

Appendix-4 Hydrologic Study of Pisco 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 PISCO
RIVER**

Appendix-4

December 2012



HYDROLOGY OF MAXIMUM FLOODS IN PISCO RIVER

CONTENTS

I.	INTRODUCTION	1
II.	GENERAL ASPECTS	1
2.1	Location	1
2.1.1	Political Location	1
2.1.2	Geographic Location	1
2.2	Background	2
2.3	Justification of the Project	2
2.4	Objectives of the Study	2
III.	PROJECT DESCRIPTION	3
3.1	Hydrographic System of Pisco River	3
3.1.1	General Description of the Basin	3
3.1.2	Hydrography of the Pisco River Basin	4
3.2	Climatology	6
3.2.1	Rainfall	6
3.2.2	Temperature	1
3.3	Hydrometry	2
3.4	Comments on the meteorologic and hydrometric and network in the Pisco River Catchement.	25
3.4.1	On Pluviometric Stations.	25
3.4.2	On Hydrometric Stations.	25
3.4.3	Recommendations	26
IV.	HYDROLOGY OF MAXIMUM FLOOD	28
4.1	Preliminary Considerations	28
4.2	Hydrology characterization, analysis of rainfall and river information	29
4.2.1	Hydrology Characterization	29
4.2.2	Maximum 24-Hours Rainfall Analysis	30
4.2.2.1	<i>Distribution Functions</i>	31
4.2.2.2	<i>Calculation of Adjustment and Return Period for Maximum Rainfall in 24 Hours</i>	33
4.2.2.3	<i>Selection of Distribution Theory with better Adjustment to the Series Record Rainfall in 24 Hours</i>	34

4.2.2.4	<i>Determination of Maximum 24-Hours Rainfall for Different Return Periods in the Base Point</i>	42
4.2.2.5	<i>Determination of Maximum 24- Hours Rainfalls for Different Return Period in the Pisco River Subwatersheds</i>	42
4.2.3	Maximum Daily Discharge Analysis	45
4.2.4	Simulation Model, Application of HEC-HMS Software	46
4.2.4.1	<i>Hydrological Model</i>	46
4.2.4.2	<i>HEC – HMS Modeling</i>	50
4.3	Results of the Simulation, Peak Flows in the Base Point	64
V.	REFERENCES	64
	ANNEXES	65

HYDROLOGY OF MAXIMUM FLOODS IN PISCO RIVER

LIST OF TABLES

<i>Table N° 3.1. Period and longitude of the available information of the Rainfall stations</i>	7
<i>Table N° 3.2. Average Monthly Rainfall Stations Considered in the Study Area</i>	9
<i>Table N° 3.3. Results of the linear fit equation of Totora and Acnocochoa station</i>	10
<i>Table N° 3.4. Monthly half temperature (C°) of the stations of the Pisco River basin and adjacent basins</i>	2
<i>Table N° 3.5. Characteristics of Hydrometric Stations in the Pisco River Basin and Surrounding Basins</i>	3
<i>Table N° 4.1. Geomorphological Characteristics of the basis point watershed (station Letrayoc)</i>	29
<i>Table N° 4.2. Maximum 24-hours rainfall Annual for Stations located within the Study Scope</i>	30
<i>Table N° 4.3. Determination Coefficient for each Distribution Function and for each Rainfall Station</i>	34
<i>Table N° 4.4. Maximum 24-hours rainfall of each Rainfall Station for each Return Period</i>	35
<i>Table N° 4.5. Maximum Areal 24- Hours Rainfall at the Base Point (Letrayoc Station) for each Return Period</i>	42
<i>Table N° 4.6. Rainfall for Different Return Periods in each river Basin of Pisco</i>	44
<i>Table N° 4.7. Maximum Daily Discharge of station Letrayoc, Pisco River (m³/s)</i>	45
<i>Table N° 4.8. Maximum Daily Discharges for each Return Period at te Station Letrayoc, Pisco River (m³/s)</i>	46
<i>Table N° 4.9. Concentration and Travel Times for the Base Point (station Letrayoc)</i>	46
<i>Table N° 4.10. Maximum Rainfall according to Dick - Peschke</i>	47
<i>Table N° 4.11. Hyetograph for different Return Periods</i>	48
<i>Table N° 4.12. CN Based on Land Use and Soil Hydrological</i>	48
<i>Table N° 4.13. Estimated Value of Curve Number (CN) for initial calibration of HEC-HMS Model</i>	49

<i>Table N° 4.14. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 2 Years</i>	53
<i>Table N° 4.15. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 5 Years</i>	55
<i>Table N° 4.16. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 10 Years</i>	57
<i>Table N° 4.17. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 25 Years</i>	59
<i>Table N° 4.18. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 50 Years</i>	61
<i>Table N° 4.19. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 100 Years</i>	63
<i>Table 4.20 summarizes the peak flows for different return periods obtained with the application of the software HEC-HMS in Pisco river basin for the location of hydrometric station Letrayoc.</i>	64
<i>Table N° 4.21. Summary of Peak Flows at the Base Point for each Return Period</i>	64

HYDROLOGY OF MAXIMUM FLOODS IN PISCO RIVER

LIST OF FIGURES

<i>Figure N° 3.1. Location Map of the Pisco River Basin</i>	5
<i>Figure N° 3.2. Period and longitude of the available information of the rainfall stations</i>	7
<i>Figure N° 3.3. Location of the rainfall stations in Pisco River basin and adjacent basins</i>	8
<i>Figure N° 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope</i>	9
<i>Figure N° 3.5. Annual Rainfall Trends at the Stations considered within the Study Scop</i>	11
<i>Figure N° 3.6. Isohyets for Mean Monthly Rainfall in the Pisco Basin, in January</i>	12
<i>Figure N° 3.7. Isohyets for Mean Monthly Rainfall in the Pisco Basin, in February</i>	13
<i>Figure N° 3.8. Isohyets Mean Monthly Rainfall in the Pisco Basin, in March</i>	14
<i>Figure N° 3.9. Isohyets Mean Monthly Rainfall in the Pisco Basin, in April</i>	15
<i>Figure N° 3.10. Isohyets Mean Monthly Rainfall in the Pisco Basin, in May</i>	16
<i>Figure N° 3.11. Isohyets Mean Monthly Rainfall in the Pisco Basin, in June</i>	17
<i>Figure N° 3.12. Isohyets Mean Monthly Rainfall in the Pisco Basin, in July</i>	18
<i>Figure N° 3.13. Isohyets Mean Monthly Rainfall in the Pisco Basin, in August</i>	19
<i>Figure N° 3.14. Isohyets Mean Monthly Rainfall in the Pisco Basin, in September</i>	20
<i>Figure N° 3.15. Isohyets Mean Monthly Rainfall in the Pisco Basin, in October</i>	21
<i>Figure N° 3.16. Isohyets Mean Monthly Rainfall in the Pisco Basin, in November</i>	22
<i>Figure N° 3.17. Isohyets Mean Monthly Rainfall in the Pisco Basin, in December</i>	23
<i>Figure N° 3.18. Isohyets Annual Mean Monthly Rainfall in the Pisco Basin</i>	24
<i>Figure N° 3.19. Distribution of the monthly half temperature of the weather stations located in the Pisco River basin</i>	2
<i>Figure N° 3.20. Period and longitude of the available information of the Hydrometric Stations</i>	3
<i>Figure N° 3.21. Location of the hydrometric station Letrayoc in Pisco River basin</i>	8
<i>Figure N° 4.1. Rainfall Stations considered for HEC - HMS Software application</i>	30
<i>Figure N° 4.2. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin</i>	36

<i>Figure N° 4.3. Isohyets for the 5 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin</i>	37
<i>Figure N° 4.4. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin</i>	38
<i>Figure N° 4.5. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin</i>	39
<i>Figure N° 4.6. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin</i>	40
<i>Figure N° 4.7. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin</i>	41
<i>Figure N° 4.8. The Pisco River Subbasin</i>	43
<i>Figure N° 4.9. Model Pisco River Basin in the HEC-HMS Software</i>	52
<i>Figure N° 4.10. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period of 2 years</i>	52
<i>Figure N° 4.11. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 2 years</i>	53
<i>Figure N° 4.12. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period of 5 years</i>	54
<i>Figure N° 4.13. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 5 years</i>	55
<i>Figure N° 4.14. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period of 10 years</i>	56
<i>Figure N° 4.15. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 10 years</i>	56
<i>Figure N° 4.16. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period 25 years</i>	58
<i>Figure N° 4.17. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 25 years</i>	58
<i>Figure N° 4.18. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period 50 years</i>	60

Figure N° 4.19. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 50 years 60

Figure N° 4.20. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period 100 years 62

Figure N° 4.21. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 100 years 62

HYDROLOGY OF MAXIMUM FLOODS IN PISCO RIVER

I. INTRODUCTION

In the last two extraordinary events (El Niño) occurred in 1983 and 1988, rainfall was very intense in the study area, which resulted in the activation of a number of rivers and streams adjacent to the Pisco River, causing severe damage in populated areas, irrigation and drainage infrastructure, agricultural lands, likewise, floods with catastrophic damage in the areas of Pisco, San Clemente and Humay.

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 Pisco, San Clemente, Tupac Amaru Inca, San Andres, Humay and Independencia of the province of Pisco, in the Department of Ica.

2.1.2 Geographic Location

The study area is located approximately at coordinates UTM at 365,978 y 495,455 in East Coordinates, and 8'473, 994 and 8'576, 196 in North Coordinates (Zone 18).

2.2 Background

As part of the project: "Study on Flood Control of Valley Village In West Coast of Republic of Peru " Protection of Rural Areas and Valleys and Flood Vulnerable", it is required a supporting technical document of the maximum flood flows on Pisco River, to define the hydrologic and hydraulic proposals for Pisco 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 Pisco River overflowed causing flooding of extensive crop areas and cities such Pisco, San Clemente, Humay and San Andres, 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 Letrayoc. 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

Pisco 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 Pisco 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 Pisco River

3.1.1 General Description of the Basin

Politically, the Pisco River basin is part of the provinces of Pisco (districts: Paracas, Pisco, San Andres, Tupac Amaru Inca, San Clemente, Independencia, Humay and Huáncano) and Castrovirreyna (districts: Ticrapo, Mollepampa, Cokes, and Santa Castrovirryena Ana), and belongs to the departments of Ica and Huancavelica, respectively, covering an area of 4,122.38 Km².

Geographically, its endpoints are located between Parallel 12 ° 52 'and 13 ° 48' South latitude and 75 ° 02 'and 76 ° 13' West Longitude. In the projection UTM - WGS84 its extreme points are between Parallel 365.978 and 495.455 of Coordinates East and 8'473, 994 and 8'576, 196 of North Coordinate.

In altitude ranges from sea level to the line of peaks of the Cordillera Occidental of the Andes, this is the continental divide of the waters. The highest point is Cerro San Juan de Dios (5.218 m).

The valley of Pisco (23,356.02 ha of agricultural area under irrigation, PROFODUA report - Pisco Valley, 2004), is located on the Central Coast of Peru, in the central sector of the department of Ica. In Physiographical terms, this valley is formed mainly by the Pisco River floodplain, and by their fans and ecological and marine landscapes.

The Pisco River Valley is connected to the capital of the Republic and other major towns in the South Coast of the country by the Panamericana Highway, the most important route of the road network in the country. This fully paved road crosses the valley along its coastal zone, connecting the cities of Lima and Pisco through a 243 Km asphalt section.

Another important roadway for the area is the longitudinal highway of the basin, known as "Via de los Libertadores ". This road of 364 Km long starts at Km 233.3 of the Panamericana Highway, just before the Huamaní Bridge over the Pisco River. This road links the towns of Pisco, Independencia, Humay, Huáncano, Ticrapo, Castrovirreyna, Santa Ines and Ayacucho.

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

3.1.2 Hydrography of the Pisco River Basin

The Andes Mountains divides the country in hydrographic terms. Two main branches drain their waters into the Pacific and Atlantic Oceans, respectively, thus forming the Continental Divide of the waters. There is also a third branch in the south-east of the country, consisting of a high inter-Andean basin whose waters drain into Titicaca Lake.

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. Pisco River is one of them, being located in the central region of this side.

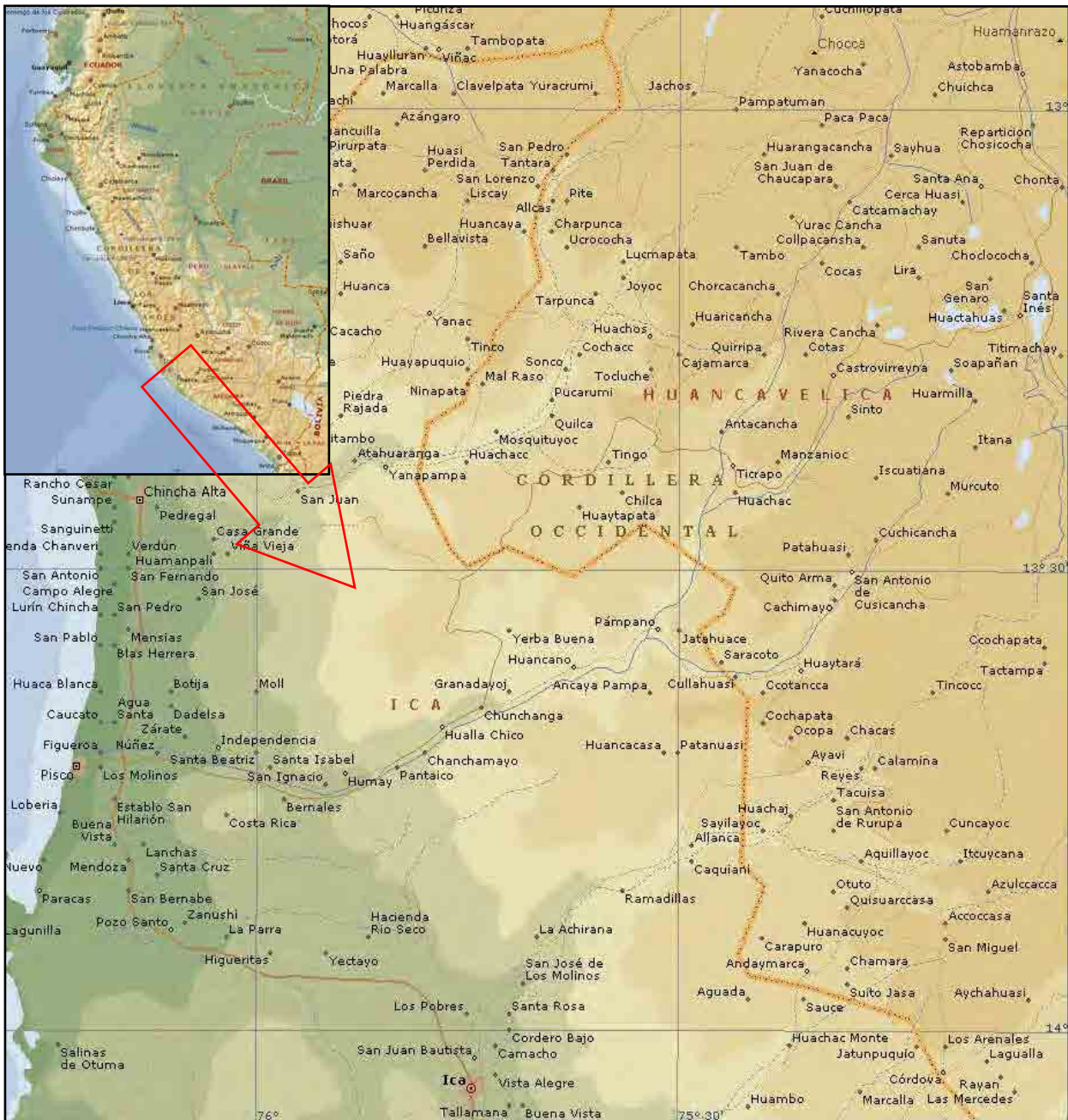


Figure N° 3.1. Location Map of the Pisco River Basin

Pisco River Basin has a sui generis form, with some semblance of a crescent. The basin bounds on the north by the San Juan River basin, on the south with the Ica River basin, on the east with the Mantaro and Pampas river basins and to the western the Pacific Ocean.

Pisco River Basin has a drainage area of 4,122.38 km², of which 62% (2,376 km²) located above the 2,500 msnm corresponds to the wet or hydrographical basin.

The Pisco River is a main drain of the runoff of the basin, begins at the confluence of the rivers Huaytará and Chiris, near the city of Pompano. Chiris River, the main tributary, in turn starts in the highest part of the basin at the confluence of the rivers Santa Ana and Luicho, which born in a series of small lakes, among these are the Pultoc , Acnococha and Tacococha lakes.

The Pisco River and their tributaries have a longitudinal development of about 472 km from its source to its mouth with an average slope of 3% which becomes more pronounced in some sectors, reaching 8%, especially in the section between the headwaters of Sanctuary River and its confluence with the Chiris River and the Veladero gully, right bank tributary of the Pisco River.

From its origin, downstream Pampano, the Pisco River presents a somewhat winding course up to the vicinity of the town of Huáncano, where takes a general east-west direction.

Downstream of the town of Humay, the valley widens considerably and the slope of the river is much softer, allowing the deposition of suspended materials which results in the formation of a small alluvial plain or alluvial fan, which extends to the coastline.

The Pisco River, similar to all the rivers of the coast, has a very irregular and torrential regime. Based on rainfall information, this regime is concentrated from December to April, while the extreme drought period is from July to November.

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 Pisco Basin, and in the neighboring San Juan, Mantaro, Pampas and Ica river basins.

Rainfall information is available from 12 control pluviometric stations located in the vicinity of the study area; these are located in the Pisco 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 N° 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 Pisco Basin and adjacent watersheds.

