	PIURA	PIURA	LAS LOMAS	80° 12'1	04° 40'1	230	Paralyzed	Not Available	
200426	SALIDA RESERVORIO POECHOS	HLM	CHIRA	PIURA	SULLANA	MARCAVELICA	80° 41'1	04° 31'1	333	Paralyzed	1991-03	1997-08
4724B080	EL CIRUELO	EHA	CHIRA	PIURA	AYABACA	SUYO	80° 09'1	04° 18'1	300	Operating	2001-01	2012-06
472606Operating/	AYABACA	EMA	CHIRA	PIURA	AYABACA	AYABACA	79° 43'1	04° 38'1	2757	Operating	2000-12	2011-12

HLM = Hydrometric Station with staff gauge. It records water level manually (at 06:00, 10:00, 14:00 and 18:00 hours) to calculate daily discharges.
HLG = Hydrometric Station with staff gauge and Limnigraph (floater type). It records water level manually (at 06:00, 10:00, 14:00 and 18:00 hours) to calculate daily discharges. I also it records continuously (hourly) water level data graphed in a recording paper.
EHA = Automatic Hydrometric Station (hourly data of water level using sensors).

Figure Nº 3.22, shows the period and the length of the data available from the hydrometric stations and Figure No. 3.23 shows the locations in the Chira Basin and adjacent watersheds.

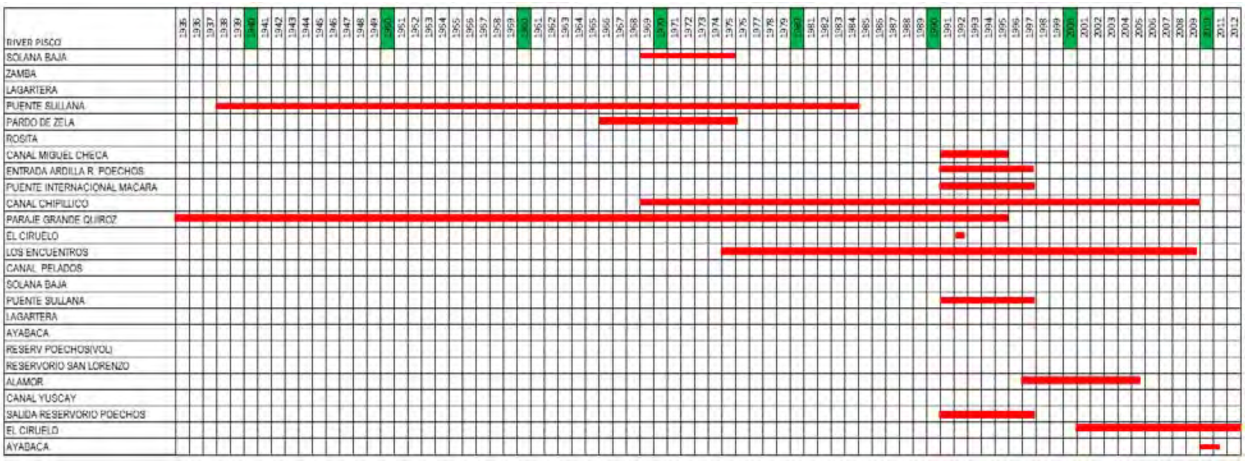


Figure Nº 3.22. Period and longitude of the available information of the Hydrometric Stations

The information of the hydrometric station Ardilla will be used for calibration of the hydrologic model to be described in item 4.2.4. This station is located downstream of the "wet basin" of the catchment, therefore flows registered in this station are practically the same discharge that flows to the Pacific Ocean.

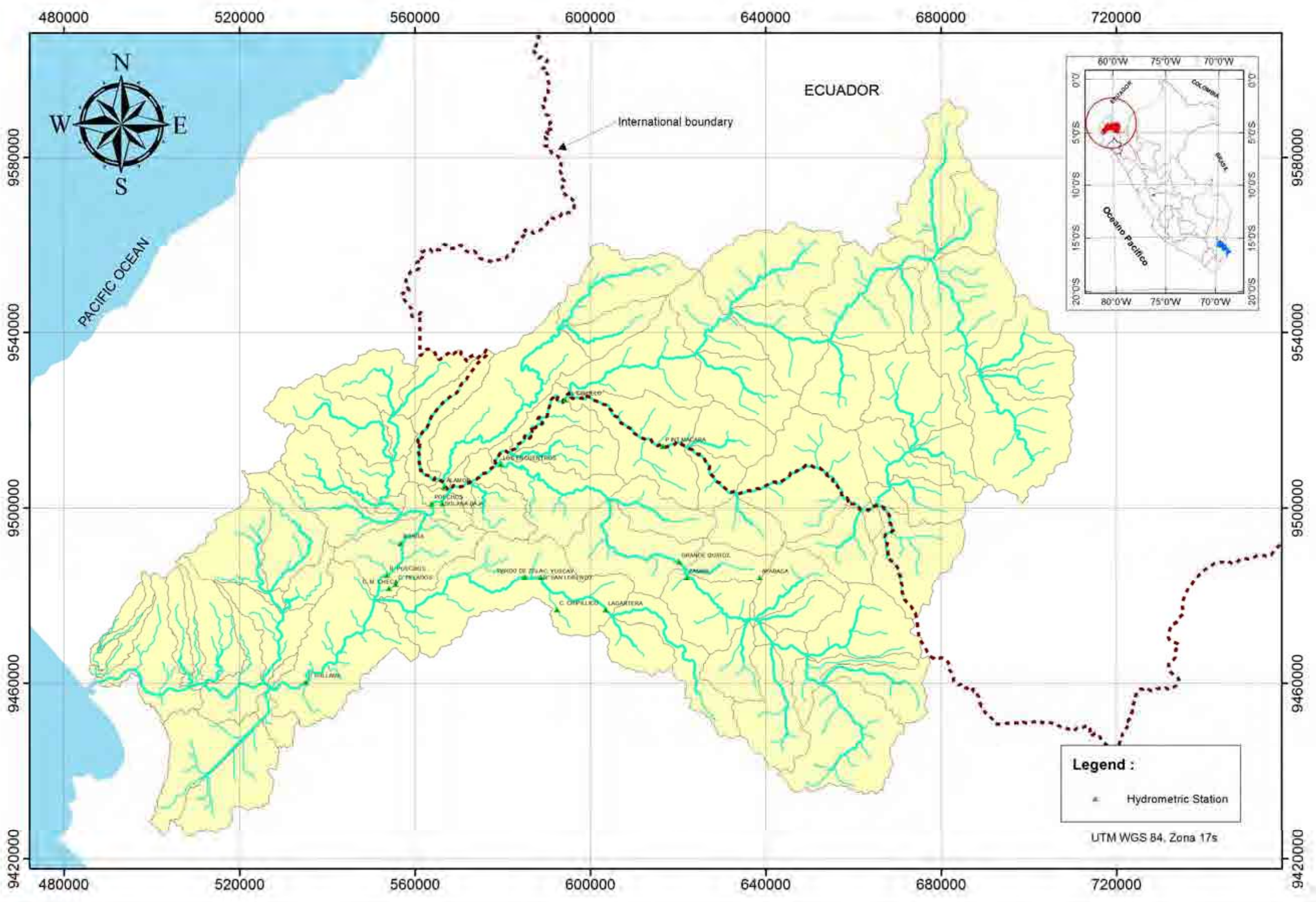


Figure Nº 3.23. Location of the hydrometric stations in Chira River Basin and Adjacent Basins

3.4 Comments on the pluviometric and hydrometric network in the Chira River Catchement.

3.4.1 On Pluviometric Stations.

As it was stated previously the pluviometric information used in the analysis has been provided by SENAMHI. From the 13 stations, 5 stations have data until year 2010, 04 station has data until 1996, 02 station has data until 1995 and 01 station has data until 1987.

The stations with information previously to 2007 are not operative anymore, although we don't have the exact information, it is possible that the remaining stations are currently operative. Although the information coming from stations which have data until years previously to 1991 could be considered somewhat old, this data have been used because their period of information are longer than 12 years and still could be used for statistical analysis. From the 13 stations, 10 were used for the flood peak discharges analysis, the remaining were not used due to their short period of information or the bad quality of their data.

Rainfall records are done using manual rain gages, these devices accumulate rain for a certain length of time after which the accumulated height of rain is measured manually. In some cases, the readings are made once a day (at 7 am); in others, twice a day (at 7 am and 7 pm), the exact interval or readings for the pluviometric stations used in the present analysis is not available.

3.4.2 On Hydrometric Stations.

Although these stations were operated and maintained by SENAMHI, the hydrometric information used in the analysis was provided by The General Directorate of Water Infrastructure (DGIH) of the Ministry of Agriculture.
From the 25 stations, 1 station has data until year 2012, 01 station has data until 2011, 02 station have data until 2009, 01 station has data until 2005, 04

station have data until 1997, 01 station has data until 1995, 01 station has data until 1992, 01 station has data until 1984 and 02 stations have data until 1975.

For the purpose of the present study the information of hydrometric stations Ardilla and Puente Sullana were used. Station Ardilla. The hydrometric station Ardilla measures natural ("without project") flows upstream the Poechos Reservoir. The hydrometric station Puente Sullana measures flows downstream of Poechos reservoir, these flows have lamination effect originated by the reservoir.

In these stations water levels are measured by reading the level in a staff gages (or rulers), lectures are transferred to a notebook and discharges are found using an equation of the type:

$$Q = aH^{b}$$

Where Q is the discharge in m^3/s and H is the reading in meters. These types of stations don´t register maximum instantaneous discharge, because recordings are not continuous and automatic, but manual. Four readings a day are taken. Readings are taken at 6 am, 10 am, 14 pm and 18 pm. The largest of all readings is called the daily maximum discharge, but this value is not the maximum instantaneous daily discharge.

3.4.3 Recommendations

From a technical viewpoint, the following main recommendations can be given:

On the Equipment

- In order to consider the possible differences in climates along the catchment due to orographic effects, the number of weather and hydrometric stations networks should be increased.

- In order to register the maximum instantaneous values of rainfall and discharges, the existing manual weather and hydrometric stations should be automated.

- The limnigraphic equipment of the hydrometric stations should be upgraded from the conventional paper band type to the digital band type

.

- Having the collected data available in real time is desirable.

- Study the possibility of establishing an early warning system based on improving and increasing the number of existing hydrometric and pluviometric stations.

- For complementary studies, it is advisable to acquire:
  - Equipment to sample sediment material.
  - Equipment for measuring of physical parameters for water quality control (pH, DO, turbity and temperature)

- Establishment of Bench Mark (BM) for each weather and hydrometric station using a differential GPS. This information will be useful to replenish the station in case of its destruction by vandalism or natural disasters.

On the Operation and Maintenance of the Equipments

- Weather and hydrometric stations in the study areas should be inspected frequently.
- Maintenance of equipment should be in charge of qualified technicians that are certified by the manufacturers.
- Periodic calibration of the equipment should be done according to the hours of use.

On the Quality of the Measured Data

- Data taken manually by SENAMHI operators should be verified independently.

- In order to guarantee the quality of the information collected in previous years a verification study program of the data should be done by the government.
- Redundant equipment should be available in the main weather stations. This means that duplicate equipment should be installed in selected stations to compare readings with pattern equipment.

- When automatic stations are available they should operate simultaneously with manual stations at least for one year to verify the consistency of the data registered automatically.

It is necessary to mention that there is currently an agreement between Peru's National Water Authority (ANA) and SENAMHI to provide equipment to SENAMHI weather stations financed by an external source, it is recommended that action be taken in order to include Chira Basin in this agreement..

4 HYDROLOGY OF MAXIMUM FLOOD

4.1 Preliminary Considerations

This chapter describes the work methodology developed for the generation of flood flows in the so-called Base Points (point of interests, Puente Sullana station and Ardilla station) for return periods of 2, 5, 10, 25, 50, and 100 years.

The estimated maximum discharges were made from the information of maximum 24-hours rainfalls with a rainfall - runoff model, using the HEC-HMS Software. The model was calibrated using historical records of annual maximum daily flow of the hydrometric stations Ardilla.

<u>Field Reconnaissance:</u>

The field survey has included a review of the general characteristics of the Puente Sullana hydrometric station and the base point (point of interest, where the peak discharges will be estimated), the major topographic features and land use in the watershed to the study area, which has supported the definition of some parameters to consider for the generation of flood flows.

<u>Methodology and Procedures:</u>

Methodology and procedures developed for maximum discharge estimations are summarized below:

- Identification and delimitation of the sub – watershed to the point of interests (Puente Sullana Station and Ardilla Station), based on Charts at 1:100000 and / or 1:25000 scale, and satellite images.
- Selection of existing pluviometer stations in the study area and collections of historical record of maximum 24 hour rainfall.
- Frequency analyses of maximum 24 hours rainfalls for each station and selection of the distribution function showing the best adjustment.
- Areal rainfall calculation of the watershed to the point of interests from the isohyetal line maps that were prepared for the 5, 10, 25, 50, and 100 – year return periods
-
- The rainfall – runoff model generates flood flows for 5, 10, 25, 50, and 100 – year return periods, by using the HEC – HMS software.

○ The model is calibrated based on the flow frequency law adopted for hydrometric station Ardilla.

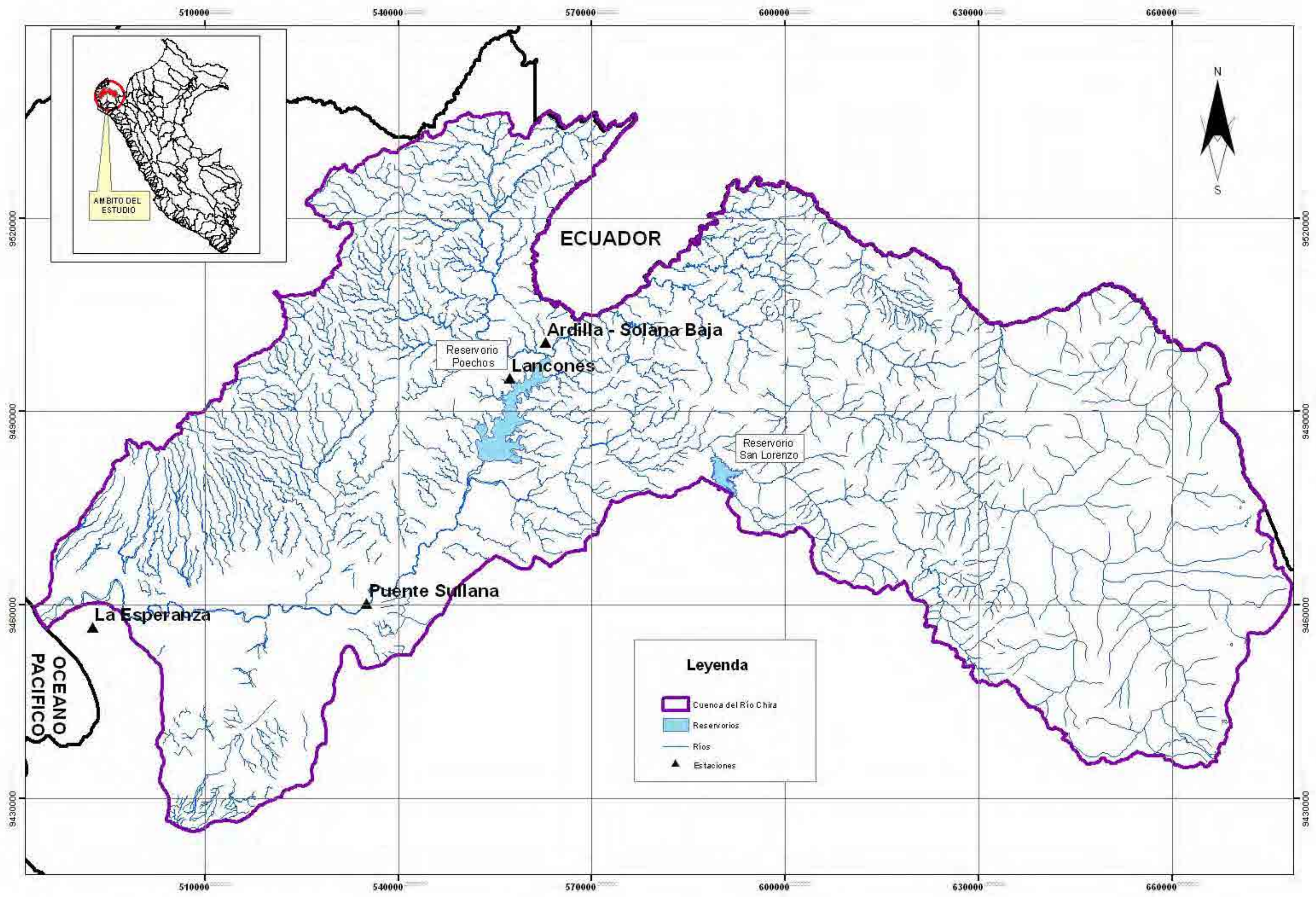


Figure Nº 4.1. Relative Position of Hydrological Stations in the Study Area

4.2 Hydrologic Modeling

4.2.1 Basin Outlining

The area of Chira River catchment until the Bridge Simón Rodriguez is 17059 km^2, for modeling purposes the catchment was split in sub-basins. As this is a bi – national basin, information was gathered from the sub – basins in the areas relevant to the Ecuadorian side (where the Catamayo – Piura River is born) and the Peruvian side, where the Chira River finally discharges its flows to the Pacific Ocean.

Table 4.1 shows basins identified in a study of the Catamayo – Piura System and their respective contribution areas.

Table Nº 4.1. Characteristics of the Chira River Topographic Basins

Sub - Basin		Area (km^2)
Catamayo		4184
Macara		2833
Quiroz		3108
Alamor		1190
Chipillico		1170
Chira	C-1	878
	C-2	1301
	C-3	636
	C-4	921
	C-5	414
	C-6	99
	C-7	325
	Total	17059

4.2.2 Design Rainfall

4.2.2.1 Distribution Functions

The following describes the distribution functions:

1. Distribution Normal or Gaussian

   It is said that a random variable X has a normal distribution if its density function is,

$$f(x) = \frac{1}{\sqrt{2\pi}S} EXP\left[-\frac{1}{2}\left(\frac{x - X}{S}\right)^2\right]$$

To $-\infty < x < \infty$

Where:

f(x) = Normal density function of the variable x.

x = Independent Variable.

X = Location parameter equal to the arithmetic mean of x.

S = Scale parameter equal to the standard deviation of x.

EXP = Exponential function with base e of natural logarithms.

2. Two-Parameter Log-normal Distribution

When the logarithms, ln(x) of a variable x are normally distributed, then we say that the distributivo of x is the probability distribution as log–normal probability function log–normal f(x) is represented as:

$$f(x) = \frac{1}{x\sigma_y\sqrt{2\pi S}} EXP\left\{-\frac{1}{2}\left[\frac{lnx - \mu_y}{\sigma_y}\right]^2\right\}$$

To $0<x<\infty$, must be $x \sim logN(\mu_y, \sigma_y 2)$

Where:

μ_y, σ_y = Are the mean and standard deviation of the natural logarithm of x, i.e. de ln(x), representing respectively the scale parameter and shape parameter distribution.

3. Log–Normal Distribution of Three Parameters

Many cases the logarithm of a random variable x, the whole are not normally distributed but subtracting a lower bound parameter xo, before taking logarithms, we can get that is normally distributed.

The density function of the three-parameter lognormal distribution is:

$$f(x) = \frac{1}{(x - x_o)\sigma_y\sqrt{2\pi}} EXP\left\{-\frac{1}{2}\left[\frac{ln(x - x_o) - \mu_y}{\sigma_y}\right]^2\right\}$$

To $x_o \leq x < \infty$

Where:

xo = Positional parameter in the domain x

μ_y, = Scale parameter in the domain x.

σ_y^2 = Shape parameter in the domain x

4. Two-Parameter Gamma Distribution

It is said that a random variable X has a 2-parameter gamma distribution if its probability density function is:

$$f(x) = \frac{x^{\gamma-1} e^{-\frac{x}{\beta}}}{\beta^{\gamma} \Gamma_{\gamma}}$$

To:

$0 \leq x < \infty$

$0 < y < \infty$

$0 < \beta < \infty$

As:

γ = Shape parameter (+)

β = Scale Parameter (+)

$\Gamma_{(\gamma)}$ = Complete gamma function, defined as:

$\Gamma_{(\gamma)}$ = $\int x^{\gamma-1} e^{-x} dx$, which converges if $\gamma > 0$

5. Three- Parameter Gamma Distribution or Pearson Type III

The Log-Pearson type 3 (LP3) is a very important model in statistical hydrology, especially after the recommendations of the Water Resources of the United States (Water Resources Council - WRC), to adjust the distribution Pearson Type 3 (LP3) to the logarithms of the maximum flood. Well, the LP3 distribution is a flexible family of three parameters can take many different forms, therefore it is widely used in modeling annual maximum flood series of unprocessed data.

It is said that a random variable X has a gamma distribution 3-parameter or Pearson Type III distribution, if its probability density function is:

$$f(x) = \frac{(x - x_o)^{\gamma-1} e^{\frac{(x - x_o)}{\beta}}}{\beta^{\gamma} \Gamma_{\gamma}}$$

To

$x_o \leq x < \infty$

$-\infty < x_o < \infty$

$0 < \beta < \infty$

$0 < \gamma < \infty$

4.2.2.2 Calculation of Maximum 24 hours Rainfall for Different Return Periods

Using different probability distribution functions, such as: Normal, 2 or 3 parameter Log - Normal, 2 or 3 parameter Gamma, log - Pearson III, Gumbel, Log – Gumbel, and Widespread Extreme Values, frequency analyses were done with the historical data of maximum 24 hours rainfall in each pluviometric station

From the information that has been generated for each distribution function, results showing best adjustment based on the Kolgomorov – Smirnov goodness – of - fit test will be chosen. Return periods taken into account for this study are 2, 5, 10, 25, 50, and 100 years.

Table 4.2a shows the values of the maximum 24 hours rainfall (mm) of Mallares Station for the return periods of 10. 50, 100 and 500 years. This station has been adopted has been selected as representative station for the purposes of the current study.

Table N° 4.2a. Maximum 24 Hours Raiinfall (mm) for Different Return Periods

Station	Elevation (masl)	Number of Records	Return Period (Years)			Adopted Distribution
			50	100	500	
Mallares	45	39	251	344	643	Log Pearson II

4.2.2.3 Map of Isohyets

With 24-hour maximum rainfall associated with the probability of occurrence maps were generated isohyets for return period of 2, 5, 10,25, 50 and 100 years, see Figure No. 4.2.

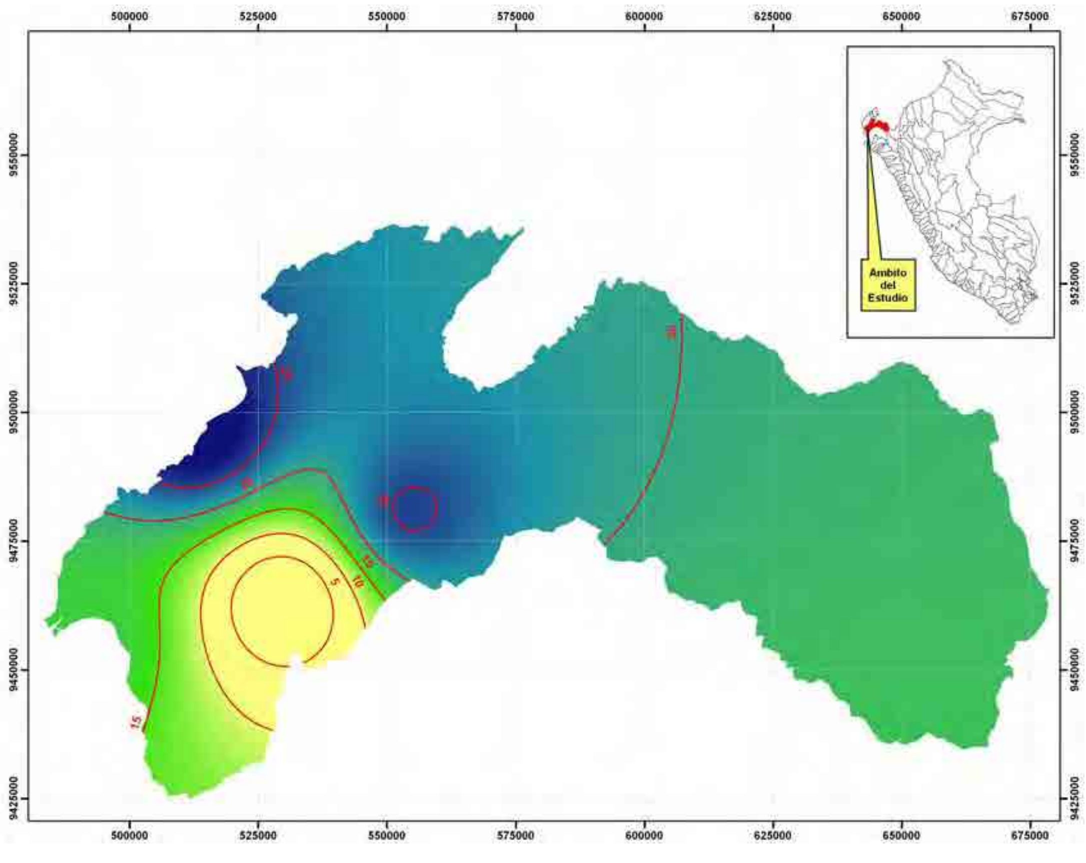


Figure N° 4.2a. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

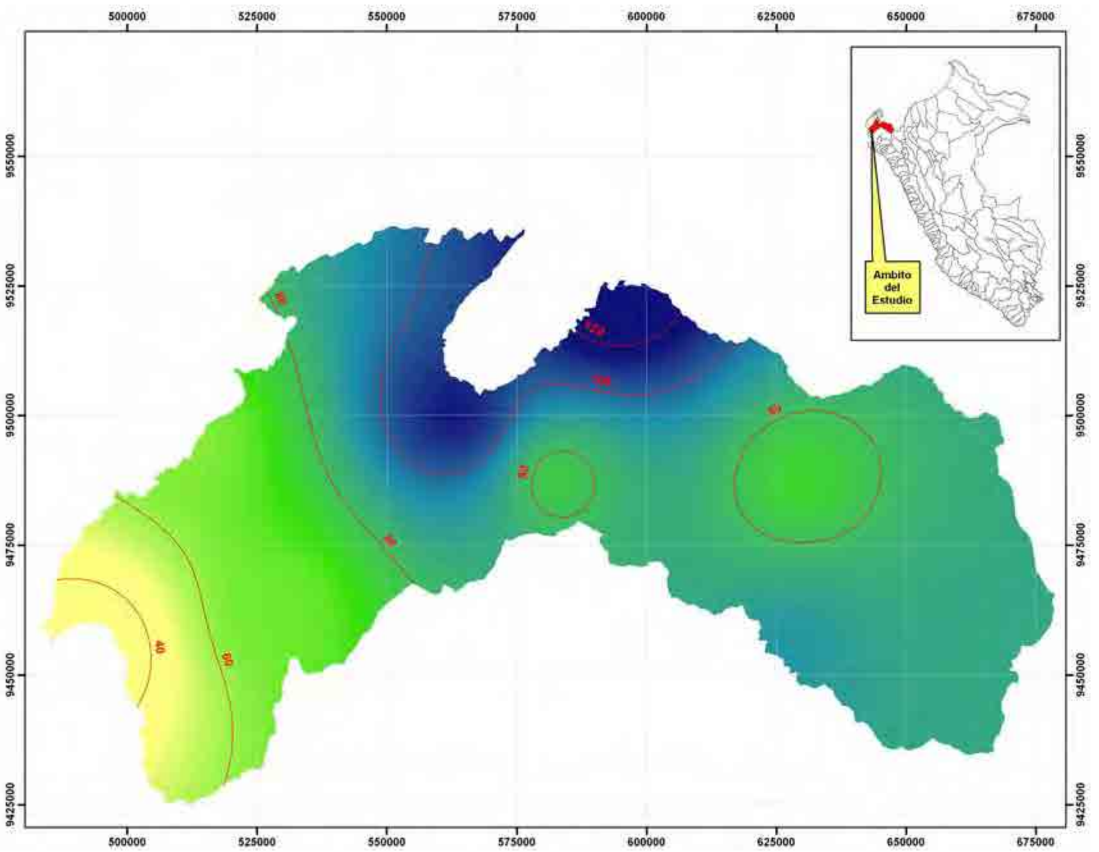


Figure Nº 4.2b. Isohyets for the 5- Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

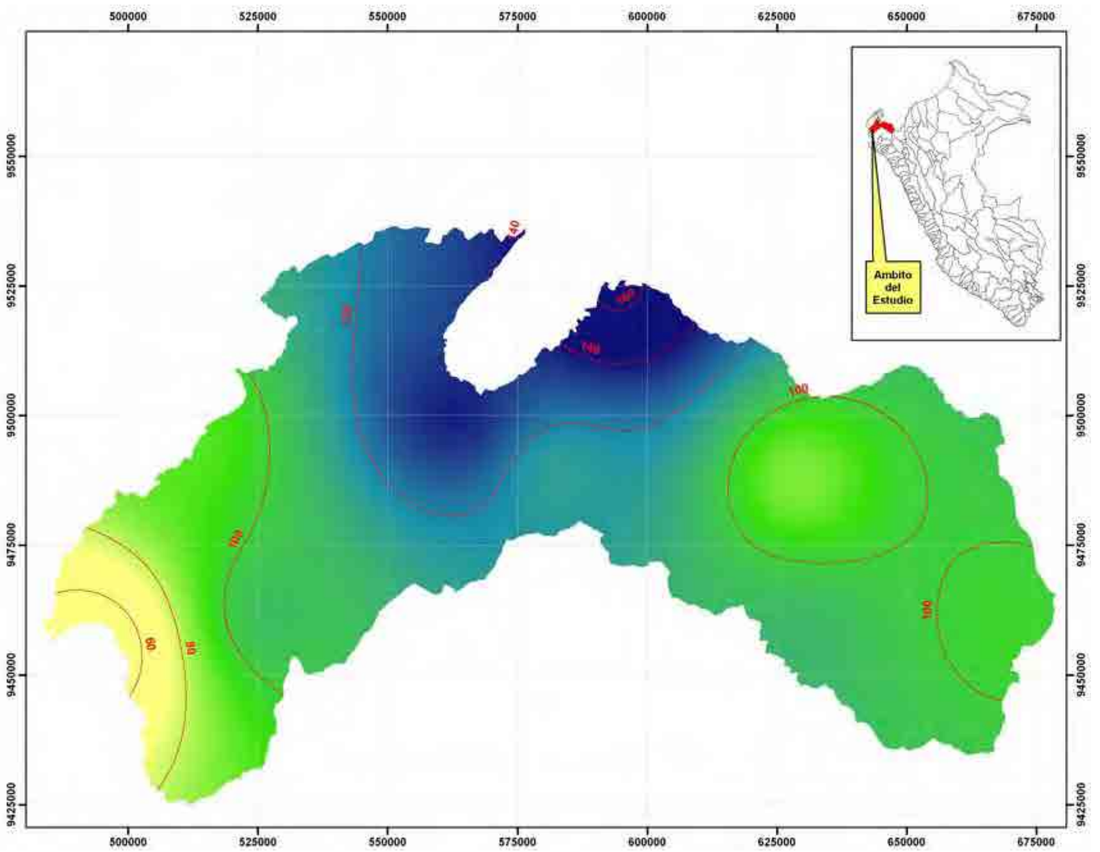


Figure Nº 4.2c. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

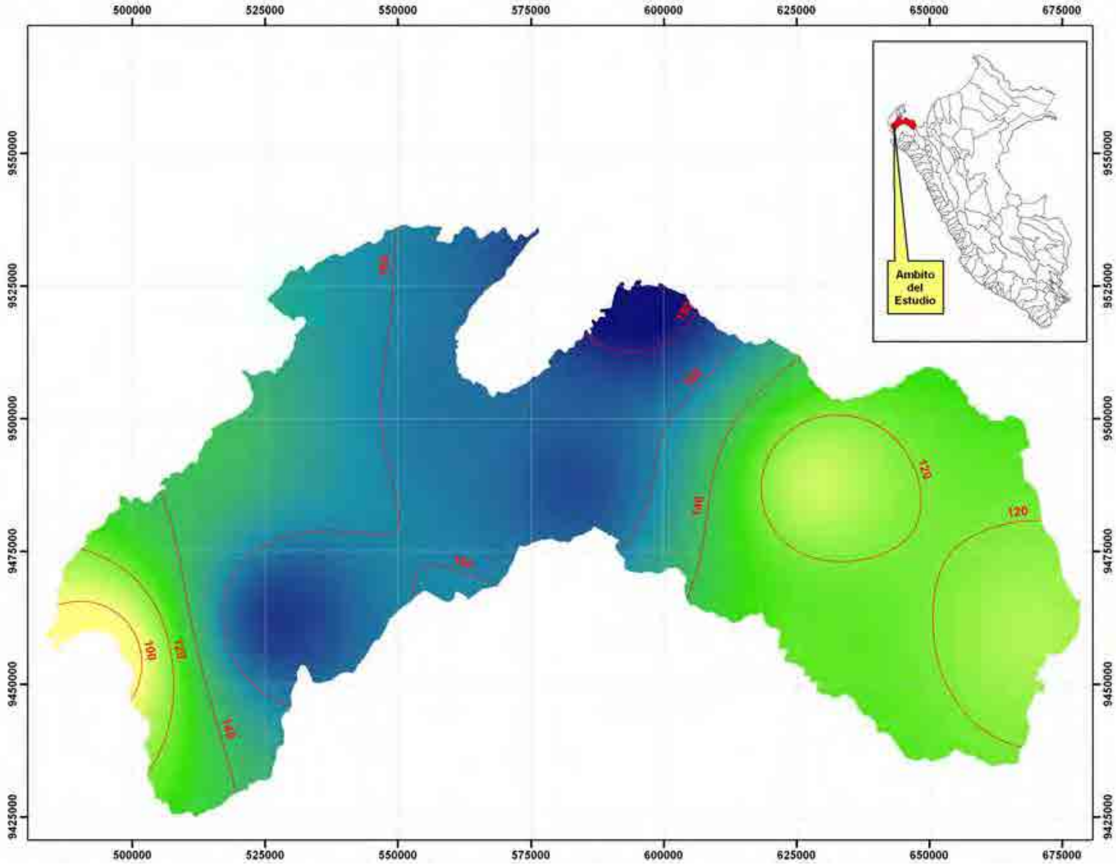


Figure Nº 4.2d. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

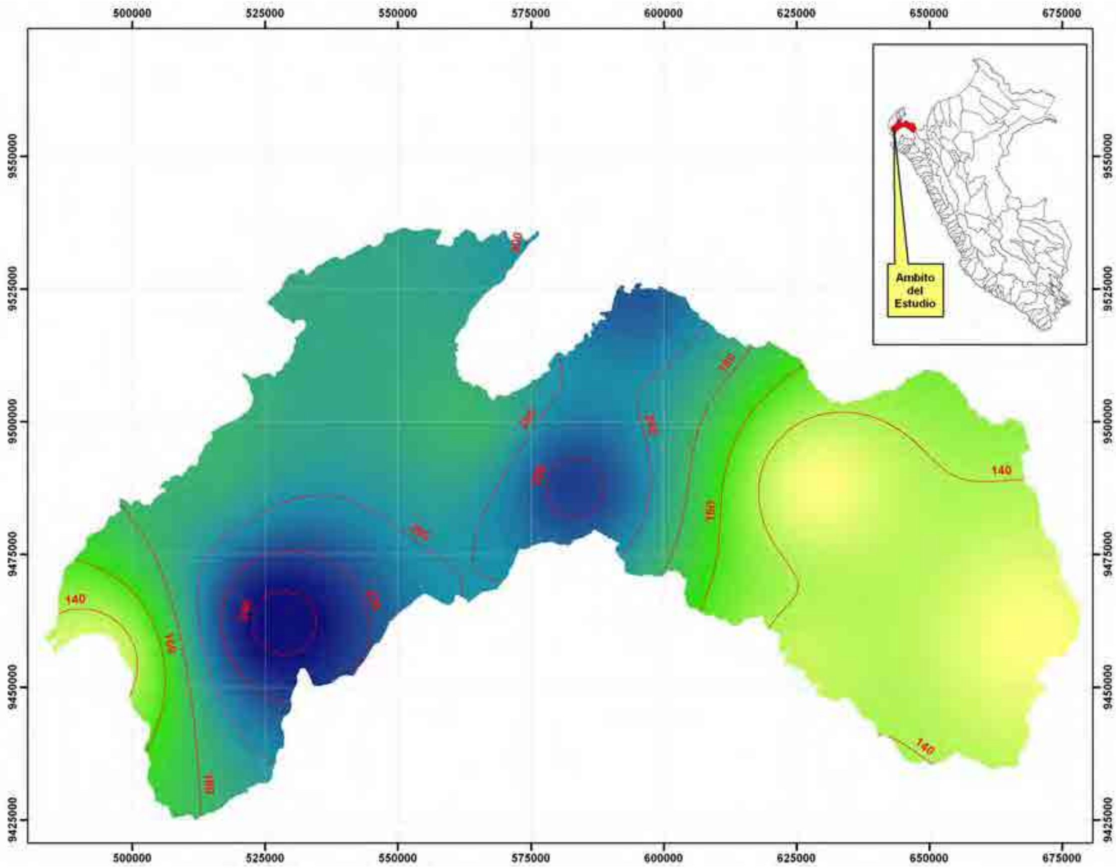


Figure Nº 4.2e. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

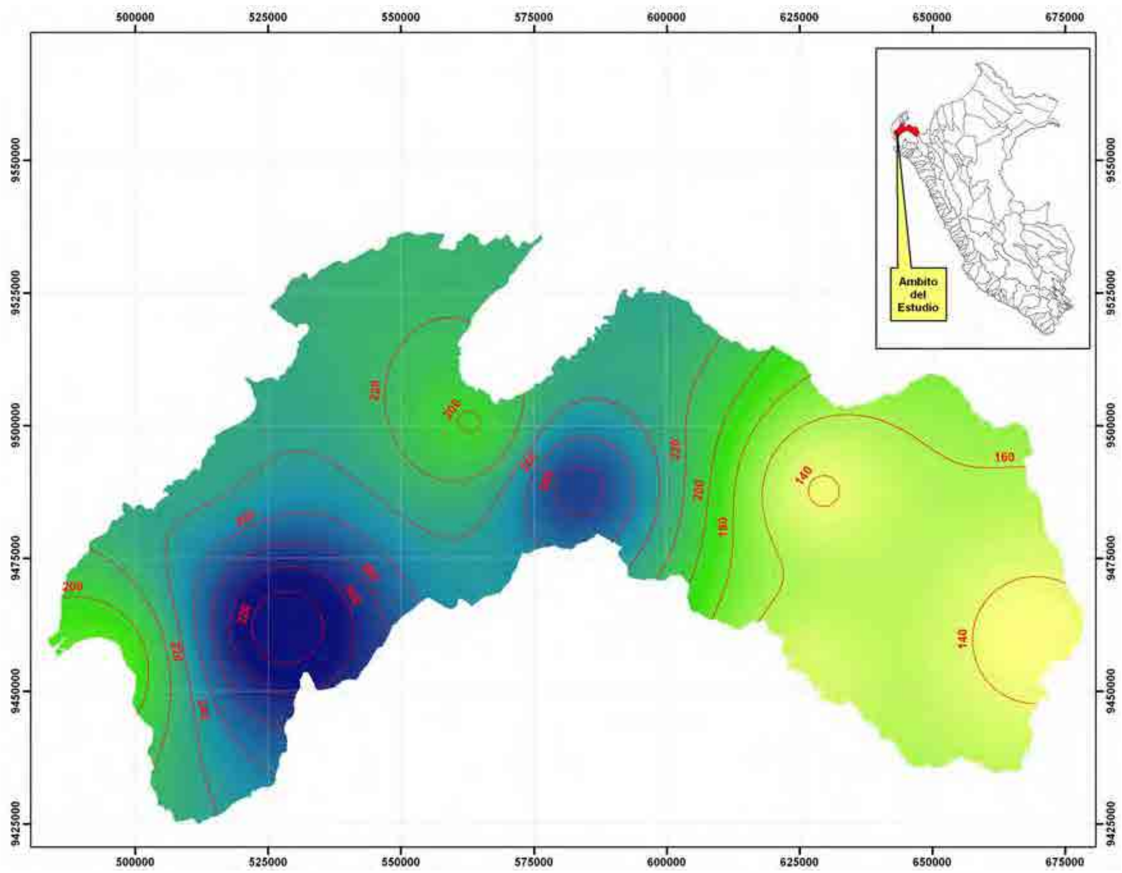


Figure Nº 4.2f. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

4.2.2.4 Determination of Maximum 24-Hours Rainfall for Different Return Periods in the Chira River Subwatershed

In addition to the hydrological study of the flow in the river Chira is required to estimate the maximum 24-hours rainfalls for different return periods in the Chira river basins. It has been estimated from maps shown in Figure isohyets No. 4.3.

In Figure Nº 4.3, shows the Chira river basins to which it has been estimated maximum 24-hours rainfalls for return period and for each subbasin. In Table Nº 4.2b are shown the values of maximum 24-hours rainfalls for each subbasin.

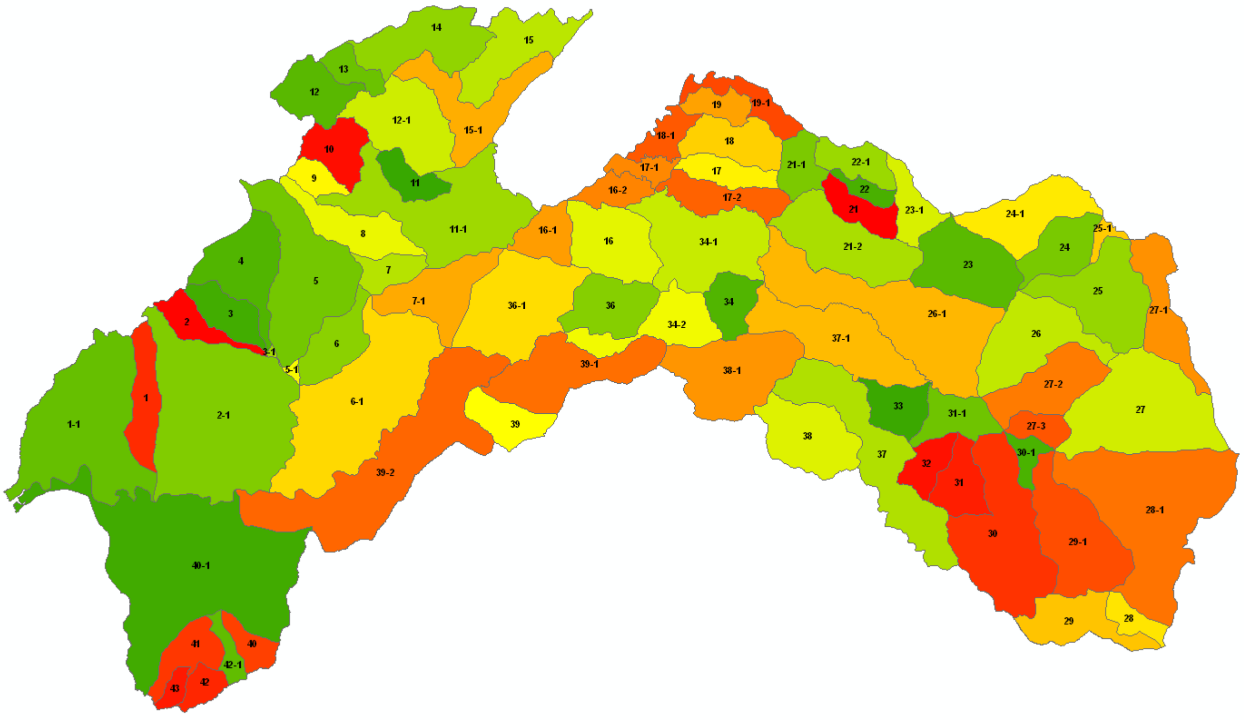


Figure Nº 4.3. Chira River Subbasin

Table Nº 4.2b. Maximum 24-Hours Rainfalls for Different Return Periods in each river Basin of Chira

SUBBASIN	AREA [m²]	RETURN PERIOD T [YEARS]					
		PT_2	PT_5	PT_10	PT_25	PT_50	PT_100
1	86,237,500	18.2	56.1	85.0	133.9	180.5	237.2
10	75,717,500	23.1	85.2	113.2	154.1	189.2	229.0
11	50,042,500	22.1	97.9	124.5	160.1	188.6	219.4
1-1	362,845,000	17.6	45.5	70.9	115.4	159.1	213.4
11-1	293,953,000	22.3	103.0	128.8	161.5	186.6	212.8
12	89,780,000	23.2	83.7	111.7	153.0	188.7	229.2
12-1	166,428,000	22.1	95.5	122.5	159.3	189.5	222.4
13	41,395,000	22.5	88.6	116.2	155.8	189.4	227.0
14	152,510,000	21.7	95.7	122.9	160.3	191.1	224.9
15	137,462,000	21.2	104.1	131.0	166.5	194.6	224.5
15-1	145,695,000	21.5	101.4	128.1	163.2	191.1	220.8
16	142,630,000	21.4	91.9	122.8	167.6	205.8	248.5
16-1	65,240,000	22.1	107.1	132.8	164.5	188.1	212.0
16-2	48,107,500	21.2	102.1	130.3	168.5	199.2	232.4
17	57,030,000	20.3	111.4	138.7	173.8	201.0	229.3
17-1	33,225,000	20.9	108.4	136.4	173.2	202.2	232.9
17-2	86,517,500	20.4	103.2	130.6	167.6	197.3	229.2
18	96,660,000	20.3	120.3	147.5	181.0	205.7	230.5
18-1	47,667,500	20.7	120.8	148.4	182.6	207.9	233.5
19	43,655,000	20.3	131.1	158.7	190.9	213.5	235.1
19-1	61,020,000	20.2	126.1	153.3	185.7	208.9	231.6
2	53,395,000	24.9	63.7	94.0	142.8	187.7	240.4
21	56,507,500	19.6	88.7	109.7	137.7	159.9	183.5
2-1	506,098,000	11.7	62.5	96.3	154.0	209.5	277.1
21-1	58,172,500	19.9	105.0	130.3	163.2	188.7	215.4
21-2	182,920,000	19.6	86.1	106.7	134.5	156.8	180.5
22	25,087,500	19.6	90.9	112.4	140.9	163.6	187.5
22-1	61,055,000	19.7	96.8	119.8	150.0	173.7	198.7

23	160,990,000	19.1	77.8	94.1	115.8	132.8	150.7
23-1	60,807,500	19.4	84.2	103.2	128.5	148.6	169.8
24	88,725,000	18.9	82.9	100.6	124.0	142.5	161.9
24-1	138,042,000	19.1	83.2	101.4	125.5	144.6	164.8
25	183,868,000	18.8	83.9	100.9	123.0	140.3	158.5
25-1	14,605,000	18.9	84.6	102.6	126.4	145.2	165.0
26	173,022,000	18.8	81.0	97.4	118.9	135.6	153.1
26-1	356,860,000	19.3	79.2	96.9	120.9	140.0	160.3
27	298,545,000	18.5	85.9	99.9	117.4	130.6	144.0
27-1	118,018,000	18.7	85.5	101.8	123.1	139.6	156.8
27-2	129,760,000	18.7	83.7	99.8	120.5	136.4	152.9
27-3	39,367,500	18.6	85.0	100.9	121.0	136.2	151.7
28	37,610,000	18.0	86.5	101.5	120.4	134.6	149.2
28-1	415,970,000	18.3	86.4	99.3	115.2	126.9	138.5
29	108,838,000	18.0	87.0	102.9	122.8	137.8	153.1
29-1	200,455,000	18.2	86.7	101.6	119.9	133.5	147.2
3	68,880,000	25.0	64.9	95.2	144.2	189.0	241.8
30	278,207,000	18.2	88.2	104.4	123.7	137.6	151.5
30-1	29,172,500	18.5	86.1	102.1	121.9	136.7	151.8
31	73,605,000	18.5	89.0	105.2	123.9	137.0	149.7
3-1	2,480,000	16.2	67.8	100.3	153.7	203.9	263.9
31-1	73,252,500	18.7	83.6	100.3	121.2	137.1	153.4
32	51,690,000	18.6	88.6	105.0	124.1	137.5	150.5
33	69,917,500	18.9	82.8	100.0	122.1	139.1	156.8
34	64,765,000	20.2	85.9	115.4	159.2	197.0	239.7
34-1	220,632,000	20.5	91.8	121.6	164.9	201.7	242.7
34-2	113,755,000	21.0	80.9	115.1	168.2	215.6	270.1
36	109,398,000	21.7	80.8	115.7	170.3	219.0	275.0
36-1	231,535,000	23.6	97.9	125.9	163.9	194.8	228.3
37	253,405,000	18.8	87.4	105.3	127.3	143.8	160.5
37-1	200,245,000	19.4	81.6	101.5	128.9	151.2	175.2
38	145,362,000	19.0	85.9	106.6	134.2	156.3	180.0
38-1	207,370,000	19.9	84.1	112.0	153.2	188.7	228.8
39	73,337,500	22.5	84.6	114.7	160.1	200.0	246.0
39-1	189,248,000	22.4	84.8	116.7	164.9	207.3	255.7
39-2	414,015,000	12.9	74.0	108.2	164.6	217.8	281.6
4	141,155,000	27.0	66.2	96.1	143.7	187.0	237.5
40	40,020,000	11.3	61.3	92.2	144.8	195.5	257.4
40-1	629,967,000	11.8	52.1	81.7	133.4	184.3	247.4
41	69,150,000	13.1	55.3	83.9	133.1	180.9	239.8
42	33,795,000	13.2	57.9	86.7	135.5	182.7	240.5
42-1	27,905,000	12.0	59.4	89.5	140.8	190.3	251.0
43	20,060,000	13.8	55.4	83.3	131.0	177.2	234.0
5	258,320,000	22.1	73.9	103.9	151.0	193.5	243.3
5-1	5,315,000	12.4	68.5	102.4	158.9	212.5	277.2
6	89,277,500	16.9	74.7	106.6	157.7	204.9	260.9
6-1	400,045,000	12.6	73.7	108.1	164.8	218.2	282.5
7	48,662,500	22.0	90.7	118.6	158.4	192.0	229.7
7-1	130,528,000	23.4	97.5	124.6	161.2	190.9	223.3
8	106,590,000	22.7	86.0	114.1	155.1	190.3	230.0
9	35,200,000	23.9	80.2	108.8	151.6	189.0	231.9

4.2.2.5 Storm Distribution

Rainfall records in some stations having pluviographic stations, that is, that they automatically measure rainfall at fixed time intervals, show that rainfall distribution in the study area resembles a former SCS Type IA rainfall.

Table 4.3 shows rainfall distribution for the Type I, Type IA, Type II and Type III. As seen in Figure 4.4, the highest slopes of an extreme event registered in 1998 at El Tigre Station in Tumbes, Northern Peru, resemble that of the Type I. These events are very rare and have occurred in 1925, 1983 and 1998. No records exist for the 1925 event, because no automatic weather stations were available. The 1983 event destroyed the weather station.

Table Nº 4.3. Comparison of Time Distribution of the Extreme 24 Hour Rainfall Observed at El Tigre Station with Typical SCS Storm Distribution.

		24 hr precipitation temporal distribution			
Time (hr)	**t/24**	**Type I**	**Type IA**	**Type II**	**Type III**
0.00	0.000	0.000	0.000	0.000	0.000
2.00	0.083	0.035	0.050	0.022	0.020
4.00	0.167	0.076	0.116	0.048	0.043
6.00	0.250	0.125	0.206	0.080	0.072
7.00	0.292	0.156	0.268	0.098	0.089
8.00	0.333	0.194	0.425	0.120	0.115
8.50	0.354	0.219	0.480	0.133	0.130
9.00	0.375	0.254	0.520	0.147	0.148
9.50	0.396	0.303	0.550	0.163	0.167
9.75	0.406	0.362	0.564	0.172	0.178
10.00	0.417	0.515	0.577	0.181	0.189
10.50	0.438	0.583	0.601	0.204	0.216
11.00	0.458	0.624	0.624	0.235	0.250
11.50	0.479	0.654	0.645	0.283	0.298
11.75	0.490	0.669	0.655	0.357	0.339
12.00	0.500	0.682	0.664	0.663	0.500
12.50	0.521	0.706	0.683	0.735	0.702
13.00	0.542	0.727	0.701	0.772	0.751
13.50	0.563	0.748	0.719	0.799	0.785
14.00	0.583	0.767	0.736	0.820	0.811
16.00	0.667	0.830	0.800	0.880	0.886
20.00	0.833	0.926	0.906	0.952	0.957
24.00	1.000	1.000	1.000	1.000	1.000

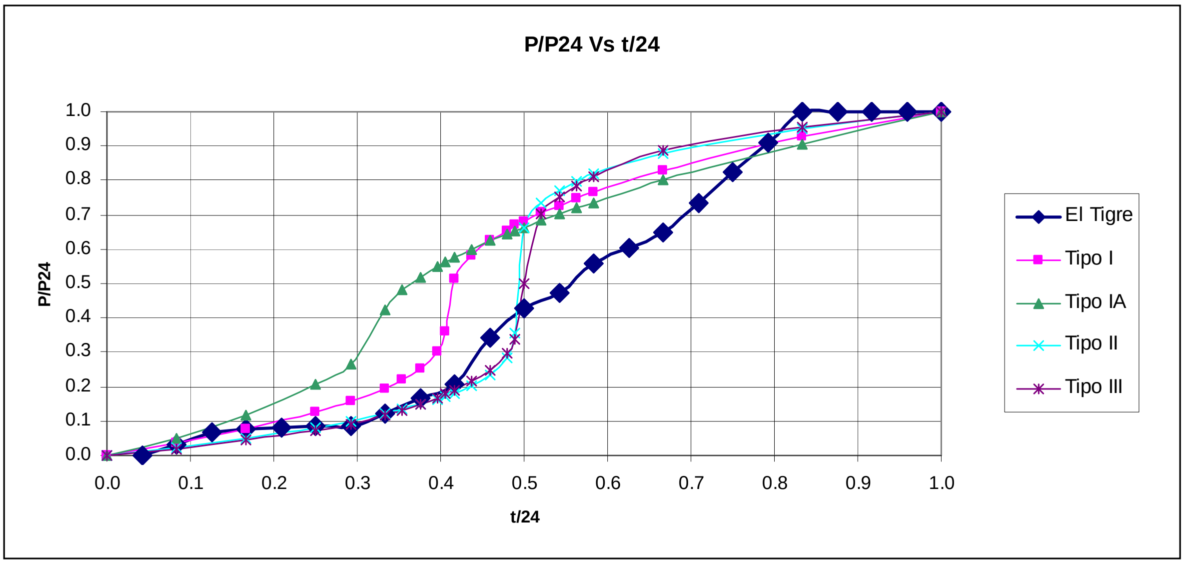


Figure Nº 4.4. SCS 25-Hr Rainfall Distribution for the Type I, Type IA, Type II and Type III Rainfall Distributions. Compare to Data Registers at El Tigre Station

4.2.3 Maximum Daily Discharge Analysis

For the analysis of Maximum Daily Discharges of River Chira, the information of the hydrometric stations Puente Sullana and Ardilla have been used. These station have contributions areas of 14933 and 13074 km^2. Figure 3.23 shows its location in the river Chira catchment.

The Directorate General of Water Infrastructure (DGIH) of the Ministry of Agriculture has provided information on annual maximum daily discharge of Puente Sullana and Ardilla station whose values are shown in Table Nº 4.4

Table Nº 4.4. Maximum Daily Discharge of station Puente Sullana and Ardilla, Chira River (m^3/s)

Año	Puente Sullana	Ardilla
1976		2,242.00
1977	848.33	1,647.90
1978	56.12	281.10
1979	177.69	348.00
1980	57.07	438.00
1981	455.55	830.30
1982	288.18	589.10
1983	3,227.08	2,469.30
1984	1,043.00	1,663.00
1985	88.40	243.80
1986	40.00	355.60
1987	551.80	1,180.30
1988	37.70	379.50
1989	558.00	936.00
1990	45.20	253.40
1991	121.00	668.60
1992	2,355.00	3,133.50

1993	1,400.00	1,654.00
1994	1,100.00	1,044.00
1995	58.00	276.10
1996	140.00	439.40
1997	925.00	1,275.80
1998	3,005.00	3,620.80
1999	1,195.20	1,927.00
2000	1,111.00	1,303.20
2001	2,252.90	2,264.80
2002	2,517.00	2,825.20
2003	169.00	371.90
2004	231.00	293.80
2005	480.00	629.00
2006	815.00	1,089.90
2007		431.10
2008		3,141.97
2009		2,387.93

These values have been analyzed with the different distribution functions described in item 4.2..2.1. The goodness test of Kolmogrov – Smirnov shows that the data of the hydrometric station Ardilla fits with the Log – Normal distribution and the data of the hydrometric distribution Puente Sullana fits with the Gumbel distribution. . The frequency analysis results are shown in Table No 4.5.

Table Nº 4.5. Maximum Discharges for each Return Period at Station Puente Sullana and Ardilla, Chira River (m^3/s)

Periodo de Retorno (Años)	Puente Sullana	Ardilla
2	890.00	895.12
5	1727.00	1853.45
10	2276.00	2712.53
25	2995.00	4070.88
50	3540.00	5291.22
100	4058.00	6698.22

It is necessary to mention that the Poechos Reservoir has a capacity to store water during the wet (rainy) season to supply water for irrigation and other purposes during the dry season. The maximum recommended operating level is 103 m.a.s.l., when the storage capacity is 490 million cubic meters (MCM), as of December 2005. Storage capacity at the emergency spillway level (104 m.a.s.l. elevation) is 548 MCM. When the reservoir is full, the water surface is 62 km2. This datum will be used to estimate the reservoir volume during an extreme flood flow occurrence.

4.2.4 Simulation Model, Application of HEC-HMS Software

4.2.4.1 Hydrological Model

Lag Time

The Snyder formula was used to calculate the sub-basins lag time (tp):

$$t_P = 0.75C_t\left(L \cdot L_C\right)^{0.3}$$

Where:

Ct is a parameter related to the basin geographic characteristics.

L is the major water course length in kilometers, and

Lc is the length from the water course point that is closest to the basin's gravity center to the basin outlet.

Table 4.6 shows the basins identified in the Catamayo – Chira system, its contribution areas and the parameters used for calculating lag times.

Table Nº 4.6. Characteristics of the Chira River Topographic Basins

Basin	Area (km^2)	L (km)	Lc (km)	tp (hr)
Catamayo	4184	199.33	78.29	24.45
Macara	2833	155.68	73.13	22.24
Quiroz	3108	201.48	83.60	25.02
Alamor	1190	102.9	56.27	18.16
Chipillico	1170	119.44	52.80	18.63
Lower Chira	4711	119	(*)	(*)

Lower Chira been sub – divided, as its sub – basins are identified as C - 1 to C – 7, Table 4.7. shows its contribution areas and the parameters used for calculating lag times.

Table Nº 4.7. Sub-Basins of the Chira Major Basins

Sub - Basin	Area (km2)	Length (km)	Lc (km)	tp (hr)
C-1	878	34.59	15.30	8.86
C-2	1301	55.31	40.95	13.70
C-3	636	42.9	27.34	11.25
C-4	921	47.1	19.80	10.50
C-5	414	15.85	12.03	6.52
C-6	99	14.78	8.31	5.72

C-7	325	36.24	21.11	9.90

Maximum Rain Storm Duration

According to the "Study of the Hydrology of Peru" (Refence "d"), the average duration of rains of Perú is 15.2 hours, due to the large size of the modeled sub-basins, in order to be conservative a 24 hours storm duration has been assumed.

Storm Depth

The values of the maximum 24- hours rainfalls showed in Table 4.8 were used for the calculations, these values correspond to spatial average rainfall for the sub-basins that conform the total catchment.

Table Nº 4.8. Maximum 24-Hours Rainfall (mm) for Sub-Basins of the Chira River Catchment

Subbasin		Maximum 24-Hours Rainfall for different Return Periods "Tr"			
		Tr= 10 years	Tr= 50 years	Tr= 100 years	Tr= 500 years
Catamayo		99.43	250.9	344.36	643.50
Macara		99.43	250.9	344.36	643.50
Quiroz		99.43	250.9	344.36	643.50
Alamor		99.43	250.9	344.36	643.50
Chipillico		99.43	250.9	344.36	643.50
Chira	C-1	99.43	250.9	344.36	643.50
	C-2	99.43	250.9	344.36	643.50
	C-3	99.43	250.9	344.36	643.50
	C-4	99.43	250.9	344.36	643.50
	C-5	99.43	250.9	344.36	643.50
	C-6	99.43	250.9	344.36	643.50
	C-7	99.43	250.9	344.36	643.50

For all the subbasins the precipitation values of Mallares station have been adopted. This asumption is conservative because, as can be seen in Table 4.2, the areal average precipitation values estimated for the different sectors in the catchment show lower values of precipitation than the observed in Mallares station.

Based on item 4.2.34 a type IA distribution of the former Soil Conservation Service storm distribution was adopted for modelling purposes.

Selection of Curve Number

Because of the basin’s extension, information on soil type and land use was gathered. Forests are predominant on the Ecuadorian side, although there are tundras in the high areas that are basically made up of silty soils with sand and clay contents that come close to type B soil definition. Curve numbers (CN) were estimated with these data, by using tables from the former U.S. Soil Conservation Service (SCS), and a weight based on the gathered information. Table 4.9 shows the Curve Numbes for each major basin. Value obtained from the Chira Basin will be applied for sub – basins C – 1 to C – 7, because the area covered by the Bajo (Lower) Chira has similar characteristics.

Table Nº 4.9. Curve Numbers for Major Basins

Basin	Estimated Curve Numbers					Optimized Curve Numbers
	CN_1	% Area	CN_2	% Area	CN_II_Comp	
Catamayo	55	30	65	70	62	57
Macara	55	80	65	20	57	57
Quiroz	55	30	65	70	62	58
Alamor	55	60	65	40	59	60
Chipillico	55	50	65	50	60	58
Chira	55	85	65	15	56.5	57

After calibration, compound curve numbers were optimized to the values showed in column “Optimized Curve Numbers”. Values obtained from the Chira Basin were applied for sub – basins C – 1 to C – 7, because the area covered by the Bajo (Lower) Chira has similar characteristics.

4.2.4.2 HEC – HMS Modeling

The U.S. Engineer Corps’ Hydrological Engineering Center designed the ***Hydrological Modeling System (HEC – HMS)*** computer program. This program provides a variety of options to simulate rainfall – runoff processes, flow routes, etc. (US Army, 2000).

HEC-HMS includes a graphic interface for the user (GUI), hydrological analysis components, data management and storage capabilities, and facilities to express results through graphs and reports in charts. The Guide provides all necessary means to specify the basin's components, introduce all relevant data of these components, and visualize the results (Reference "e").

Chira Basin Model.- SCS's Curve Number method was used to estimate losses. Snyder Unit Hydrograph method was used to transform actual rainfall into flow. The river Chira catchemt until Puente Simón Rodriguez, of 17059 km^2 , was splited in 12 sub-basins.

Table 4.10 shows the base flows adopted in the simulation to be representative for conditions previous to the occurrence of the flood flows. This values resulted from the available information of low flows.

Table Nº 4.10. Adopted Base Flows for Major Basins

Basin		Base Flows (m3/s)
Catamayo		46.02
Macara		31.16
Quiroz		34.19
Alamor		13.09
Chipillico		12.87
Chira	C-1	9.66
	C-2	14.31
	C-3	7.00
	C-4	10.13
	C-5	4.55
	C-6	1.09
	C-7	3.58

Meteorological Model.- Based on calculation under Nº 3.2 Pluviometer Information Analysis and Frequency Law, hyetographs are introduced in the meteorological model for a 2, 5, 10, 25, 50, and 100 – year floods, and a storm duration of 24 hours.