Table N° 3.1. Period and longitude of the available information of the Rainfall stations

CODE	STATION	DEPARTMENT	LONGITUDE	LATITUDE	ENTITY
646	ACNOCOCHA	HUANCAVELICA	75° 05'1	13° 13'1	SENAMHI
156130	CHOCLOCOCHA	HUANCAVELICA	75° 02'1	13° 06'1	SENAMHI
643	COCAS	HUANCAVELICA	75° 22'1	13° 16'1	SENAMHI
156121	CUSICANCHA	HUANCAVELICA	75° 18'18	13° 29'29	SENAMHI
156131	PARIONA	HUANCAVELICA	75° 04'1	13° 32'1	SENAMHI
156114	SAN JUAN DE CASTROVIRREYNA	HUANCAVELICA	75° 38'38	13° 12'12	SENAMHI
156122	TAMBO	HUANCAVELICA	75° 16'16	13° 41'41	SENAMHI
156117	TICRAPO	HUANCAVELICA	75° 26'1	13° 23'1	SENAMHI
156119	TOTORA	HUANCAVELICA	75° 19'1	13° 07'1	SENAMHI
647	TUNEL CERO	HUANCAVELICA	75° 05'5	13° 15'15	SENAMHI
650	HACIENDA BERNALES	ICA	75° 57'57	13° 45'45	SENAMHI
640	HUAMANI	ICA	75° 35'35	13° 50'50	SENAMHI

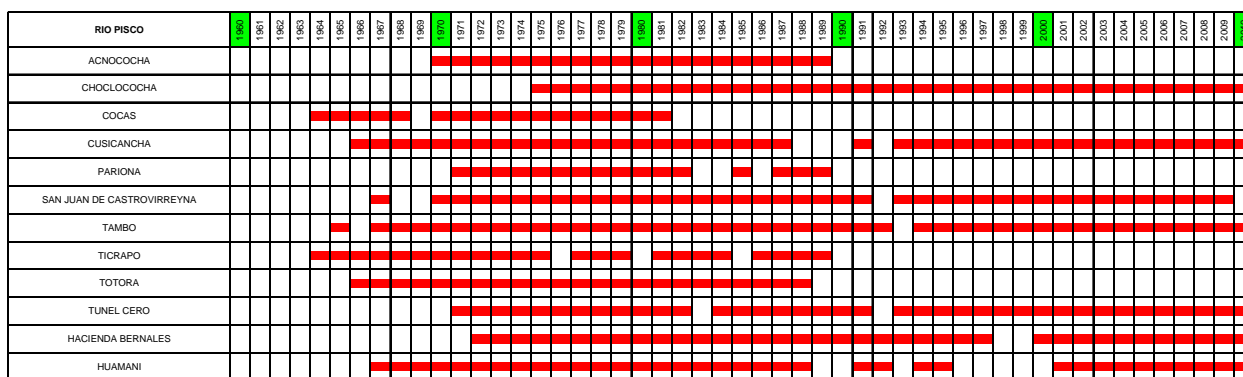


Figure N° 3.2. Period and longitude of the available information of the rainfall stations

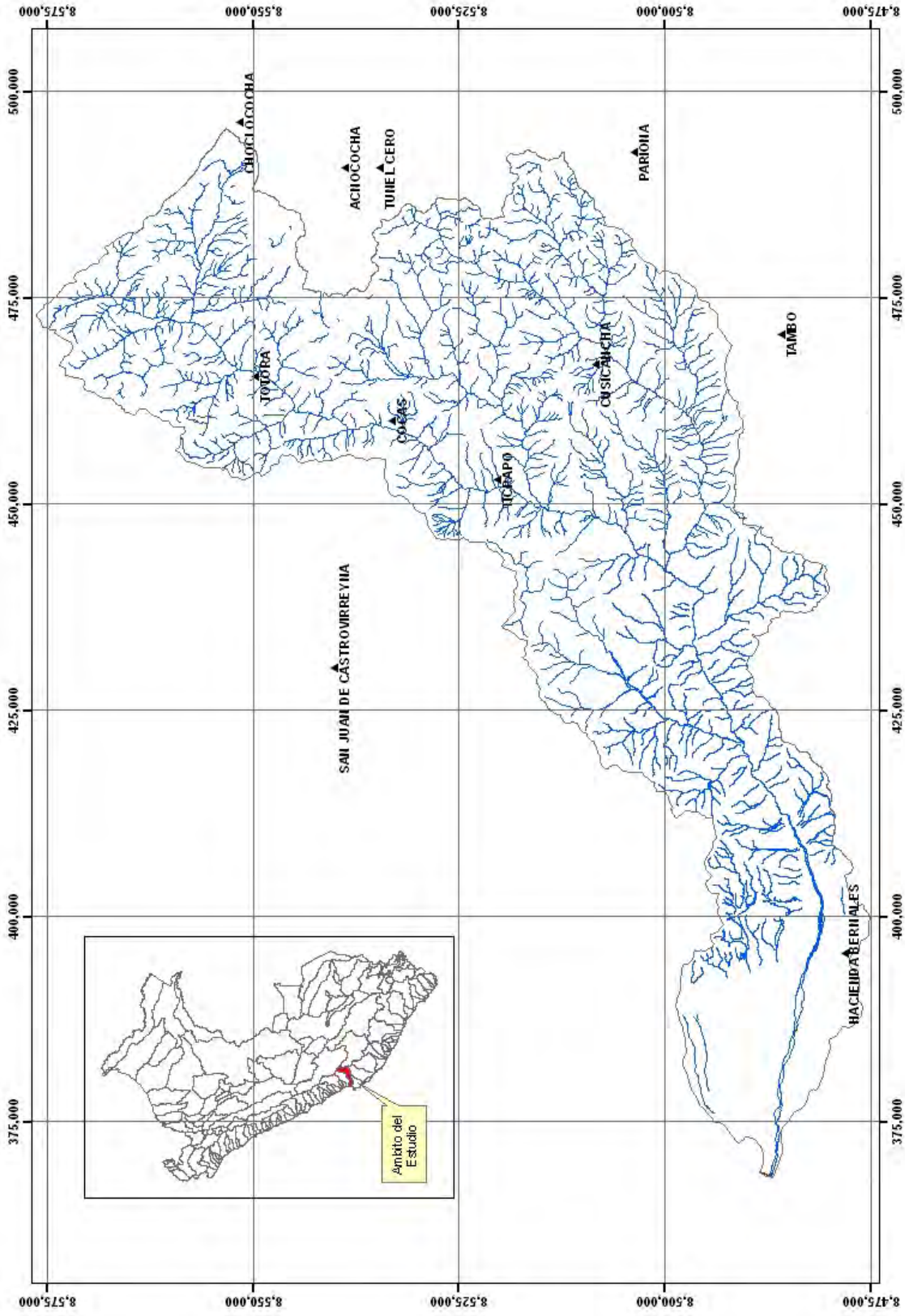


Figure N° 3.3. Location of the rainfall stations in Pisco River basin and adjacent basins

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 N° 3.2. Average Monthly Rainfall Stations Considered in the Study Area

ESTACION	Mes												Total
	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic	
ACNOCOCHA	139.08	145.04	129.35	56.57	17.74	8.18	5.65	13.73	21.69	40.59	52.30	83.59	713.51
CHOCLOCOCHA	147.66	161.73	156.09	80.13	26.52	14.25	8.03	22.18	35.24	59.48	68.69	103.97	883.97
COCAS	94.93	111.50	138.93	29.87	5.31	0.26	0.36	1.54	6.70	11.83	15.36	40.73	457.31
CUSICANCHA	74.40	88.26	104.57	33.77	1.74	0.00	0.01	0.71	3.48	4.85	12.38	36.37	360.55
PARIONA	161.82	155.42	174.45	68.15	13.61	3.06	3.12	4.02	16.39	32.52	54.23	90.91	777.70
SAN JUAN DE CASTROVIRREYNA	49.69	54.27	46.95	8.78	0.96	0.09	0.17	0.67	0.95	3.50	7.06	19.24	192.34
TAMBO	82.19	120.28	130.42	32.03	3.95	0.00	0.12	0.51	0.88	9.53	11.48	40.40	431.78
TICRAPO	54.24	75.45	73.35	14.10	0.44	0.20	0.03	0.45	0.98	3.99	5.05	24.32	252.60
TOTORA	125.39	133.76	104.56	46.33	18.20	4.07	4.90	7.76	24.24	32.59	41.47	81.67	624.95
TUNEL CERO	163.61	162.53	150.68	72.29	20.96	7.59	6.98	14.51	29.20	56.12	72.29	121.55	878.32
HACIENDA BERNALES	0.84	1.50	0.05	0.03	0.07	0.14	0.08	0.08	0.02	0.01	0.03	0.09	2.93
HUAMANI	3.08	3.75	3.45	0.05	0.00	0.00	0.01	0.00	0.08	0.00	0.00	0.17	10.60

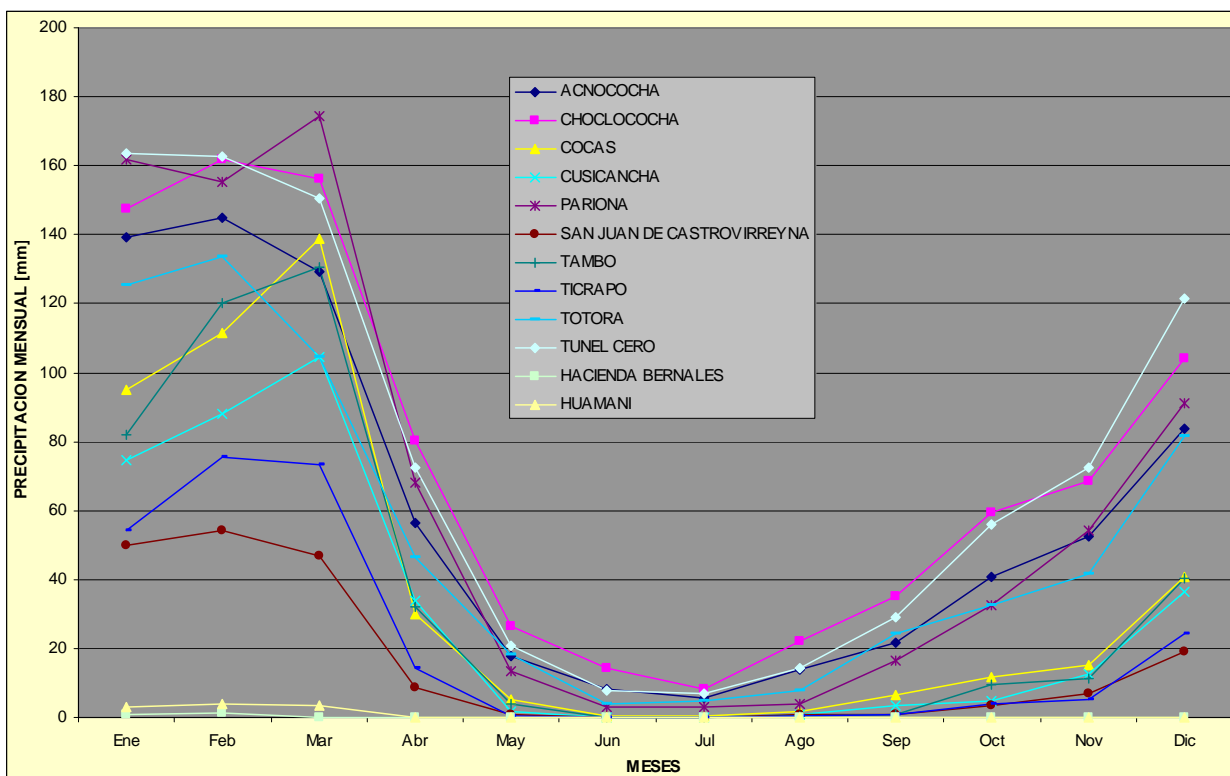


Figure N° 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope

Table N° 3.3 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 Pisco River Basin is noted to vary from 884 mm (Choclococha Station) to 2.93 mm (Hacienda Bernales).

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 Totora and Acnocochoa with approximately 20 years of record, 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 N° 3.3. Results of the linear fit equation of Totora and Acnocochoa station

Station	m	b	R²
Totora	-12.08	777.5	0.212
Acnocochoa	6.80	638.1	0.075

The value of the regression coefficients (R^2) is very low. For Totora Station would be a seasonally weak downward trend and for Acnocochoa Station a very weak upward trend. 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° 3.3 and support from ArcGIS software have allowed for generating monthly isohyets 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 February and March, and they vary between 20 mm and 160 mm. The least rainfalls are in July, and they vary between 10 mm in the basin's higher area and 0 mm in the basin's lower area.

Total annual rainfall in the Pisco River Basin varies between 800 mm and 100 mm, as shown in Figure N° 3.18.

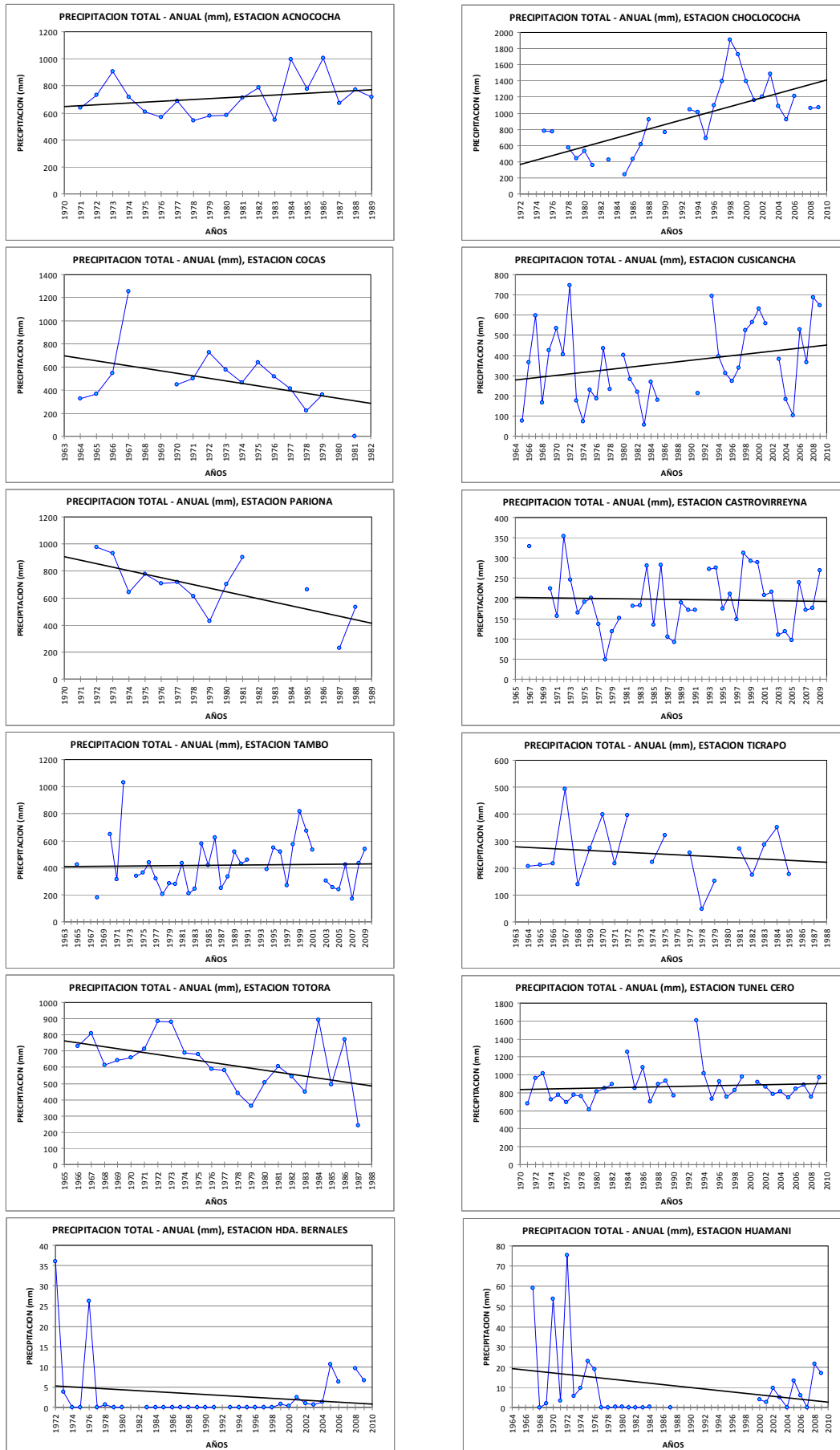


Figure N° 3.5. Annual Rainfall Trends at the Stations considered within the Study Scop

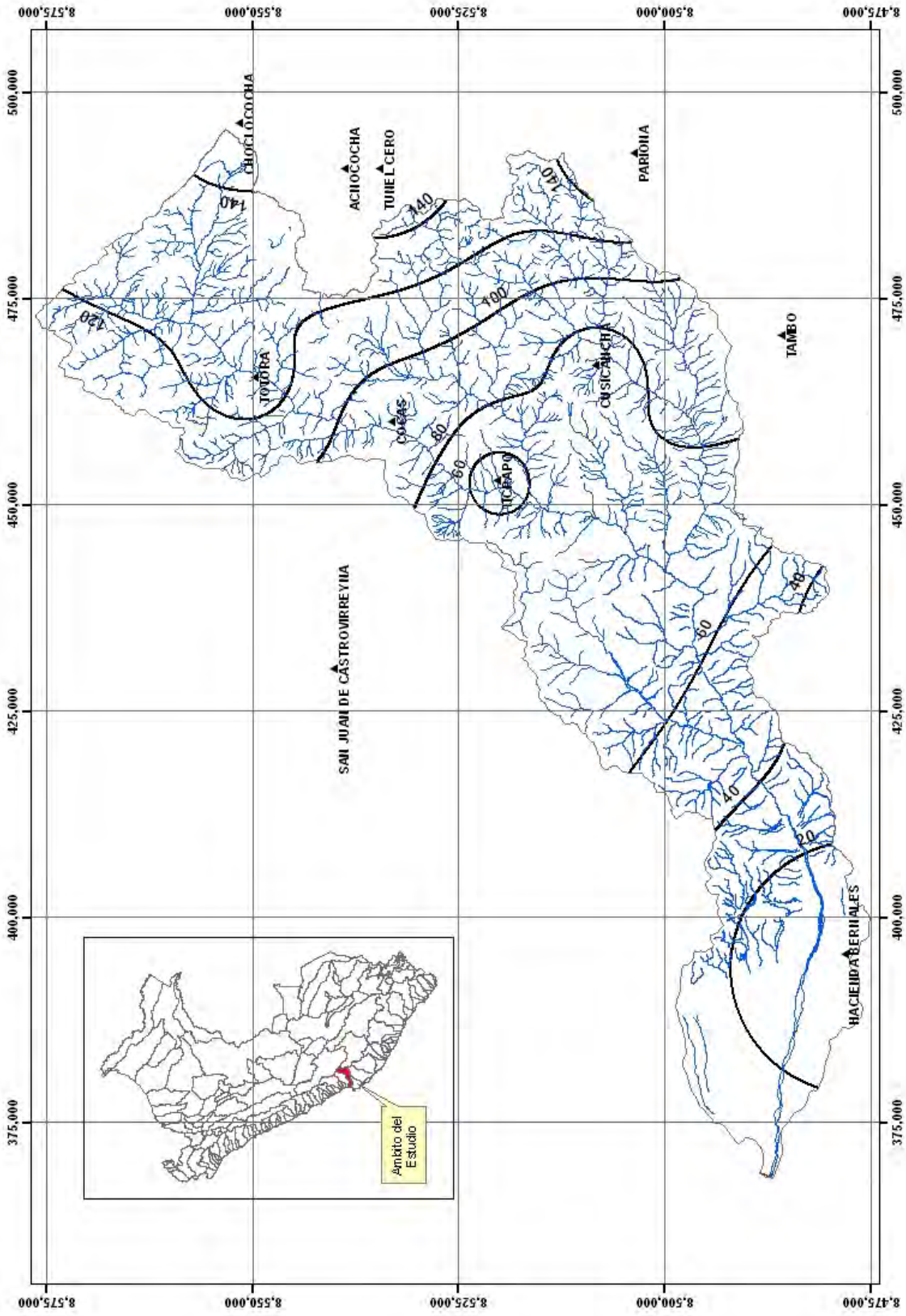


Figure N° 3.6. Isohyets for Mean Monthly Rainfall in the Pisco Basin, in January

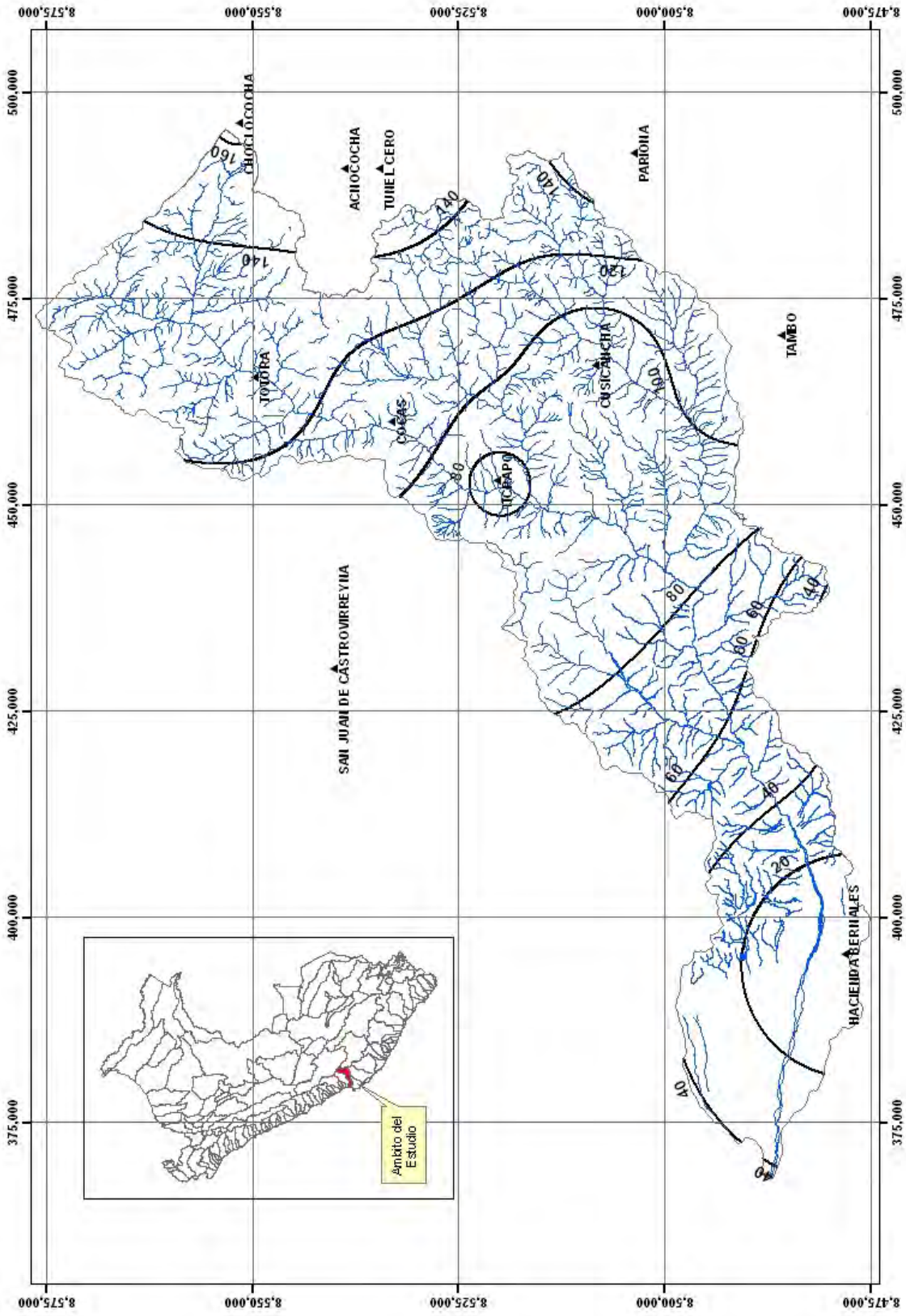


Figure N° 3.7. Isohyets for Mean Monthly Rainfall in the Pisco Basin, in February