Control Specifications.- Starting and ending dates are specified within the range for the flood simulation to be carried out. Simulation results and flood hydrograph will be submitted. In this case, starting date is February 2nd, 2010, 00:00, and end date is February 4th, 2010, 12:00 pm. Based on the recommendation of the HEC-HMS Technical Reference Manual the minimum computational time interval is calculated as 0.29 times the Lag Time. From

Tables 4.14 and 4.15 a minimum lag time of 5.72 hours is observed, from this value a minimum computational time of 1.66 hours is obtained. For being conservative a computational time interval of 1 hour was used.

Calibration of the Model. Due to the fact that there was no available information on simultaneous storm hyetographs and flood hydrographs which would allow to calibrate model parameters for doing forecasts, the model was calibrated based on information of estimated daily discharges.

As it was stated previously, the concept of the calibration was to adjust the curve numbers of the sub-basings to values which produce values of peak discharges in the point of interest Ardilla similar to the obtained for the hydrometric station Ardilla from the statistical analysis of the maximum daily discharges. This similitude is obtained for the different return period scenarios.

Below, Figure Nº 4.5 shows the watershed considered by HEC-HMS model for the simulation.

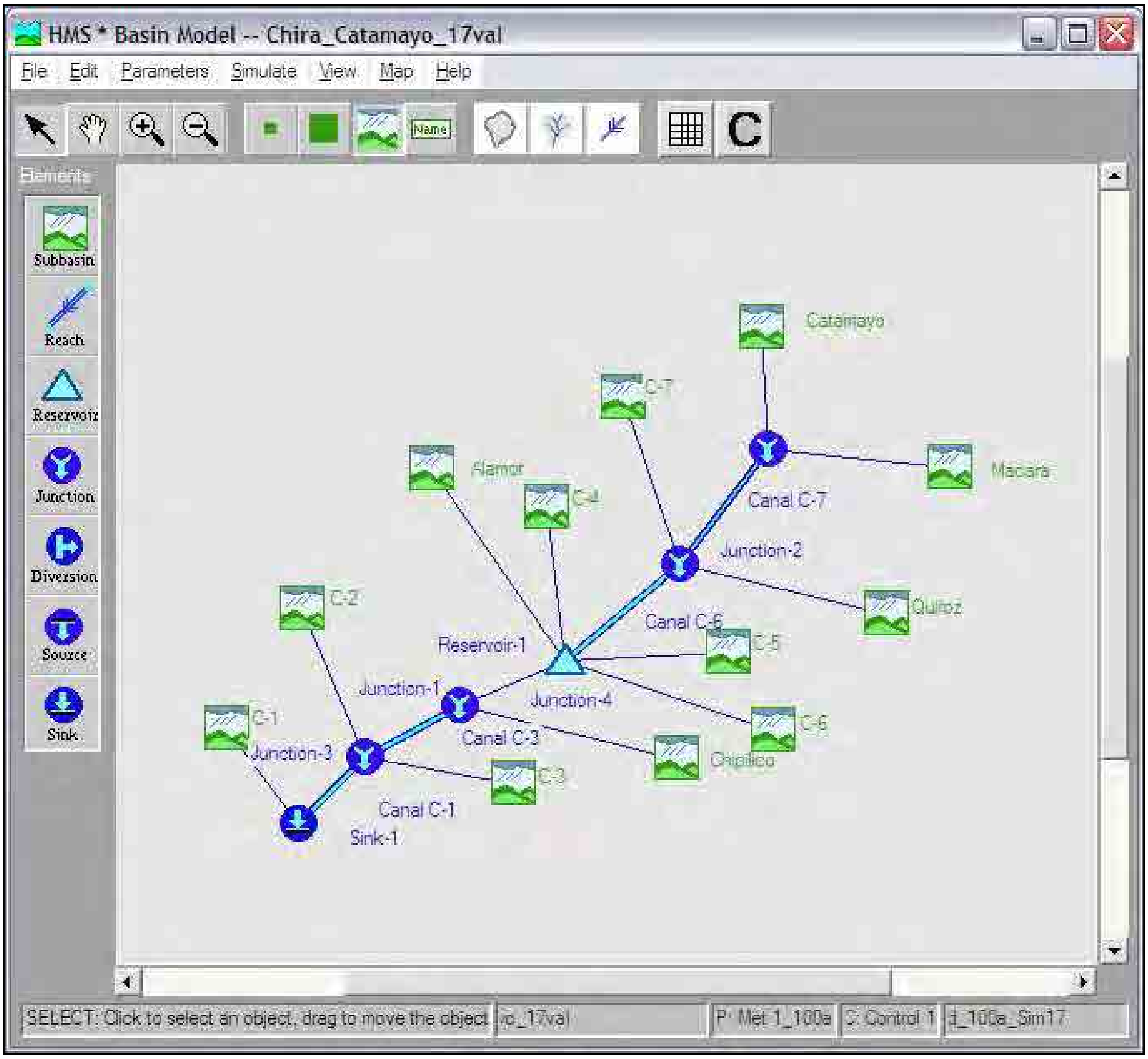


Figure Nº 4.5. Watershed considered by HEC-HMS model for the simulation.

4.2.4.3 Results of the Simulation, Peak Flows in the Base Poinst

Table 4.11 summarizes the peak flows for different return periods obtained with the application of the software HEC-HMS in Chira river basin for the location of hydrometric stations Ardilla and Puente Sullana.

Table Nº 4.11. Summary of Peak Flows (m3/s) at the Base Points for each Return Period

T [Años]	Station Ardilla	Station Puente Sullana
2	881.6	1014.3
5	1858.9	1683.7
10	2714.1	2472.1
25	4084.1	3003.6
50	5124.2	3413.7
100	6691.3	4137.6

Peak flows at the base points obtained with HEC-HMS model for the return periods of 2, 5, 10, 25, 50 and 100 years have been estimated from the maximum rainfall generated for these return periods, adopted curve numbers and geomorphological parameters of the basin.

As it was considered in the calibration, peak discharges obtained with HEC-HMS model for hydrometric station Ardilla for different return periods are similar to the correspondent maximum daily discharges showed in Table 4.5.

The detailed results of the simulations for the floods of 2, 5, 10, 25, 50 and 100 years return period are shown in the Annexes.

5 REFERENCES

a) Association BCEOM-SOFI CONSULT S.A., "Hydrology and Meteorology Study in the Catchments of the Pacific Littoral of Perú for Evaluation and Forecasting of El Niño Phenomenon for Prevention and Disaster Mitigation", 1999.

b) Chow, Maidment and Mays, "Applied Hydrology",1994.

c) Guevara, Environmental Hydrology, 1991.

d) IILA-SENAMHI-UNI, "Study of the Hydrology of Perú", 1982.

e) U.S. Corp of Engineers, "Manual de Referencias Técnicas del Modelo HEC-HMS", 2000.

Appendix-6 Hydrologic Study of Yauca River Basin

Japan International Cooperation Agency

PROJECT OF THE PROTECTION OF FLOOD PLAIN AND VULNERABLE RURAL POPULATION AGAINST FLOODS IN THE REPUBLIC OF PERU

HYDROLOGY OF MAXIMUM FLOODS IN YAUCA RIVER

Appendix-6

December 2012

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HYDROLOGY OF MAXIMUM FLOODS IN YAUCA RIVER

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HYDROLOGY OF MAXIMUM FLOODS IN YAUCA RIVER

I. INTRODUCTION

In the last two extraordinary events (El Niño) occurred in 1983 and 1998, rainfall was very intense in the study area, which resulted in the activation of a number of rivers and streams adjacent to the Yauca River, causing severe damage in populated areas, irrigation and drainage infrastructure, agricultural lands, likewise, floods with catastrophic damage in the areas of Yauca and Jaqui.

El Niño is defined as the presence of abnormally warmer waters in the west coast of South America for a period longer than 4 consecutive months, and has its origin in the Central Equatorial Pacific. The phenomenon is associated with abnormal conditions of the atmospheric circulation in the Equatorial Pacific region. Abnormal conditions are considered when the equatorial circulation scheme takes the following three possibilities: may intensify, weaken or change direction.

This study contains a diagnosis of the problem, in order to explain the causes of the event and guide the actions to be implemented to provide greater security to the population, irrigation infrastructure, agricultural areas, etc. The report contains the hydrologic analysis to allow the characterization of the event in technical terms. With these analyses it has been possible to outline alternative structural solutions and no structural measures.

II. GENERAL ASPECTS

2.1 Location

2.1.1 Political Location

The study area is located in the districts of Jaqui and Yauca in the province of Caravelí, in the department of Arequipa and districts of Chavin, San Pedro, Sancos in the province of Lucanas of department Ayacucho.

2.1.2 Geographic Location

The study area is located approximately at coordinates UTM at 546,665 y 642,595 in East Coordinates, and 8’2633,132 y 8’376,058 in North Coordinates (Zone 18).

2.2 Background

As part of the project: “Protection of Rural Areas and Valleys and Flood Vulnerable”, it requires a supporting technical document of the maximum flooding of the Yauca River, to define planning proposals hydrologic and hydraulic Yauca River system.

The occurrence of extreme events such as El Niño in the northern and southern coast of Peru has resulted in the presence of heavy rains, increased river flows and streams activation of contributors to the main course, such as occurred in the last two events of 1983 and 1998. The Yauca River overflowed causing flooding of extensive crop areas and cities such Yauca and Jaqui, and resulting in damage to agriculture, road infrastructure, housing, irrigation infrastructure and drainage. Currently there are vulnerable areas in river sections that require the application of structural measures for flood mitigation.

An assessment of maximum floods has been made based on data from the hydrometric station San Francisco Alto. With the results obtained, the hydraulic box of the will be size base to the return period chosen in specific areas and also the design of protective structures.

2.3 Justification of the Project

Yauca River allows drainage of floods from rainfalls and inflows from the watershed.

The presence of normal hydrological events causes some damage in agricultural areas, irrigation and drainage infrastructure, service roads and towns, therefore it requires structural measures that allow the mitigation of extreme events up to some degree magnitude.

2.4 Objectives of the Study

The objective of the study is to determine the maximum instant Yauca River floods for different return periods, to allow an appropriate measurement of the hydraulic section of river channelization and the design of protection works, mitigating the potential damage from extreme hydrological events.

III. PROJECT DESCRIPTION

3.1 Hydrographic System of Yauca River

3.1.1 General Description of the Basin

Politically, the Yauca River basin is part of the provinces of Carvelí and Lucanas, in the departments of Arequipa and Ayacucho respectively.

Its boundaries are: on the north by the Pampas river basins, south to Chaparra and Chala Rivers Basin, East by the Ocoña River Basins and West by the Pacific Ocean.

It has a total area of 4,312.29 km2 and its waters drain into the Pacific Ocean with a tour of the main course predominantly southwesterly.

Yauca Valley, an area affected by the floods, is located in the lower basin between latitudes 15º42'36" – 14º41'20" South and longitude 74º33'52" – 73º40'33" West. Politically it belongs to the province of Caravelí, Department of the Arequipa.

Figure 3.1 shows the location and area of the Yauca River Basin.

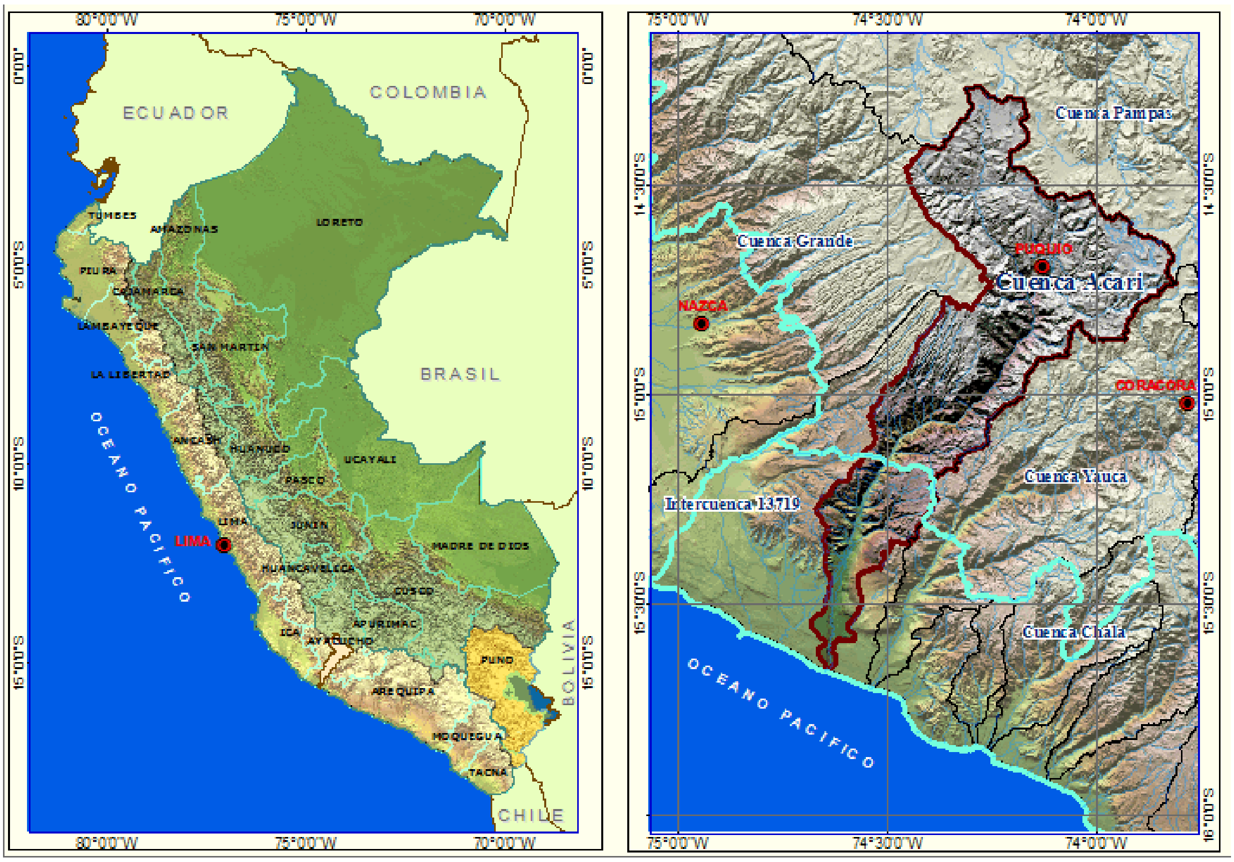

Figure Nº 3.1. Location Map of the Yauca River Basin

3.1.2 Hydrography of the Yauca River Basin

The Andes Mountains catchment areas to the country divided into two main branches that drain their waters into the Pacific and Atlantic Oceans, respectively, thus forming the continental divide of the waters. There is also a third strand in the south-east of the country, consisting of a high inter-Andean basin whose waters drain into Lake Titicaca

The basin of the Pacific or Western has an approximate area of 290.000 km², equivalent to 22% of the total area of the country. As a result of rainfall and melting snow and glaciers in the upper part, 52 rivers, in some importance, run to the Pacific Ocean predominantly towards the southwest. Yauca River is one of them, being located in the central region of this side.

Yauca River has an intermittent regimen and torrential character; its discharges are presented in the months of January to April. The mean annual discharge of 8.38 m³/s equivalent to an average annual volume of 258.89 MMC.

The supply of water to the valley of Yauca is regulated, due to intermittent regimen Yauca River which has downloads only between the months of January to April, during the remainder of the river dries up considerably. During this period, the dry season, water is discharged regulation of the gap between the months of August through December.

3.2 Climatology

3.2.1 Rainfall

The rainfall, as a main parameter of the runoff generation is analyzed considering the available information of the stations located in the interior of the Yauca Basin, and in the neighboring Pampas, Chaparra, Chala and Ocoña.

Rainfall information is available from 7 pluviometric stations located in the vicinity of the study area; these are located in the Yauca River Basin and surrounding basins. These stations are operated and maintained by the Peruvian National Service of Meteorology and Hydrology (SENAMHI by their initials in Spanish)

Table No. 3.1, shows the list of stations included in this study with their respective characteristics, such as code, name, and location. Historical records of monthly total rainfall and their histograms are presented in the Annex. Figure Nº 3.2, shows the period and the length of the data available from meteorological stations and Figure No. 3.3 shows the locations in the Yauca Basin and adjacent watersheds.

Table Nº 3.1. Characteristics of Rainfall Stations in the Yauca River Basin and Surrounding Basins

CODE	STATION	DEPARTAMENT	LONGITUDE	LATITUDE	ENTITY
157216	TARCO	AREQUIPA	73°45'1	15°18'1	SENAMHI
740	SANCOS	AYACUCHO	73° 57'1	15° 04'1	SENAMHI
743	CORACORA2	AYACUCHO	73° 47'1	15° 01'1	SENAMHI
154	CORA CORA	AYACUCHO	73° 47'47	15° 01'1	SENAMHI
742	CHAVIÑA	AYACUCHO	73° 50'1	14° 59'1	SENAMHI
157220	CARHUANILLAS	AYACUCHO	73° 44'1	15° 08'1	SENAMHI
732	YAUCA	AREQUIPA	74° 31'1	15° 40'1	SENAMHI

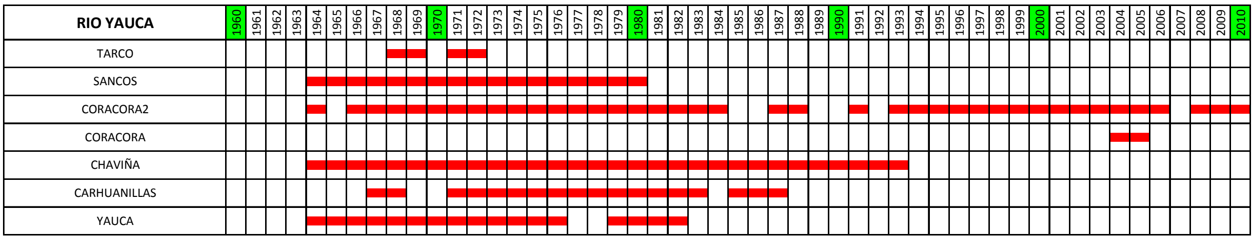

Figure Nº 3.2. Period and longitude of the available information of the rainfall stations

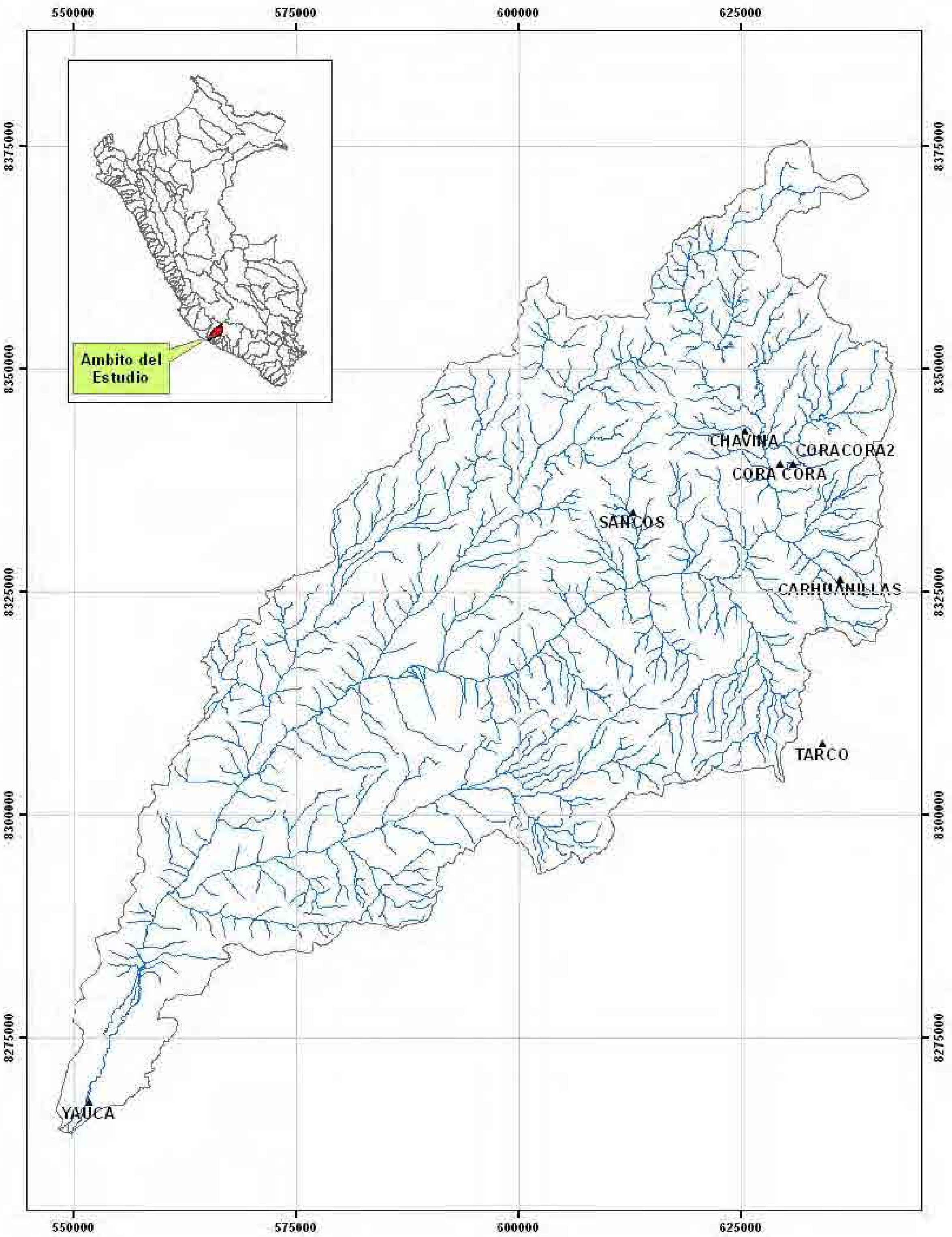

Figure Nº 3.3. Location of the Rainfall Stations in Yauca River Basin and Adjacent Basins

Table N° 3.2 shows mean monthly values for the stations that have been taken into account in the study, and Figure N° 3.4 shows the mean monthly variation for rainfall in each station; the Annex shows the historical series for each station, as well as the monthly and annual variation graphs for each station.

Table Nº 3.2. Characteristics of Rainfall Stations in the Yauca River Basin and Surrounding Basins

ESTACION	Mes												Total
	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic	
TARCO	116.76	85.09	121.13	26.66	0.00	0.00	0.00	0.00	1.36	7.07	15.80	29.27	403.13
SANCOS	131.88	133.65	105.28	4.96	0.39	0.00	0.41	0.00	0.63	2.38	1.72	10.46	391.75
CORACORA2	102.06	118.34	104.25	19.40	2.08	1.09	1.76	2.54	6.13	7.09	10.78	34.86	410.36
CORA CORA	176.24	163.85	301.90	155.00	216.45	234.55	137.45	68.05	127.76	199.38	274.25	188.46	2,243.33
CHAVIÑA	115.10	142.42	161.44	32.21	5.12	0.87	0.93	3.86	10.45	11.79	10.76	45.59	540.54
CARHUANILLAS	116.28	150.78	145.02	37.01	1.26	0.00	0.64	2.03	3.57	9.73	13.91	32.15	512.38
YAUCA	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

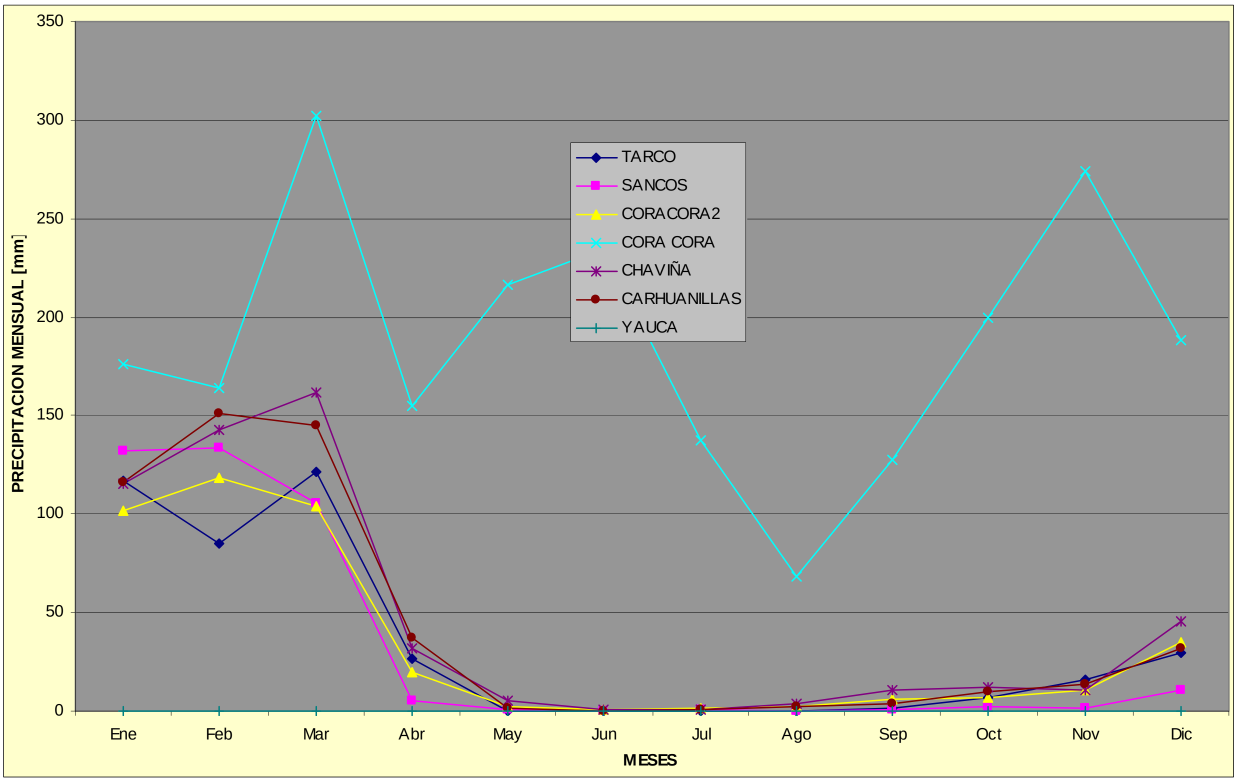

Figure Nº 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope

Table 3.2 and Figure No. 3.4 show that the information of Coracora station does not have the same behavior against the other stations, so we discard the information in this station. Also, Table N° 3.2 and Figure N° 3.4 show that heaviest rainfalls are from November to April, and east rainfalls are from May to September. In addition, annual rainfall in the YaucaRiver Basin is noted to vary from 540.54 mm (Chaviña Station) to 0.00 mm (Yauca Station).

Figure N° 3.5 shows total annual rainfall variation for the stations included in this study, with their relevant trends. Taking into account only stations Chaviñas and Carhuanillas which are the station that have the most amount of data , we established a linear equation: P = mt + b, where P is annual rainfall and t is time in years, m and b are the variables that provide the best fit in a linear equation. The results are presented in Table 3.3, giving the following values of the trends:

Table Nº 3.3.Results of the linear fit equation of Chaviñas and Carhuanillas station

Station	**m**	**b**	**R^2**
Chaviñas	10.12	435.9	0.081
Carhuanillas	-20.25	813.2	0.198

The value of the regression coefficients (R^2) is very low. For Chaviñas Station would be a seasonally weak upward trend and for Carhuanillas Station a seasonally weak downward trend. $\mathbf{R^2}$ values indicate that the trends are not significant very and can be said that even in these stations with maximum numbers of data there is no clear trend to increase or decrease regarding the rainfall.

Information shown in Table N° 3.2 and support from ArcGIS software have allowed for generating monthly isohyet maps (from January to December) and annual isohyets maps , as shown in Figures N° 3.6 – N° 3.17, and N° 3.18, respectively.

The annual rainfall in the river Yauca basin varies in ranges from 500 mm to 100 mm, as shown in Figure No. 3.18.