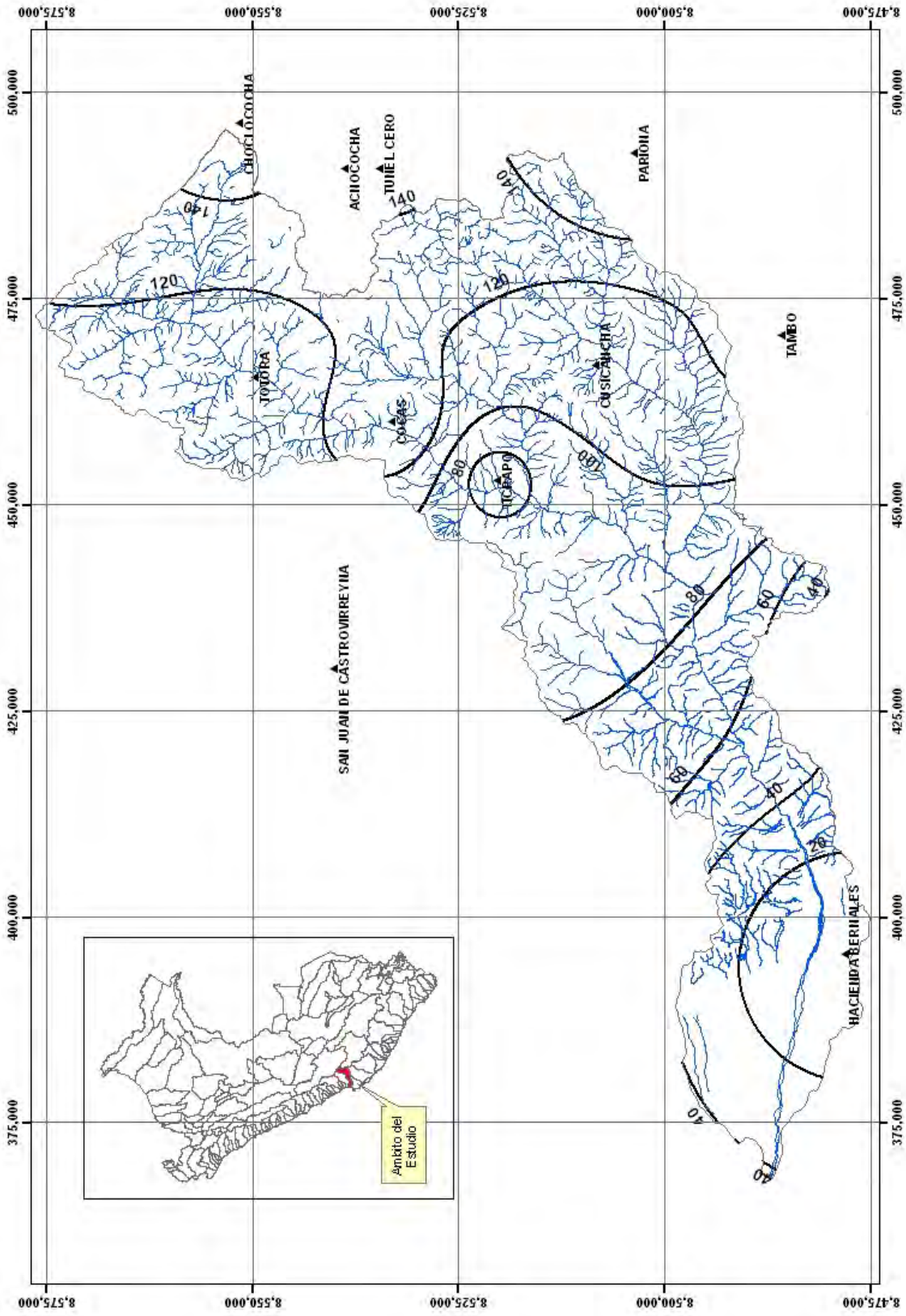


Figure N° 3.8. Isohyets Mean Monthly Rainfall in the Pisco Basin, in March

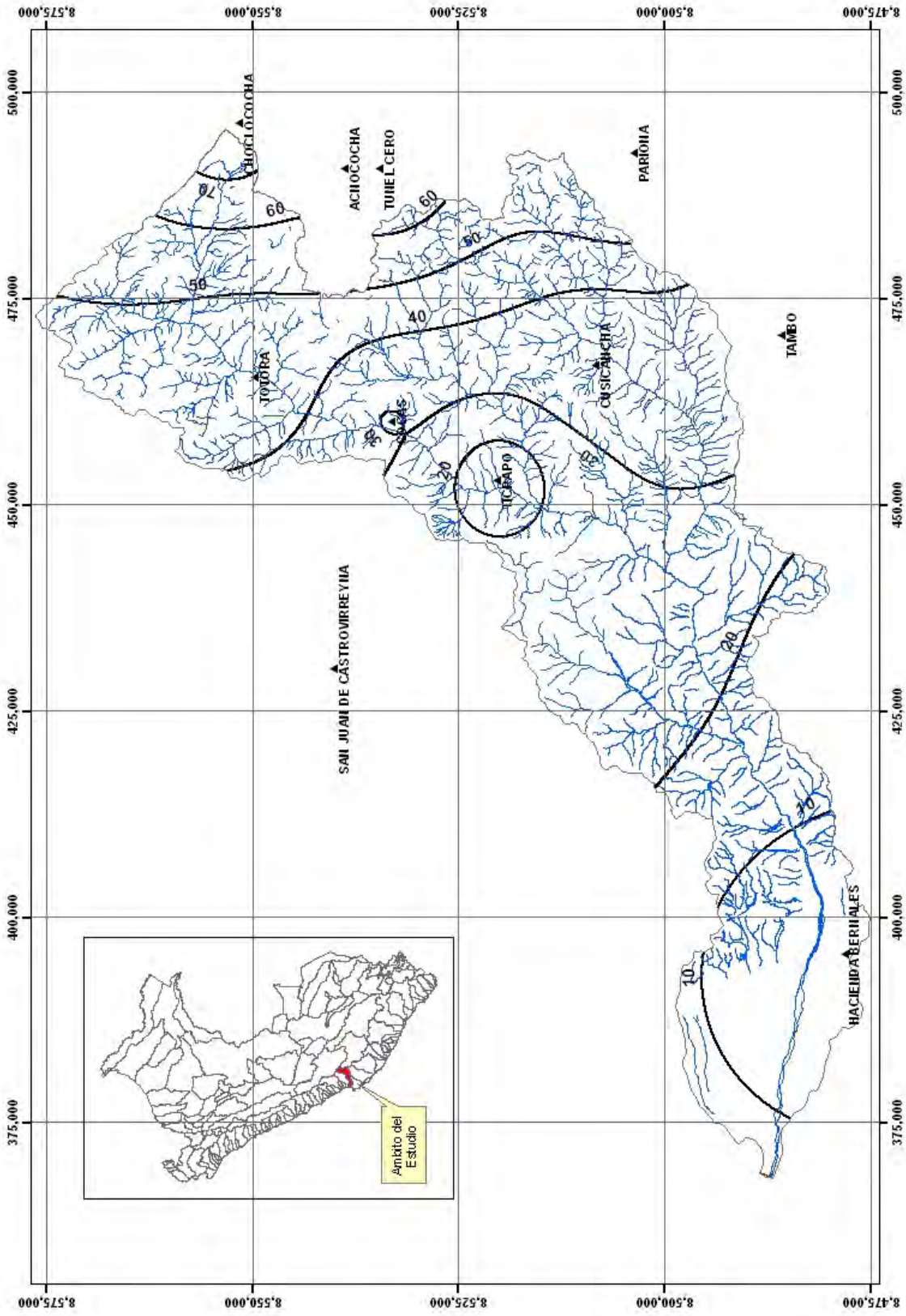


Figure N° 3.9. Isohyets Mean Monthly Rainfall in the Pisco Basin, in April

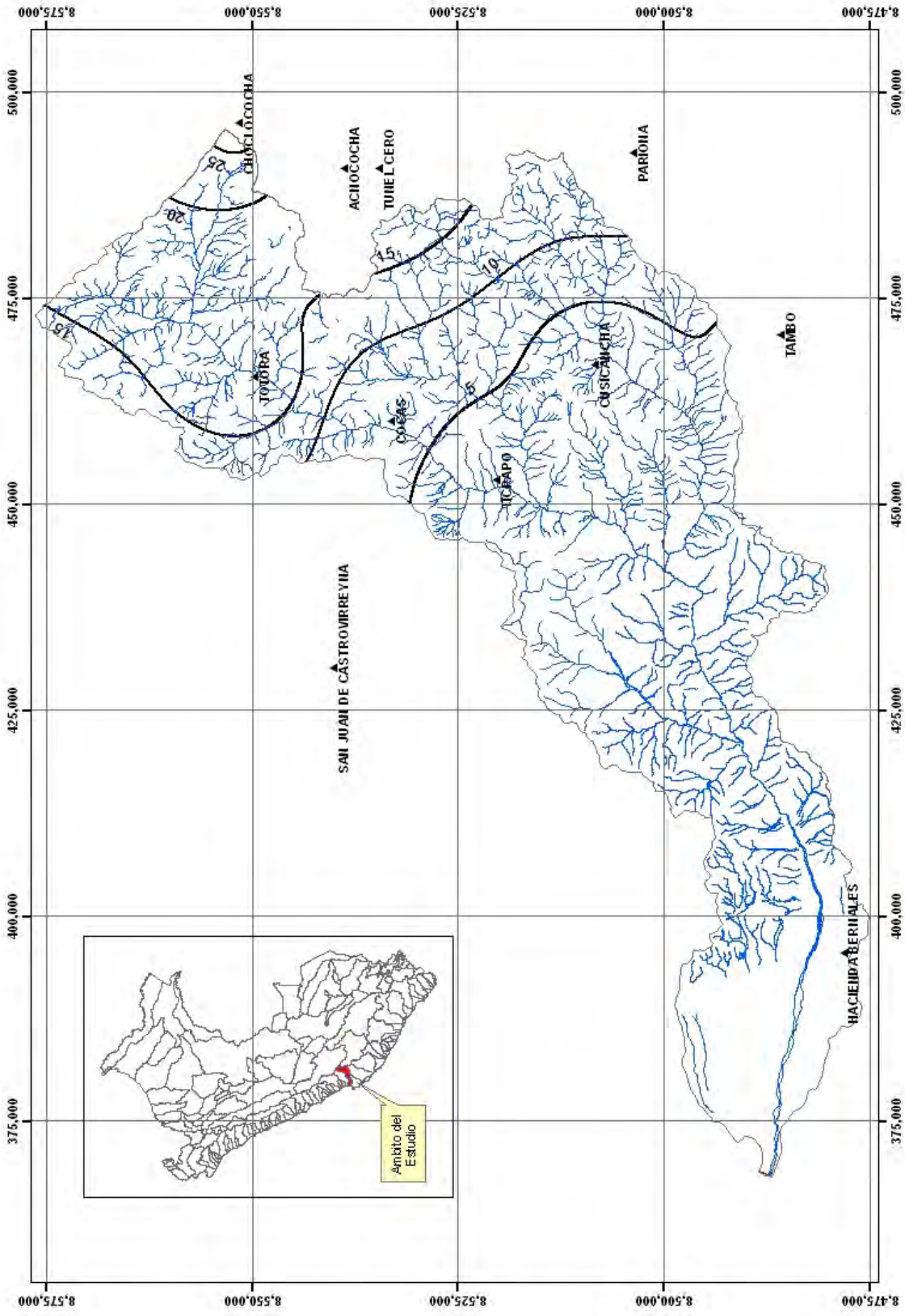


Figure N° 3.10. Isohyets Mean Monthly Rainfall in the Pisco Basin, in May

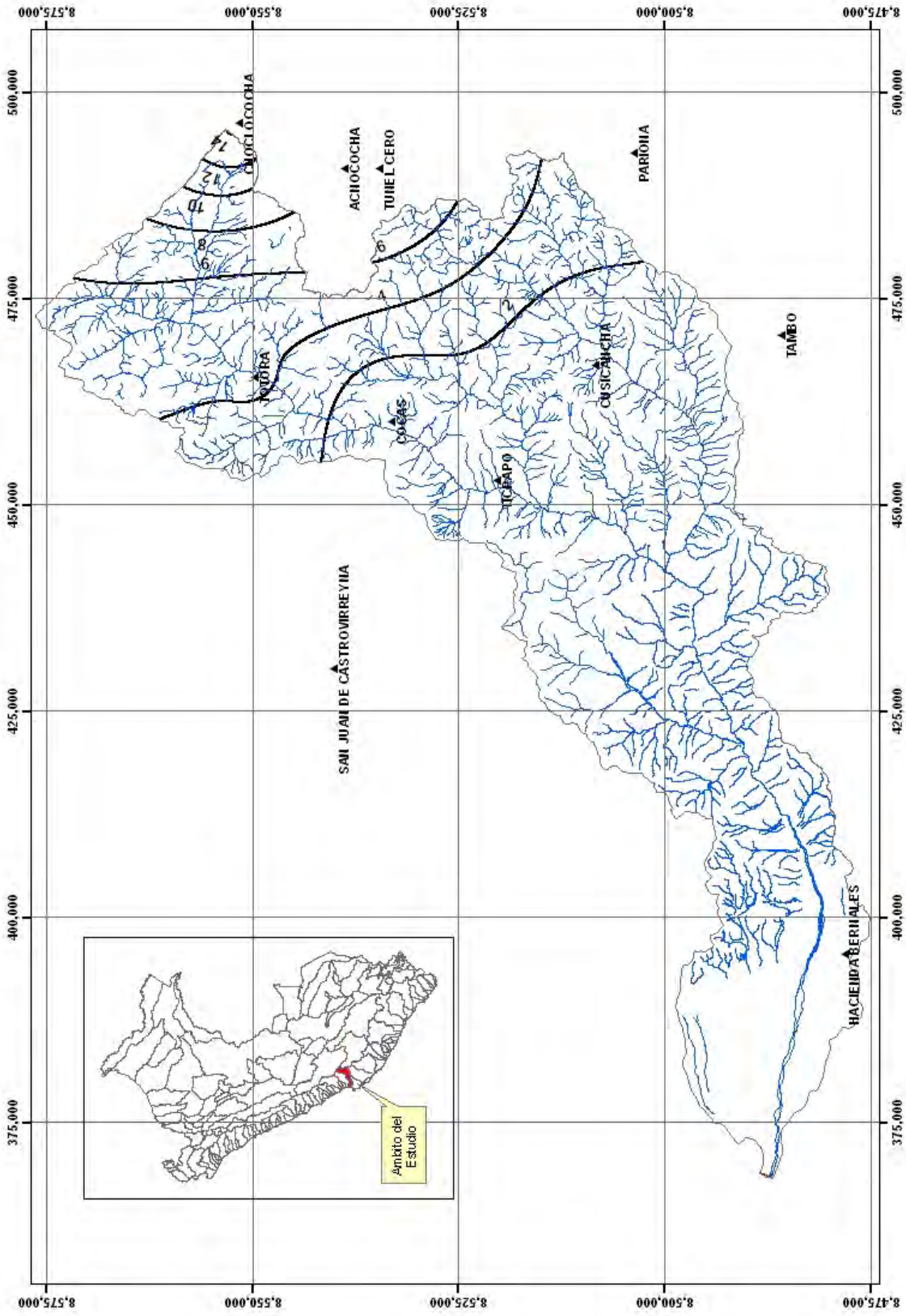


Figure N° 3.1.1. Isohyets Mean Monthly Rainfall in the Pisco Basin, in June

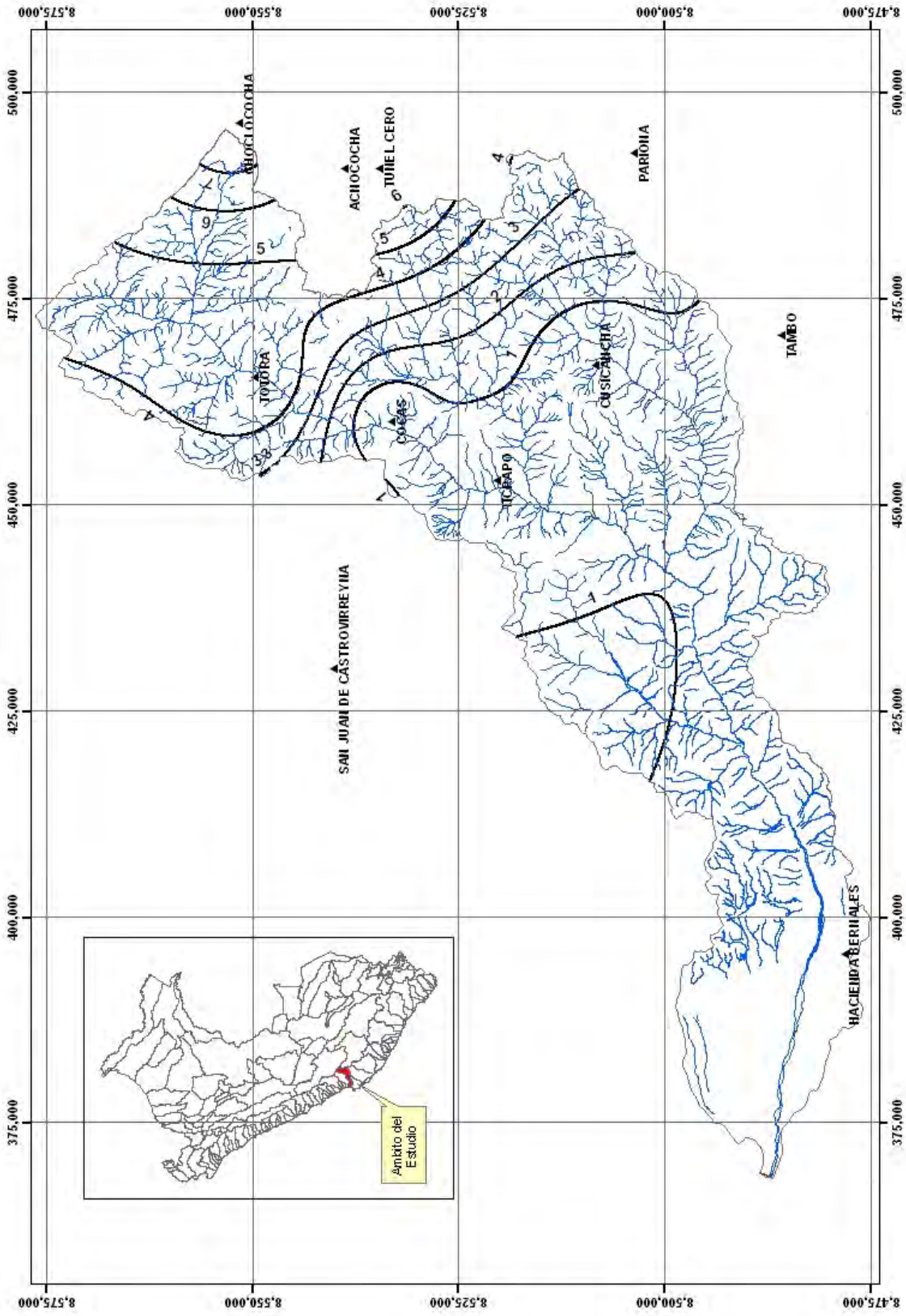


Figure N° 3.12. Isohyets Mean Monthly Rainfall in the Pisco Basin, in July

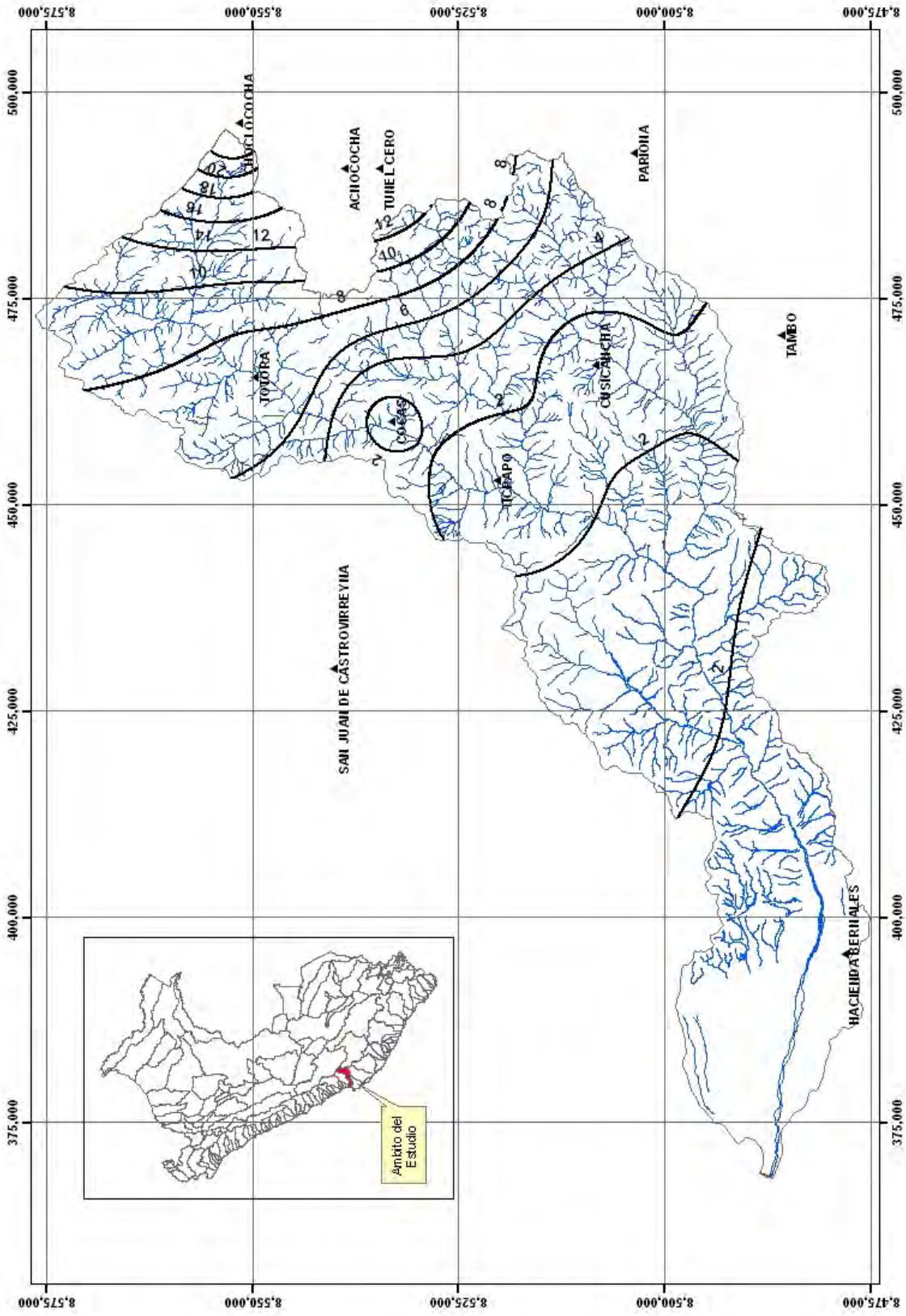


Figure N° 3.13. Isohyets Mean Monthly Rainfall in the Pisco Basin, in August

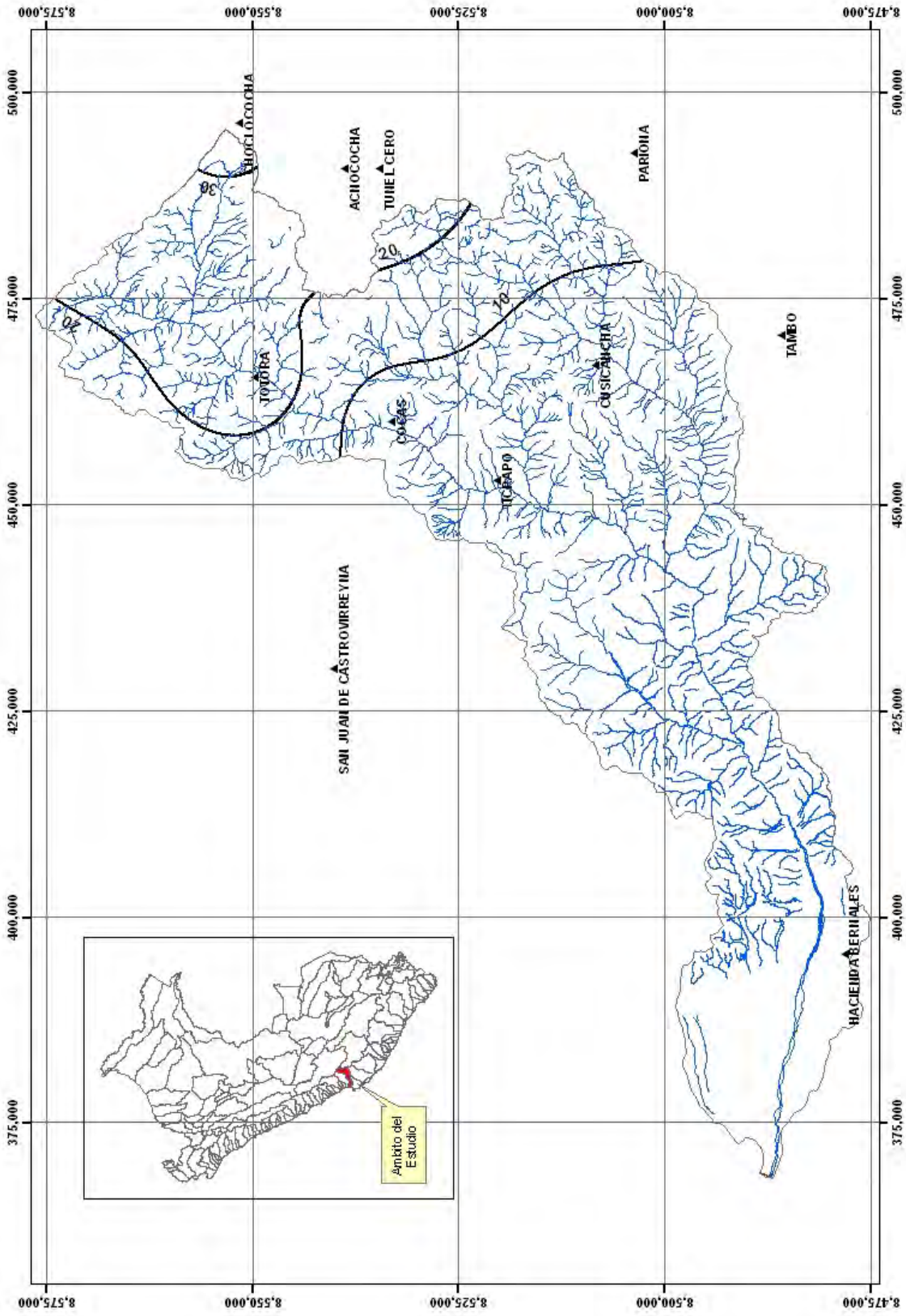


Figure N° 3.14. Isohyets Mean Monthly Rainfall in the Pisco Basin, in September

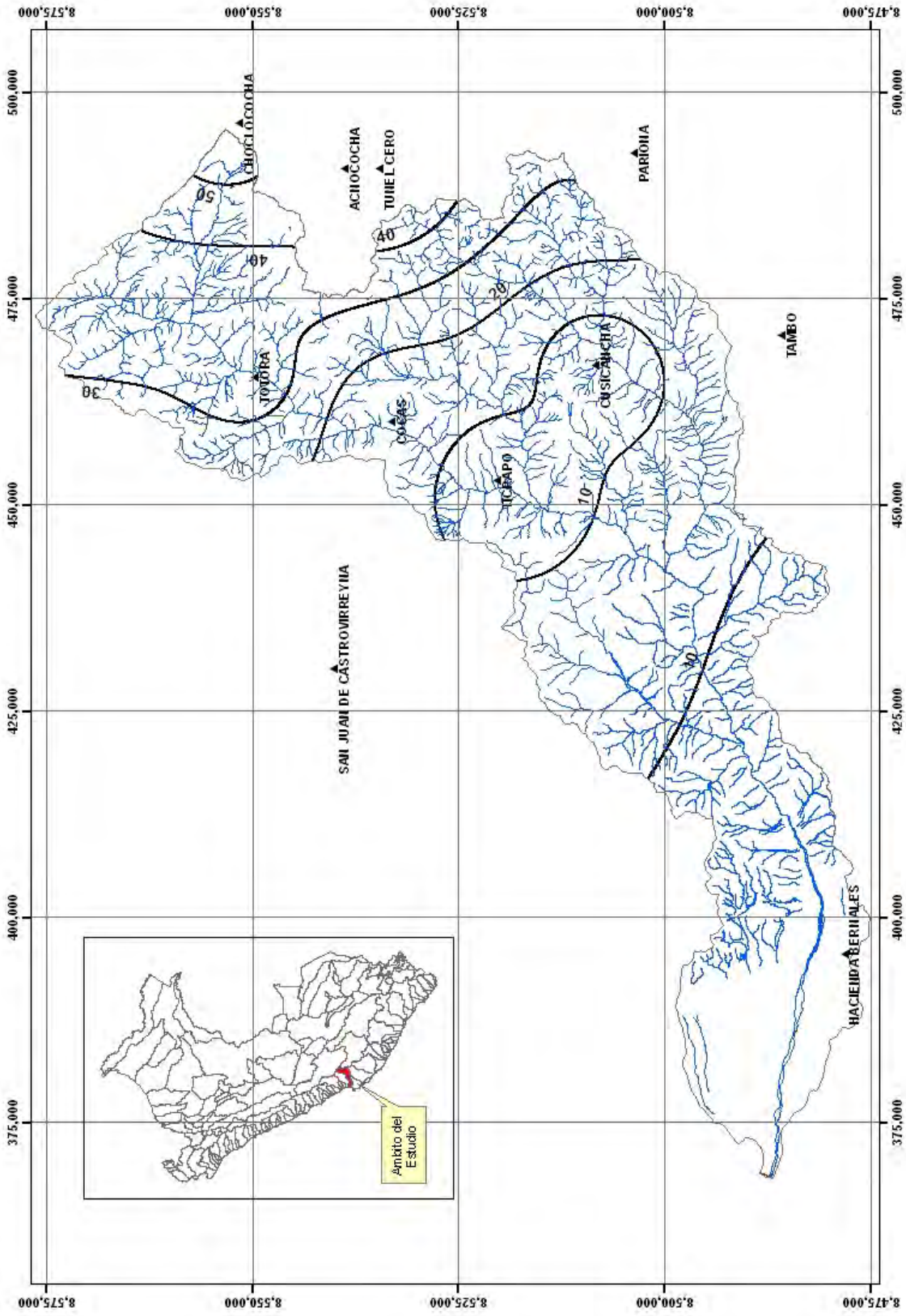


Figure N° 3.15. Isohyets Mean Monthly Rainfall in the Pisco Basin, in October

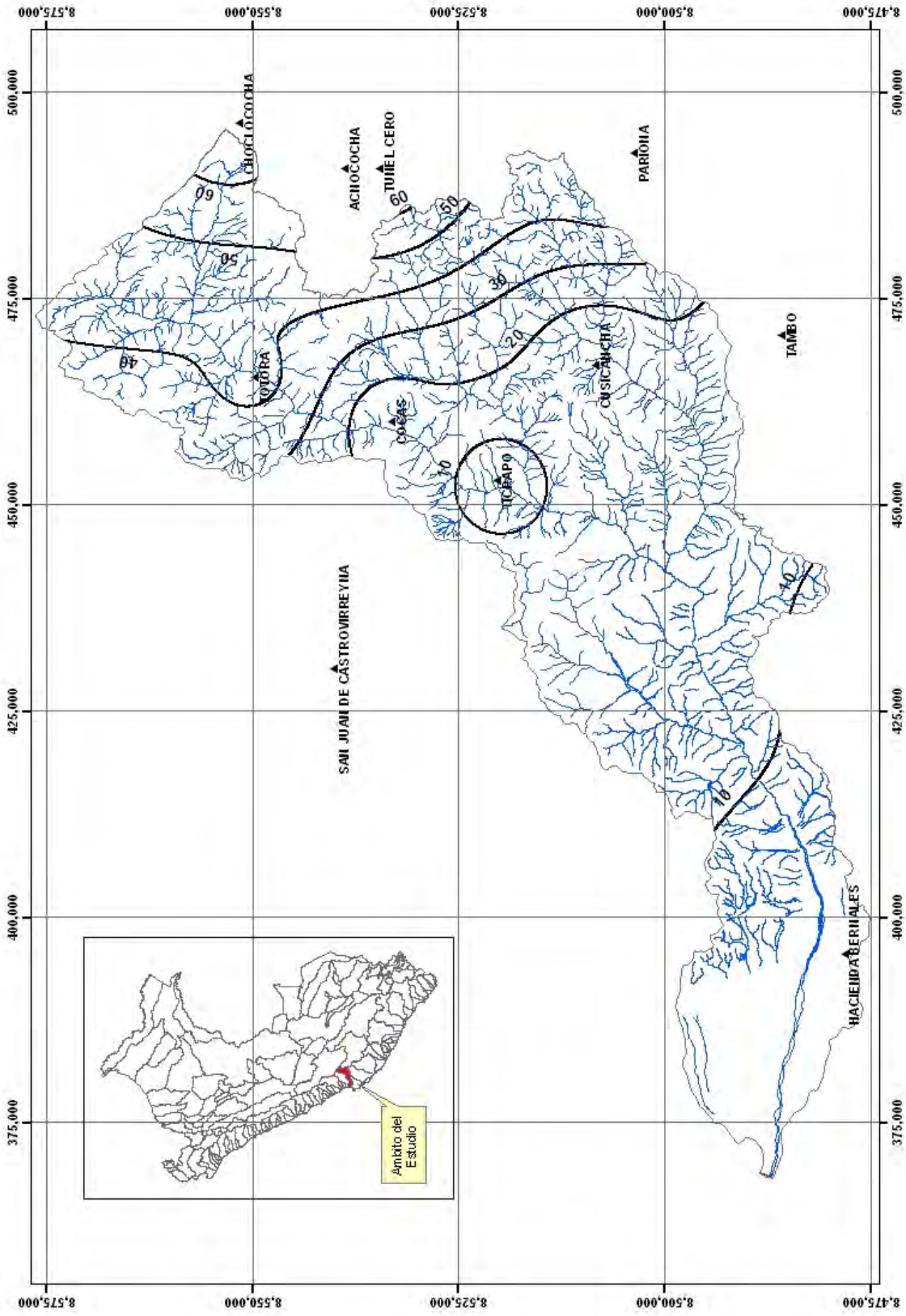


Figure N° 3.16. Isohyets Mean Monthly Rainfall in the Pisco Basin, in November

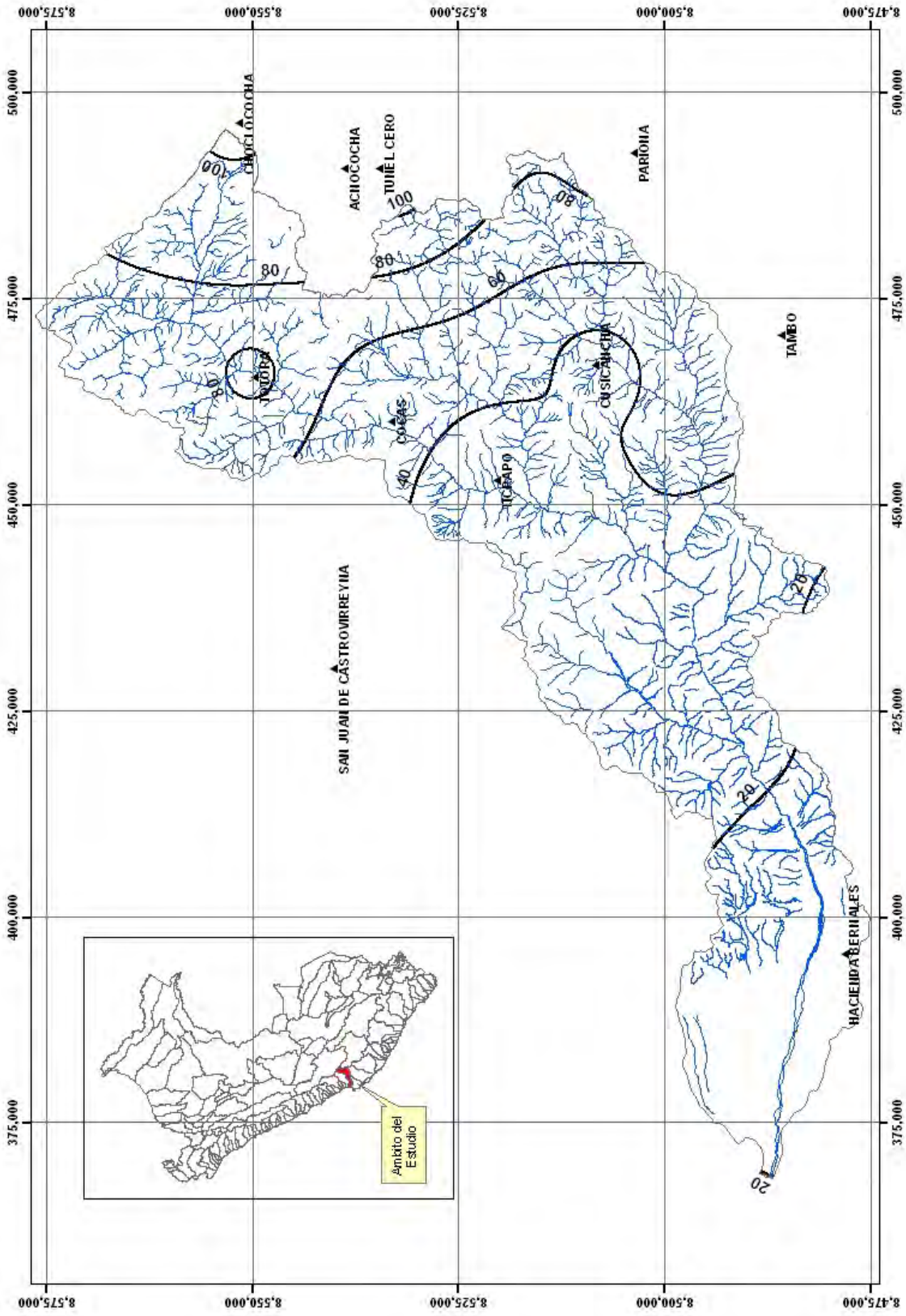


Figure N° 3.17. Isohyets Mean Monthly Rainfall in the Pisco Basin, in December

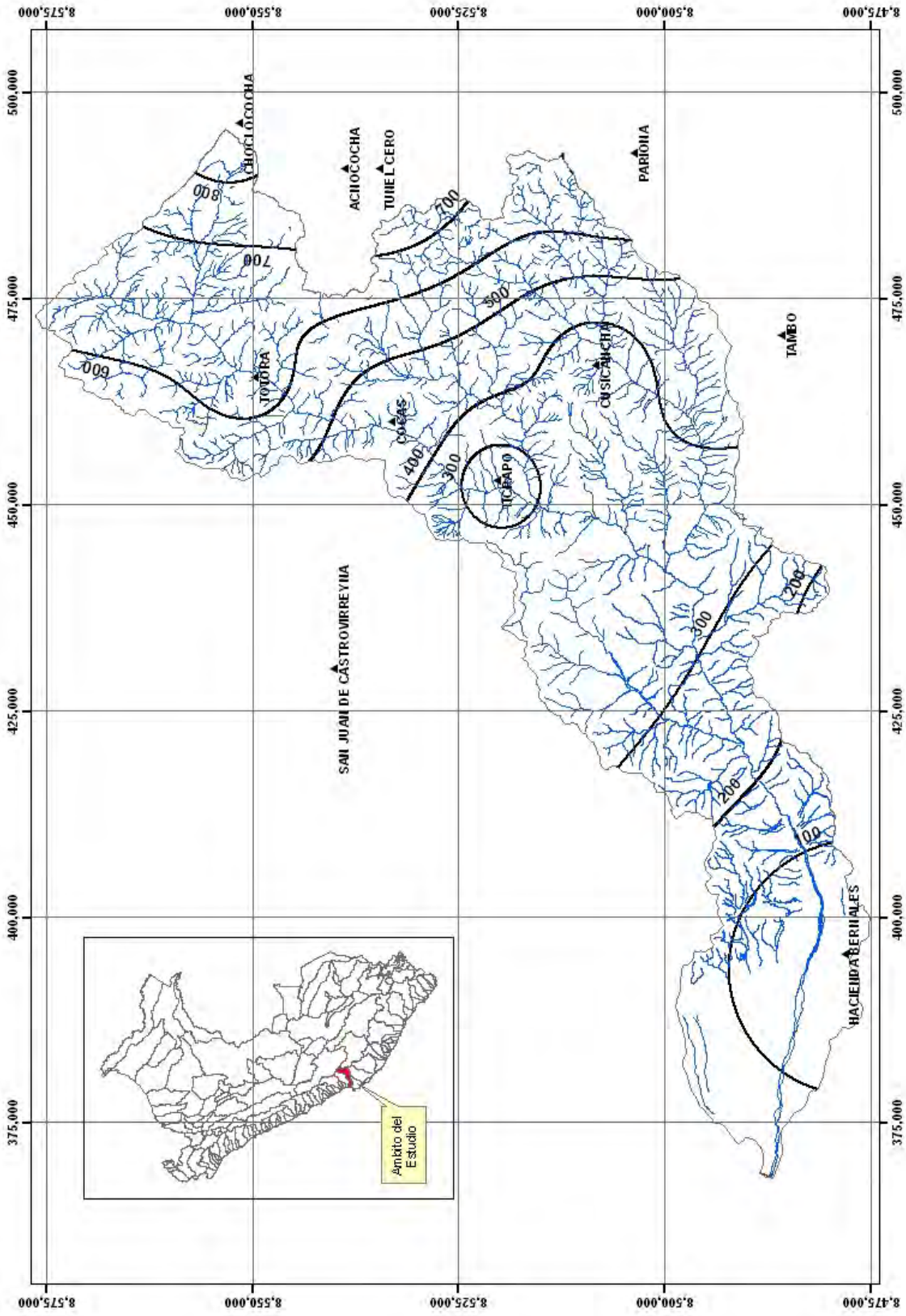


Figure N° 3.18. Isohyets Annual Mean Monthly Rainfall in the Pisco Basin

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.

In the area of Pisco Basin, the climate variable is measured by a network of meteorological stations, which are summarized in Table No. 3.4., this shows the historical averages of monthly mean temperature at stations of Pisco, Bernales, Huáncano, Cokes, and Acnocochoa Castrovirreyña located within the basin, and Huamaní, Acora, Tunnel Zero and San Pedro de Huacarpana to neighboring basins of Ica, Pampas and San Juan.

From the information shown in the Table No. 3.4., there is an inverse relationship between temperature and altitude, this is the effect of reduced atmospheric pressure due to higher altitude, likewise observed that annual average temperatures are higher in the Huamani stations (20, 5) and Huancano (20.6) and minima occur in the stations Tunel Cero (3.7) and Acnocochoa (2.8).

Figure N° 3.19 shows the distribution of the monthly average temperature from weather stations located in the Pisco Basin, where we note that the monthly average temperatures are higher in the stations of Pisco, and Huancano Bernales, and the minimum occurs at the station Acnocochoa.

Table N° 3.4. Monthly half temperature (C°) of the stations of the Pisco River basin and adjacent basins

N°	ESTACION METEOROLOGICA	ALTITUD msnm	AÑO PROMEDIO												MEDIA ANUAL
			Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic	
1	PISCO	7	21.5	22.2	22.0	20.4	18.3	16.7	15.9	15.8	16.3	17.1	18.2	20.0	18.7
2	BERNALES	250	22.6	22.9	22.2	20.6	17.8	15.7	15.2	15.5	16.3	17.4	18.5	20.6	18.8
3	HUAMANI	800	23.0	23.8	23.7	22.0	20.1	17.5	16.6	17.5	18.8	19.9	20.7	22.0	20.5
4	HUANCANO	1008	22.4	22.8	22.9	22.4	20.4	18.3	17.9	18.4	19.7	20.3	20.3	21.1	20.6
5	ACORA	1800	17.2	17.4	17.8	17.3	16.7	16.2	16.5	16.6	16.8	17.3	17.2	17.5	17.0
6	COCAS	3246	10.9	11.0	10.8	11.2	11.2	11.0	11.5	11.7	11.9	12.2	12.3	12.2	11.5
7	S.P.HUACARPANA	3680	9.1	8.6	9.5	9.4	9.8	9.3	9.6	9.2	9.5	10.2	9.6	10.1	9.5
8	CASTROVIRREYNA	3956	7.8	7.3	7.1	7.4	6.7	6.3	5.9	6.1	7.1	7.0	7.1	7.0	6.9
9	TUNEL CERO	4425	4.3	4.4	4.5	4.1	3.5	2.5	2.3	2.9	3.5	4.1	4.5	4.4	3.7
10	AGNOCOCHA	4650	3.7	3.6	3.8	3.4	2.8	2.0	1.3	1.6	2.2	3.2	3.1	3.3	2.8

Source: Assessment and Management of Water Resources of the Pisco River basin. IRH-INRENA-MINAG, 2003

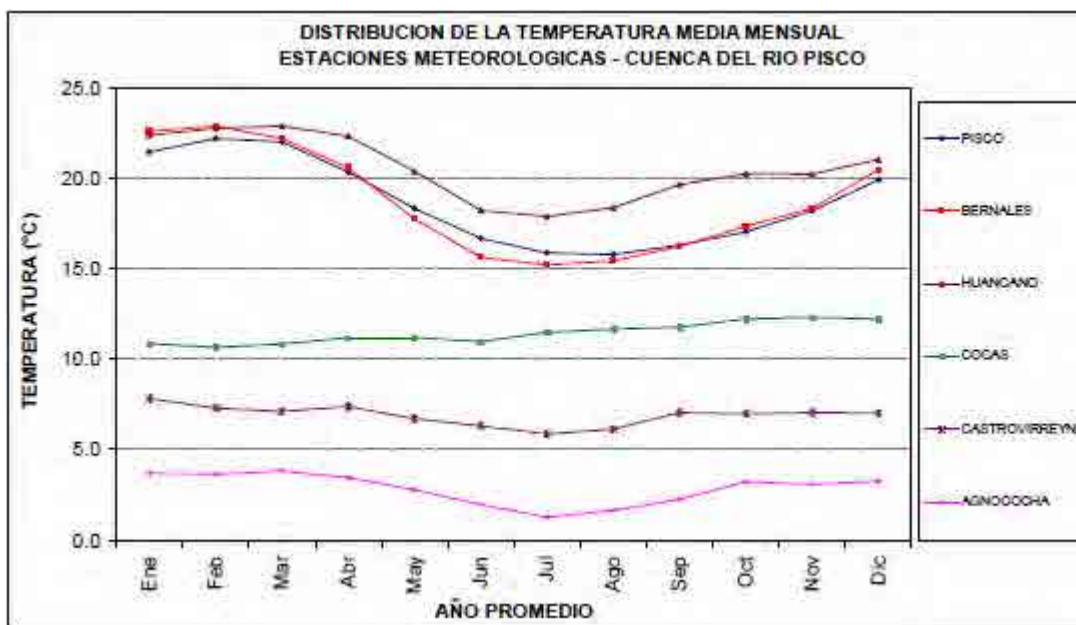


Figure N° 3.19. Distribution of the monthly half temperature of the weather stations located in the Pisco River basin