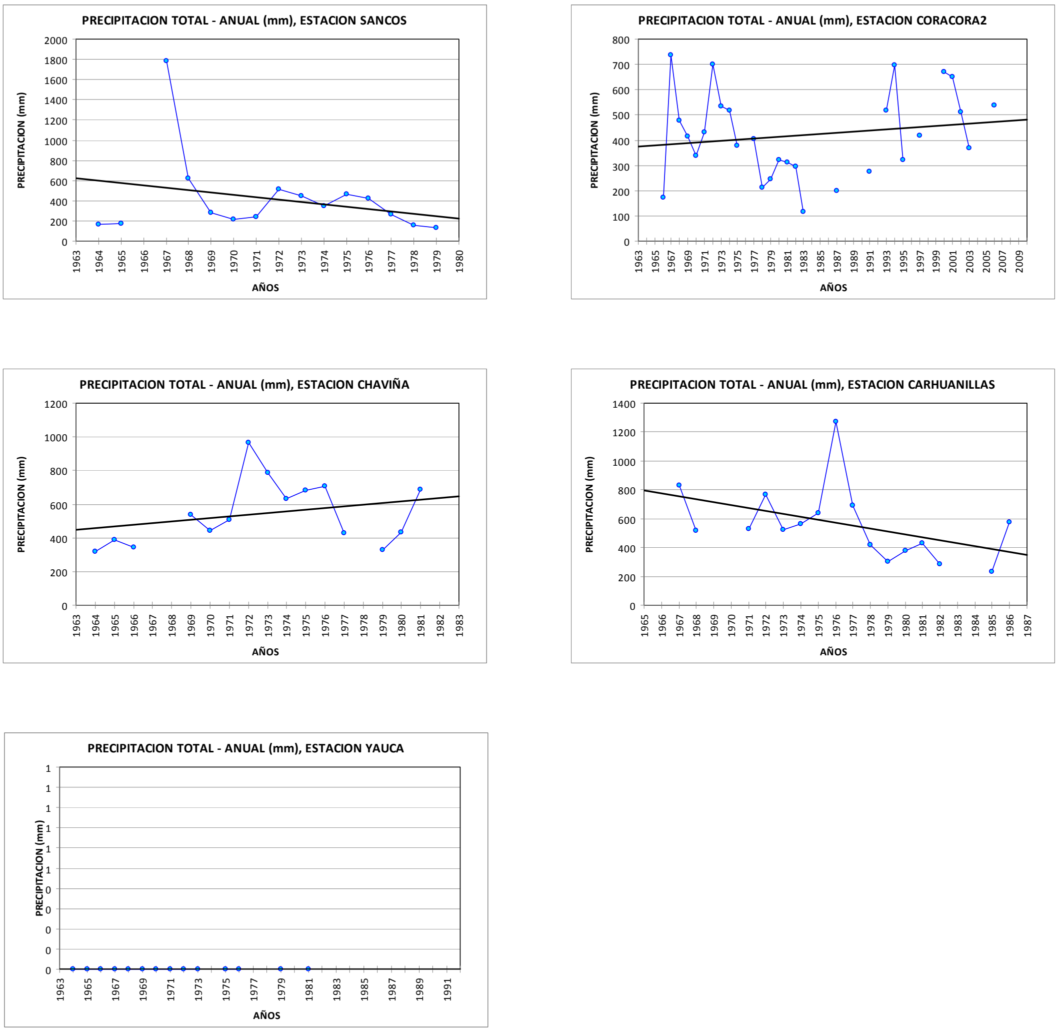

Figure Nº 3.5. Annual Rainfall Trends at the Stations considered within the Study Scop

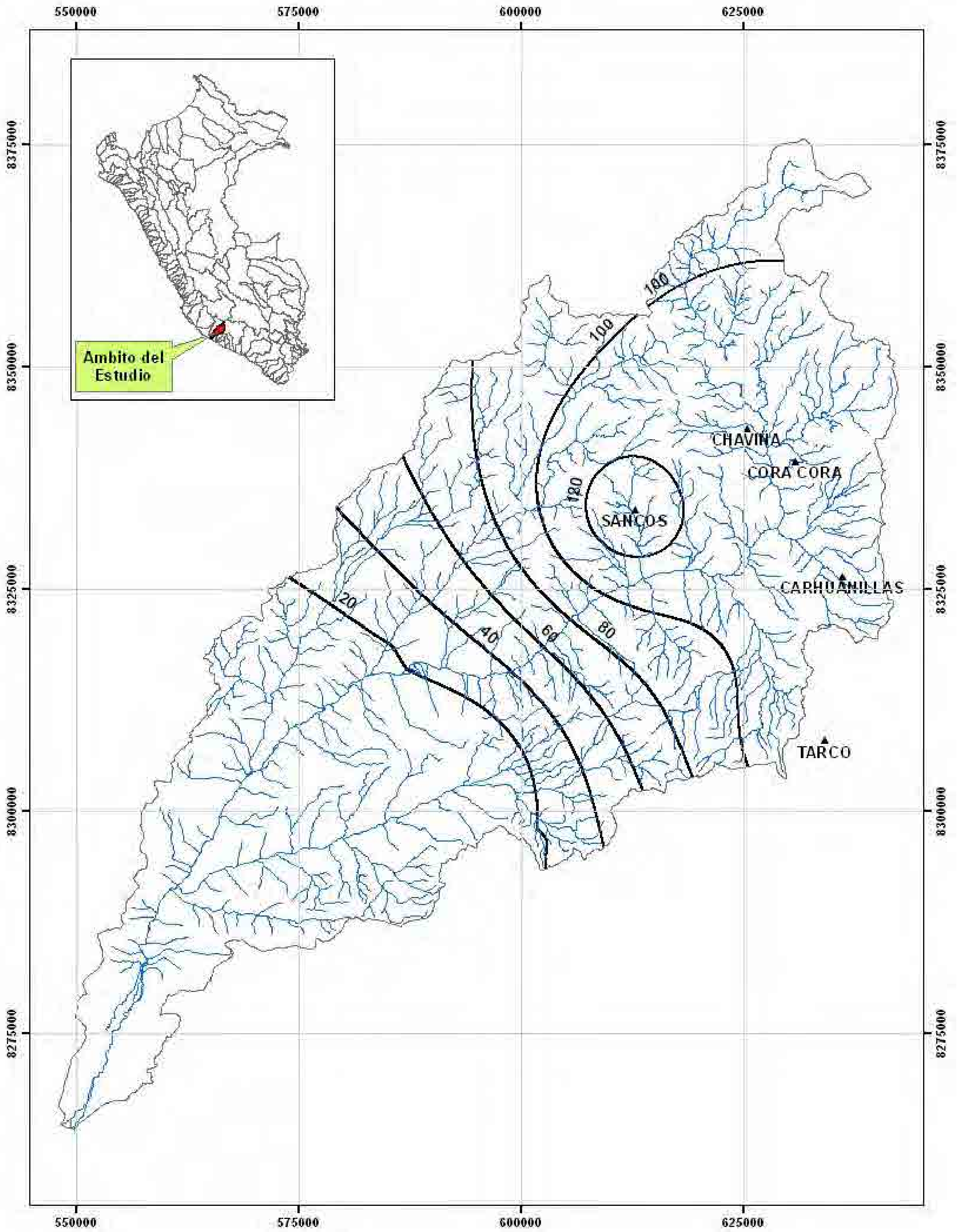

Figure Nº 3.6. Isohyets for Mean Monthly Rainfall in the Yauca Basin, in January

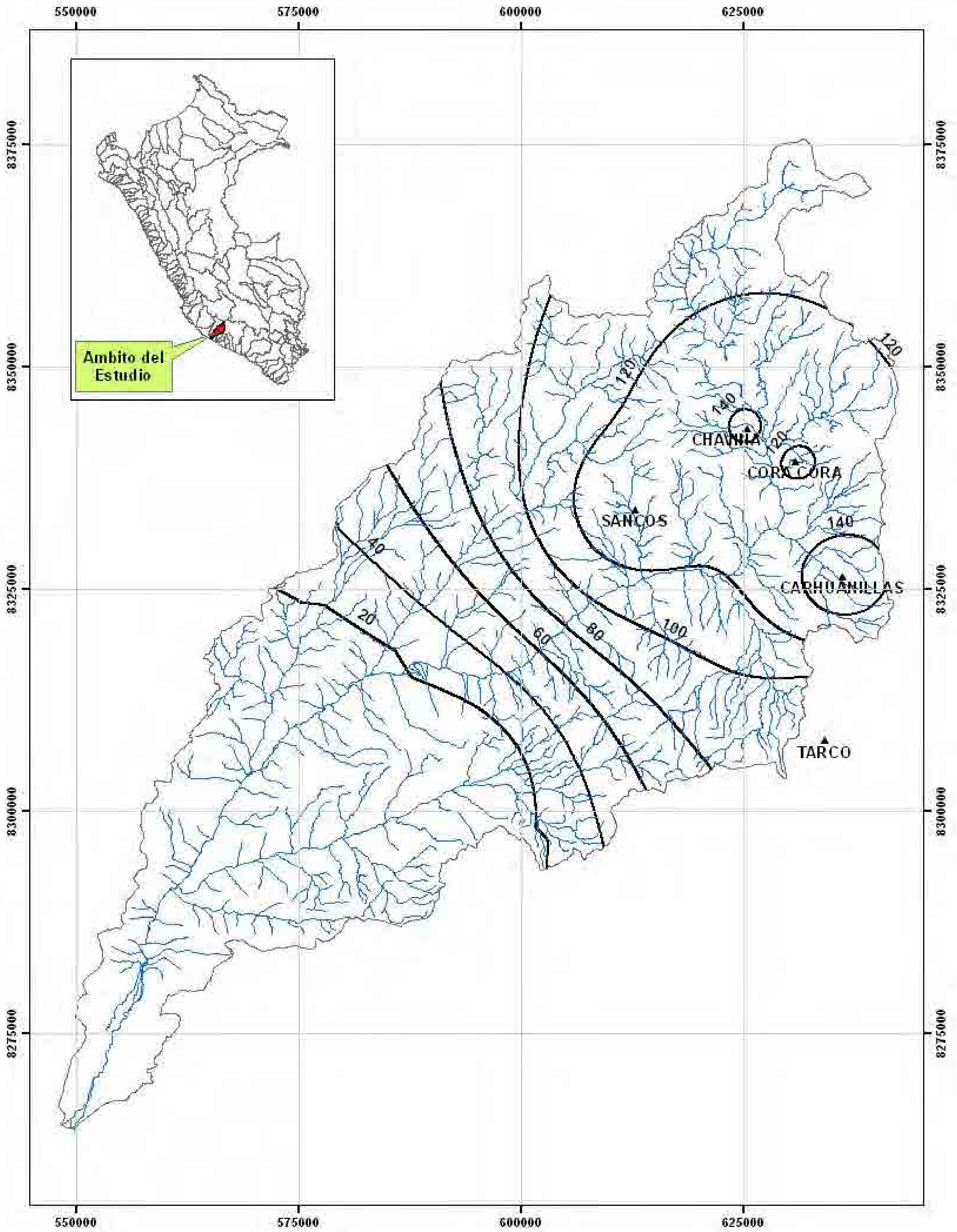

Figure Nº 3.7. Isohyets for Mean Monthly Rainfall in the Yauca Basin, in February

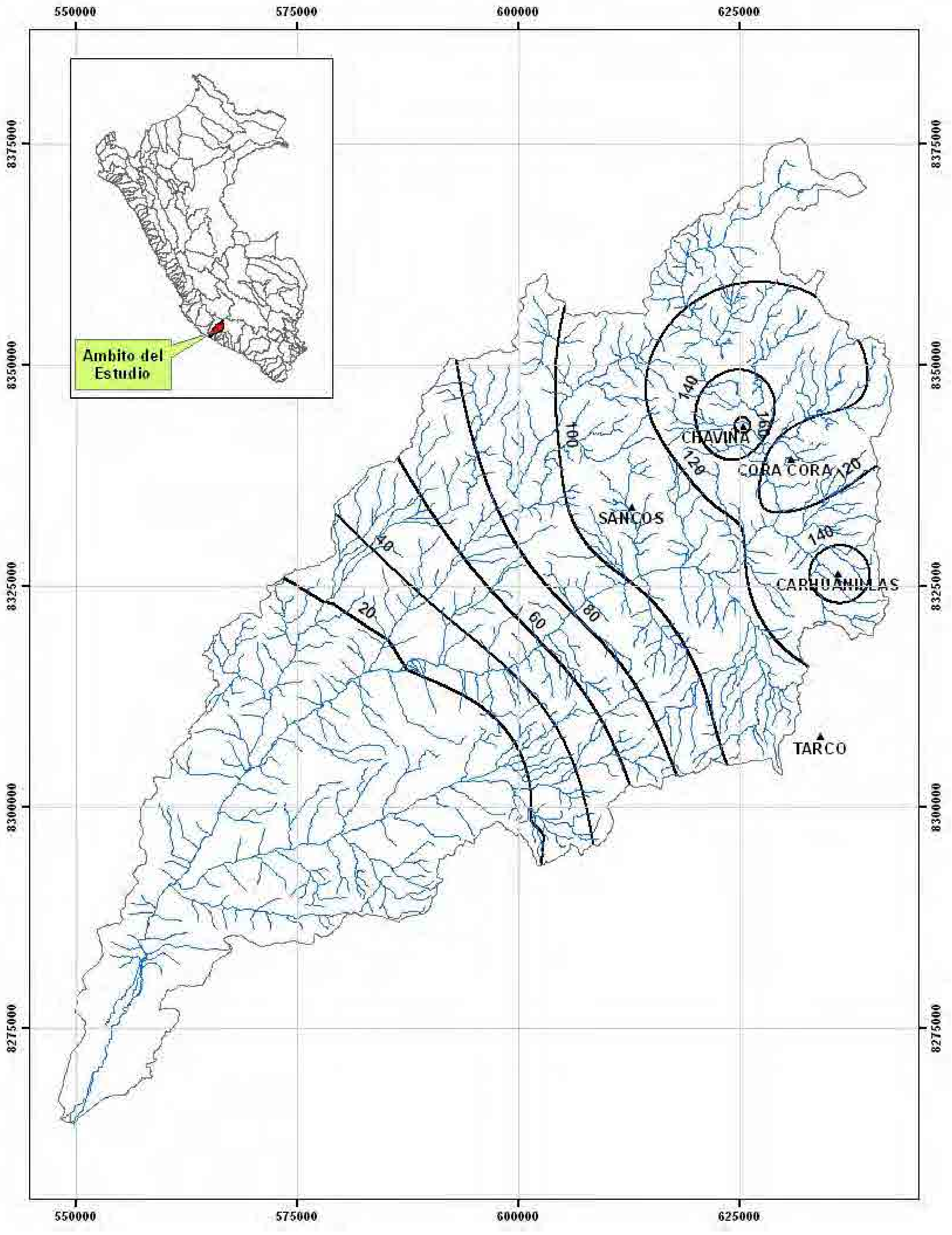

Figure Nº 3.8. Isohyets Mean Monthly Rainfall in the Yauca Basin, in March

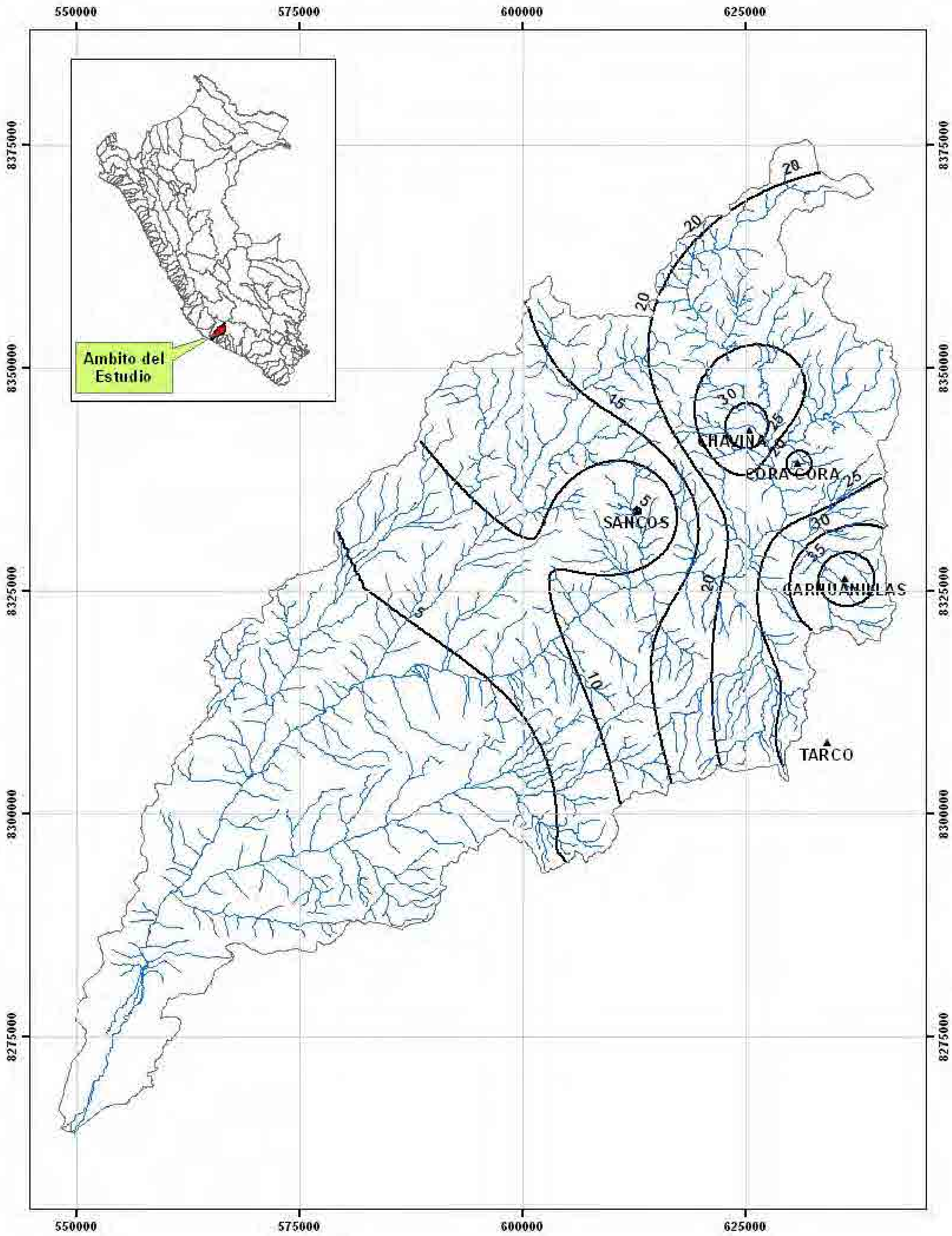

Figure Nº 3.9. Isohyets Mean Monthly Rainfall in the Yauca Basin, in April

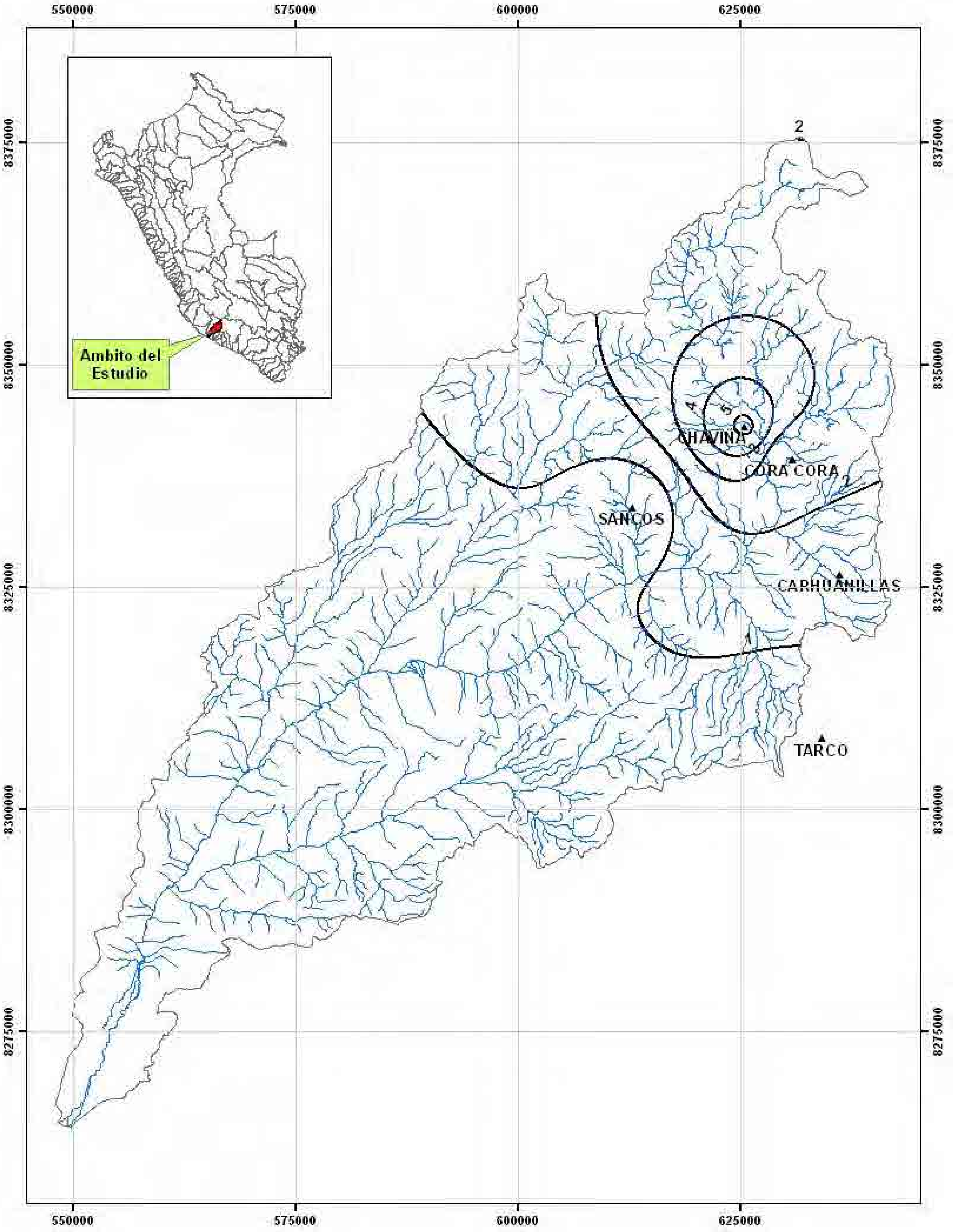

Figure Nº 3.10. Isohyets Mean Monthly Rainfall in the Yauca Basin, in May

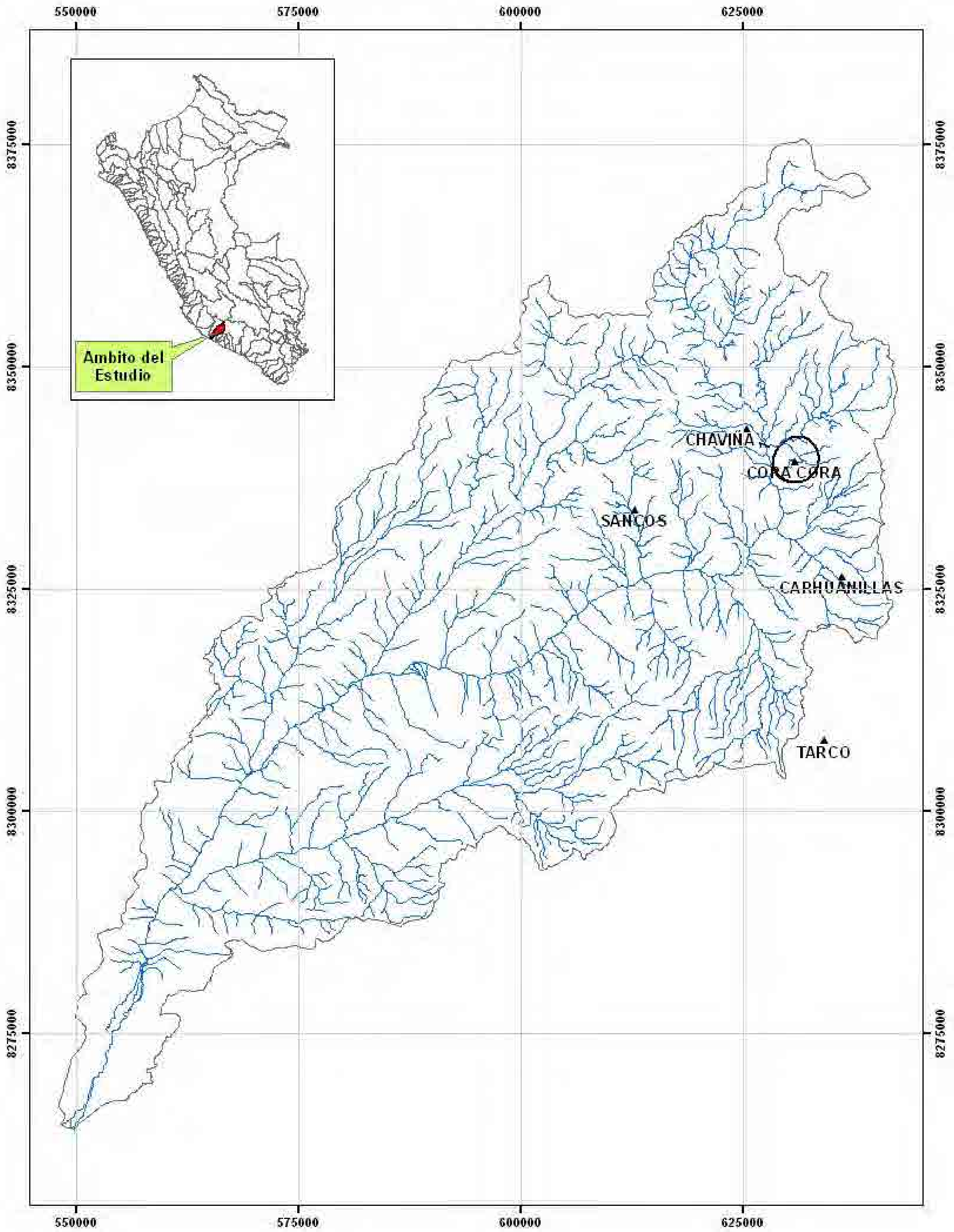

Figure Nº 3.11. Isohyets Mean Monthly Rainfall in the Yauca Basin, in June

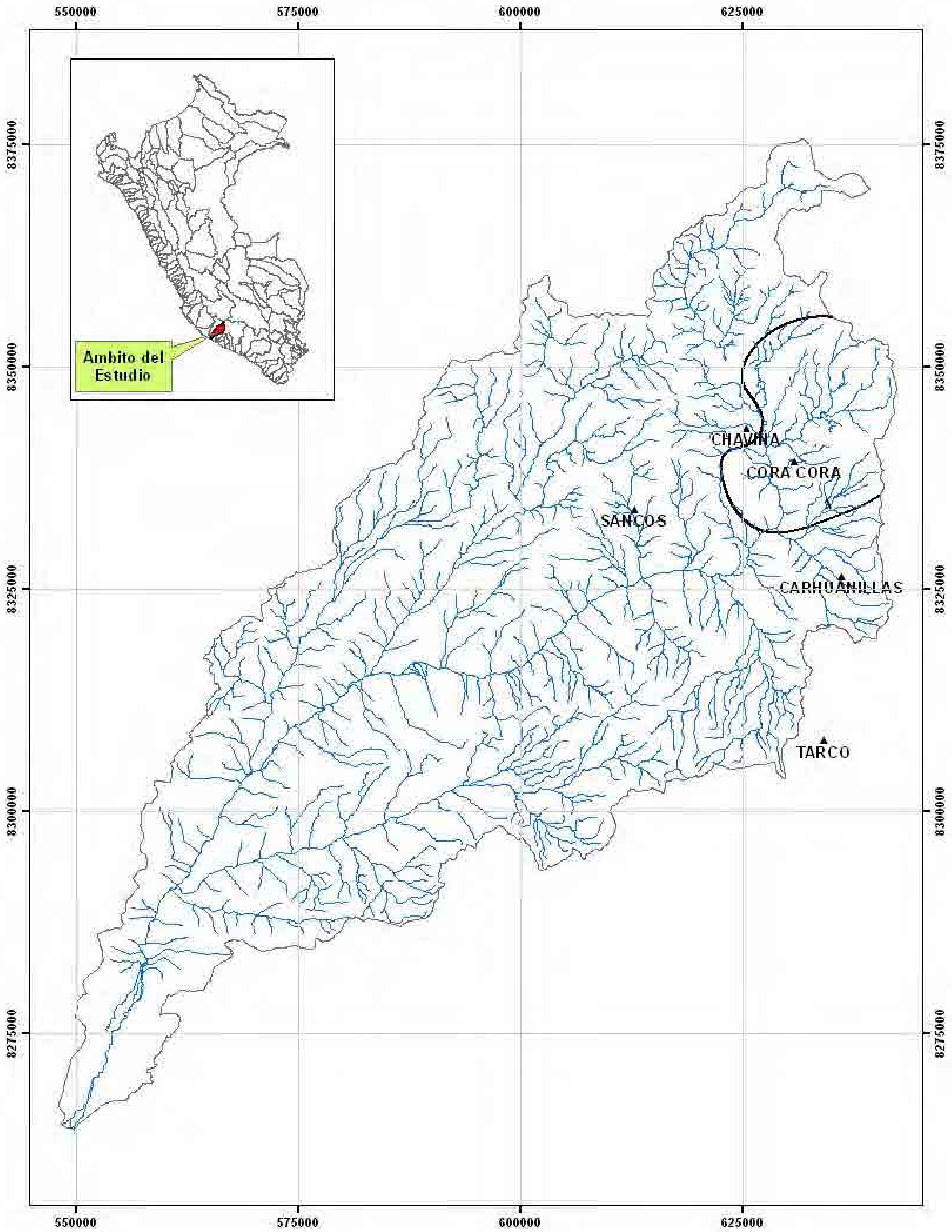

Figure Nº 3.12. Isohyets Mean Monthly Rainfall in the Yauca Basin, in July

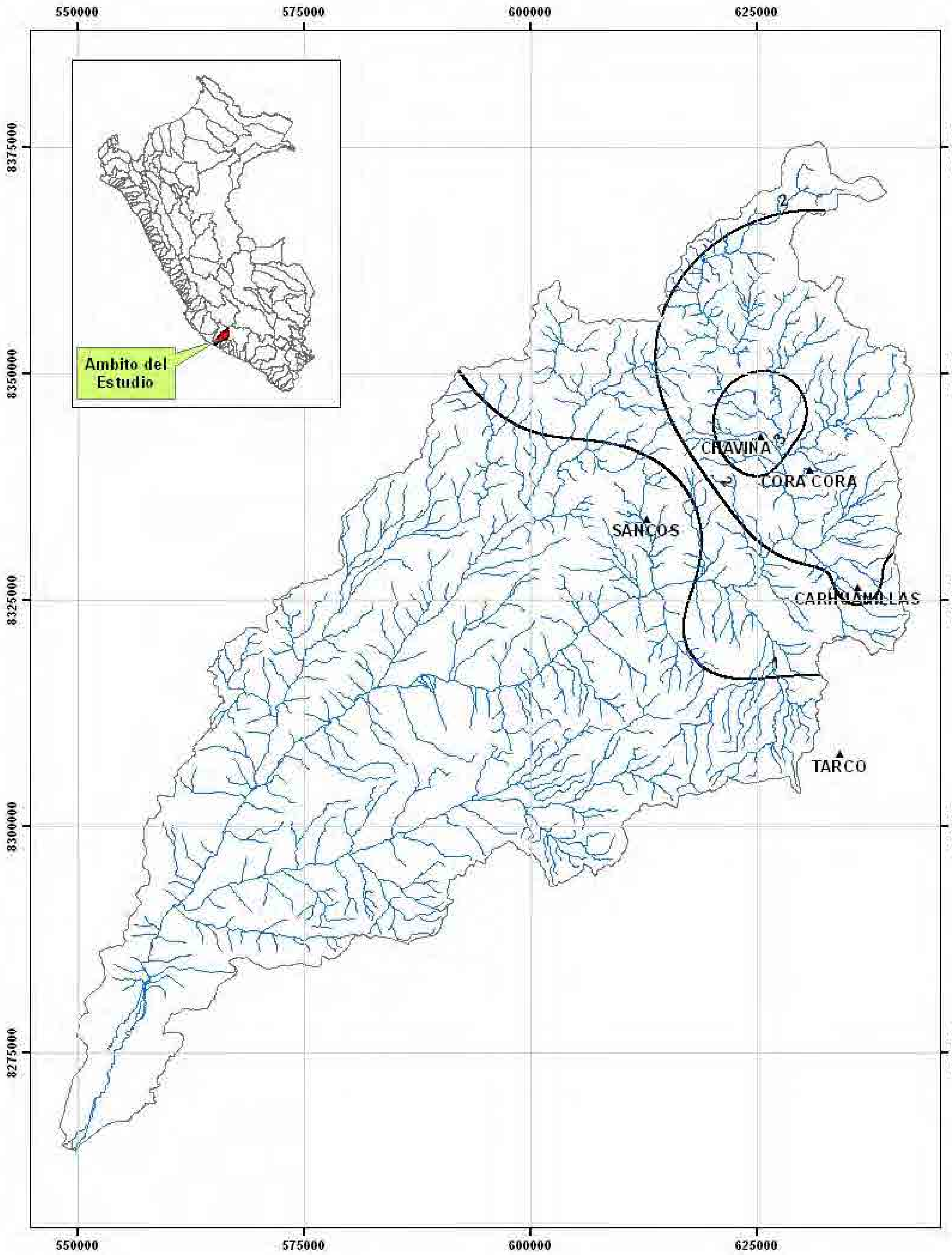

Figure Nº 3.13. Isohyets Mean Monthly Rainfall in the Yauca Basin, in August

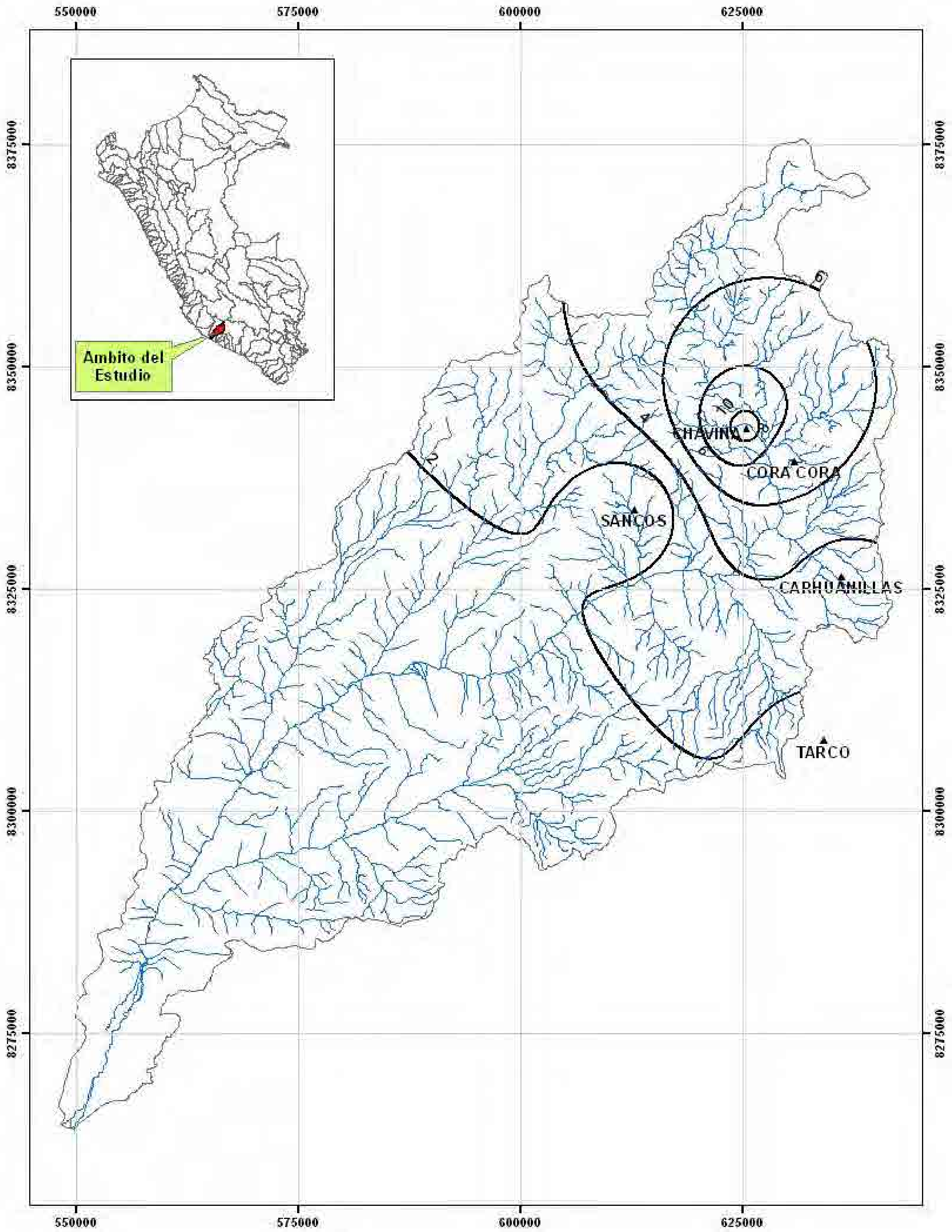

Figure Nº 3.14. Isohyets Mean Monthly Rainfall in the Yauca Basin, in September

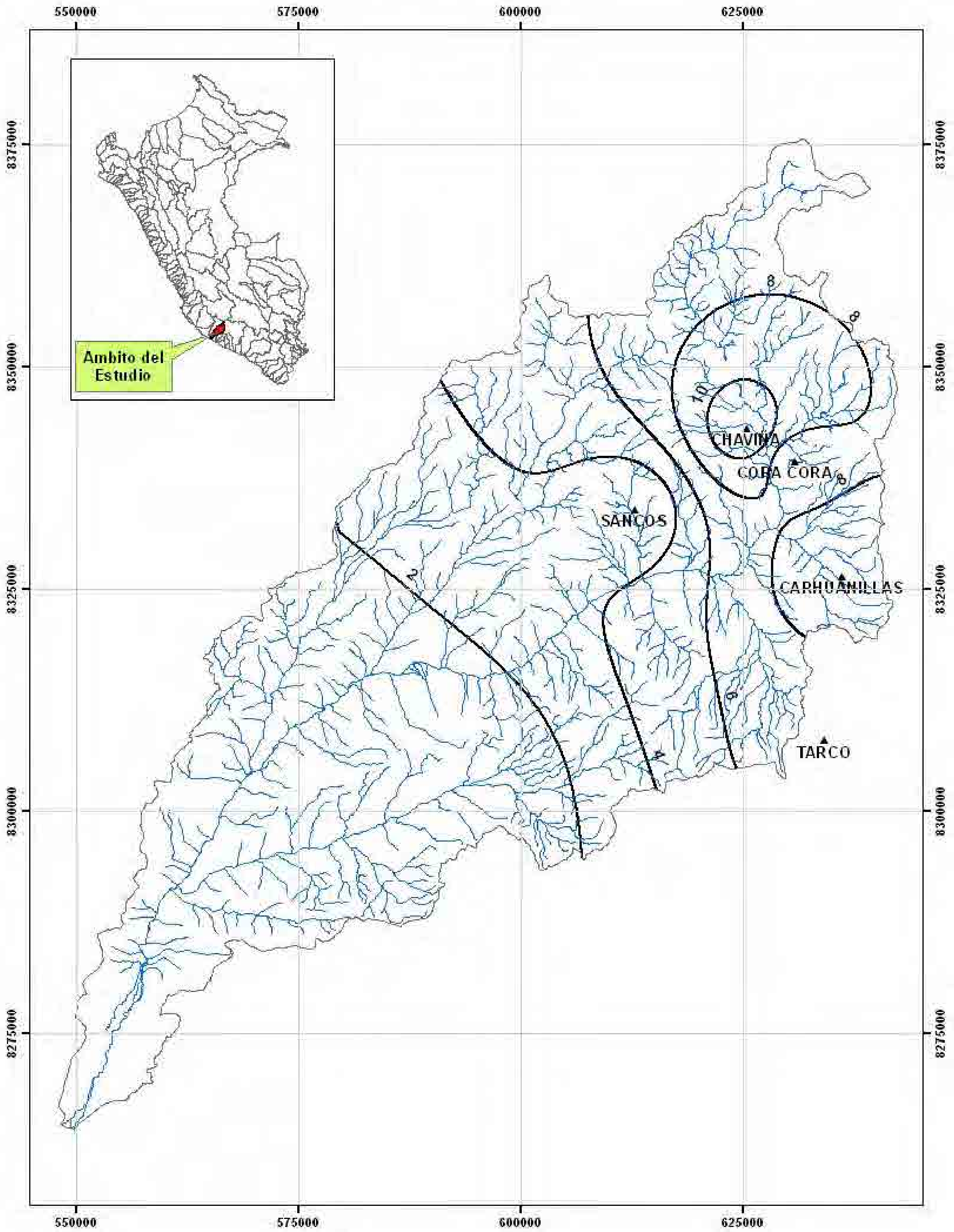

Figure Nº 3.15. Isohyets Mean Monthly Rainfall in the Yauca Basin, in October

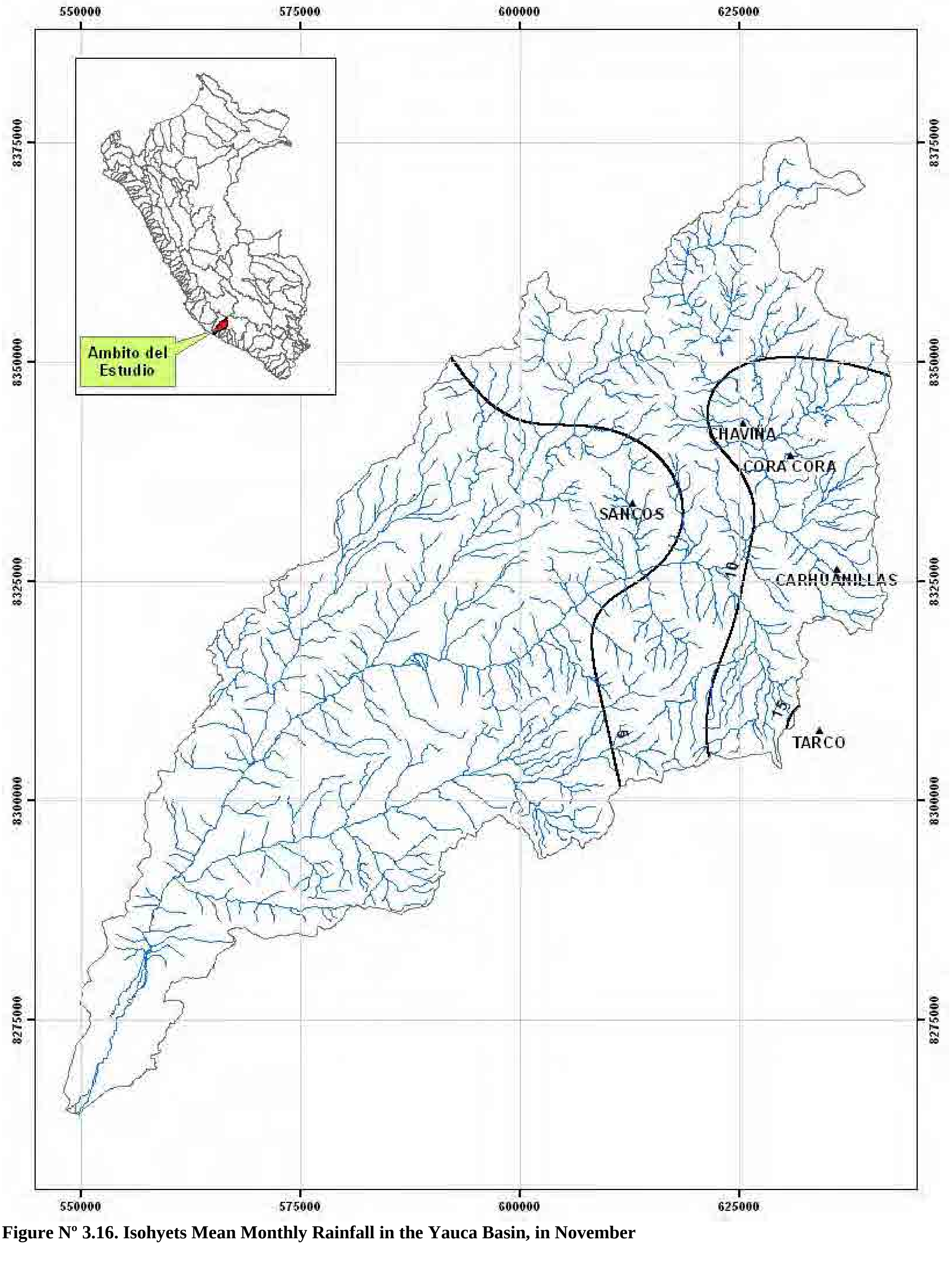

Figure Nº 3.16. Isohyets Mean Monthly Rainfall in the Yauca Basin, in November

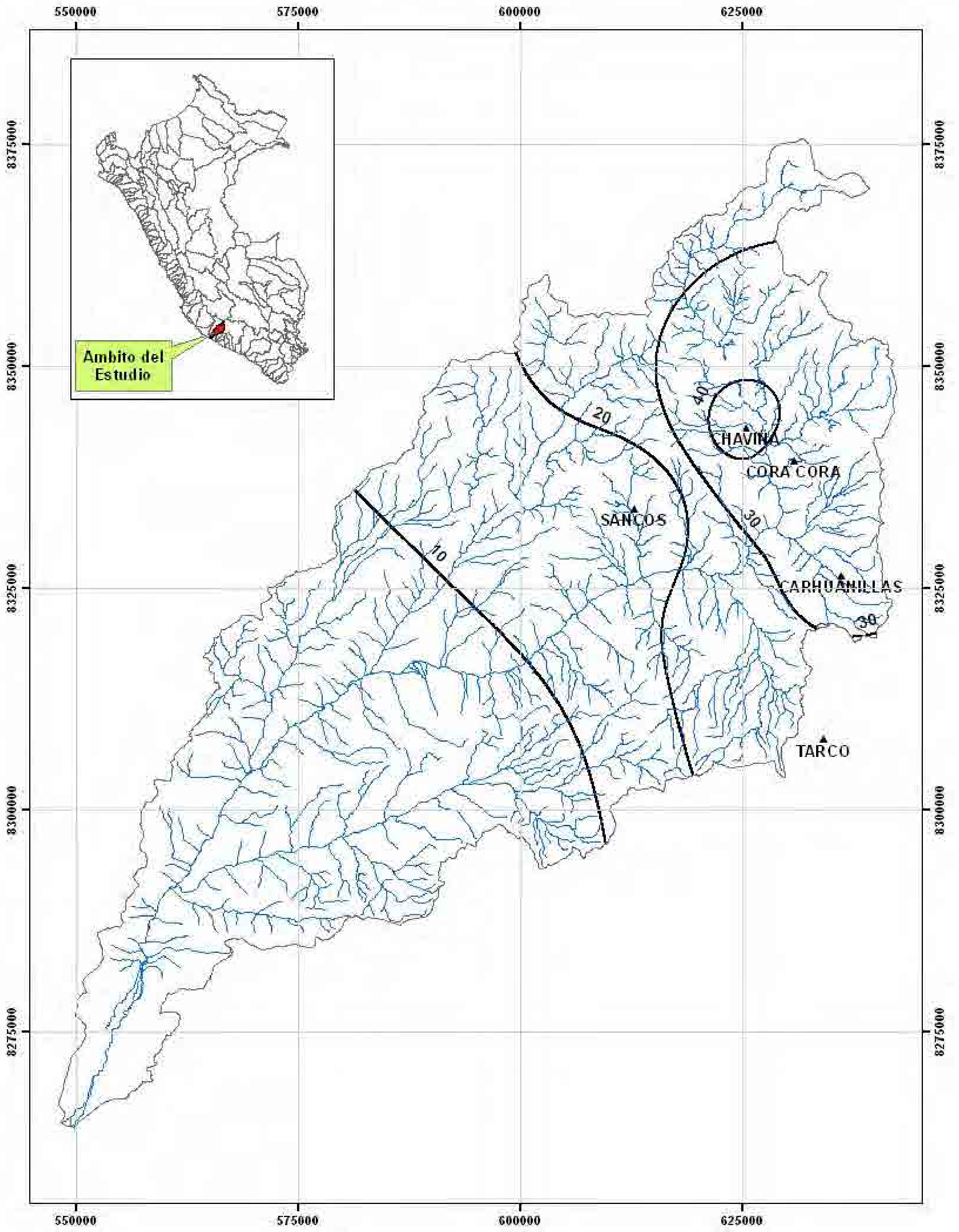

Figure Nº 3.17. Isohyets Mean Monthly Rainfall in the Yauca Basin, in December

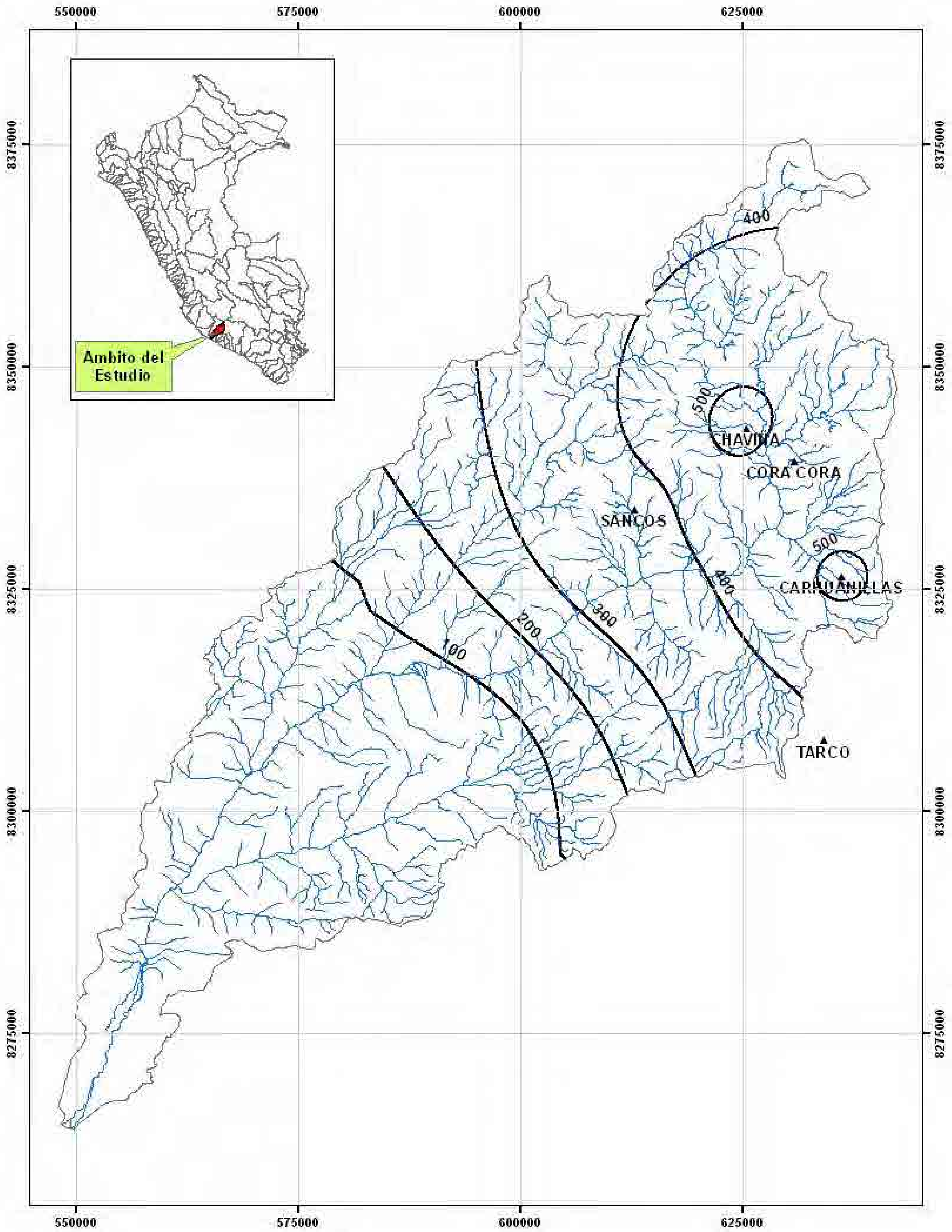

Figure Nº 3.18. Isohyets Annual Mean Monthly Rainfall in the Yauca Basin

3.2.2 Temperature

The temperature of air and its daily and seasonal variations are very important for development of plants, being one of the main factors that directly affect the growth rate, length of growing cycle and stages of development of perennial plants.

The temperature is the factor most linked to their altitudinal variations. In the basin, it has been seen that varies from semi-warm (19 °C approximately) in the area of coast to the frigid type (5 °C approximately) in the area of puna, falls between these extremes a number thermal variations that characterize each of the altitudinal appreciated in the watershed.

The existing meteorological network, only have reliable statistical data on temperature at 4 stations. Three are located in Coracora, Chavin and Sancos respectively (Sierra or mountain side), and one is in Yauca (coast side). Table No. 3.4 presents the maximum and minimum monthly temperature and Figure N ° 3.19 shows the monthly temperature varied from the station Yauca

Table Nº 3.4. Monthly maximum and minimun temperature (C°) of Yauca Station

TEMPERATURA	Mes												Promedio
	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic	
Maxima	27.40	27.90	27.60	26.00	24.00	21.90	20.30	20.10	20.70	22.10	23.90	25.80	23.98
Minima	18.30	17.80	17.70	16.30	13.60	11.30	10.90	11.00	12.20	12.80	14.40	16.40	14.39

Fuente: Asignación de Agua en Bloque en el Valle Yauca, ATDR Acari-Yauca-Puquio, 2006

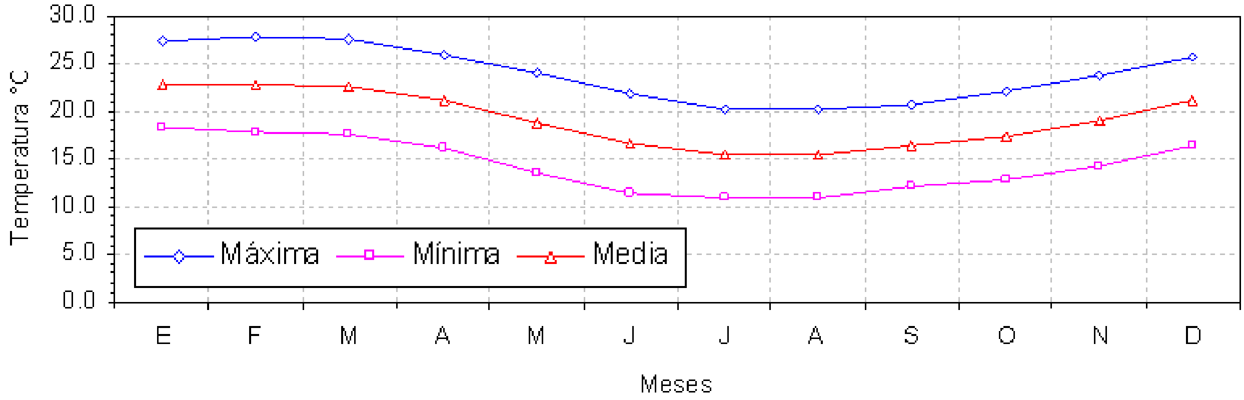

Figure Nº 3.19. Distribution of the monthly minimum and maximun temperature of Yauca Station
Fuente: Asignación de Agua en Bloque en el Valle Yauca, ATDR Acari-Yauca-Puquio, 2006

3.3 Hydrometry

There are 2 hydrometric stations located along the River Yauca catchment and surrounding basins. These stations are operated and maintained by the Peruvian National Service of Meteorology and Hydrology (SENAMHI by their initials in Spanish).

Table No. 3.5, shows the list of stations included in this study with their respective characteristics, such as code, name, and location. Historical records of monthly total rainfall and their histograms are presented in the Annex.

Table Nº 3.5. Characteristics of Hydrometric Stations in the Yauca River Basin and Surrounding Basins

CODE	STATION NAME	CATEGORY*	CATCHMENT	DEPARTAMENT	PROVINCE	DISTRICT	LONGITUDE	LATITUDE	ELEVATION	CONDITION	WORKING PERIOD	
											START	END
204002	PUENTE JAQUI	HLG	YAUCA	AREQUIPA	CARAVELI	JAQUI	74° 27'1	15° 29'1	247	Closed	1951-09	1986-09
213801	LA PALMA	HLG	YAUCA	AYACUCHO	LUCANAS	SANCOS	74° 19'0	15° 18'0	618	Paralyzed	Not Available	
-----	SAN FRANCISCO ALTO	HLG	YAUCA	AREQUIPA	CARAVELI	SAN FRANCISCO ALTO	74º 25' 43	15º27'84	385	Operating	1961	2010

HLG = Hydrometric Station with staff gauge and Limnigraph (floater type). It records water level manually (at 06:00, 10:00, 14:00 and 18:00 hours) to calculate daily discharges. I also it records continuously (hourly) water level data graphed in a recording paper.

Figure Nº 3.20, shows the period and the length of the data available from the hydrometric stations and Figure No. 3.21 shows the locations in the Yauca Basin and adjacent watersheds.

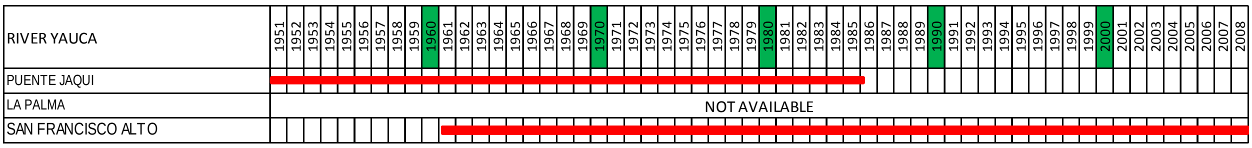

Figure Nº 3.20. Period and longitude of the available information of the Hydrometric Stations

The information of the hydrometric station San Francisco Alto will be used for calibration of the hydrologic model to be described in item 4.2.4. This station is located downstream of the "wet basin" of the catchment, therefore flows registered in this station are practically the same discharge that flows to the Pacific Ocean.

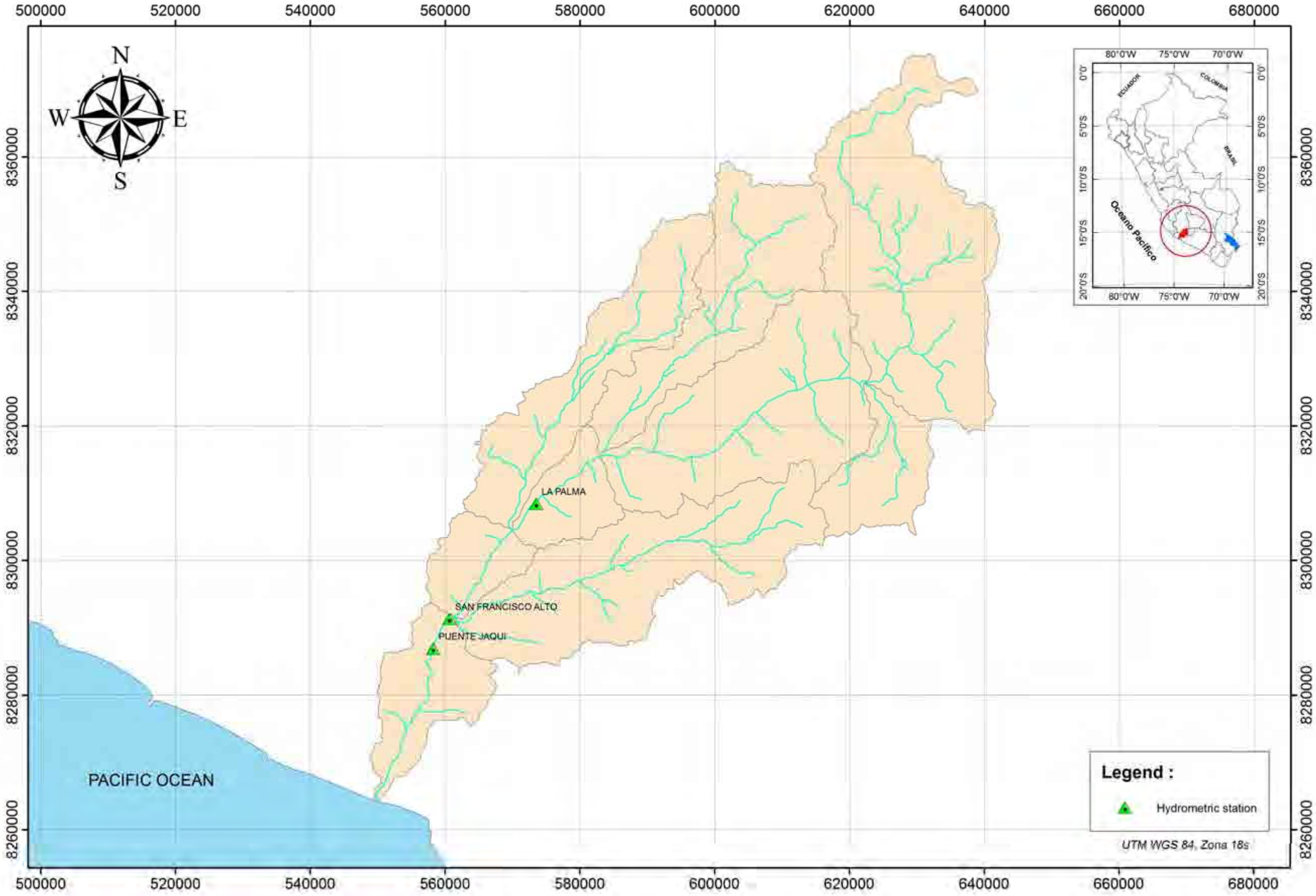

Figure Nº 3.21. Location of the Hydrometric Stations Yauca River basin

3.4 Comments on the hydrologic and meteorologic network in the Yauca River Catchement.

3.4.1 On Pluviometric Stations.

As it was stated previously the pluviometric information used in the analysis has been provided by SENAMHI. From the 7 stations, only one station has data until year 2010, 1 station has data until 2005, 1 station has data until 1993, 1 station has data until 1987, 1 station has data until 1982, 1 station has data until 1980, and 1 station has data until 1972. The stations with information previously to 1992 are not operative anymore; only Cora Cora 2 station is operative.

Rainfall records are done using manual rain gages, these devices accumulate rain for a certain length of time after which the accumulated height of rain is measured manually. In some cases, the readings are made once a day (at 7 am); in others, twice a day (at 7 am and 7 pm), the exact interval or readings for the pluviometric stations used in the present analysis is not available.

3.4.2 On Hydrometric Stations.

Although these stations were operated and maintained by SENAMHI, the hydrometric information used in the analysis was provided by The General Directorate of Water Infrastructure (DGIH) of the Ministry of Agriculture.

From the 3 stations, 1 stations has data until year 2008, 01 station has data until 1986, the data from the remaining two stations ware not available.

For the purpose of the present study the information of hydrometric station San Francisco Alto was used. In this station water levels are measured by reading the level in a staff gage (or ruler), lectures are transferred to a notebook and discharges are found using an equation of the type:

$$Q = aH^b$$

Where Q is the discharge in m^3/s and H is the reading in meters. These types of stations don´t register maximum instantaneous discharge, because recordings are not continuous and automatic, but manual. Four readings a day are taken.

Readings are taken at 6 am, 10 am, 14 pm and 18 pm. The largest of all readings is called the daily maximum discharge, but this value is not the maximum instantaneous daily discharge.

3.4.3 Recommendations

From a technical viewpoint, the following main recommendations can be given:

On the Equipment

- In order to consider the possible differences in climates along the catchment due to orographic effects, the number of weather and hydrometric stations networks should be increased.

- In order to register the maximum instantaneous values of rainfall and discharges, the existing manual weather and hydrometric stations should be automated.

- The limnigraphic equipment of the hydrometric stations should be upgraded from the conventional paper band type to the digital band type

.

- Having the collected data available in real time is desirable.

- Study the possibility of establishing an early warning system based on improving and increasing the number of existing hydrometric and pluviometric stations.

- For complementary studies, it is advisable to acquire:
  - Equipment to sample sediment material.
  - Equipment for measuring of physical parameters for water quality control (pH, DO, turbity and temperature)

- Establishment of Bench Mark (BM) for each weather and hydrometric station using a differential GPS. This information will be useful to replenish the station in case of its destruction by vandalism or natural disasters.

On the Operation and Maintenance of the Equipments

- Weather and hydrometric stations in the study areas should be inspected frequently.
- Maintenance of equipment should be in charge of qualified technicians that are certified by the manufacturers.
- Periodic calibration of the equipment should be done according to the hours of use.

On the Quality of the Measured Data

- Data taken manually by SENAMHI operators should be verified independently.
- In order to guarantee the quality of the information collected in previous years a verification study program of the data should be done by the government.
- Redundant equipment should be available in the main weather stations. This means that duplicate equipment should be installed in selected stations to compare readings with pattern equipment.

- When automatic stations are available they should operate simultaneously with manual stations at least for one year to verify the consistency of the data registered automatically.

It is necessary to mention that there is currently an agreement between Peru's National Water Authority (ANA) and SENAMHI to provide equipment to SENAMHI weather stations financed by an external source, it is recommended that action be taken in order to include Chincha Basin in this agreement.

IV. HYDROLOGY OF MAXIMUM FLOOD

4.1 Preliminary Considerations

This chapter describes the work methodology developed for the generation of flood flows in the so-called Base Point (point of interest, San Francisco Alto station) for return periods of 2, 5, 10, 25, 50, and 100 years.

The estimated maximum discharge was made from the information of rainfall up to 24 hours with a rainfall - runoff models, using the HEC-HMS Software. The model was calibrated using historical records of annual maximum daily flow of the San Francisco Alto station.

Field Reconnaissance:

The field survey has included a review of the general characteristics of the San Francisco Alto hydrometric station and the base point (point of interest, where the peak discharges will be estimated), the major topographic features and land use in the watershed to the study area, which has supported the definition of some parameters to consider for the generation of flood flows.

Methodology and Procedures:

Methodology and procedures developed for maximum discharge estimations are summarized below:

- Identification and delimitation of the sub – watershed to the point of interest (San Francisco Alto Station), based on Charts at 1:100000 and / or 1:25000 scale, and satellite images.
- Selection of existing pluviometer stations in the study area and collections of historical record of maximum24 – hours rainfall.
- Frequency analyses of maximum 24 – hour rainfalls for each station and selection of the distribution function showing the best adjustment.
- Areal rainfall calculation of the watershed to the interest point from the isohyetal line maps that were prepared for the 2, 5, 10, 25, 50, and 100 – year return periods.

- Establishment of the maximum rainfall for a storm's duration no less than the time of concentration (time in which the entire basin inputs to the discharge) through the Dick and Peschke model.

- The rainfall – runoff model generates flood flows for 2, 5, 10, 25, 50, and 100 – year return periods, by using the HEC – HMS software, and modeled the basin based on the following steps:

  - Based on the daily maximum annual flow historical series, the flow frequency law is calculated by means of statistical methods.

  - Calibration of the rainfall – runoff model based on the flow frequency law.

4.2 Hydrology characterization, analysis of rainfall and river information

4.2.1 Hydrology Characterization

The geomorphological characteristics of the basis point watershed (station San Francisco Alto) shown in Table Nº 4.1.

Table Nº 4.1. Geomorphological Characteristics of the Basis Point Watershed (station San Francisco Alto)

Caracteristic	Value
Catchment Area (km2)	3,190.000
Major water course length (km)	136.000
Maximum Altitude (msnm)	4,540.000
Minimum Slope (msnm)	447.000
Average Slope (m/m)	0.030

4.2.2 Maximum 24-Hours Rainfall Analysis

Table N° 3.1 and Figure N° 3.3 show the stations located within the study scope (the Yauca River Basin and adjacent basins). Maximum 24 – hour annual rainfall in these stations are shown in Table N° 4.2; daily and maximum 24- hour information is shown in the Annex.

From the Information in Table N° 4.2 and Figure N° 3.3,we conclude that the stations are located throughout the area of study .