Source: Assessment and Management of Water Resources of the Pisco River basin. IRH-INRENA-MINAG, 2003

3.3 Hydrometry

There are 5 hydrometric stations located along the River Pisco 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 N° 3.5. Characteristics of Hydrometric Stations in the Pisco River Basin and Surrounding Basins

STATION NAME	CATEGORY*	CATCHMENT	DEPARTAMENT	PROVINCE	DISTRICT	LONGITUDE	LATITUDE	ELEVATION	CONDITION	WORKING PERIOD	
										START	END
LETRAYOC	HLM	PISCO	ICA	PISCO	HUANCANO	75° 43'43	13° 39'39	1304	Operating	1922-01	2010-12
LETRAYOC	EHA	PISCO	ICA	PISCO	HUMAY	75° 45'1	13° 40'1	1020	Operating	2000-12	2009-05
RESERVORIO LAGUNA ACNOCOCHA	HLG	PISCO	HUANCVELICA	CASTROVIRREYNA	SANTA ANA	75° 11'1	13° 06'1	4734	Paralyzed	Not Available	
RESERVORIO LAGUNA PALCOCOCHA	HLG	PISCO	HUANCVELICA	CASTROVIRREYNA	CASTROVIRREYNA	75° 18'1	13° 13'1	4533	Paralyzed	Not Available	
DIQUE ORCOCOCHA	HLG	PISCO	HUANCVELICA	CASTROVIRREYNA	CASTROVIRREYNA	75° 12'1	13° 16'1	4552	Closed	1968-09	1975-11

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 N° 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 Pisco Basin and adjacent watersheds.

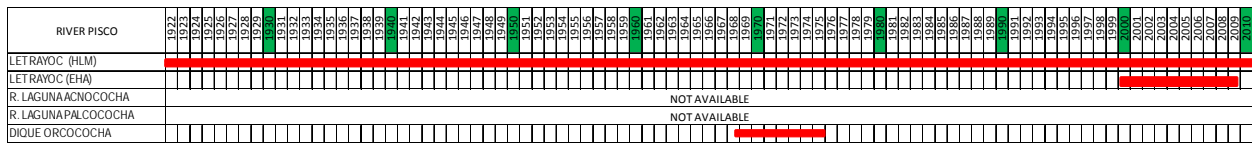


Figure N° 3.20. Period and longitude of the available information of the Hydrometric Stations

The information of the hydrometric station Letrayoc 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.

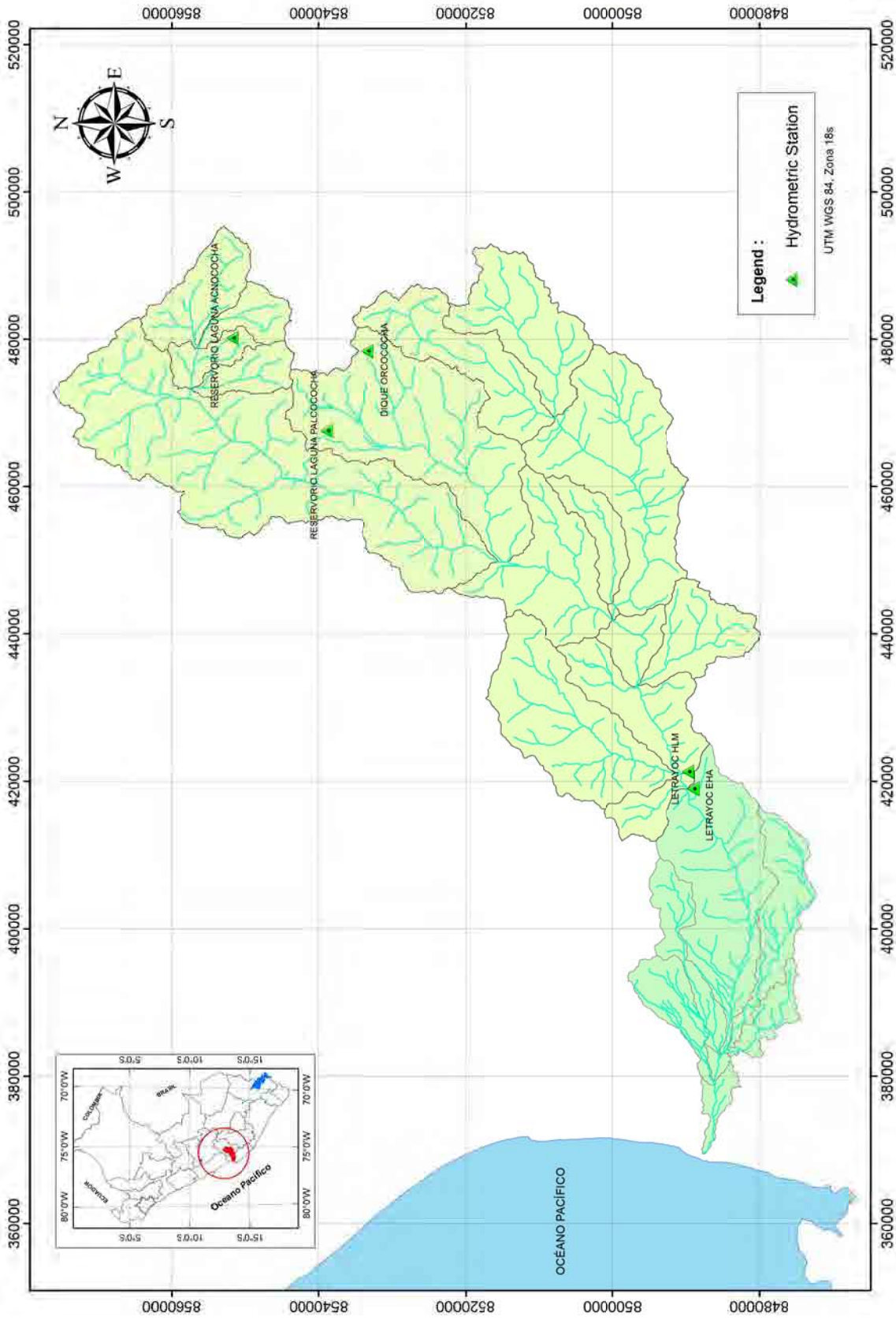


Figure N° 3.21. Location of the hydrometric station Letrayoc in Pisco River basin

3.4 Comments on the meteorologic and hydrometric and network in the Pisco 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 12 stations, 6 stations have data until year 2010, 03 station has data until 1990, 01 station has data until 1989 and 01 stations has data until 1987, and 01 station has data until 1981.

The stations with information previously to 1990 are not operative anymore, although we don't have the exact information, it is possible that the remaining stations are currently operative. Also although the information coming from stations which have data until years previously to 1990 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. All stations were used for the flood peak discharges analysis, the remaining were not used 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 5 stations, one station has data until year 2010, 01 station has data until 2009, 01 station has data until 1975, the data from the remaining two stations was not available.

For the purpose of the present study the information of hydrometric station Letrayoc 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 m³/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, turbidity 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 Pisco Basin in this agreement..

IV. HYDROLOGY OF MAXIMUM FLOOD

4.1 Preliminary Considerations

This chapter describes the methodology of work developed for the generation of flood flows with in the so called point (point of interest, Letrayoc 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 station Letrayoc.

Field Reconnaissance:

Reconnaissance has involved revising general characteristics of the Letrayoc hydrometric station and the interest point for discharges to be generated, the major topographic and characteristics and the land use characteristic of the watershed to the study area. This has supported the definition of some parameters to be taken into account for flood flow generations.

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 (Letrayoc Station), based on Charts at 1:100000 and / or 1:25000 scale, and satellite images.
- Selection of existing pluviometric stations in the study area and 24 – hour maximum rainfall historical record collections.