Table Nº 4.2. Maximum 24-hours rainfall for Stations located within the Study Scope

Year	Pluviometric Stations

	TARCO	SANCOS	CORACORA	CHAVIÑA	CARHUANILLAS	YAUCA
1960						
1961						
1962						
1963						
1964		25.00		24.50		0.00
1965		25.20		26.50		0.00
1966		17.10	21.00	30.60		0.00
1967	44.80	53.40	35.70		45.00	0.00
1968	30.00	49.30	31.00		35.50	
1969	25.00	32.00	24.00	32.90		0.00
1970		40.10	28.50	29.70		0.00
1971	15.60	20.50	30.00	41.40	49.50	0.00
1972	10.90	57.50	27.00	57.30	32.00	0.00
1973	15.00	38.01	32.00	46.40	20.00	0.00
1974		28.00	30.00	34.00	30.00	
1975		61.90	28.00	30.90	53.00	0.00
1976		44.80		44.40	37.00	0.00
1977		45.20	36.50	20.00	32.00	
1978		33.00	15.40		79.50	
1979		13.80	20.80	22.80	13.10	0.00
1980		19.90	21.70	29.70	23.00	
1981			27.40	34.00	30.50	0.00
1982			25.40		12.10	
1983			13.50			
1984						
1985					15.10	
1986					19.10	
1987			34.80			
1988						
1989						
1990						
1991			30.20			
1992						
1993			30.40			
1994			30.00			
1995			28.00			
1996						
1997			30.70			
1998						
1999						
2000			28.00			
2001			31.60			
2002			29.10			
2003			29.00			
2004						
2005			157.80			
2006			59.50			
2007						
2008						
2009						
2010						

Figure N° 4.1 shows the stations included in the following analyses, as applied to HEC – HMS software.

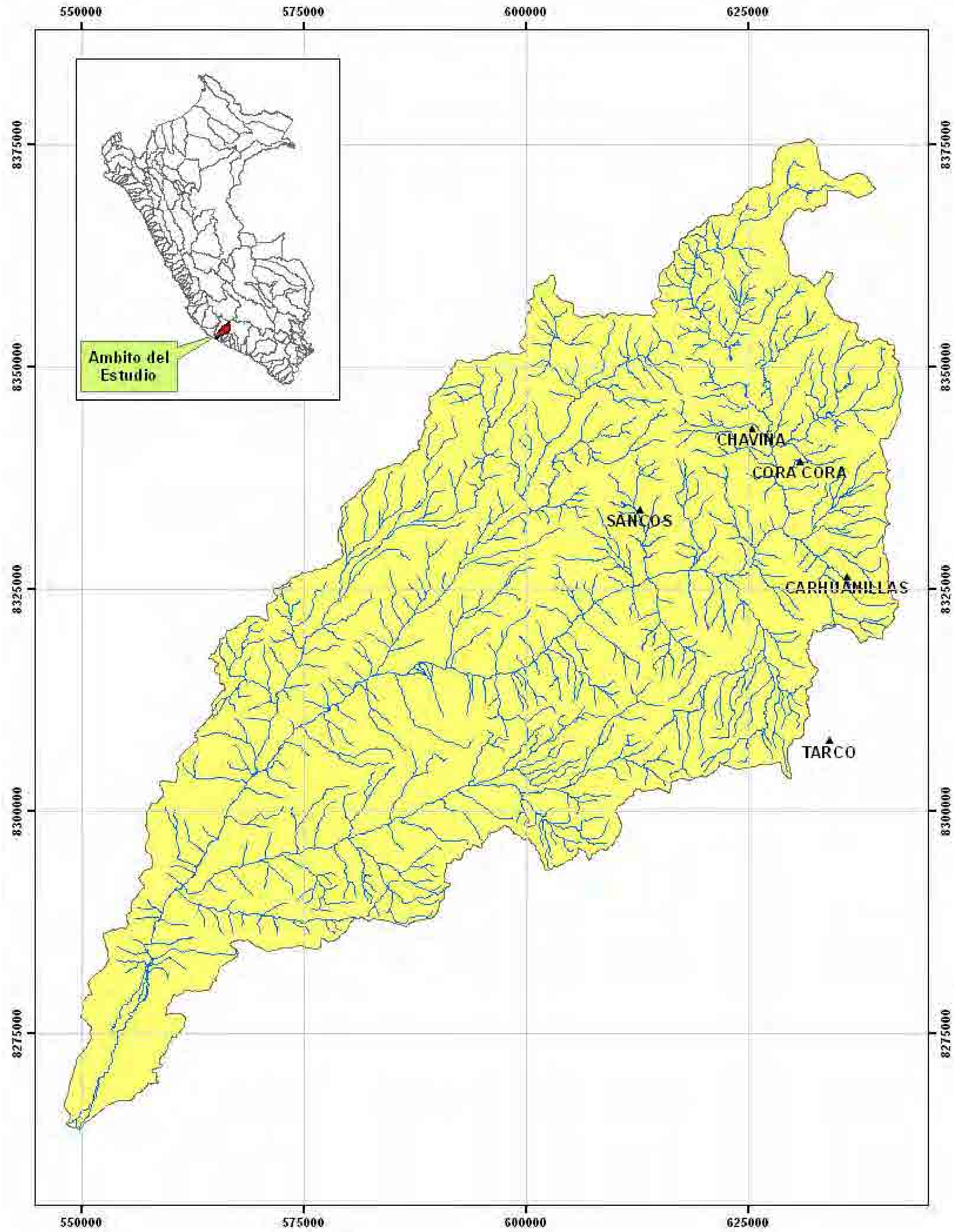

Figure Nº 4.1. Rainfall Stations considered for HEC - HMS Software application

Each maximum annual rainfall series for all five (5) selected rainfall stations will be adjusted to a specific distribution type. In this sense, most common distribution functions are described, as applied to the extreme event hydrological studies.

4.2.2.1 Distribution Functions

The following describes the distribution functions:

1. Distribution Normal or Gaussiana

   It is said that a random variable X has a normal distribution if its density function is,

$$f(x) = \frac{1}{\sqrt{2\pi}S} EXP\left[-\frac{1}{2}\left(\frac{x-X}{S}\right)^2\right]$$

To $-\infty < x < \infty$

Where:

f(x) = Normal density function of the variable x.

x = Independent Variable.

X = Location parameter equal to the arithmetic mean of x.

S = Scale parameter equal to the standard deviation of x.

EXP = Exponential function with base e of natural logarithms.

2. Two-Parameter Log-normal Distribution

   When the logarithms, ln(x) of a variable x are normally distributed, then we say that the distributivo of x is the probability distribution as log–normal probability function log–normal f(x) is represented as:

$$f(x) = \frac{1}{x\sigma_y\sqrt{2\pi}S} EXP\left\{-\frac{1}{2}\left[\frac{\ln x - \mu_y}{\sigma_y}\right]^2\right\}$$

To $0<x<\infty$, must be $x \sim \log N(\mu_y, \sigma_y 2)$

Where:

μ_y, σ_y = Are the mean and standard deviation of the natural logarithm of x, i.e. de ln(x), representing respectively the scale parameter and shape parameter distribution.

3. Log–Normal Distribution of Three Parameters

Many cases the logarithm of a random variable x, the whole are not normally distributed but subtracting a lower bound parameter xo, before taking logarithms, we can get that is normally distributed.

The density function of the three-parameter lognormal distribution is:

$$f(x) = \frac{1}{(x - x_o)\sigma_y\sqrt{2\pi}} EXP\left\{-\frac{1}{2}\left[\frac{ln(x - x_o) - \mu_y}{\sigma_y}\right]^2\right\}$$

To $x_o \leq x < \infty$

Where:

xo = Positional parameter in the domain x

μ_y, = Scale parameter in the domain x.

σ_y^2 = Shape parameter in the domain x

4. Two-Parameter Gamma Distribution

It is said that a random variable X has a 2-parameter gamma distribution if its probability density function is:

$$f(x) = \frac{x^{\gamma-1} e^{-\frac{x}{\beta}}}{\beta^{\gamma}\Gamma_{\gamma}}$$

To:

$0 \leq x < \infty$

$0 < y < \infty$

$0 < \beta < \infty$

As:

γ = Shape parameter (+)

β = Scale Parameter (+)

$\Gamma_{(\gamma)}$ = Complete gamma function, defined as:

$\Gamma_{(\gamma)}$ = $\int x^{\gamma-1} e^{-x} dx$, which converges if $\gamma>0$

5. Three- Parameter Gamma Distribution or Pearson Type III

The Log-Pearson type 3 (LP3) is a very important model in statistical hydrology, especially after the recommendations of the Water Resources of the United States (Water Resources Council - WRC), to adjust the distribution Pearson Type 3 (LP3) to the logarithms of the maximum flood. Well, the LP3 distribution is a flexible family of three parameters can take many different forms, therefore it is widely used in modeling annual maximum flood series of unprocessed data.

It is said that a random variable X has a gamma distribution 3-parameter or Pearson Type III distribution, if its probability density function is:

$$f(x) = \frac{(x - x_o)^{\gamma-1} e^{\frac{(x-x_o)}{\beta}}}{\beta^{\gamma} \Gamma_{\gamma}}$$

To

$x_o \leq x < \infty$

$-\infty < x_o < \infty$

$0 < \beta < \infty$

$0 < \gamma < \infty$

4.2.2.2 Calculation of Adjustment and Return Period for Maximum Rainfall in 24 Hours

Frequency of maximum 24-hours rainfall in each station (see Table N° 4.2) was analyzed by using the “CHAC” Extreme Hydrological Events Software (developed by CEDEX - Spain),. This software calculates Maximum 24 – hour rainfall for different return periods, based on the probability distribution functions, such as: Normal, 2 or 3 parameter Log - Normal, 2 or 3 parameter Gamma, log - Pearson III, Gumbel, Log – Gumbel, and Widespread Extreme Values.

From the information that has been generated for each distribution function, results showing best adjustment based on the Kolgomorov – Smirnov goodness – of - fit test will be chosen. Return periods taken into account for this study are 2, 5, 10, 25, 50, and 100 years.

4.2.2.3 Selection of Distribution Theory with better Adjustment to the Series Record Rainfall in 24 Hours

According to the analysis with the software CHAC note that the data fit the distribution function of Generalized Extreme Value (GEV) as the distribution coefficient, see Table No 4.3. The values for each return period are shown in Table No 4.4.

Table Nº 4.3. Determination Coefficient for each Distribution Function and for each Rainfall Station

Station	Determination Coeffcient for Each Distribution Function				
	Log Pearson III	GEV	SQRT	Gumbel	Log-Normal
Acnococha	0.94	0.95	0.93	0.93	0.90
Choclococha	0.94	0.95	0.93	0.90	0.91
Cocas	0.94	0.95	0.90	0.93	0.93
Hacienda Bernales	0.89	0.93	0.88	0.90	0.90
Huamani	0.94	0.95	0.94	0.92	0.89

Table Nº 4.4. Maximum 24-hours rainfall of each Rainfall Station for each Return Period

NAME OF STATION	RETURN PERIOD T [YEARS]						
	PT_2	PT_5	PT_10	PT_25	PT_50	PT_100	PT_200
CARHUANILLAS	26.0	42.0	54.0	70.0	84.0	98.0	114.0
CHAVIÑA	32.0	42.0	48.0	54.0	59.0	62.0	66.0
CORA CORA	28.0	36.0	41.0	46.0	49.0	52.0	54.0
SANCOS	34.0	48.0	57.0	67.0	74.0	80.0	86.0
TARCO	20.0	32.0	41.0	54.0	65.0	77.0	91.0

Information shown in Table N° 4.4 and the Interpolate to Raster's IDW (Inverse Distance Weighted) tool in the ArcGIS Spatial Analyst module have allowed to generate spatial rainfall distribution for each return period.

To generate maps isohyets tool has been used Contour Surface Analysis of Spatial Analyst module of ArcGIS Software, whose results are shown in Figures N° 4.2 to 4.7.

Based on the isohyets maps for each return period, maximum rainfall for the basin area has been estimated, as established for the Base Point (San Francisco Station). Methodology and results are described under 4.2.2.4.

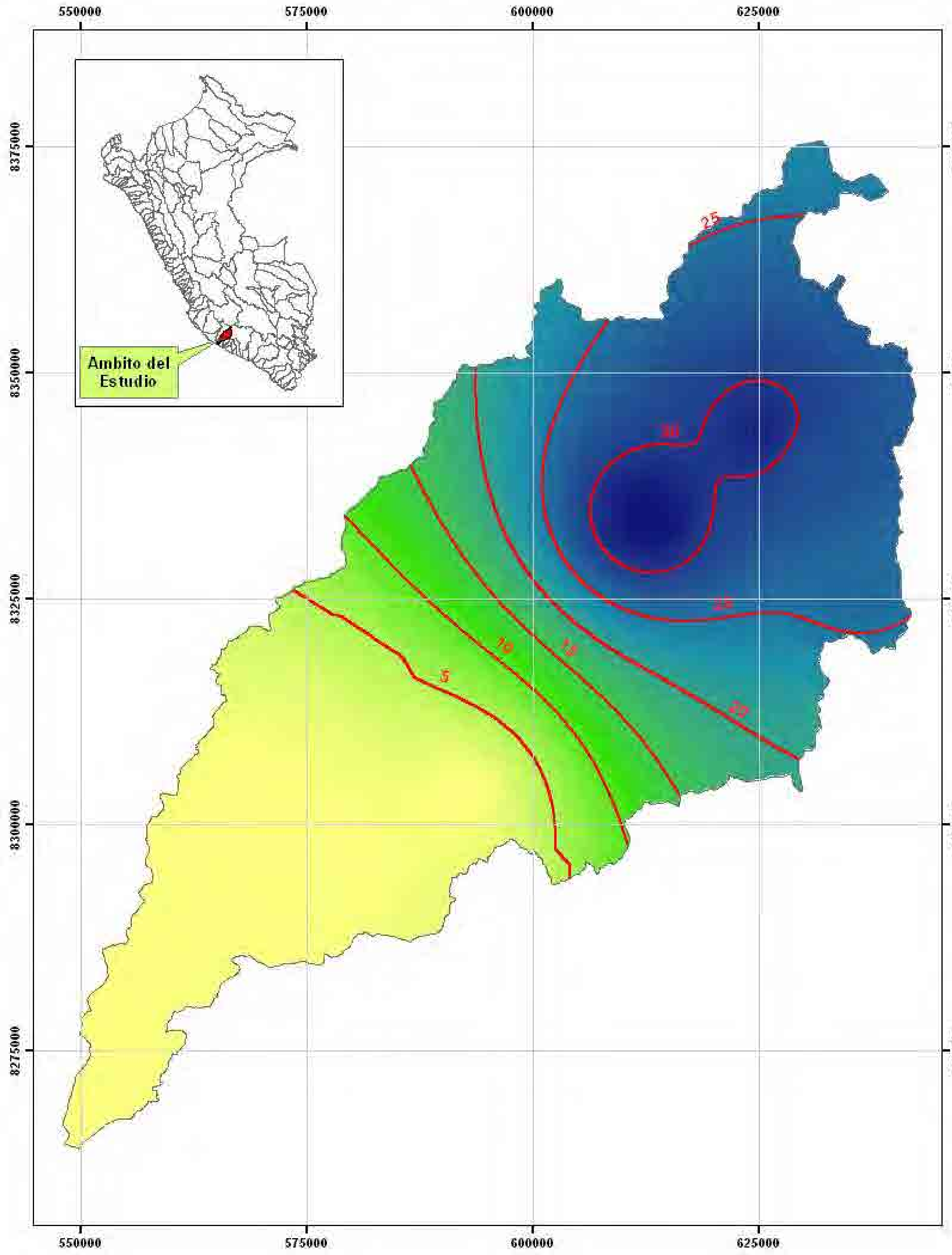

Figure Nº 4.2. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin

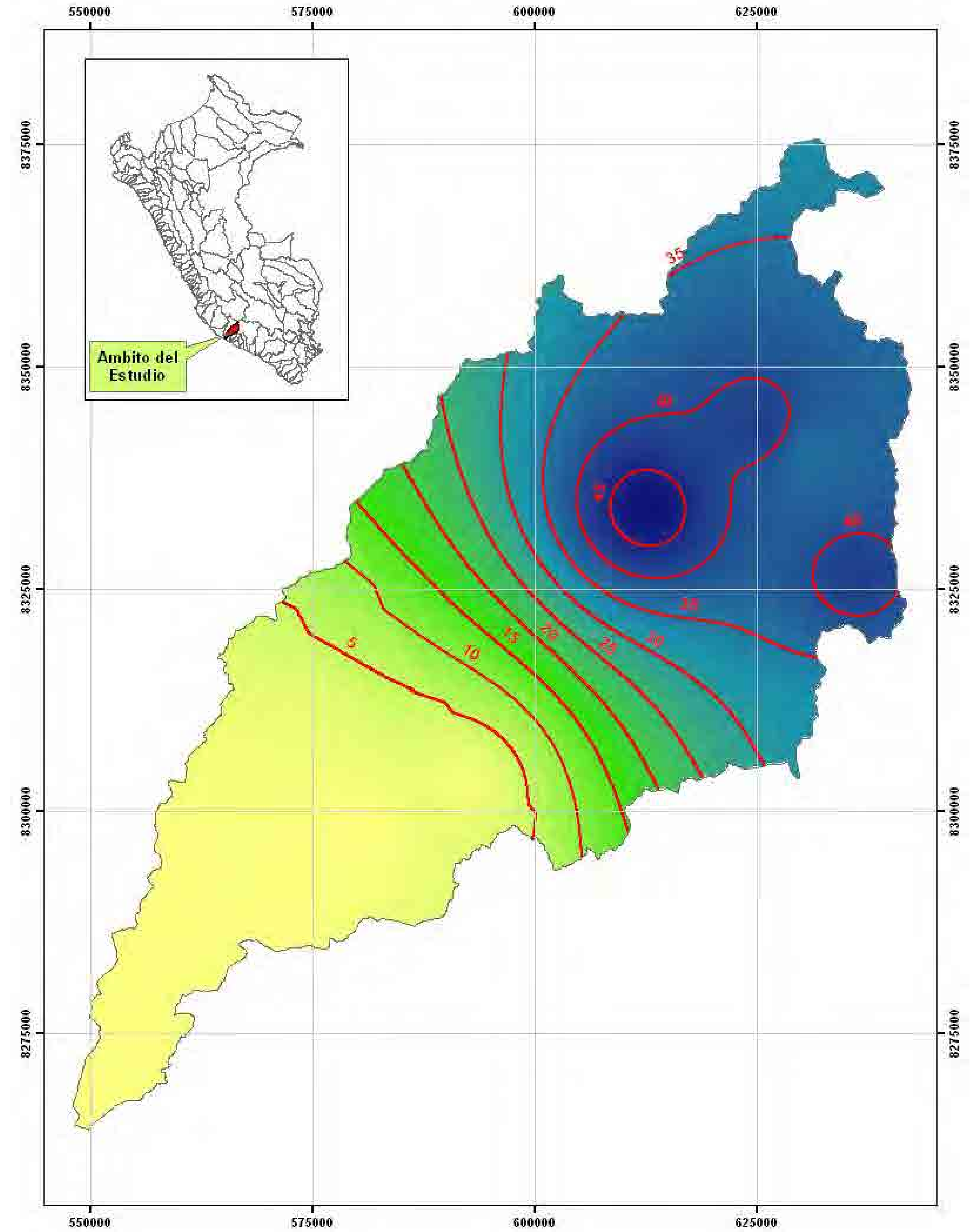

Figure Nº 4.3. Isohyets for the 5 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin

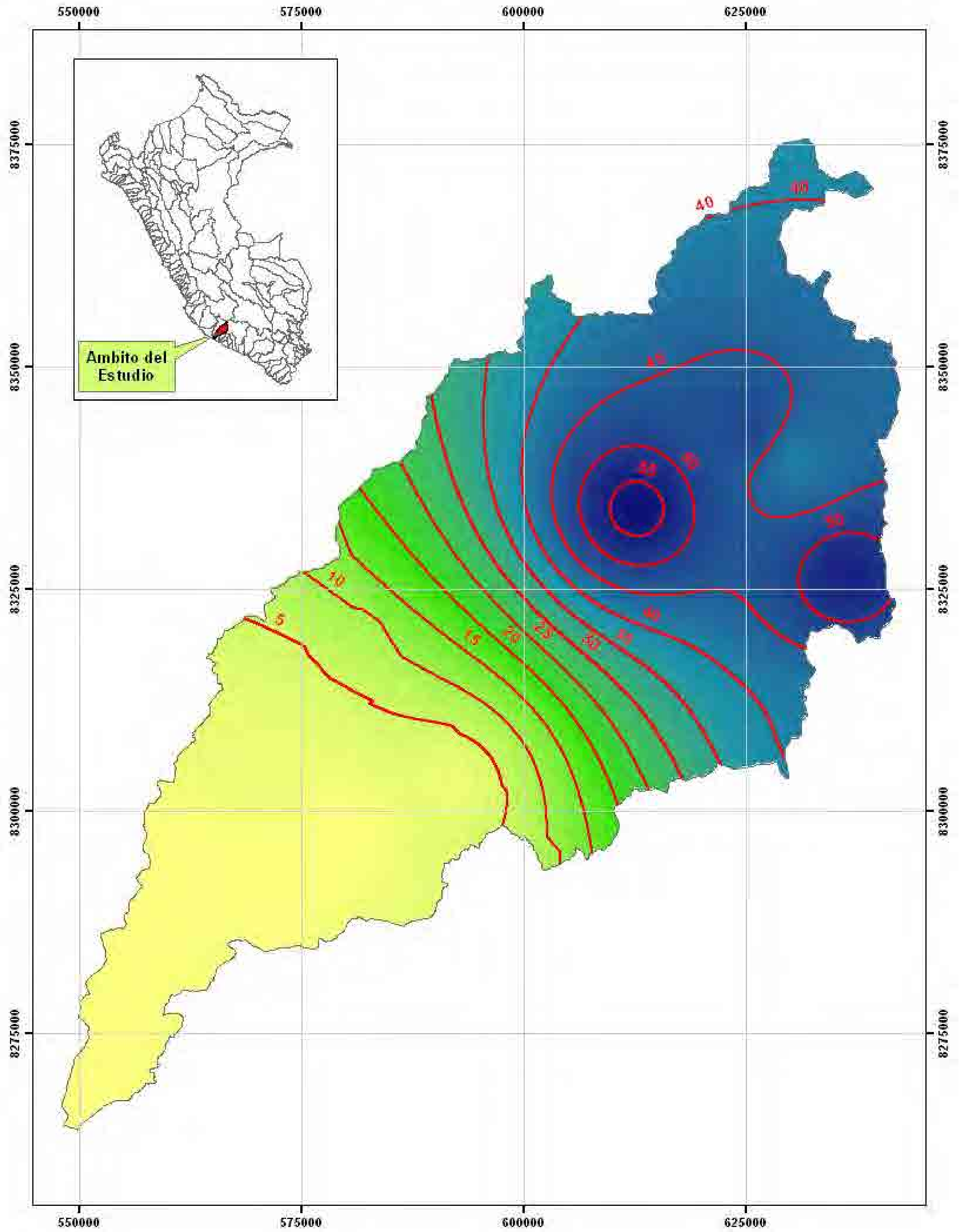

Figure Nº 4.4. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin

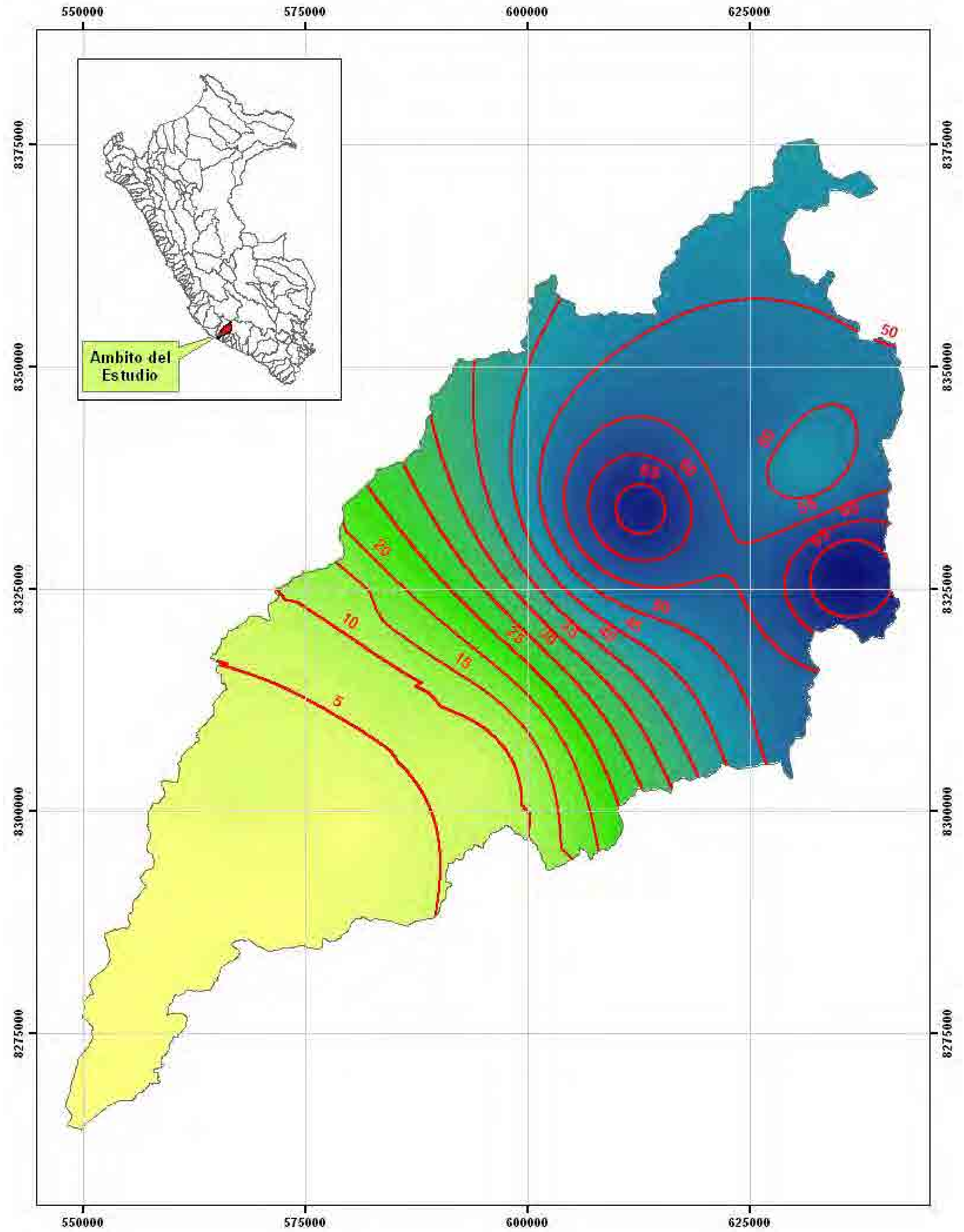

Figure N° 4.5. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin

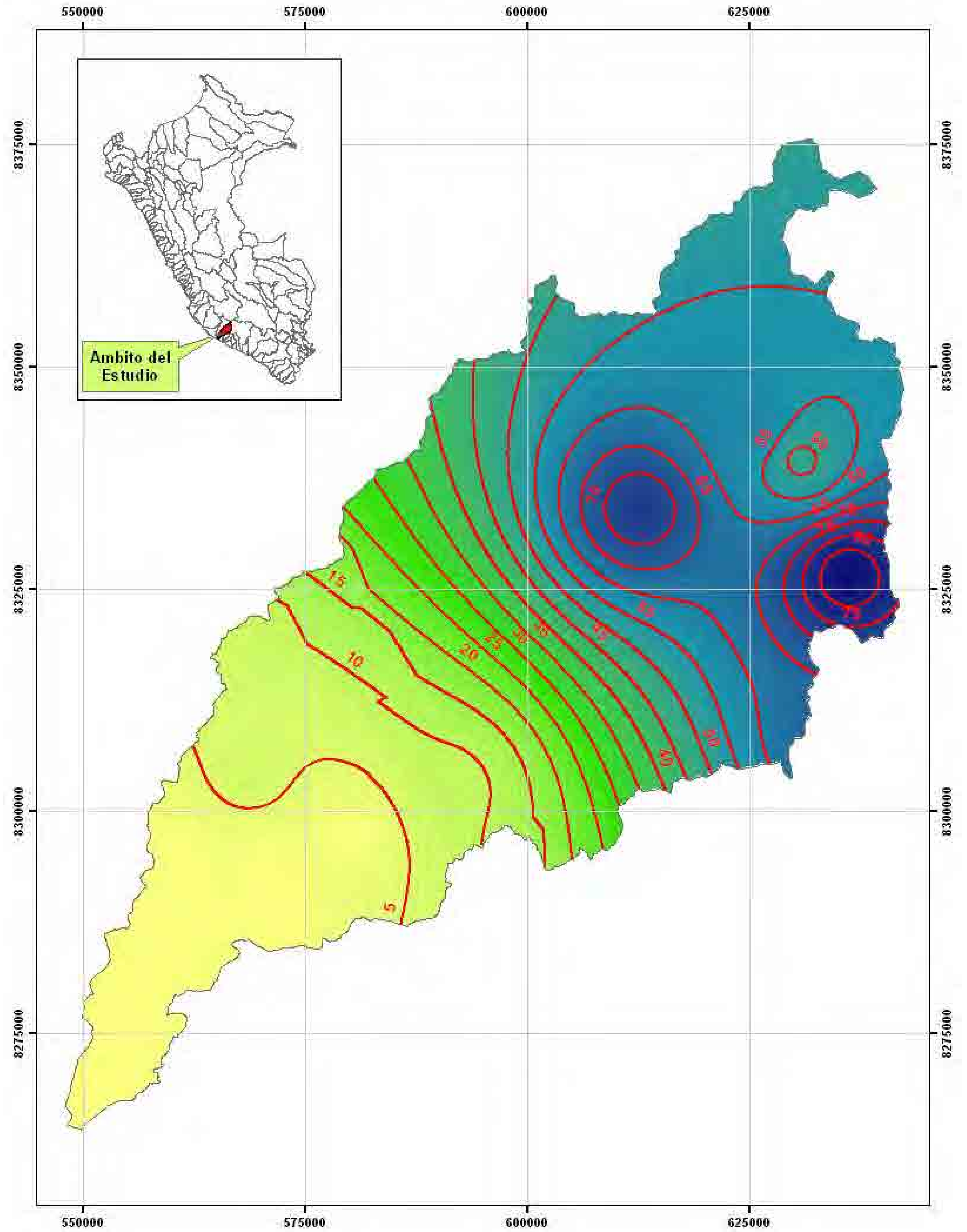

Figure Nº 4.6. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin

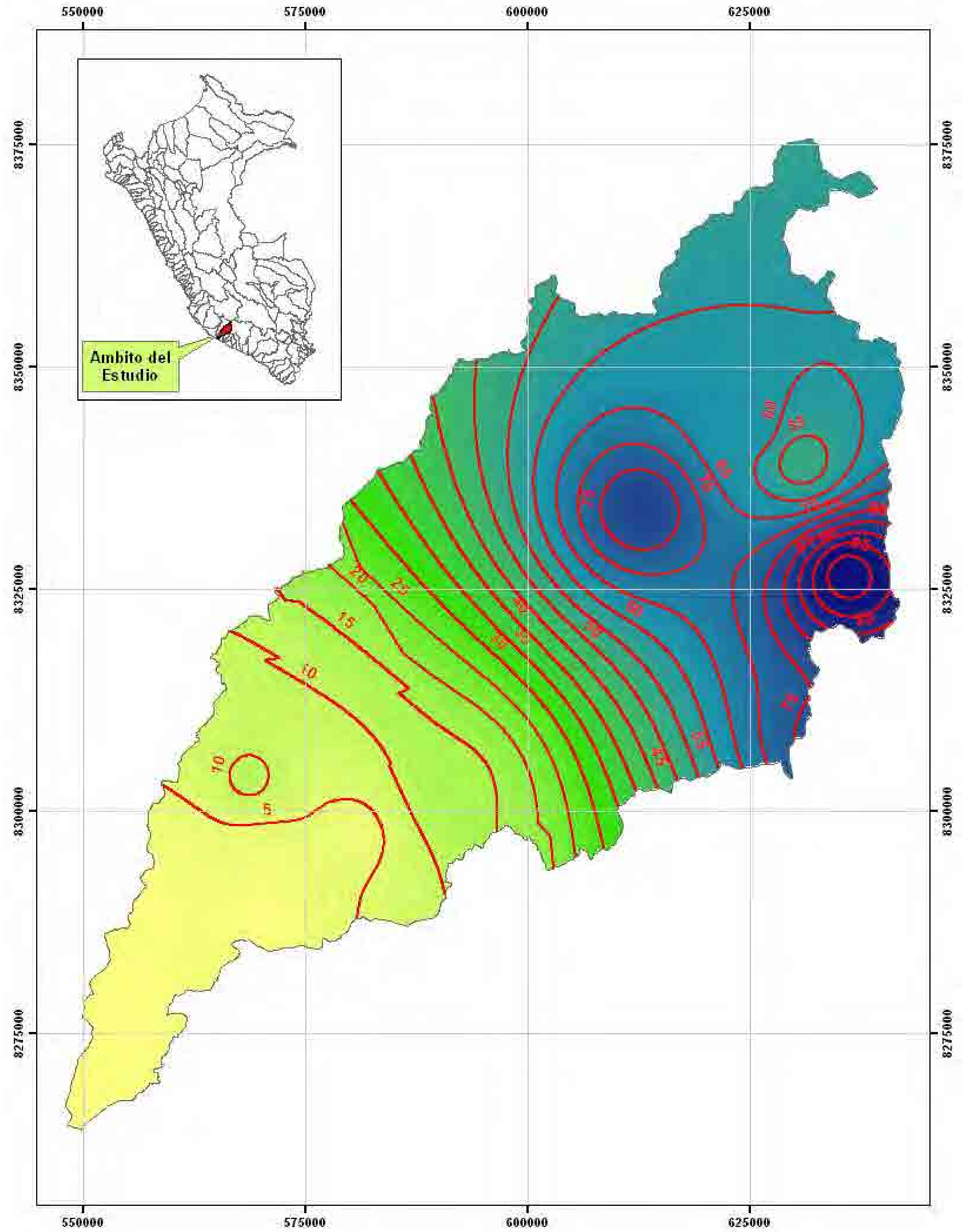

Figure Nº 4.8. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin

4.2.2.4 Determination of Maximum 24-Hours Rainfall for Different Return Periods in the Base Point

Isohyet maps for each return period (2, 5, 10, 25, 50, and 100 years) and the Zonal Statistics tool from the ArcGIS software's Spatial Analyst module have allowed for calculating maximum 24 – hour areal rainfall at the base point (San Francisco Alto Station) for each return period. Results are shown in Table N° 4.5.

Table Nº 4.5. Maximum Areal Rainfall in 24 Hours at the Base Point (San Francisco Alto Station) for each Return Period

Return Period "T" [Years]	Maximum Areal 24 Hours Rainfall [mm]
2	23.00
5	28.00
10	33.00
25	39.00
50	45.00
100	50.00

4.2.2.5 Determination of Maximum 24- HoursRainfall for Different Return Period in the Yauca River Subwatershed

In addition to the hydrological study of the flow in the river Yauca is required to estimate the maximum rainfall for different return periods in the Yauca river basins. It has been estimated from isohyet maps shown in Figures N° 4.2. to N° 4.7 and the methodology that is briefly described under 4.2.2.4.

Figure Nº 4.8 shows the Yauca river subbasins to which it has been estimated maximum rainfall for each return period and for each subbasin. Table Nº 4.6 shows the values of rainfall for each subbasin.

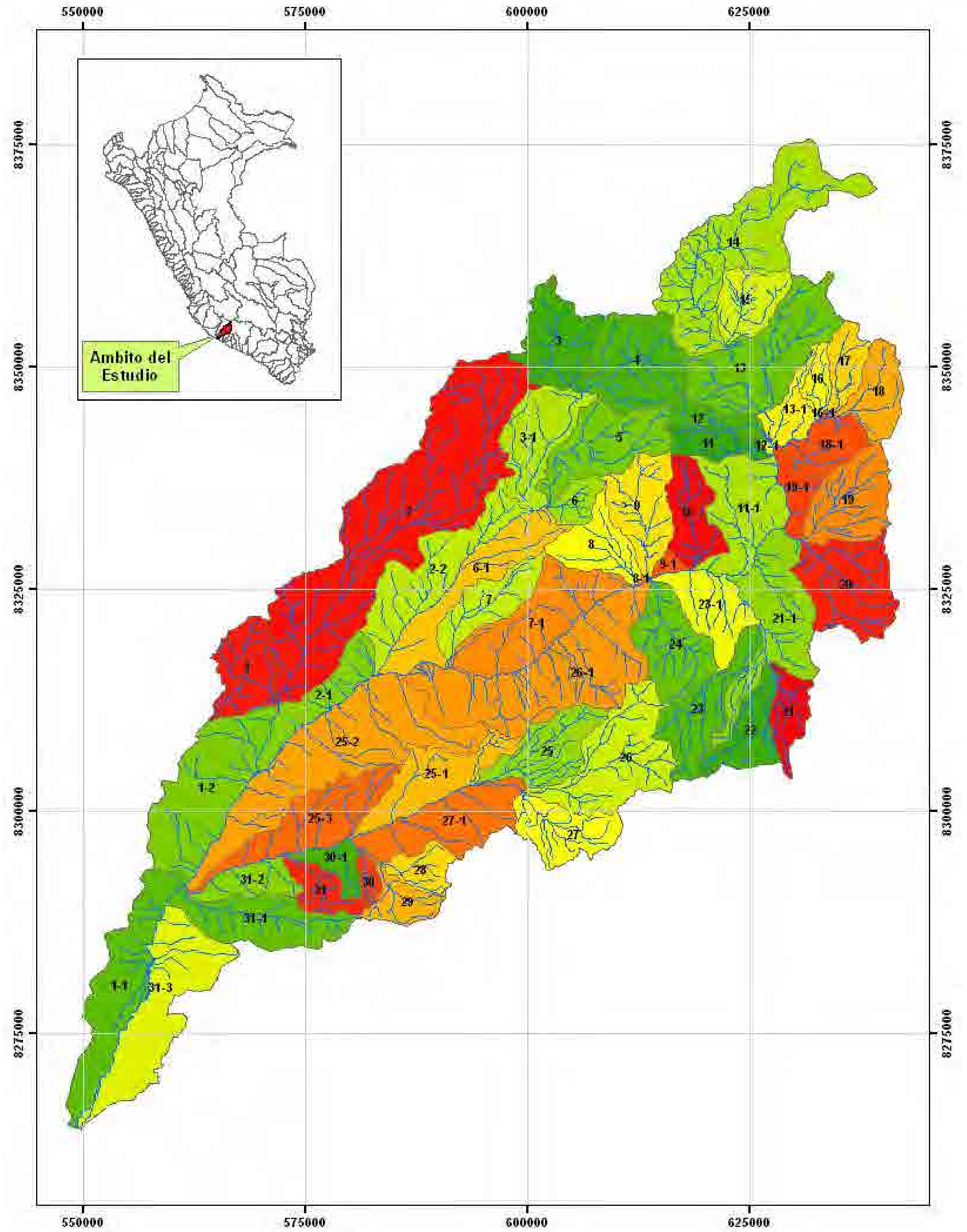

Figure Nº 4.8. Yauca River Subbasin

Table Nº 4.6. Rainfall for Different Return Periods in each river Basin of Yauca

SUBCUENCA	AREA [m²]	PERIODO DE RETORNO T [AÑOS]					
		PT_2	PT_5	PT_10	PT_25	PT_50	PT_100
1	61,284,500	1.6	2.6	3.4	5.2	6.9	9.4
10	55,272,700	30.3	42.3	50.1	58.9	65.4	71.0
11	30,944,400	30.5	40.8	47.2	54.0	59.3	63.3
1-1	118,833,000	0.1	0.2	0.2	0.4	0.5	0.8
11-1	93,098,900	28.6	39.1	45.9	53.6	59.5	64.8
12	26,390,500	30.7	40.8	47.1	53.7	58.9	62.6
1-2	143,100,000	0.3	0.8	1.3	2.7	4.0	6.3
12-1	1,383,670	30.5	40.0	45.9	51.8	56.4	59.6
13	137,225,000	28.9	38.7	44.9	51.5	56.7	60.8
13-1	32,052,500	29.7	39.1	45.0	51.0	55.6	59.1
14	192,151,000	25.6	35.0	41.1	48.1	53.5	58.3
15	50,349,700	27.4	37.0	43.2	50.0	55.4	59.9
16	16,954,800	28.6	38.1	44.1	50.5	55.4	59.5
16-1	568,670	28.5	37.7	43.5	49.6	54.1	57.9
17	32,660,500	27.7	37.3	43.5	50.3	55.5	60.0
18	48,910,200	27.2	36.9	43.3	50.4	55.9	60.9
18-1	43,177,700	28.1	36.9	42.5	48.3	52.4	56.1
19	78,792,400	26.9	38.2	45.9	55.4	62.9	70.3
19-1	25,910,700	27.9	37.3	43.4	50.1	54.9	59.5
2	386,631,000	12.2	17.4	20.9	25.4	29.1	33.1
20	98,980,600	25.6	40.4	51.3	65.8	78.3	90.8
21	34,183,400	20.6	32.2	40.7	52.8	62.9	73.7
2-1	55,336,800	1.9	3.2	4.2	6.2	8.2	11.2
21-1	112,005,000	24.1	36.2	44.8	56.0	65.3	74.7
22	50,395,500	19.8	30.4	38.1	48.9	57.9	67.4
2-2	104,677,000	11.8	16.9	20.4	25.1	28.9	33.1
23	73,007,700	19.2	28.8	35.5	44.6	52.2	60.1
23-1	60,112,300	25.1	36.3	43.9	53.4	61.0	68.3
24	77,914,200	22.3	32.3	39.2	47.8	54.7	61.5
25	68,850,300	6.8	10.4	13.0	17.3	21.3	26.1
25-1	77,030,500	0.8	1.9	2.8	5.4	8.3	12.4
25-2	213,313,000	1.1	2.1	2.9	4.8	6.8	9.8
25-3	91,892,800	0.3	0.6	0.8	2.1	2.7	4.7
26	120,127,000	12.2	18.2	22.5	28.5	33.7	39.4
26-1	208,752,000	12.5	18.2	22.1	27.5	32.2	37.2
27	61,181,900	5.8	9.0	11.3	15.3	19.1	23.7
27-1	93,813,100	0.8	1.8	2.7	5.1	7.8	11.6
28	29,264,100	0.9	1.7	2.4	4.3	6.0	8.8
29	31,413,300	0.9	1.6	2.1	3.7	4.9	7.1
3	75,074,500	23.9	33.2	39.2	46.3	51.7	56.7
30	11,649,000	0.4	0.8	1.0	2.3	2.9	4.9
30-1	23,518,800	0.2	0.4	0.6	1.7	2.1	3.9
31	32,366,600	0.3	0.6	0.8	1.7	2.2	3.6
3-1	78,873,900	24.4	34.2	40.6	48.1	53.7	58.9
31-1	85,790,400	0.2	0.3	0.4	0.9	1.1	1.8
31-2	36,947,100	0.1	0.2	0.3	1.0	1.2	2.1
31-3	134,614,000	0.2	0.3	0.4	0.7	0.8	1.2
4	104,276,000	27.2	37.3	43.8	51.1	56.7	61.5
5	90,318,700	28.7	40.1	47.4	55.6	61.8	67.1
6	22,411,600	29.0	40.8	48.5	57.3	63.6	69.3
6-1	89,267,400	14.4	20.5	24.6	30.0	34.3	38.8
7	56,625,200	13.8	19.7	23.8	29.1	33.5	38.1
7-1	111,631,000	16.4	23.4	28.2	34.3	39.2	44.2
8	52,246,200	28.9	40.8	48.5	57.4	63.8	69.6
8-1	812,255	28.1	39.7	47.3	56.2	62.8	68.8
9	71,716,500	32.4	45.7	54.2	63.7	70.5	76.4
9-1	6,557,560	29.3	41.4	49.3	58.3	65.1	71.1

4.2.3 Maximum Daily Discharge Analysis

For the analysis of Maximum Daily Discharges of River Yauca, the information of the hydrometric station San Francisco Alto has been used. This station has a contribution area of 3190 km^2. Figure 3.21 shows its location in the river Yauca catchment.

The Directorate General of Water Infrastructure (DGIH) of the Ministry of Agriculture has provided information on annual maximum daily discharge of San Francisco Alto station whose values are shown in Table Nº 4.7.

Table Nº 4.7. Maximum Daily Discharge of station San Francisco Alto, Yauca River (m3/s)

AÑO	Q max
1961	109.82
1962	58.93
1963	54.11
1964	15.77
1965	36.54
1966	26.49
1967	211.06
1968	68.51
1969	64.97
1970	36.65
1971	20.70
1972	151.38
1973	123.13
1974	31.96
1975	137.20
1976	41.82
1977	69.11
1978	4.51
1979	20.10
1980	15.72
1981	23.56
1982	26.72
1983	12.60
1984	52.20
1985	17.65
1986	30.54
1987	24.06
1988	32.30
1989	198.39
1990	11.12
1991	42.60
1992	0.67
1993	19.57
1994	60.41
1995	20.93
1996	17.50
1997	13.09
1998	45.65
1999	195.03
2000	62.64
2001	118.06
2002	39.77

2003	45.81
2004	33.46
2005	6.61
2006	78.54
2007	50.14
2008	42.28

These values have been analyzed with different distribution functions described in item 4.2.1.1. and evidence of Kolmogrov - Smirnok best fits the Log - Pearson 3 parameters. The results are shown in Table No 4.8.

Table Nº 4.9. Maximum Discharges for each Return Period at te Station San Francisco Alto, Yauca River (m^3/s)

Return Period (Years)	Maximum Daily Discharge (m^3/s)
2	38.39
5	79.21
10	119.90
25	187.03
50	263.41
100	354.38

4.2.4 Simulation Model, Application of HEC-HMS Software

4.2.4.1 Hydrological Model

<u>Time of Concentration and Travel Time</u>

USDA/SCS Unit Synthetic Hydrograph model was used to calculate the following parameters:

Concentration time (Tc) with the Bransby-Williams formula

$$Tc = 0{,}95*(L^3/H)^{0{,}385}$$

Where:

L = The largest raindrop route at the main river bed (km)

H = Head (m)

Tc = Concentration time (Hr)

Travel time (Tv) = 0,6*Tc

Table Nº 4.9. Concentration and Travel Times for the Base Point (station San Francisco Alto)

L =	136.00	Km

H =	4,093.00	Mts
Tc =	**11.25**	Hrs
Tv =	**6.75**	Hrs

Maximum Rain Storm Duration

Because the information of storms given by SENAMHI was provided in a daily basis, the information about the duration of the storm was not known. For this reason, based on the information of duration of storms in Perú, mentioned in the "Study of the Hydrology of Peru" (Refence "d"), a duration of 10 hours was adopted.

This value is lower than the time of concentration of 11.25 hours calculated in the previous item, it indicates that the peak values to be estimated in the hydrometric station San Francisco Alto won´t correspond to the simultaneous contribution of runoff of the whole catchement of the river Yauca until the hydrometric station San Francisco Alto.

Storm Depth

The storm depths for a duration of 10 hours were calculated using the equation of Dick and Peschke (Reference "c") which allows to estimate the maximum rainfall for a given storm duration from a 24-hour maximum rainfall. The values of 24 hour maximum rainfall showed in Table 4.5 were used for the calculations, these values correspond to an spatial average rainfall for the catchment until hydrometric station San Francisco Alto.

Dick and Peschke equation :

$$Pd = Pd_{24}*(Tc/1440)^{0,25}$$

Where:

Pd = Maximum rainfall for a duration d

Pd_{24}= 24 – hour maximum rainfall

Tc= Concentration time (minutes)

Table Nº 4.10. Maximum Rainfall according to Dick - Peschke

T [Años]	Pp Areal Max 24 Horas [mm]	Pp Max, [mm]
2	23.00	18.92
5	28.00	22.50
10	33.00	26.51
25	39.00	31.33
50	45.00	36.15
100	50.00	40.17

The maximum daily rainfall for return periods of 2, 5, 10, 25, 50, and 100 – year are 23, 28, 33, 39, 45 and 50 mm, respectively, and for a duration of 10 hour storm are 19, 23, 27, 31, 36 and 40 mm, respectively.

In the study cited above (Study of the Hydrology Service of Peru, 1982), for a frequency interval 1 hour storm duration for up to 10 hours, has the intensity distribution, see Table Nº 4.11.

Table Nº 4.11. Hyetograph for different Return Period

Return Period [Years]	Hour										Total Rainfall
	1	2	3	4	5	6	7	8	9	10	
2	1	2	2	4	3	2	2	2	1	1	18.92
5	1	2	3	4	3	3	2	2	1	1	23.04
10	1	2	4	5	4	3	3	2	2	1	27.15
25	2	3	4	6	4	4	3	3	2	1	32.09
50	2	3	5	7	5	4	4	3	2	1	37.03
100	2	4	5	8	6	5	4	3	2	2	41.14

Selection of Curve Number

When maximum flood records are available at local or regional hydrometric stations, curve numbers can be calculated from calibration.

Typically, selection of the curve number (CN) is done based on the hydrologicsoil group and the land use description.

Group A: Deep sand, deep wind – deposited soils, aggregate silts.
Group B: Shallow wind – deposited soils, sandy marl.

Group C: Clayey marls, sandy shallow marls, soils with high clay contents.

Group D: Expansive soils, highly plastic clays.

Table Nº 4.12 shows the CN as a function of hydrologic soil group and land uses.

Table Nº 4.12. Curve Number CN Based on Land Use and Soil Hydrological

Uso del Suelo			Grupo hidrológico del suelo			
			A	B	C	D
Tierras cultivadas	sin tratamiento de conservación		72	81	88	91
	con tratamiento de conservación		62	71	78	81
Pastizales	condiciones pobres		68	79	86	89
	condiciones óptimas		39	61	74	80
Praderas (Vegas de ríos: condiciones óptimas)			30	58	71	78
Bosques	troncos delgados, cubierta pobre, sin hierbas		45	66	77	83
	cubierta buena		25	55	70	77
Espácios abiertos, césped, parques, campos de golf, cementerios, etc.	óptimas condiciones: cubierta de pasto en el 75% o más		39	61	74	80
	condiciones aceptables: cubierta de pasto en el 50 al 75%		49	69	79	84
Áreas comerciales de negocios (85% impermeables)			89	92	94	95
Zonas industriales (72% impermeables)			81	88	91	93
Zonas residenciales	Tamaño lote (m^2)	% impermeable				
	500	65	77	85	90	92
	1000	38	61	75	83	87
	1350	30	57	72	81	86
	2000	25	54	70	80	85
	4000	20	51	68	79	84
Parqueaderos pavimentados, techos, accesos, etc.			98	98	98	98
Calles y carreteras	pavimentados con cunetas y alcantarillados		98	98	98	98
	grava		76	85	89	91
	tierra		72	82	87	89

Based on land uses, and adopting the hydrologic soil group C for the whole catchment, an initial areal averaged curve number of 85.5 was adopted for Yauca Basin. In Table 4.13 the estimated percentages of land use with their respective values of curves of number for river Yauca are shown.

Table Nº 4.13. Estimated Value of Curve Number (CN) for initial calibration of HEC-HMS Model

Uso del Suelo		%	CN
Tierras Cultivadas	Sin Tratamiento de Consevacion	40.00	88.0
	Con Tratamiento de Consevacion	5.00	78.0
Tierras Cultivadas	Condicones Pobres	30.00	86.0
	Condicones Optimas	5.00	74.0
Praderas		4.00	71.0
Bosques	Troncos delgados	5.00	77.0
	Cubierta Buena	1.00	70.0
Area comerciales		1.00	94.0
Zonas Industriales		1.00	91.0
Zonas residensiales		5.00	81.0

Calles y carreteras	Pavimentadas con cunetas	1.00	98.0
	Grava	1.00	89.0
	Tierra	2.00	87.0
Curva de Numero de la Cuenca		101.00	**85.5**

After the process of calibration of the model HEC-HMS, this value was adjusted to 74.

4.2.4.2 HEC – HMS Modeling

The U.S. Engineer Corps' Hydrological Engineering Center designed the ***Hydrological Modeling System (HEC – HMS)*** computer program. This program provides a variety of options to simulate rainfall – runoff processes, flow routes, etc. (US Army, 2000).

HEC-HMS includes a graphic interface for the user (GUI), hydrological analysis components, data management and storage capabilities, and facilities to express results through graphs and reports in charts. The Guide provides all necessary means to specify the basin's components, introduce all relevant data of these components, and visualize the results (Reference "e").

San Francisco Alto Basin Model.- SCS's Curve Number method was used to estimate losses. SCS's Unit Hydrograph method was used to transform actual rainfall into flow. In addition, the 2981 km2 basin area is taken into account as basic information. Due to the small averages discharges generally observed in river Yauca it was assumed that there was no base flow previous to the occurrence of the flood flows.

Meteorological Model.- Based on calculation under Nº 3.2 Pluviometer Information Analysis and Frequency Law, hyetographs are introduced inthe meterological model for a 2, 5, 10, 25, 50, and 100 – year floods, and a storm duration of 10 hours.

Control Specifications.- Starting and ending dates are specified for the flood simulation to be carried out. Simulation results and flood hydrograph will be submitted. In this case, starting date is February 2nd, 2010, 00:00, and end date is February 4th, 2010, 12:00 pm. Based on the recommendation of the HEC-HMS Technical Reference Manual the minimum computational time interval is calculated as 0.29 times the Lag Time. Aproximating the Lag Time as 0.6 times the Concentration Time, a lag time of 6.75 hours and a minimum computational time of 1.95 hours are obtained. For the simulation a computational time interval of 1 hour was used.

Calibration of the Model. Due to the fact that there was no available information on simultaneous storm hyetographs and flood hydrographs which would allow to calibrate model parameters for doing forecasts, the model was calibrated based on information of estimated daily discharges.

The concept of the calibration was to adjust a curve number which produces peak discharges values similar to the estimated maximum daily discharge. Following this procedure a curve number of 74 was obtained.

Below, Figure Nº 4.9 shows the watershed considered by HEC-HMS model for the simulation. Figures Nº 4.10 to 4.21 show the results of the simulations for the floods of 2, 5, 10, 25, 50 and 100 years return period.

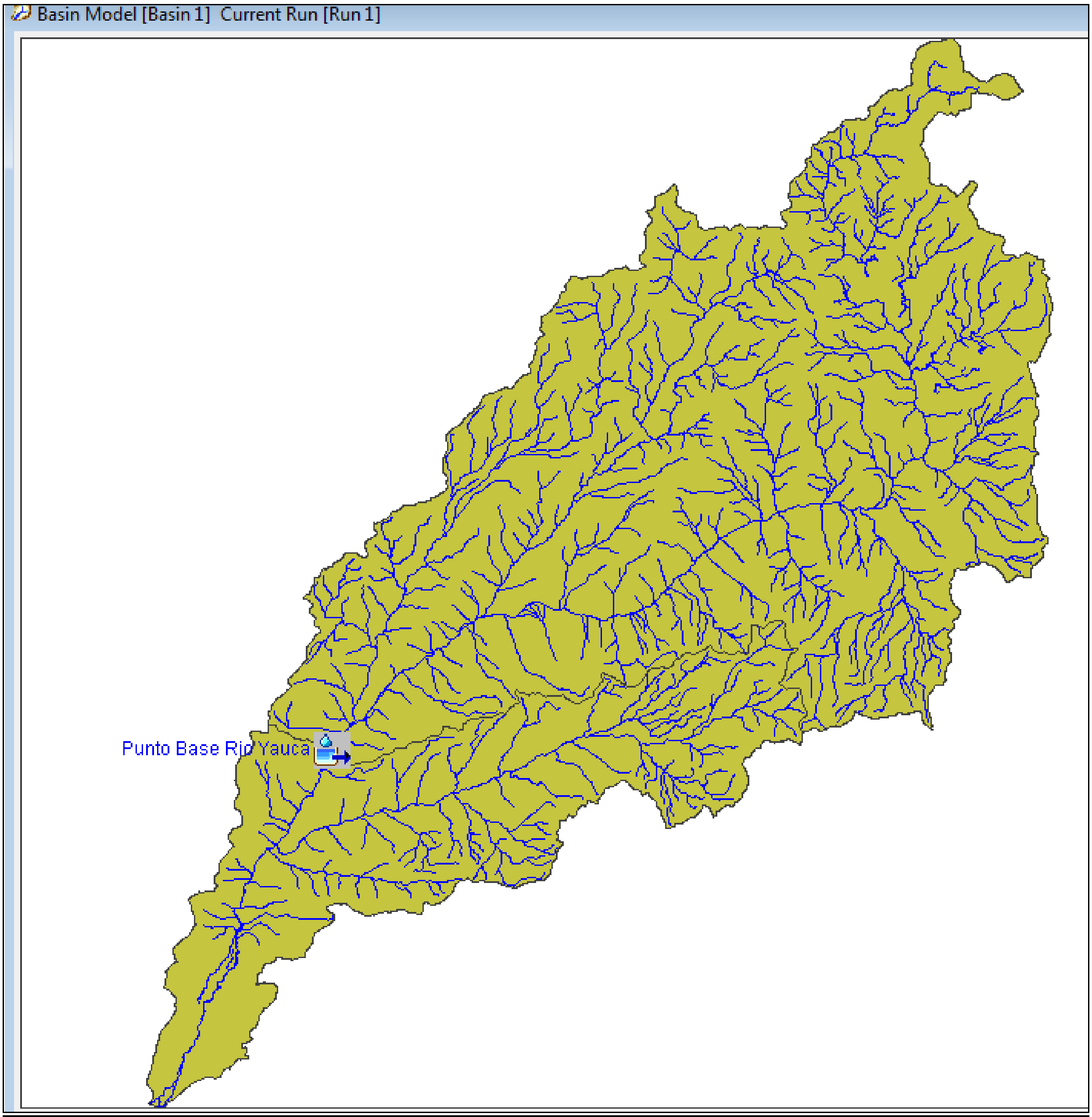

Figure Nº 4.9. Model Yauca River Basin in the HEC-HMS Software

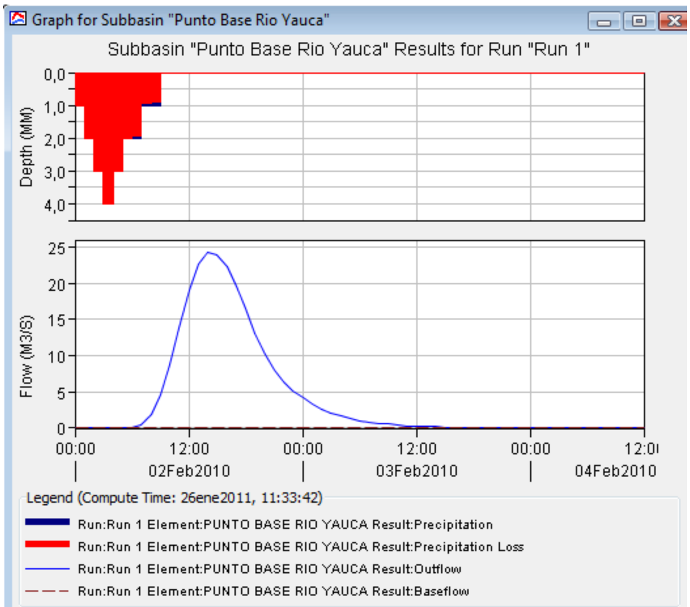

Figure Nº 4.10. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period of 2 years

In the upper part of Figure 4.10 the design hyetograph is shown, the red portion corresponds to the infiltrated rainfall, the blue portion corresponds to the effective rainfall, the infiltration have been computed by the software HEC-HMS using the Curve Number method from the U.S. Ex-Soil Conservation Service.

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 26 hours after it got started.

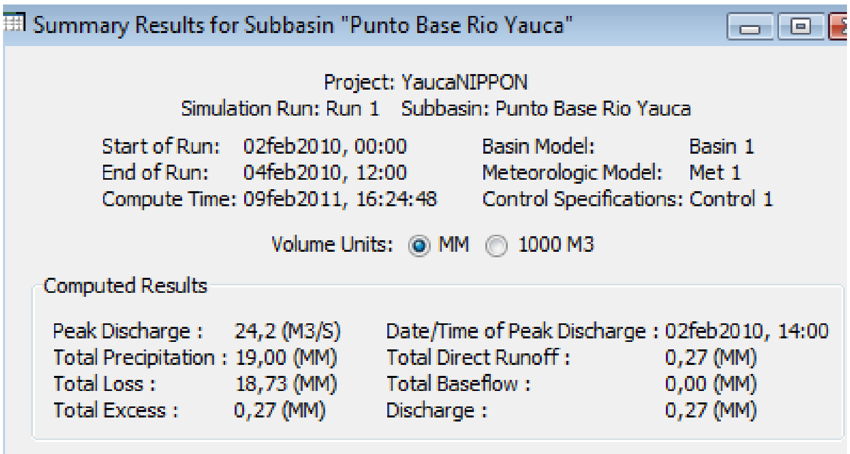

Figure Nº 4.11.Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 2 years

In Figure Nº 4.11 is the maximum flow is calculated for a return period of 2 years of 24.2 m^3/s. The maximum discharge spends approximately 15 hours after the storm started in the tax (for extreme conditions as defined above).

Table No. 4.14 shows the values of the hydrograph of the flood return period of 2 years.

Table Nº 4.14. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 2 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
02-Feb-10	00:00				0,0
02-Feb-10	01:00	1,00	1,00	0,00	0,0
02-Feb-10	02:00	2,00	2,00	0,00	0,0
02-Feb-10	03:00	3,00	3,00	0,00	0,0
02-Feb-10	04:00	4,00	4,00	0,00	0,0
02-Feb-10	05:00	3,00	3,00	0,00	0,0
02-Feb-10	06:00	2,00	2,00	0,00	0,0
02-Feb-10	07:00	2,00	1,92	0,08	0,5
02-Feb-10	08:00	1,00	0,92	0,08	1,8
02-Feb-10	09:00	1,00	0,90	0,10	4,6
02-Feb-10	10:00	0,00	0,00	0,00	8,7
02-Feb-10	11:00	0,00	0,00	0,00	13,9
02-Feb-10	12:00	0,00	0,00	0,00	19,0
02-Feb-10	13:00	0,00	0,00	0,00	22,6
02-Feb-10	14:00	0,00	0,00	0,00	24,2
02-Feb-10	15:00	0,00	0,00	0,00	23,9
02-Feb-10	16:00	0,00	0,00	0,00	22,4
02-Feb-10	17:00	0,00	0,00	0,00	19,7
02-Feb-10	18:00	0,00	0,00	0,00	16,4
02-Feb-10	19:00	0,00	0,00	0,00	13,1
02-Feb-10	20:00	0,00	0,00	0,00	10,2
02-Feb-10	21:00	0,00	0,00	0,00	8,1
02-Feb-10	22:00	0,00	0,00	0,00	6,5
02-Feb-10	23:00	0,00	0,00	0,00	5,2
03-Feb-10	00:00	0,00	0,00	0,00	4,2
03-Feb-10	01:00	0,00	0,00	0,00	3,3
03-Feb-10	02:00	0,00	0,00	0,00	2,7
03-Feb-10	03:00	0,00	0,00	0,00	2,1
03-Feb-10	04:00	0,00	0,00	0,00	1,7
03-Feb-10	05:00	0,00	0,00	0,00	1,4
03-Feb-10	06:00	0,00	0,00	0,00	1,1
03-Feb-10	07:00	0,00	0,00	0,00	0,9
03-Feb-10	08:00	0,00	0,00	0,00	0,7
03-Feb-10	09:00	0,00	0,00	0,00	0,6
03-Feb-10	10:00	0,00	0,00	0,00	0,4
03-Feb-10	11:00	0,00	0,00	0,00	0,4
03-Feb-10	12:00	0,00	0,00	0,00	0,3
03-Feb-10	13:00	0,00	0,00	0,00	0,2
03-Feb-10	14:00	0,00	0,00	0,00	0,2
03-Feb-10	15:00	0,00	0,00	0,00	0,2
03-Feb-10	16:00	0,00	0,00	0,00	0,1
03-Feb-10	17:00	0,00	0,00	0,00	0,1
03-Feb-10	18:00	0,00	0,00	0,00	0,0

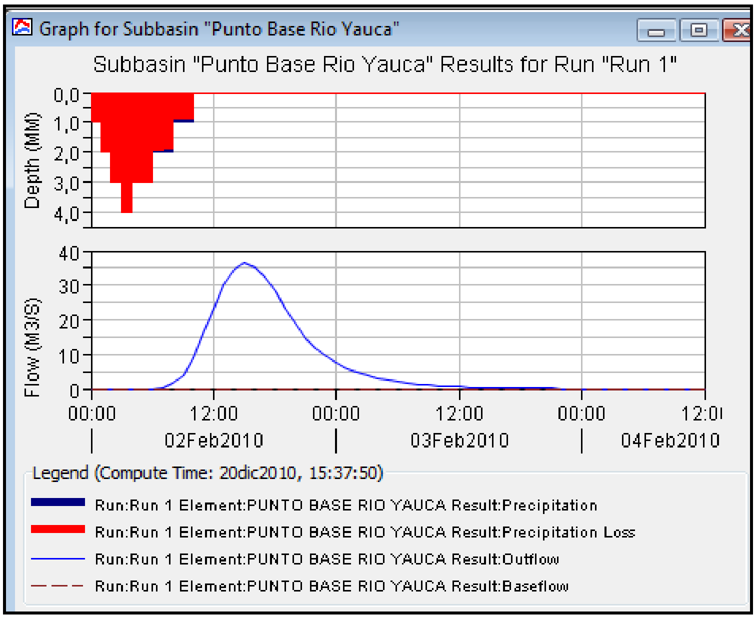

Figure N° 4.12. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period of 5 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 26 hours after it got started.