- Frequency analyses of 24 – hour maximum 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 concentration time (time in which all the 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 Letrayoc) shown in Table N° 4.1.

Table N° 4.1. Geomorphological Characteristics of the basis point watershed (station Letrayoc)

Characteristic	Value
Catchment Area (km ²)	3,096.000
Major water course length (km)	113.400
Maximum Altitude (msnm)	4,758.000
Minimum Slope (msnm)	630.000
Average Slope (m/m)	0.036

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 Pisco River Basin and adjacent basins). Maximum 24 – hours annual rainfall in these stations are shown in Table N° 4.2; daily and maximum 24- hours information is shown in the Annex.

From the Information show in Table N° 4.2 and observing Figure N° 3.3, we conclude that the stations are located throughout the area of study and that the reporting period is greater than 10 years, so that in subsequent analysis uses information from all stations.

Table N° 4.2. Maximum 24-hours rainfall Annual for Stations located within the Study Scope

Year	Pluviometric Stations											
	ACNOCOCHA	CHOCLOCOCHA	COCAS	CUSICANCHA	PARIONA	SAN JUAN DE CASTROVIRREYNA	TAMBO	TICRAPO	TOTORA	TUNEL CERO	HACIENDA BERNALES	HUAMANI
1960												
1961												
1962												
1963												
1964			19.80					21.50				
1965			21.60				35.00	20.70				
1966			20.20	18.70				12.60	15.00			
1967			36.00	23.50		20.10		24.40	24.00			25.50
1968				12.30			24.00	10.00	20.00			0.00
1969				23.00				35.80	22.00			1.60
1970			22.10	25.30		33.30	13.30	40.20	23.00			33.50
1971	32.30		29.40	28.60		13.70	18.20	28.40	21.00	30.70		1.70
1972	29.20		30.80	26.90	40.01	28.00	30.70	32.00	27.00	28.20	29.50	18.80
1973	24.60		36.80	13.10	37.80	23.00			25.00	34.60	1.60	2.11
1974	31.10		20.60	9.70	36.90	12.10	21.00	14.00	22.00	24.20	0.00	4.11
1975	24.10	27.40	22.40	6.60	39.10	17.00	42.40	19.50	19.00	29.20	0.00	23.00
1976	26.40	36.10	21.40	6.60	34.40	17.20	40.00		20.00	22.80	20.80	12.50
1977	26.90		20.60	24.20	29.70	15.50	20.50	24.00	25.00	31.30	0.00	0.00
1978	28.10	22.90	14.40	20.00	20.61	7.80	32.00	5.40	20.01	19.50	0.60	0.00
1979	22.30	15.40	27.40		25.40	21.60	20.40	18.00	25.01	33.20	0.00	0.20
1980	23.00	14.80		19.00	44.40	40.00	21.20		35.00	27.30	0.00	0.30
1981	22.60	13.50		20.00	28.50		25.60	33.00	29.00	35.90		0.00
1982	32.10			10.10		17.10	15.70	10.90	29.01	52.20		0.00
1983	30.10	26.50		5.00		28.00	35.00	30.00	24.01		0.00	0.00
1984	28.70			20.00		24.00	40.00	20.80	37.01	38.30	0.00	0.40
1985	26.50	19.00		11.00	26.50	11.50	30.00	18.00	30.00	22.70	0.00	7.50
1986	29.20	36.00				14.70	30.00		27.00	35.30	0.00	
1987	22.40	24.40			14.80	12.30	20.00		13.01	23.10	0.00	0.00
1988	26.90	39.10			28.00	13.50	17.00			27.80	0.00	
1989	20.30					31.80	36.70			31.90	0.00	0.00
1990		39.50				13.10	29.00			54.50	0.00	
1991				21.00		11.00	40.00				0.00	0.00
1992												
1993		39.30		29.00		13.70				36.50	0.00	

1994		37.30		17.80		12.30	22.00			30.50	0.00	
1995		28.10		14.30		12.00	43.20			26.20	0.00	
1996		35.90		10.80		19.20	42.00			27.30	0.00	
1997		67.50		22.20		10.50	30.00			21.60	0.00	
1998		55.50		42.00		37.90	40.00			25.10	0.00	
1999		34.40		25.70		25.00	23.00			26.10	0.50	
2000		38.00		20.10		18.80	26.00				0.30	2.50
2001		29.30		28.40		23.20	16.00			29.60	1.30	2.20
2002		30.70				19.51				23.70	0.50	3.10
2003		57.70		18.90		10.50	22.00			27.40	0.02	2.70
2004		45.00		9.90		10.30	16.00			28.70	0.40	0.01
2005		36.10		12.40		16.10	27.00			47.80	4.60	13.00
2006		36.70		27.70		21.40	38.00			25.00	3.20	4.21
2007				18.80		18.40	16.50			35.80		0.01
2008		24.60		20.60		14.50	26.00			28.60	5.10	6.20
2009		58.40		19.20		17.20	38.00			36.20	1.30	8.30
2010												