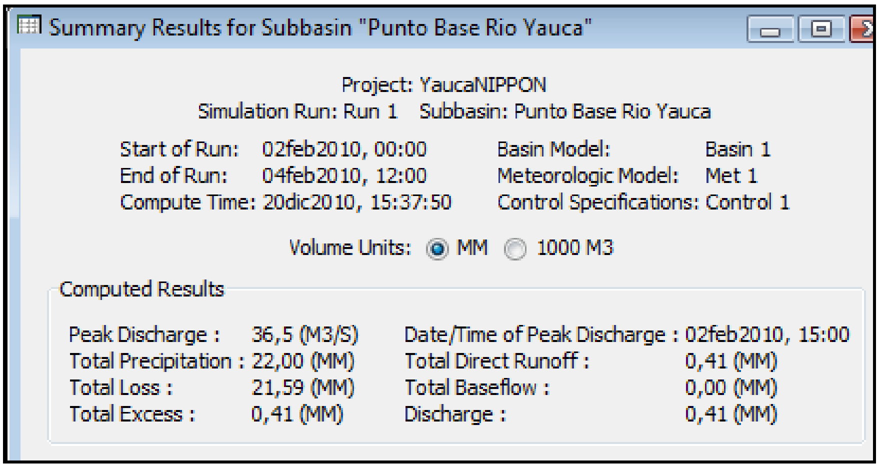

Figure N° 4.13.Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 5 years

In Figure N° 4.13 is the maximum flow is calculated for a return period of 5 years of 36.5 m^3/s. The maximum discharge spends approximately 15 hours after the storm started in the tax (for extreme conditions as defined above).

Table No. 4.15 shows the values of the hydrograph of the flood return period of 5 years.

Table N° 4.15. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 5 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
02-Feb-10	00:00				0,0
02-Feb-10	01:00	1,00	1,00	0,00	0,0
02-Feb-10	02:00	2,00	2,00	0,00	0,0
02-Feb-10	03:00	3,00	3,00	0,00	0,0
02-Feb-10	04:00	4,00	4,00	0,00	0,0
02-Feb-10	05:00	3,00	3,00	0,00	0,0
02-Feb-10	06:00	3,00	3,00	0,00	0,0
02-Feb-10	07:00	2,00	1,95	0,05	0,2
02-Feb-10	08:00	2,00	1,86	0,14	1,4
02-Feb-10	09:00	1,00	0,90	0,10	4,1
02-Feb-10	10:00	1,00	0,88	0,12	8,9
02-Feb-10	11:00	0,00	0,00	0,00	15,7
02-Feb-10	12:00	0,00	0,00	0,00	23,4
02-Feb-10	13:00	0,00	0,00	0,00	30,3
02-Feb-10	14:00	0,00	0,00	0,00	34,9
02-Feb-10	15:00	0,00	0,00	0,00	36,5
02-Feb-10	16:00	0,00	0,00	0,00	35,4
02-Feb-10	17:00	0,00	0,00	0,00	32,6
02-Feb-10	18:00	0,00	0,00	0,00	28,2
02-Feb-10	19:00	0,00	0,00	0,00	23,3
02-Feb-10	20:00	0,00	0,00	0,00	18,5
02-Feb-10	21:00	0,00	0,00	0,00	14,5
02-Feb-10	22:00	0,00	0,00	0,00	11,5
02-Feb-10	23:00	0,00	0,00	0,00	9,2
03-Feb-10	00:00	0,00	0,00	0,00	7,4
03-Feb-10	01:00	0,00	0,00	0,00	6,0
03-Feb-10	02:00	0,00	0,00	0,00	4,7
03-Feb-10	03:00	0,00	0,00	0,00	3,8
03-Feb-10	04:00	0,00	0,00	0,00	3,0
03-Feb-10	05:00	0,00	0,00	0,00	2,4
03-Feb-10	06:00	0,00	0,00	0,00	1,9
03-Feb-10	07:00	0,00	0,00	0,00	1,5
03-Feb-10	08:00	0,00	0,00	0,00	1,2
03-Feb-10	09:00	0,00	0,00	0,00	1,0

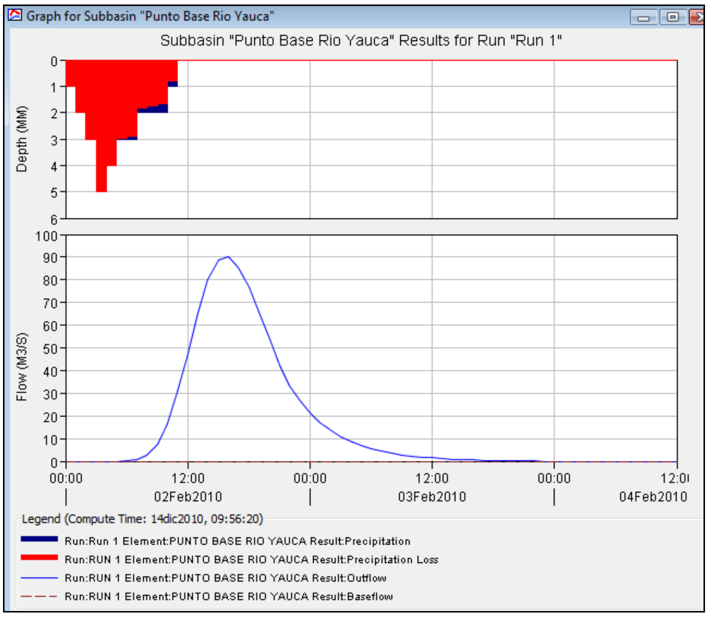

Figure Nº 4.14. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period of 10 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 26 hours after it got started.

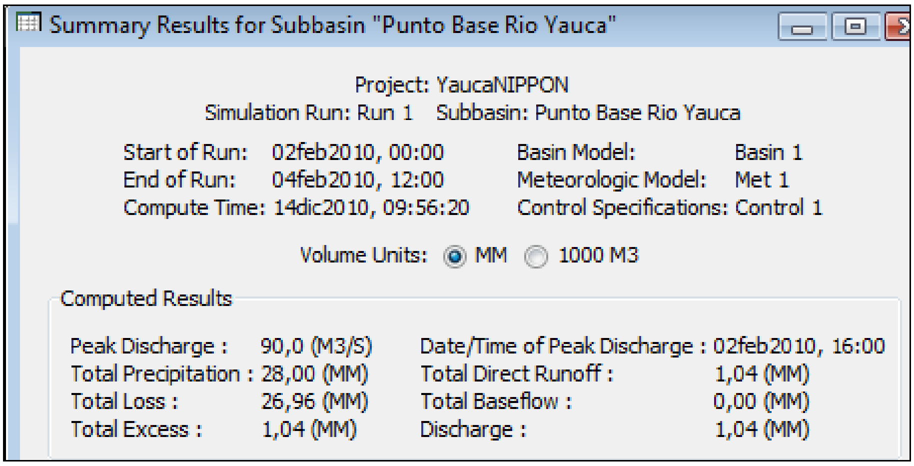

Figure Nº 4.15. Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 10 years

In Figure Nº 4.15 is the maximum flow is calculated for a return period of 10 years of 90.0 m^3/s. The maximum discharge spends approximately 16 hours after the storm started in the tax (for extreme conditions as defined above).

Table No. 4.16 shows the values of the hydrograph of the flood return period of 10 years.

Table Nº 4.16. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 10 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
02-Feb-10	00:00				0,0
02-Feb-10	01:00	1,00	1,00	0,00	0,0
02-Feb-10	02:00	2,00	2,00	0,00	0,0
02-Feb-10	03:00	3,00	3,00	0,00	0,0
02-Feb-10	04:00	5,00	5,00	0,00	0,0
02-Feb-10	05:00	4,00	4,00	0,00	0,0
02-Feb-10	06:00	3,00	3,00	0,00	0,0
02-Feb-10	07:00	3,00	2,89	0,11	0,6
02-Feb-10	08:00	2,00	1,83	0,17	2,6
02-Feb-10	09:00	2,00	1,75	0,25	7,2
02-Feb-10	10:00	2,00	1,68	0,32	16,4
02-Feb-10	11:00	1,00	0,81	0,19	30,4
02-Feb-10	12:00	0,00	0,00	0,00	47,6
02-Feb-10	13:00	0,00	0,00	0,00	65,4
02-Feb-10	14:00	0,00	0,00	0,00	80,3
02-Feb-10	15:00	0,00	0,00	0,00	88,7
02-Feb-10	16:00	0,00	0,00	0,00	90,0
02-Feb-10	17:00	0,00	0,00	0,00	85,6
02-Feb-10	18:00	0,00	0,00	0,00	76,8
02-Feb-10	19:00	0,00	0,00	0,00	65,6
02-Feb-10	20:00	0,00	0,00	0,00	53,7
02-Feb-10	21:00	0,00	0,00	0,00	42,5
02-Feb-10	22:00	0,00	0,00	0,00	33,4
02-Feb-10	23:00	0,00	0,00	0,00	26,6
03-Feb-10	00:00	0,00	0,00	0,00	21,4
03-Feb-10	01:00	0,00	0,00	0,00	17,2
03-Feb-10	02:00	0,00	0,00	0,00	13,7
03-Feb-10	03:00	0,00	0,00	0,00	10,9
03-Feb-10	04:00	0,00	0,00	0,00	8,7
03-Feb-10	05:00	0,00	0,00	0,00	7,0
03-Feb-10	06:00	0,00	0,00	0,00	5,6
03-Feb-10	07:00	0,00	0,00	0,00	4,4
03-Feb-10	08:00	0,00	0,00	0,00	3,5
03-Feb-10	09:00	0,00	0,00	0,00	2,8
03-Feb-10	10:00	0,00	0,00	0,00	2,3
03-Feb-10	11:00	0,00	0,00	0,00	1,8
03-Feb-10	12:00	0,00	0,00	0,00	1,5
03-Feb-10	13:00	0,00	0,00	0,00	1,2
03-Feb-10	14:00	0,00	0,00	0,00	1,0
03-Feb-10	15:00	0,00	0,00	0,00	0,8
03-Feb-10	16:00	0,00	0,00	0,00	0,6
03-Feb-10	17:00	0,00	0,00	0,00	0,5
03-Feb-10	18:00	0,00	0,00	0,00	0,3
03-Feb-10	19:00	0,00	0,00	0,00	0,2
03-Feb-10	20:00	0,00	0,00	0,00	0,1
03-Feb-10	21:00	0,00	0,00	0,00	0,0

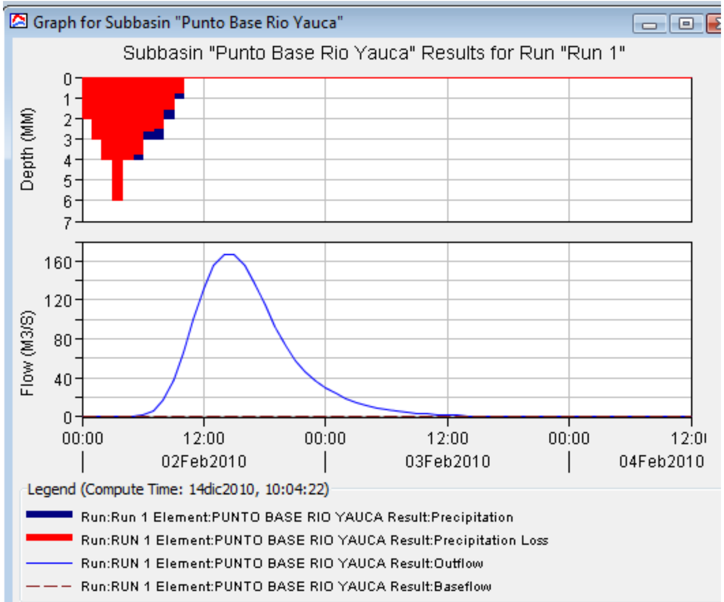

Figure N° 4.16. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period 25 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 26 hours after it got started.

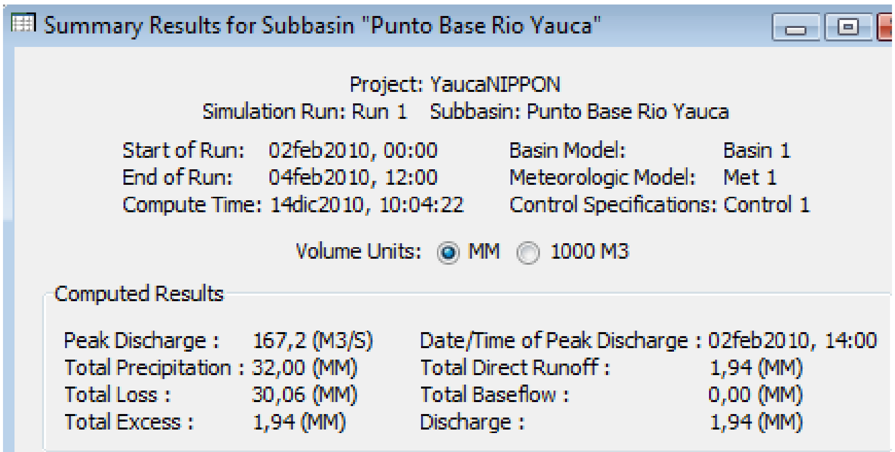

Figure N° 4.17. Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 25 years

In Figure N° 4.17 is the maximum flow is calculated for a return period of 25 years of 167.2 m^3/s. The maximum discharge spends approximately 14 hours after the storm started in the tax (for extreme conditions as defined above).

Table No. 4.17 shows the values of the hydrograph of the flood return period of 25 years.

Table Nº 4.17. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 25 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
02-Feb-10	00:00				0,0
02-Feb-10	01:00	2,00	2,00	0,00	0,0
02-Feb-10	02:00	3,00	3,00	0,00	0,0
02-Feb-10	03:00	4,00	4,00	0,00	0,0
02-Feb-10	04:00	6,00	6,00	0,00	0,0
02-Feb-10	05:00	4,00	3,99	0,01	0,1
02-Feb-10	06:00	4,00	3,73	0,27	1,6
02-Feb-10	07:00	3,00	2,60	0,40	6,6
02-Feb-10	08:00	3,00	2,44	0,56	17,9
02-Feb-10	09:00	2,00	1,55	0,45	38,0
02-Feb-10	10:00	1,00	0,75	0,25	66,8
02-Feb-10	11:00	0,00	0,00	0,00	100,3
02-Feb-10	12:00	0,00	0,00	0,00	132,1
02-Feb-10	13:00	0,00	0,00	0,00	156,0
02-Feb-10	14:00	0,00	0,00	0,00	167,2
02-Feb-10	15:00	0,00	0,00	0,00	166,1
02-Feb-10	16:00	0,00	0,00	0,00	155,1
02-Feb-10	17:00	0,00	0,00	0,00	137,0
02-Feb-10	18:00	0,00	0,00	0,00	115,3
02-Feb-10	19:00	0,00	0,00	0,00	93,4
02-Feb-10	20:00	0,00	0,00	0,00	73,8
02-Feb-10	21:00	0,00	0,00	0,00	58,3
02-Feb-10	22:00	0,00	0,00	0,00	46,5
02-Feb-10	23:00	0,00	0,00	0,00	37,4
03-Feb-10	00:00	0,00	0,00	0,00	30,0
03-Feb-10	01:00	0,00	0,00	0,00	23,9
03-Feb-10	02:00	0,00	0,00	0,00	19,1
03-Feb-10	03:00	0,00	0,00	0,00	15,2
03-Feb-10	04:00	0,00	0,00	0,00	12,2
03-Feb-10	05:00	0,00	0,00	0,00	9,7
03-Feb-10	06:00	0,00	0,00	0,00	7,7
03-Feb-10	07:00	0,00	0,00	0,00	6,2
03-Feb-10	08:00	0,00	0,00	0,00	5,0
03-Feb-10	09:00	0,00	0,00	0,00	4,0
03-Feb-10	10:00	0,00	0,00	0,00	3,2
03-Feb-10	11:00	0,00	0,00	0,00	2,5
03-Feb-10	12:00	0,00	0,00	0,00	2,1
03-Feb-10	13:00	0,00	0,00	0,00	1,7
03-Feb-10	14:00	0,00	0,00	0,00	1,4
03-Feb-10	15:00	0,00	0,00	0,00	1,1
03-Feb-10	16:00	0,00	0,00	0,00	0,8
03-Feb-10	17:00	0,00	0,00	0,00	0,6
03-Feb-10	18:00	0,00	0,00	0,00	0,3
03-Feb-10	19:00	0,00	0,00	0,00	0,2
03-Feb-10	20:00	0,00	0,00	0,00	0,1
03-Feb-10	21:00	0,00	0,00	0,00	0,0

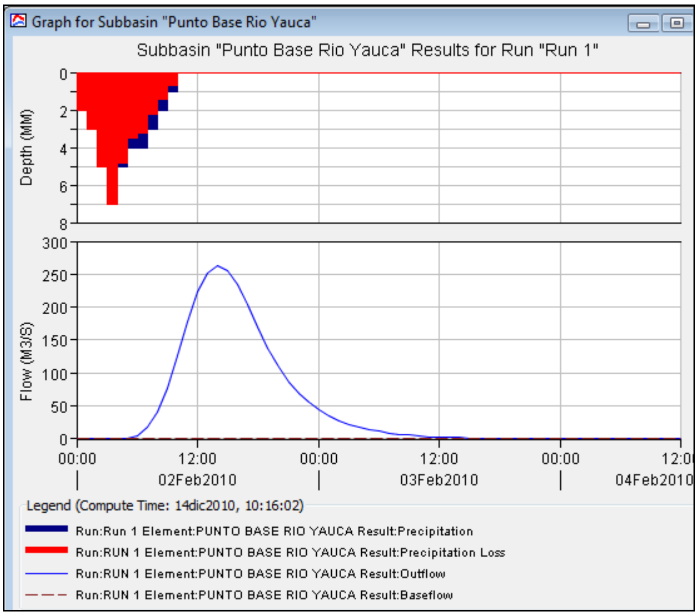

Figure Nº 4.18. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period 50 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 26 hours after it got started.

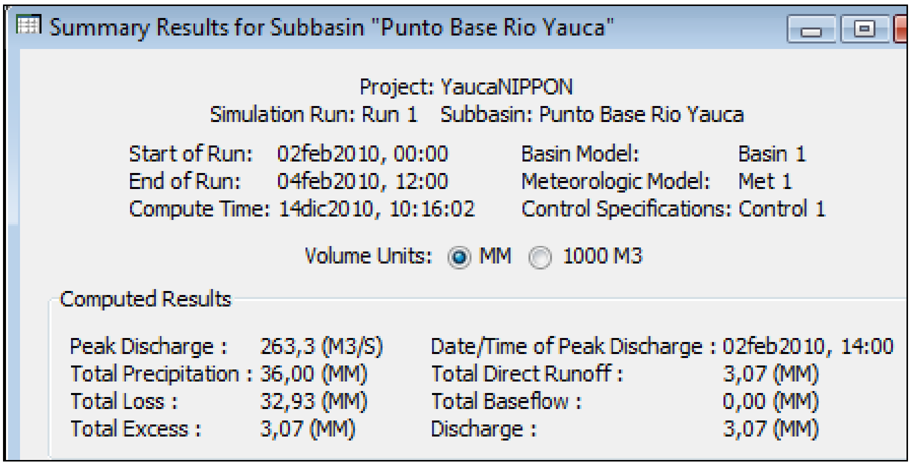

Figure Nº 4.19. Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 50 years

In Figure Nº 4.19 is the maximum flow is calculated for a return period of 50 years of 263.3 m^3/s. The maximum discharge spends approximately 24 hours after the storm started in the tax (for extreme conditions as defined above).

Table No. 4.18 shows the values of the hydrograph of the flood return period of 50 years.

Table Nº 4.18. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 50 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
02-Feb-10	00:00				0,0
02-Feb-10	01:00	2,00	2,00	0,00	0,0
02-Feb-10	02:00	3,00	3,00	0,00	0,0
02-Feb-10	03:00	5,00	5,00	0,00	0,0
02-Feb-10	04:00	7,00	7,00	0,00	0,0
02-Feb-10	05:00	5,00	4,82	0,18	1,0
02-Feb-10	06:00	4,00	3,50	0,50	5,4
02-Feb-10	07:00	4,00	3,23	0,77	17,3
02-Feb-10	08:00	3,00	2,26	0,74	40,5
02-Feb-10	09:00	2,00	1,43	0,57	77,3
02-Feb-10	10:00	1,00	0,70	0,30	125,6
02-Feb-10	11:00	0,00	0,00	0,00	177,2
02-Feb-10	12:00	0,00	0,00	0,00	222,2
02-Feb-10	13:00	0,00	0,00	0,00	252,3
02-Feb-10	14:00	0,00	0,00	0,00	263,3
02-Feb-10	15:00	0,00	0,00	0,00	256,1
02-Feb-10	16:00	0,00	0,00	0,00	234,8
02-Feb-10	17:00	0,00	0,00	0,00	204,4
02-Feb-10	18:00	0,00	0,00	0,00	170,0
02-Feb-10	19:00	0,00	0,00	0,00	137,0
02-Feb-10	20:00	0,00	0,00	0,00	108,5
02-Feb-10	21:00	0,00	0,00	0,00	85,9
02-Feb-10	22:00	0,00	0,00	0,00	68,7
02-Feb-10	23:00	0,00	0,00	0,00	55,1
03-Feb-10	00:00	0,00	0,00	0,00	44,1
03-Feb-10	01:00	0,00	0,00	0,00	35,3
03-Feb-10	02:00	0,00	0,00	0,00	28,1
03-Feb-10	03:00	0,00	0,00	0,00	22,4
03-Feb-10	04:00	0,00	0,00	0,00	17,9
03-Feb-10	05:00	0,00	0,00	0,00	14,3
03-Feb-10	06:00	0,00	0,00	0,00	11,4
03-Feb-10	07:00	0,00	0,00	0,00	9,1
03-Feb-10	08:00	0,00	0,00	0,00	7,3
03-Feb-10	09:00	0,00	0,00	0,00	5,8
03-Feb-10	10:00	0,00	0,00	0,00	4,7
03-Feb-10	11:00	0,00	0,00	0,00	3,8
03-Feb-10	12:00	0,00	0,00	0,00	3,1
03-Feb-10	13:00	0,00	0,00	0,00	2,5
03-Feb-10	14:00	0,00	0,00	0,00	2,0
03-Feb-10	15:00	0,00	0,00	0,00	1,6
03-Feb-10	16:00	0,00	0,00	0,00	1,1
03-Feb-10	17:00	0,00	0,00	0,00	0,7
03-Feb-10	18:00	0,00	0,00	0,00	0,4
03-Feb-10	19:00	0,00	0,00	0,00	0,2
03-Feb-10	20:00	0,00	0,00	0,00	0,1
03-Feb-10	21:00	0,00	0,00	0,00	0,0

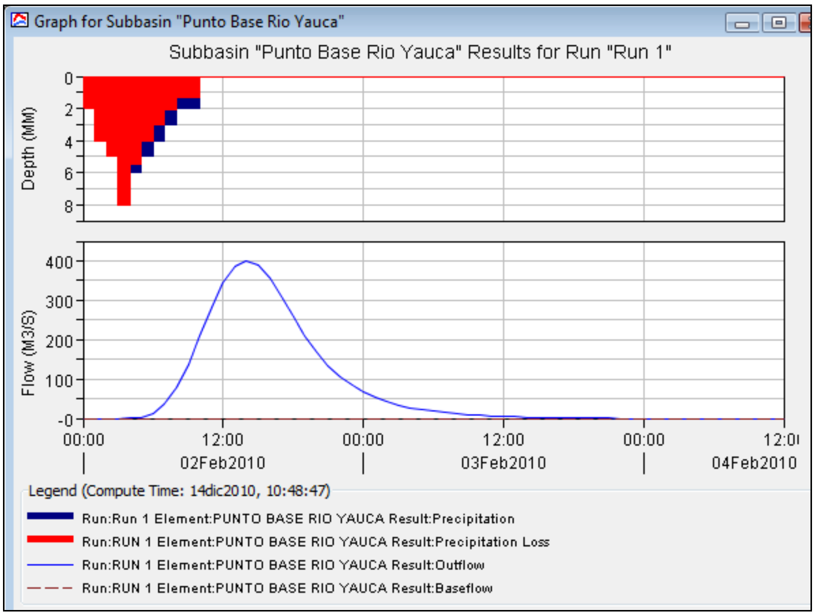

Figure Nº 4.20. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period 100 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 26 hours after it got started.

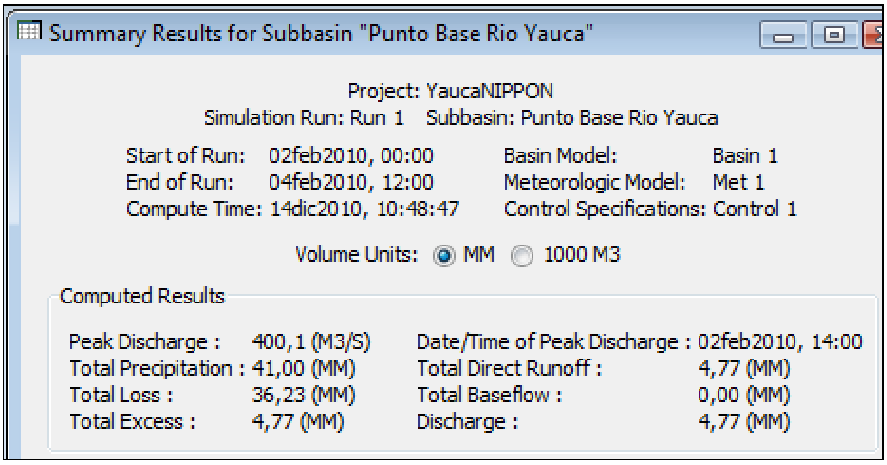

Figure Nº 4.21. Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 100 years

In Figure Nº 4.21 is the maximum flow is calculated for a return period of 100 years of 400.1 m^3/s. The maximum discharge spends approximately 14 hours after the storm started in the tax (for extreme conditions as defined above).

Table No. 4.19 shows the values of the hydrograph of the flood return period of 100 years.

Table Nº 4.19. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 100 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
02-Feb-10	00:00				0,0
02-Feb-10	01:00	2,00	2,00	0,00	0,0
02-Feb-10	02:00	4,00	4,00	0,00	0,0
02-Feb-10	03:00	5,00	5,00	0,00	0,0
02-Feb-10	04:00	8,00	7,99	0,01	0,1
02-Feb-10	05:00	6,00	5,48	0,52	2,9
02-Feb-10	06:00	5,00	4,07	0,93	13,2
02-Feb-10	07:00	4,00	2,98	1,02	35,9
02-Feb-10	08:00	3,00	2,09	0,91	76,4
02-Feb-10	09:00	2,00	1,33	0,67	135,7
02-Feb-10	10:00	2,00	1,28	0,72	208,5
02-Feb-10	11:00	0,00	0,00	0,00	281,9
02-Feb-10	12:00	0,00	0,00	0,00	343,6
02-Feb-10	13:00	0,00	0,00	0,00	385,1
02-Feb-10	14:00	0,00	0,00	0,00	400,1
02-Feb-10	15:00	0,00	0,00	0,00	388,2
02-Feb-10	16:00	0,00	0,00	0,00	354,9
02-Feb-10	17:00	0,00	0,00	0,00	309,2
02-Feb-10	18:00	0,00	0,00	0,00	258,2
02-Feb-10	19:00	0,00	0,00	0,00	210,2
02-Feb-10	20:00	0,00	0,00	0,00	167,6
02-Feb-10	21:00	0,00	0,00	0,00	132,3
02-Feb-10	22:00	0,00	0,00	0,00	105,5
02-Feb-10	23:00	0,00	0,00	0,00	84,5
03-Feb-10	00:00	0,00	0,00	0,00	67,8
03-Feb-10	01:00	0,00	0,00	0,00	54,2
03-Feb-10	02:00	0,00	0,00	0,00	43,2
03-Feb-10	03:00	0,00	0,00	0,00	34,5
03-Feb-10	04:00	0,00	0,00	0,00	27,5
03-Feb-10	05:00	0,00	0,00	0,00	22,0
03-Feb-10	06:00	0,00	0,00	0,00	17,5
03-Feb-10	07:00	0,00	0,00	0,00	14,0
03-Feb-10	08:00	0,00	0,00	0,00	11,2
03-Feb-10	09:00	0,00	0,00	0,00	9,0
03-Feb-10	10:00	0,00	0,00	0,00	7,2
03-Feb-10	11:00	0,00	0,00	0,00	5,8
03-Feb-10	12:00	0,00	0,00	0,00	4,7
03-Feb-10	13:00	0,00	0,00	0,00	3,8
03-Feb-10	14:00	0,00	0,00	0,00	3,0
03-Feb-10	15:00	0,00	0,00	0,00	2,3
03-Feb-10	16:00	0,00	0,00	0,00	1,7
03-Feb-10	17:00	0,00	0,00	0,00	1,1
03-Feb-10	18:00	0,00	0,00	0,00	0,7
03-Feb-10	19:00	0,00	0,00	0,00	0,3
03-Feb-10	20:00	0,00	0,00	0,00	0,1
03-Feb-10	21:00	0,00	0,00	0,00	0,0

4.3 Results of the Simulation, Peak Flows in the Base Point

Table 4.20 summarizes the peak flows for different return periods obtained with the application of the software HEC-HMS in Yauca river basin for the location of hydrometric station San Antonio Alto.

Table Nº 4.21. Summary of Peak Flows at the Base Point for each Return Period

T [Años]	Q [m³/s]
2	24.0
5	36.5
10	90.0
25	167.2
50	263.3
100	400.1

Peak flows at the base point obtained with HEC-HMS model for the return periods of 2, 5, 10, 25, 50 and 100 years have been estimated from the maximum rainfall generated for these return periods, a number curve and geomorphological parameters of the basin. These peak flows have been obtained with the same number of curve (equal to 74).

As it was considered in the calibration, peak discharges obtained with HEC-HMS model for different return periods are similar to the correspondent maximum daily discharges showed in Table 4.8.

V. REFERENCES

a) Association BCEOM-SOFI CONSULT S.A., "Hydrology and Meteorology Study in the Catchments of the Pacific Littoral of Perú for Evaluation and Forecasting of El Niño Phenomenon for Prevention and Disaster Mitigation", 1999.

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e) U.S. Corp of Engineers, "Manual of Technical References of HEC-HMS Software", 2000.