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

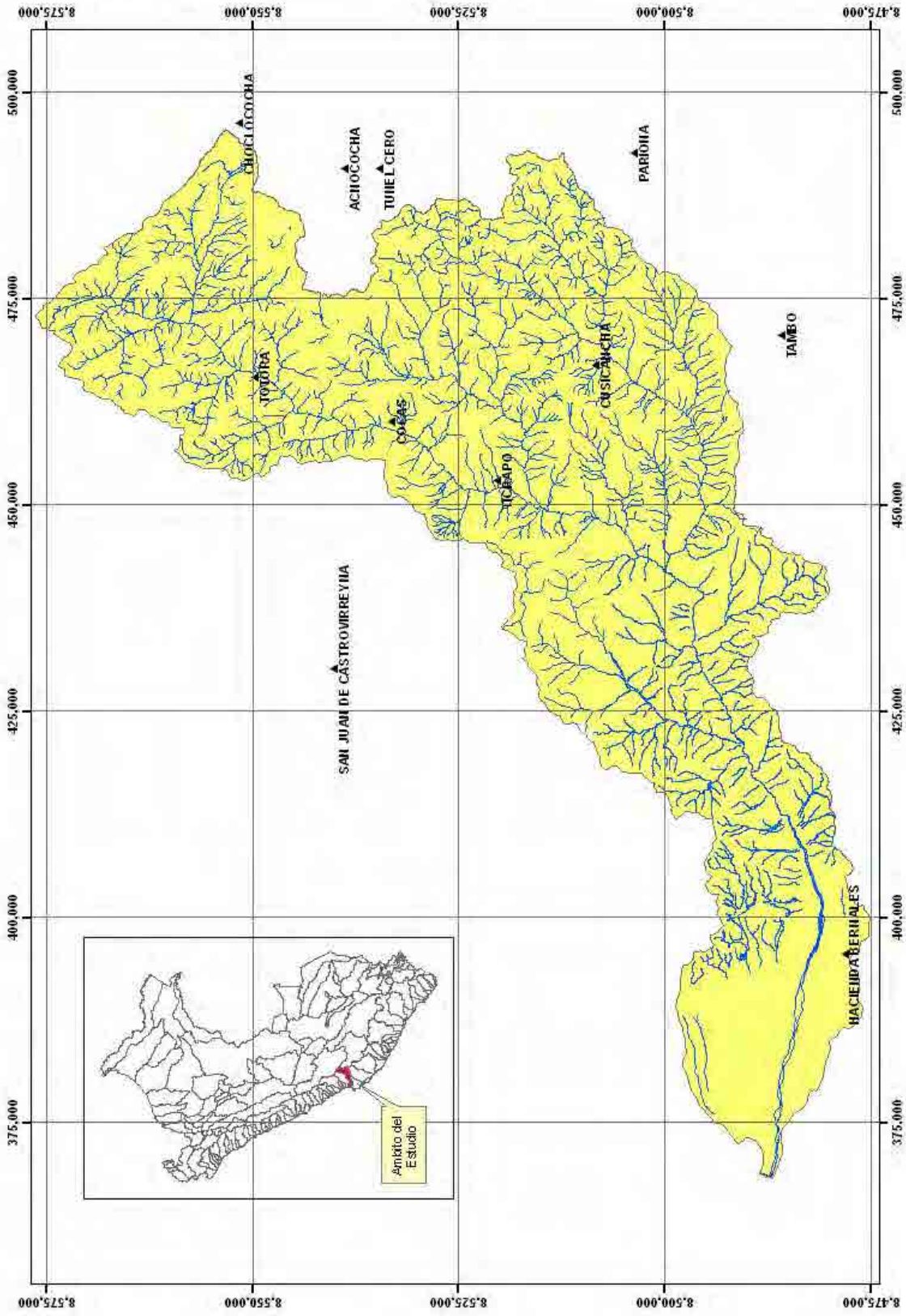


Figure N° 4.1. Rainfall Stations considered for HEC - HMS Software application

Each maximum annual rainfall series for all twelve (12) 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 Gaussian

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

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

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 distributive of x is the probability distribution as log-normal probability function log-normal $f(x)$ is represented as:

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

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

Where:

μ_y, σ_y = Are the mean and standard deviation of the natural logarithm of x , i.e. $\ln(x)$, 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 x_0 , before taking logarithms, we can get that is normally distributed.

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

$$f(x) = \frac{1}{(x - x_0)\sigma_y\sqrt{2\pi}} \text{EXP} \left\{ -\frac{1}{2} \left[\frac{\ln(x - x_0) - \mu_y}{\sigma_y} \right]^2 \right\}$$

To $x_0 \leq x < \infty$

Where:

x_0 = 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:

$0 \leq x < \infty$

$0 < \gamma < \infty$

$0 < \beta < \infty$

As:

γ = Shape parameter (+)

β = Scale Parameter (+)

$\Gamma(\gamma)$ = Complete gamma function, defined as:

$$\Gamma(\gamma) = \int_0^{\infty} x^{\gamma-1} e^{-x} dx, \text{ which converges if } \gamma > 0$$

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:

$$f(x) = \frac{(x - x_0)^{\gamma-1} e^{-\frac{(x-x_0)}{\beta}}}{\beta^{\gamma} \Gamma_{\gamma}}$$

To

$$x_0 \leq x < \infty$$

$$-\infty < x_0 < \infty$$

$$0 < \beta < \infty$$

$$0 < \gamma < \infty$$

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 N° 4.3. Determination Coefficient for each Distribution Function and for each Rainfall Station

Station	Determination Coefficient for Each Distribution Function				
	Log Pearson III	GEV	SQRT	Gumbel	Log-Normal
Acnocochoa	0.88	0.97	0.91	0.90	0.87
Choclocochoa	0.80	0.95	0.88	0.90	0.93
Cocas	0.82	0.95	0.89	0.93	0.92
Cusicancha	0.88	0.93	0.92	0.92	0.90
Pariona	0.93	0.94	0.90	0.89	0.89
San Juan de Castrovirreyna	0.93	0.95	0.94	0.93	0.89
Tambo	0.95	0.96	0.92	0.92	0.91
Ticrapo	0.96	0.96	0.94	0.92	0.89
Totora	0.90	0.93	0.90	0.89	0.91
Tunel Cero	0.92	0.93	0.90	0.92	0.90
Hacienda Bernales	0.89	0.93	0.88	0.90	0.89
Huamani	0.83	0.90	0.88	0.88	0.87

Table N° 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
ACNOCOCHA	27.0	30.0	32.0	34.0	35.0	36.0	37.0
CHOCLOCOCHA	30.0	43.0	51.0	60.0	66.0	71.0	76.0
COCAS	22.0	30.0	34.0	38.0	40.0	42.0	43.0
CUSICANCHA	19.0	26.0	29.0	33.0	35.0	37.0	39.0
HACIENDA BERNALES	0.0	1.0	3.0	6.0	11.0	19.0	34.0
HUAMANI	2.0	7.0	13.0	25.0	39.0	61.0	93.0
PARIONA	33.0	40.0	43.0	46.0	48.0	49.0	50.0
SAN JUAN DE CASTROVIRREYNA	17.0	23.0	29.0	36.0	42.0	49.0	56.0
TAMBO	26.0	35.0	40.0	46.0	49.0	52.0	55.0
TICRAPO	20.0	31.0	37.0	45.0	50.0	55.0	60.0
TOTORA	24.0	29.0	32.0	36.0	38.0	40.0	42.0
TUNEL CERO	29.0	36.0	41.0	48.0	54.0	61.0	67.0

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 (Letrayoc Station), methodology and results are described under 4.2.2.4.

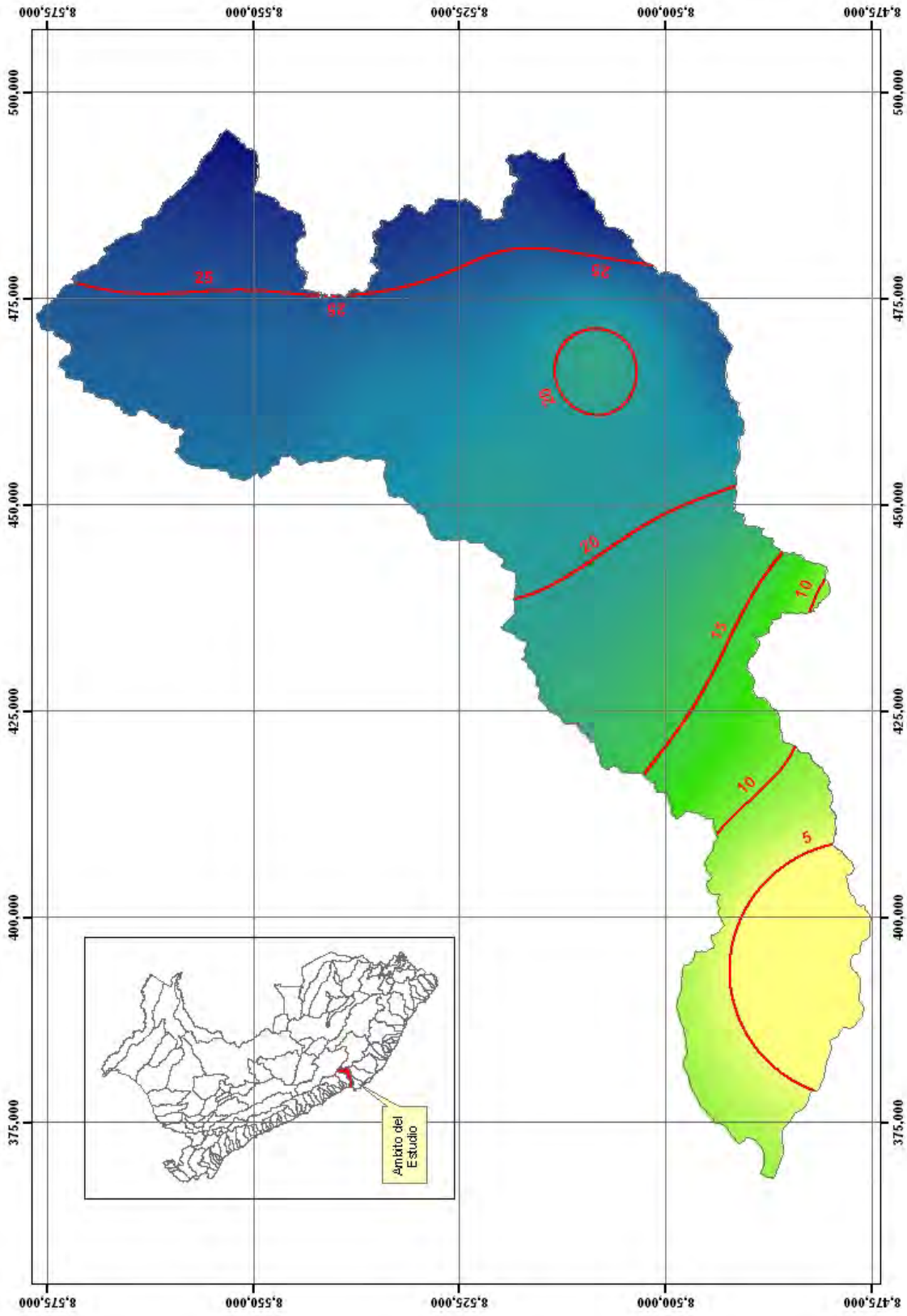


Figure N° 4.2. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin

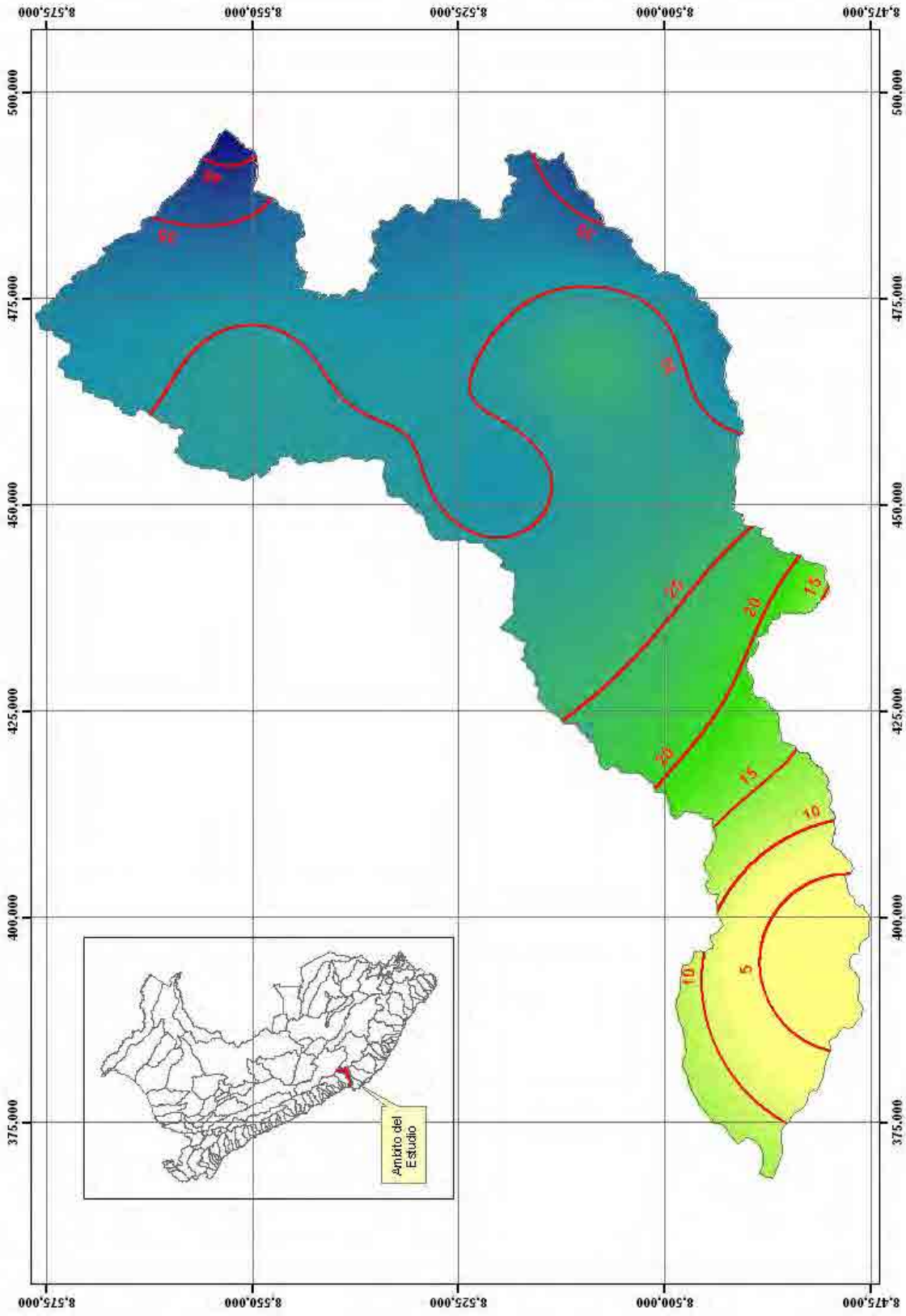


Figure N° 4.3. Isohyets for the 5 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin

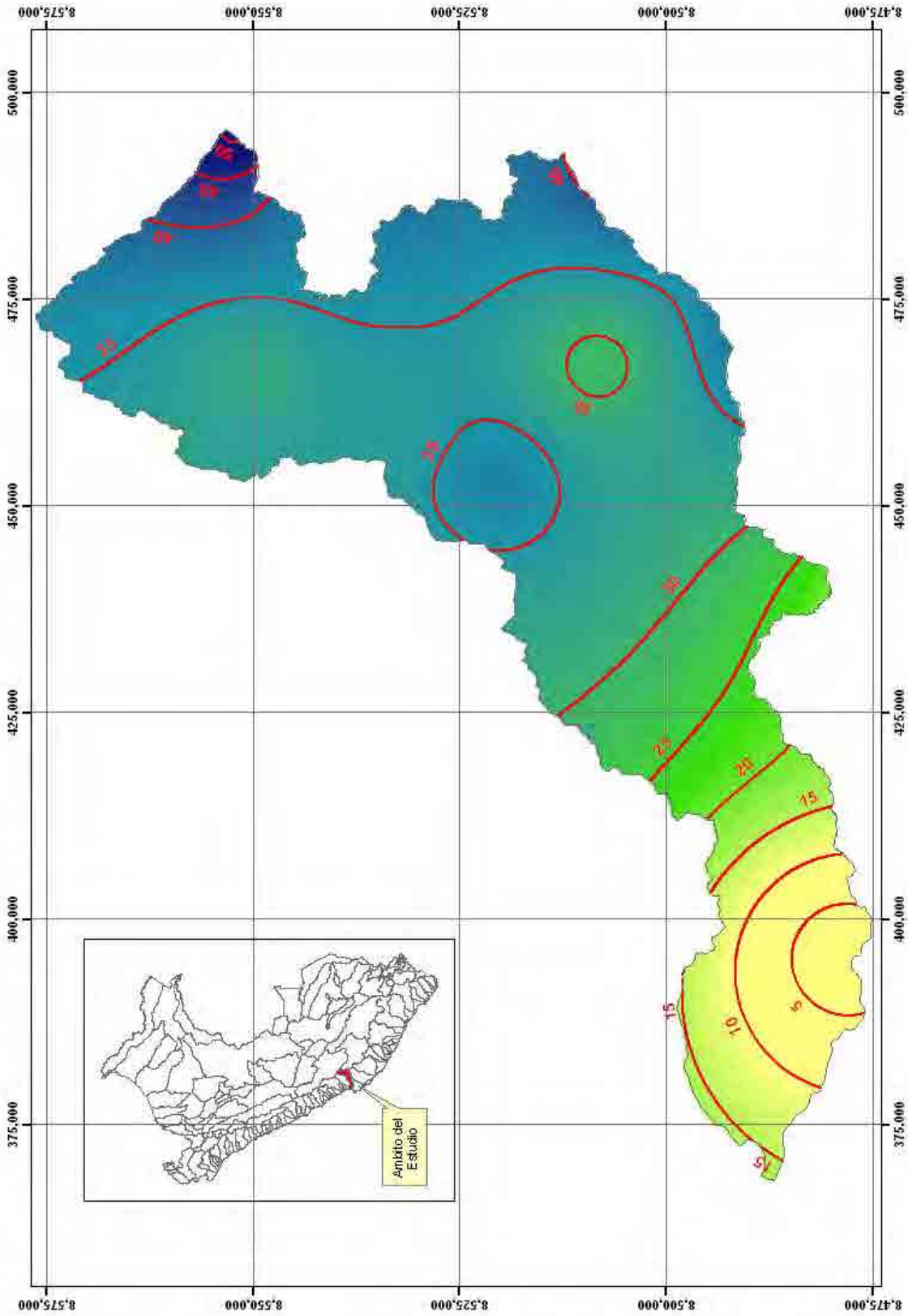


Figure N° 4.4. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin

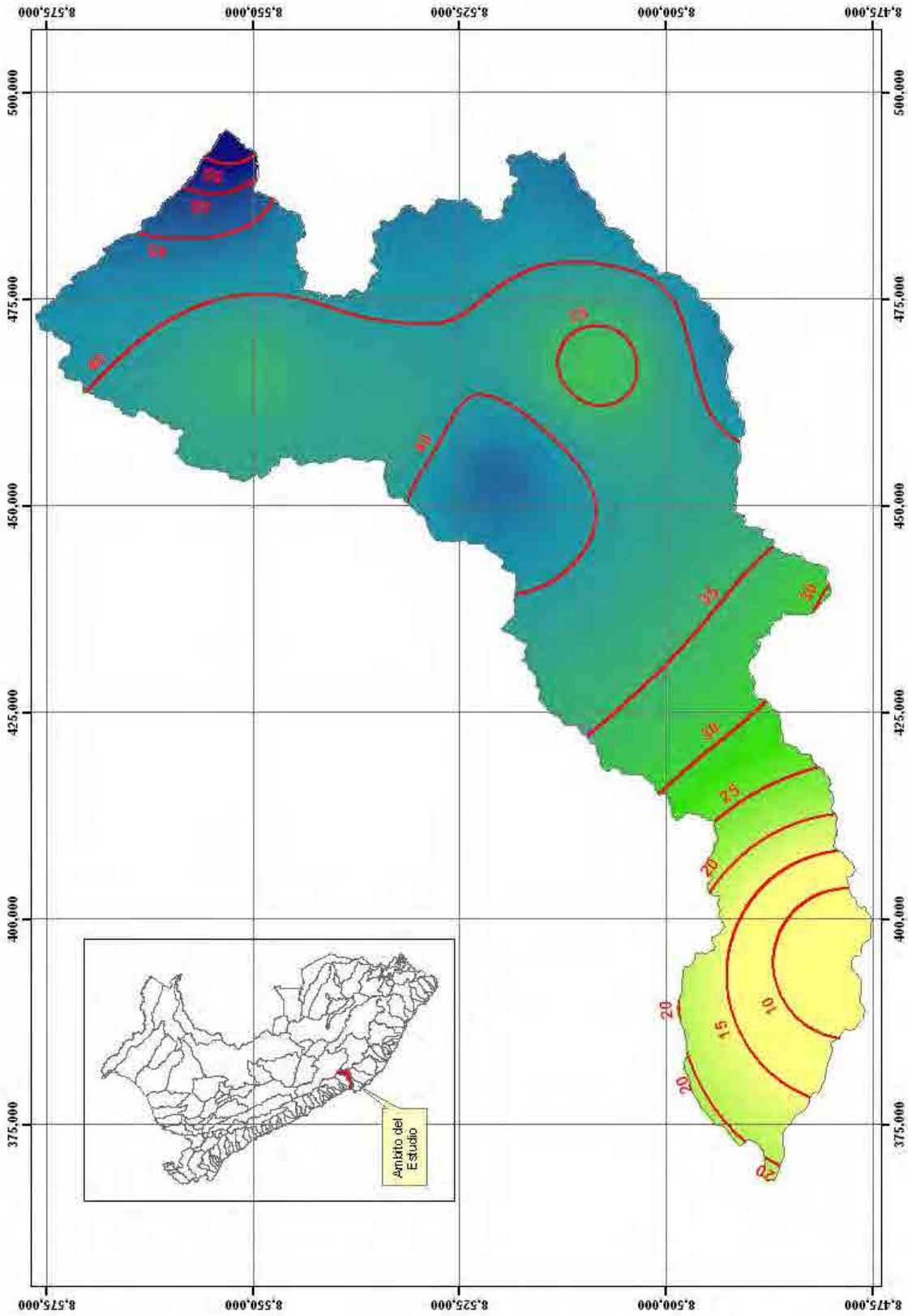


Figure N° 4.5. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin

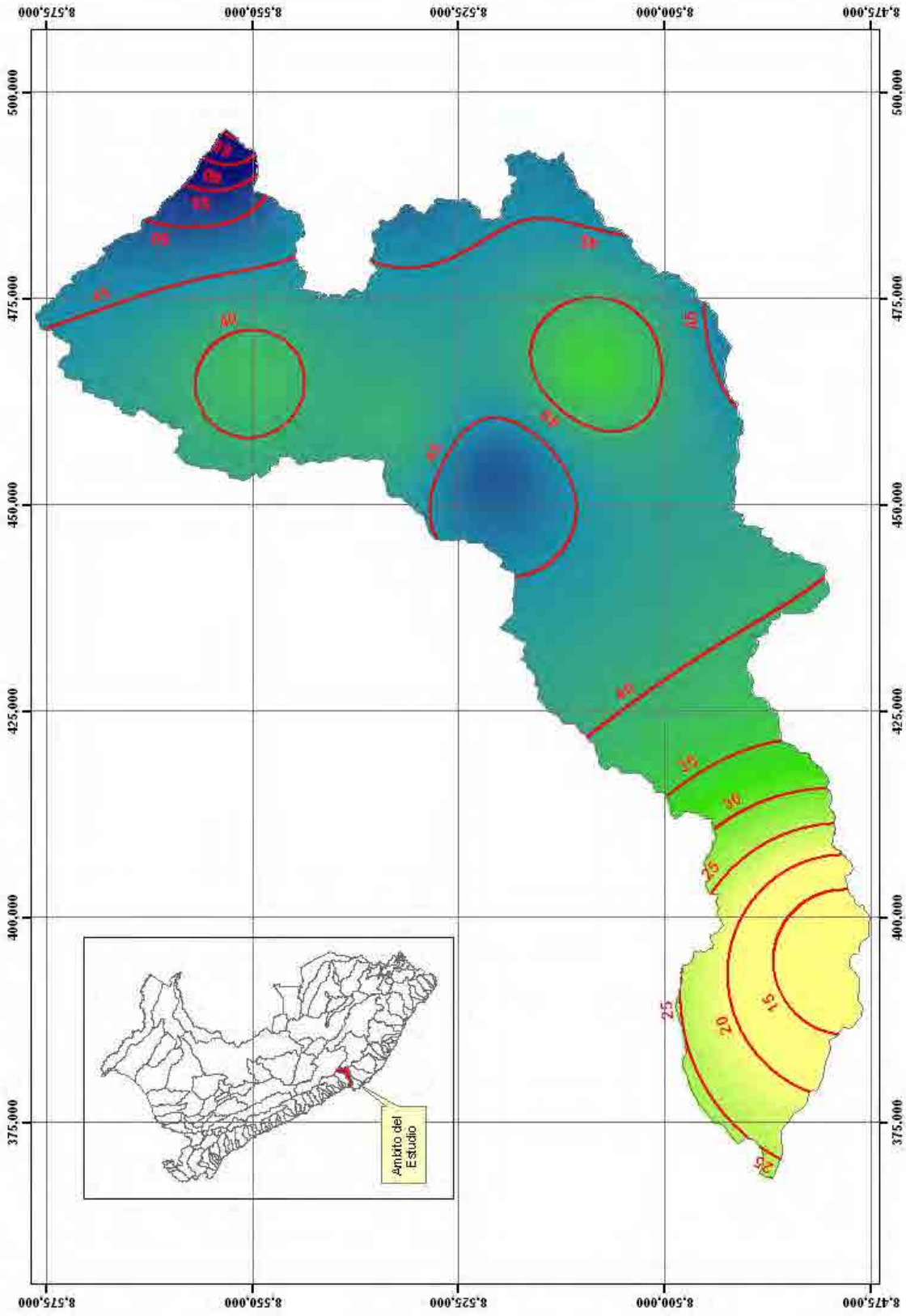


Figure N° 4.6. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin

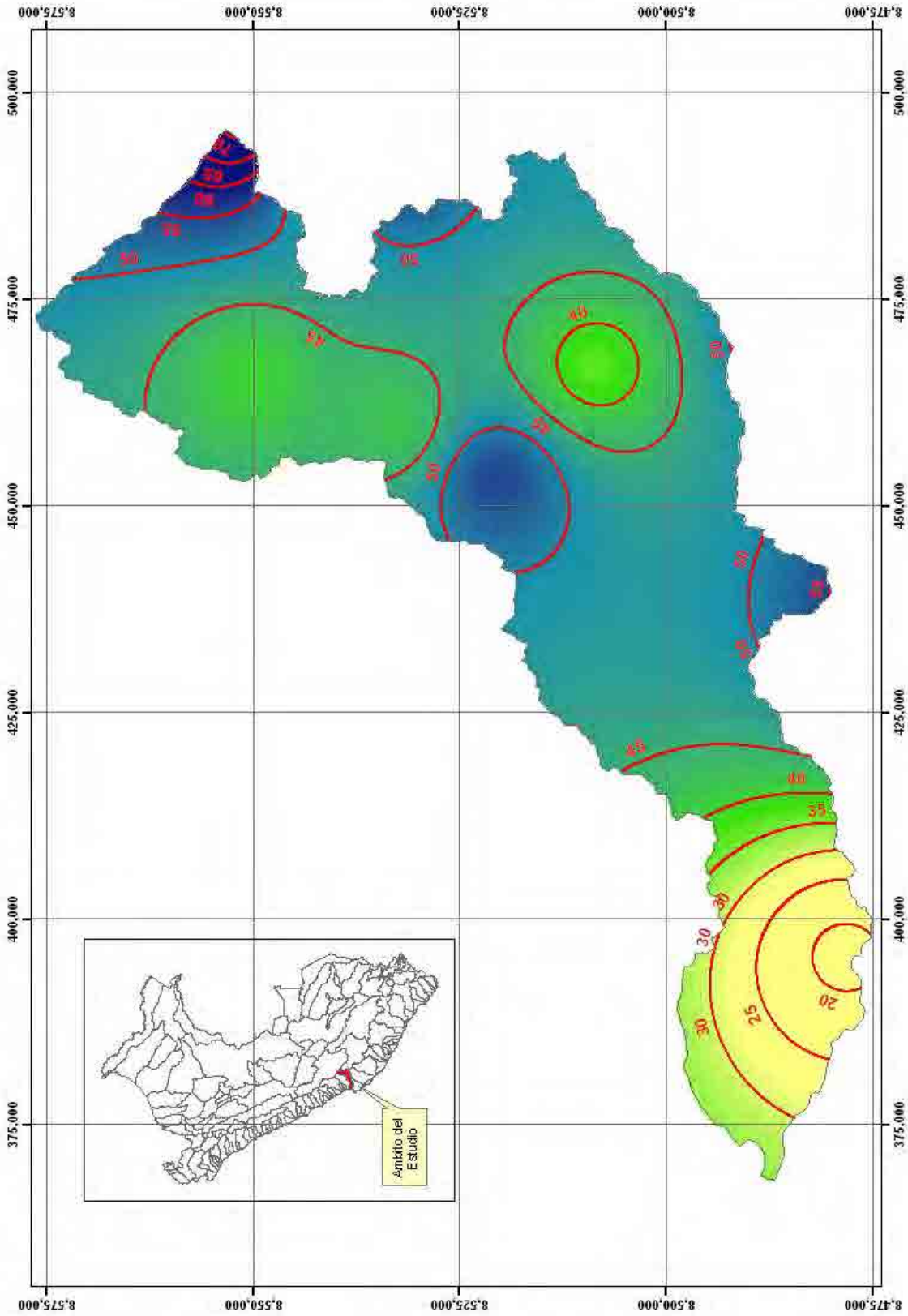


Figure N° 4.7. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Pisco Basin

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

Isohyets 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 (Letrayoc Station) for each return period. Results are shown in Table N° 4.5.

Table N° 4.5. Maximum Areal 24- Hours Rainfall at the Base Point (Letrayoc Station) for each Return Period

Return Period “T” [Years]	Maximum Areal 24 Hours Rainfall [mm]
2	25.00
5	28.90
10	33.23
25	38.78
50	42.59
100	46.92

4.2.2.5 Determination of Maximum 24- Hours Rainfalls for Different Return Period in the Pisco River Subwatersheds

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

Figure N° 4.8 shows the Pisco river subbasins to which it has been estimated maximum rainfall for each return period and for each subbasin. Table N° 4.6 shows the values of rainfall for each subbasin.

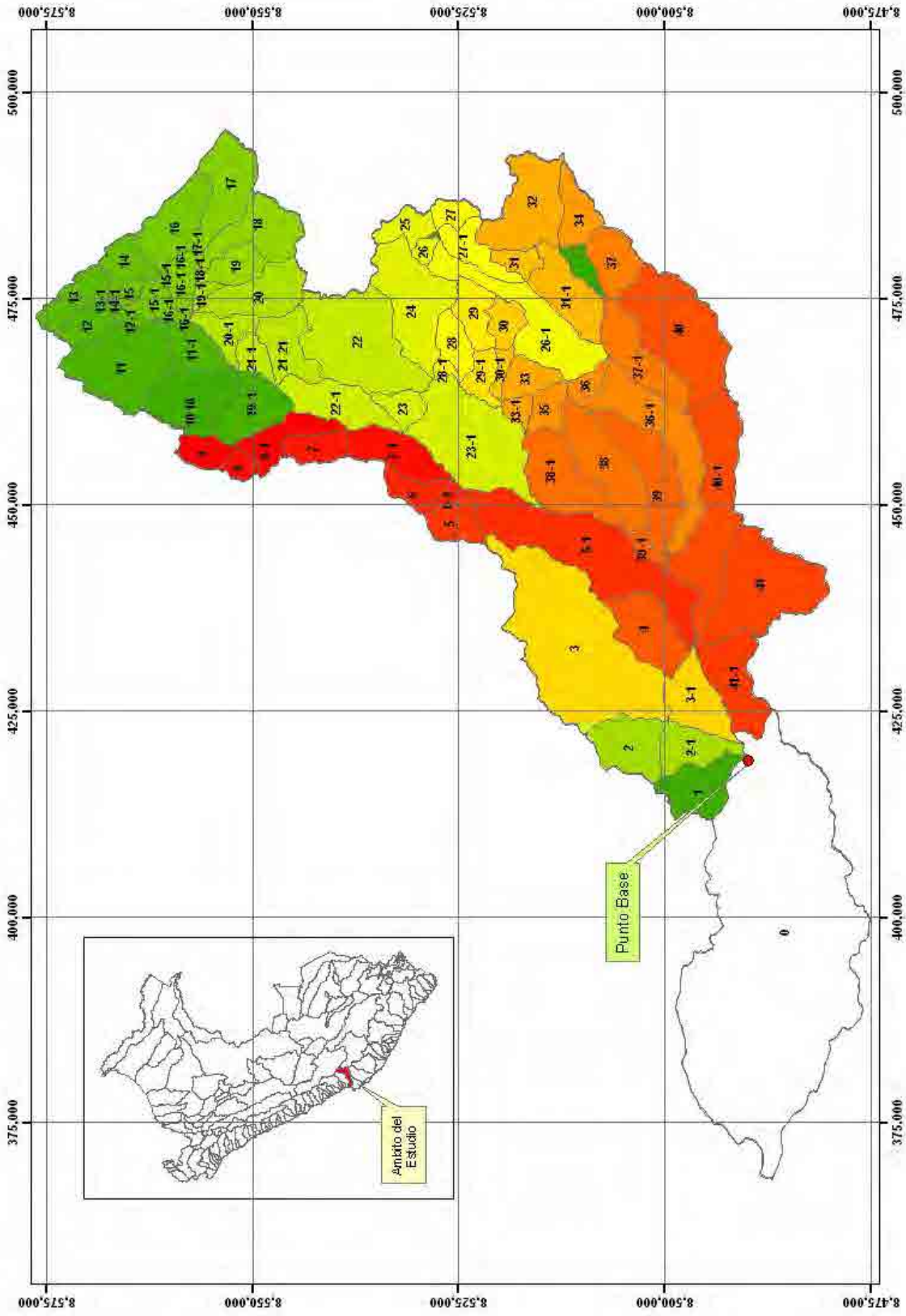


Figure N° 4.8. The Pisco River Subbasin

Table N° 4.6. Rainfall for Different Return Periods in each river Basin of Pisco

SUBCUENCA	AREA [m²]	PERIODO DE RETORNO T [AÑOS]					
		PT_2	PT_5	PT_10	PT_25	PT_50	PT_100
0	774,360,000	5.4	8.3	11.2	15.6	21.2	29.5
1	48,731,800	12.5	17.9	22.0	28.1	34.0	42.3
10	69,819,600	23.8	29.7	33.2	37.7	40.2	42.9
10-1	48,920,900	23.8	29.3	32.6	36.8	39.1	41.4
11	95,251,900	24.1	30.7	34.8	39.8	43.0	46.3
11-1	32,178,400	24.2	30.1	33.6	38.2	40.8	43.4
12	24,316,700	24.5	31.6	35.9	41.2	44.7	48.2
12-1	7,599,270	24.6	31.4	35.6	40.8	44.1	47.4
13	34,377,100	24.8	32.1	36.6	42.1	45.7	49.3
13-1	528,564	24.8	32.0	36.4	41.7	45.2	48.7
14	28,835,500	25.5	33.0	37.6	43.2	46.9	50.5
14-1	736,281	24.9	32.0	36.4	41.7	45.2	48.7
15	6,629,310	25.0	32.2	36.5	41.9	45.3	48.8
15-1	23,888,300	24.9	31.7	36.0	41.1	44.4	47.7
16	58,145,800	26.7	35.1	40.3	46.5	50.5	54.4
16-1	22,568,800	25.2	32.3	36.6	41.8	45.1	48.5
17	62,232,400	28.1	37.9	44.0	51.0	55.7	59.9
17-1	969,962	25.8	33.2	37.8	43.2	46.8	50.3
18	56,833,600	26.7	33.8	38.3	43.7	47.3	50.8
18-1	1,282,460	25.4	32.5	36.8	42.0	45.4	48.7
19	26,733,300	25.7	32.6	36.9	42.1	45.4	48.8
19-1	6,671,040	24.9	31.6	35.6	40.6	43.7	46.8
2	52,919,500	16.1	22.5	27.0	33.2	38.6	45.6
20	56,155,800	25.0	31.3	35.2	40.0	43.0	46.1
20-1	26,253,900	24.2	30.0	33.5	37.9	40.4	43.0
21	43,743,800	24.0	29.9	33.3	37.7	40.1	42.7
2-1	38,110,400	14.0	19.9	24.3	30.7	36.6	44.8
21-1	17,536,300	24.0	29.2	32.3	36.5	38.6	40.7
22	133,682,000	23.5	30.6	34.6	39.3	42.1	45.0
22-1	54,257,600	22.8	29.9	33.7	38.0	40.4	42.8
23	19,208,200	22.0	30.0	34.1	38.3	40.5	42.7
23-1	133,886,000	20.9	30.3	35.4	41.8	45.7	49.6
24	92,053,600	24.5	31.5	35.6	40.6	43.9	47.3
25	21,774,100	27.0	33.4	37.4	42.7	46.6	51.0
26	7,607,610	26.1	32.7	36.8	41.9	45.6	49.6
26-1	92,540,400	21.8	29.0	32.6	37.3	40.1	43.0
27	14,973,200	26.7	33.3	37.4	42.7	46.5	50.7
27-1	30,506,500	25.3	32.2	36.3	41.3	44.8	48.5
28	25,073,400	22.8	30.4	34.6	39.7	42.8	46.1
28-1	5,232,780	22.3	30.2	34.4	39.4	42.4	45.5
29	30,528,800	23.3	30.7	34.8	39.9	43.1	46.5
29-1	20,459,100	21.8	29.9	34.2	39.6	42.9	46.3
3	256,335,000	18.8	26.4	31.3	37.6	42.4	48.1
30	21,035,900	22.5	30.0	33.9	38.9	42.0	45.2
30-1	8,745,420	21.5	29.5	33.8	39.1	42.3	45.6
31	15,308,000	24.5	31.7	35.6	40.4	43.6	46.9
3-1	52,396,500	15.0	21.3	25.9	32.5	38.5	46.8
31-1	56,037,100	22.3	29.6	33.2	37.8	40.5	43.3
32	81,067,800	26.6	33.7	37.5	42.2	45.3	48.5
33	25,244,000	20.8	28.7	32.6	37.7	40.7	43.9
33-1	10,375,600	20.8	29.5	34.1	40.0	43.6	47.3
34	32,336,100	27.7	34.8	38.4	42.6	45.4	47.9
35	21,253,800	20.4	28.5	32.6	37.9	41.1	44.4
36	13,088,900	19.4	26.5	29.7	33.9	36.1	38.3
36-1	95,476,300	20.3	27.9	31.8	37.0	40.4	44.1
37	39,443,900	24.9	32.2	35.9	40.3	43.1	45.8
37-1	58,919,100	20.6	28.0	31.5	36.1	38.7	41.4
38	78,763,500	20.4	28.5	32.8	38.5	42.1	46.0
38-1	73,087,400	20.4	29.6	34.6	41.2	45.4	49.7
39	73,029,900	20.3	28.1	32.3	38.0	41.7	45.9
39-1	10,934,800	19.6	27.4	32.1	38.3	42.8	48.1
4	59,721,300	18.0	25.2	29.9	36.4	41.5	48.0
40	124,547,000	23.0	30.7	34.7	39.8	42.8	45.9
40-1	128,130,000	19.7	27.2	31.8	38.0	42.6	48.3
41	122,639,000	14.5	21.1	26.0	33.6	40.7	50.7
41-1	63,616,900	13.8	20.0	24.6	31.8	38.5	48.0
5	28,398,700	20.5	30.0	35.3	42.1	46.5	51.0
5-1	168,315,000	19.6	28.3	33.3	40.0	44.6	49.8
6	21,153,700	21.3	29.9	34.6	40.3	43.8	47.4
6-1	8,745,420	20.7	30.1	35.4	42.0	46.2	50.5
7	24,532,800	22.6	29.7	33.7	38.3	41.0	43.9
7-1	47,267,500	21.8	30.0	34.3	39.0	41.7	44.4
8	10,938,500	23.0	29.4	33.2	38.0	40.9	44.0
8-1	37,025,500	23.1	29.5	33.3	37.9	40.5	43.3
9	20,817,100	23.3	29.5	33.3	38.0	40.9	43.9

4.2.3 Maximum Daily Discharge Analysis

For the analysis of Maximum Daily Discharges of River Pisco, the information of the hydrometric station Letrayoc has been used. This station has a contribution area of 3096 km². Figure 3.21 shows its location in the river Pisco catchment.

The Directorate General of Water Infrastructure (DGIH) of the Ministry of Agriculture has provided information on annual maximum daily discharge of Letrayoc station whose values are shown in Table N° 4.7.

Table N° 4.7. Maximum Daily Discharge of station Letrayoc, Pisco River (m³/s)

Nº	Año	Caudal Maximo Diario (m ³ /s)	Nº	Año	Caudal Maximo Diario (m ³ /s)
1	1933	227.50	39	1971	194.45
2	1934	264.50	40	1972	509.87
3	1935	311.00	41	1973	293.62
4	1936	360.50	42	1974	194.68
5	1937	956.03	43	1975	141.88
6	1938	253.70	44	1976	237.62
7	1939	328.67	45	1977	231.26
8	1940	155.34	46	1978	80.33
9	1941	212.25	47	1979	213.13
10	1942	326.79	48	1980	91.23
11	1943	301.93	49	1981	252.00
12	1944	295.05	50	1982	274.00
13	1945	250.01	51	1983	273.00
14	1946	528.14	52	1984	485.65
15	1947	144.09	53	1985	200.50
16	1948	765.10	54	1986	355.00
17	1949	148.26	55	1987	146.20
18	1950	156.33	56	1988	369.50
19	1951	289.09	57	1989	272.50
20	1952	208.05	58	1990	49.38
21	1953	427.20	59	1991	325.00
22	1954	536.64	60	1992	47.75
23	1955	403.42	61	1993	118.00
24	1956	330.99	62	1994	312.50
25	1957	256.19	63	1995	354.37
26	1958	169.35	64	1996	190.00
27	1959	378.26	65	1997	150.00
28	1960	312.85	66	1998	800.00
29	1961	272.04	67	1999	355.00
30	1962	423.06	68	2000	215.00
31	1963	255.85	69	2001	240.00
32	1964	238.45	70	2002	300.00
33	1965	162.44	71	2003	176.25
34	1966	710.02	72	2004	215.00
35	1967	521.91	73	2005	137.50
36	1968	189.11	74	2006	350.00
37	1969	314.07	75	2007	250.00
38	1970	454.31	76	2008	300.00

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

Table N° 4.8. Maximum Daily Discharges for each Return Period at te Station Letrayoc, Pisco River (m³/s)

Return Period (Años)	Maximum Daily Discharge
2	268.91
5	398.42
10	500.18
25	648.41
50	774.26
100	914.06

4.2.4 Simulation Model, Application of HEC-HMS Software

4.2.4.1 Hydrological Model

Time of Concentration and Travel Time

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

Concentration time (Tc) with the Bransby-Williams formula

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

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 N° 4.9. Concentration and Travel Times for the Base Point (station Letrayoc)

L =	113.40	Km
H =	4,128.00	Mts
Tc =	9.09	Hrs
Tv =	5.46	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 exceeds the time of concentration of 9.09 hours calculated in the previous item, it indicates that the peak values to be estimated in the hydrometric station Letrayoc will correspond to the simultaneous contribution of runoff of the the whole catchement of the river Pisco until the hydrometric station Letrayoc.

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 Letrayoc.

Dick and Peschke equation :

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

Where:

Pd = Maximum rainfall for a duration d

Pd₂₄= 24 – hour maximum rainfall

Tc= Concentration time (minutes)

Table N° 4.10. Maximum Rainfall according to Dick - Peschke

T [Años]	Pp Areal Max 24 Horas [mm]	Pp Max, [mm]
2	25.00	19.56
5	28.90	22.62
10	33.23	26.00
25	38.78	30.35
50	42.59	33.33

100	46.92	36.72
-----	-------	-------

The maximum daily rainfall for return periods of 2, 5, 10, 25, 50, and 100 years are 25, 29, 33, 39, 43, and 47 mm, respectively, and for a duration of 10 hour storm are 20, 23, 26, 30, 33 y 37 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 N° 4.11.

Table N° 4.11. Hyetograph for different Return Periods

Return Period [Years]	Hour										PP total [mm]
	1	2	3	4	5	6	7	8	9	10	
2	1	2	3	4	3	2	2	2	1	1	19.56
5	1	2	3	4	3	3	2	2	1	1	22.62
10	1	2	3	5	4	3	3	2	2	1	26.00
25	2	3	4	6	4	4	3	2	2	1	30.35
50	2	3	4	6	5	4	3	3	2	1	33.33
100	2	3	5	7	5	4	4	3	2	1	36.72

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 N° 4.12 shows the CN as a function of hydrologic soil group and land uses.

Table N° 4.12. 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	
Espacios 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
Parqueaderos pavimentados, techos, accesos, etc.	4000	20	51	68	79	84
	Parqueaderos pavimentados, techos, accesos, etc.		98	98	98	98
	pavimentados con cunetas y alcantarillados		98	98	98	98
	Calles y carreteras	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 82.4 was adopted for Pisco Basin. In Table 4.13 the estimated percentages of land use with their respective values of curves of number for river Pisco are shown.

Table N° 4.13. Estimated Value of Curve Number (CN) for initial calibración of HEC-HMS Model

Uso del Suelo		%	CN
Tierras Cultivadas	Sin Tratamiento de Consevacion	35.00	88.0
	Con Tratamiento de Consevacion	10.00	78.0
Pastizales	Condicones Pobres	20.00	86.0
	Condicones Optimas	10.00	74.0
Praderas		5.00	71.0
Bosques	Troncos delgados	10.00	77.0
	Cubierta Buena	5.00	70.0
Area comerciales		0.50	94.0
Zonas Industriales		0.50	91.0
Zonas residenciales		0.50	81.0
Calles y carreteras	Pavimentadas con cunetas	0.50	98.0
	Grava	1.00	89.0
	Tierra	2.00	87.0
Curva de Numero de la Cuenca		100.00	82.4

After the process of calibration of the model HEC-HMS, this value was adjusted to 84.

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"). **Letrayoc 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 3096 Km² basin area is taken into account as basic information. Due to the small averages discharges generally observed in river Pisco it was assumed that there was no base flow previous to the occurrence of the flood flows.

Meteorological Model. Based on calculation under N° 3.2 Pluviometric 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 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. Approximating the Lag Time as 0.6 times the Concentration Time, a lag time of 5.45 hours and a minimum computational time of 1.68 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 84 was obtained.

Below, Figure N° 4.9 shows the watershed considered by HEC-HMS model for the simulation. Figures N° 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.

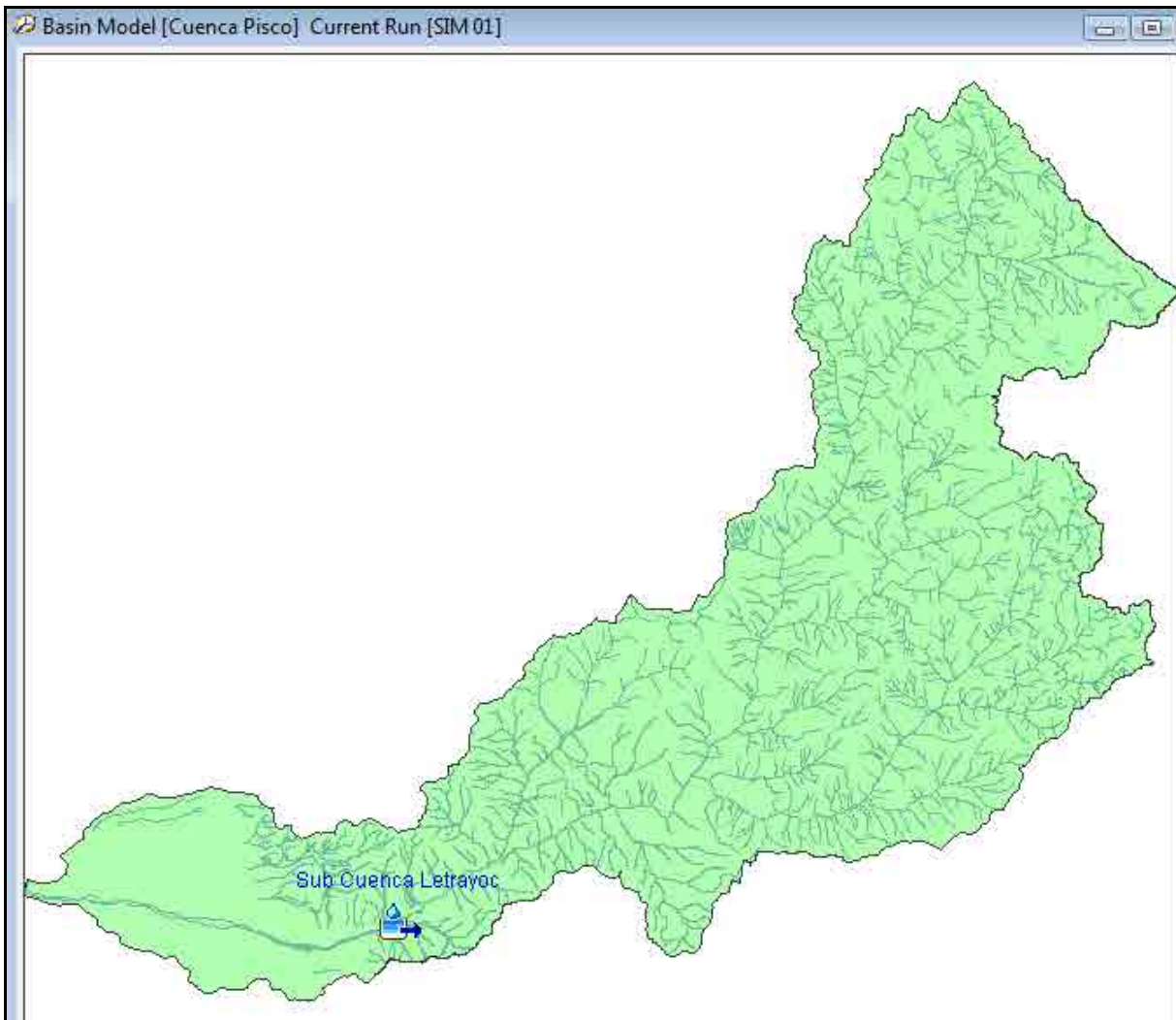


Figure N° 4.9. Model Pisco River Basin in the HEC-HMS Software

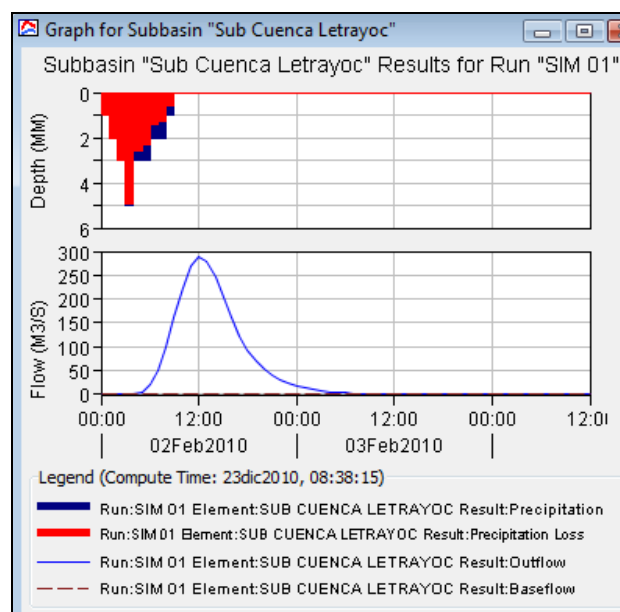


Figure N° 4.10. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period of 2 years

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 24 hours after it got started.

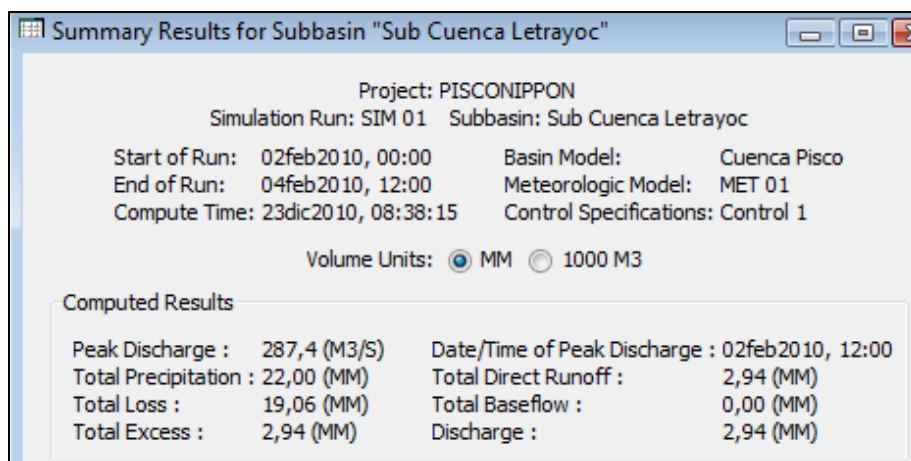


Figure N° 4.11. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 2 years

In Figure N° 4.11 is the maximum flow is calculated for a return period of 2 years of 213.8 m³/s. The maximum discharge spends approximately 12 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 N° 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	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	3,98	0,02	0,2
02-Feb-10	05:00	3,00	2,69	0,31	3,1
02-Feb-10	06:00	2,00	1,62	0,38	12,0
02-Feb-10	07:00	2,00	1,49	0,51	31,2
02-Feb-10	08:00	2,00	1,39	0,61	64,8
02-Feb-10	09:00	1,00	0,66	0,34	109,2
02-Feb-10	10:00	0,00	0,00	0,00	155,8
02-Feb-10	11:00	0,00	0,00	0,00	194,3
02-Feb-10	12:00	0,00	0,00	0,00	213,8
02-Feb-10	13:00	0,00	0,00	0,00	210,8
02-Feb-10	14:00	0,00	0,00	0,00	190,2
02-Feb-10	15:00	0,00	0,00	0,00	160,3
02-Feb-10	16:00	0,00	0,00	0,00	127,5

02-Feb-10	17:00	0,00	0,00	0,00	97,0
02-Feb-10	18:00	0,00	0,00	0,00	72,7
02-Feb-10	19:00	0,00	0,00	0,00	55,4
02-Feb-10	20:00	0,00	0,00	0,00	42,5
02-Feb-10	21:00	0,00	0,00	0,00	32,6
02-Feb-10	22:00	0,00	0,00	0,00	24,8
02-Feb-10	23:00	0,00	0,00	0,00	18,8
03-Feb-10	00:00	0,00	0,00	0,00	14,3
03-Feb-10	01:00	0,00	0,00	0,00	10,9
03-Feb-10	02:00	0,00	0,00	0,00	8,3
03-Feb-10	03:00	0,00	0,00	0,00	6,4
03-Feb-10	04:00	0,00	0,00	0,00	4,9
03-Feb-10	05:00	0,00	0,00	0,00	3,7
03-Feb-10	06:00	0,00	0,00	0,00	2,9
03-Feb-10	07:00	0,00	0,00	0,00	2,2
03-Feb-10	08:00	0,00	0,00	0,00	1,7
03-Feb-10	09:00	0,00	0,00	0,00	1,3
03-Feb-10	10:00	0,00	0,00	0,00	0,8
03-Feb-10	11:00	0,00	0,00	0,00	0,5
03-Feb-10	12:00	0,00	0,00	0,00	0,2
03-Feb-10	13:00	0,00	0,00	0,00	0,1
03-Feb-10	14:00	0,00	0,00	0,00	0,0

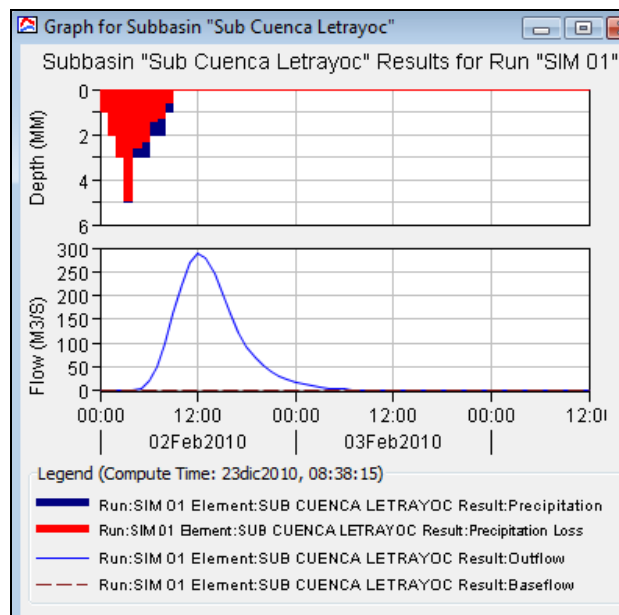


Figure N° 4.12. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period of 5 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 24 hours after it got started.

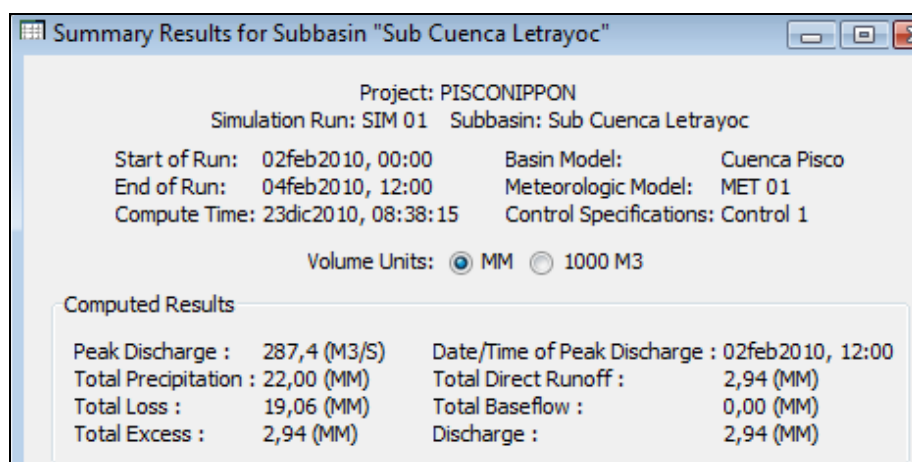


Figure N° 4.13. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 5 years

In Figure N° 4.13 is the maximum flow is calculated for a return period of 5 years of 287.4 m³/s. The maximum discharge spends approximately 12 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	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	4,91	0,09	0,7
02-Feb-10	05:00	3,00	2,58	0,42	5,6
02-Feb-10	06:00	3,00	2,29	0,71	20,7
02-Feb-10	07:00	2,00	1,39	0,61	51,1
02-Feb-10	08:00	2,00	1,29	0,71	100,6
02-Feb-10	09:00	1,00	0,61	0,39	162,8
02-Feb-10	10:00	0,00	0,00	0,00	223,0
02-Feb-10	11:00	0,00	0,00	0,00	268,2
02-Feb-10	12:00	0,00	0,00	0,00	287,4
02-Feb-10	13:00	0,00	0,00	0,00	278,0
02-Feb-10	14:00	0,00	0,00	0,00	247,2
02-Feb-10	15:00	0,00	0,00	0,00	205,4
02-Feb-10	16:00	0,00	0,00	0,00	162,4
02-Feb-10	17:00	0,00	0,00	0,00	123,4
02-Feb-10	18:00	0,00	0,00	0,00	92,9
02-Feb-10	19:00	0,00	0,00	0,00	70,8
02-Feb-10	20:00	0,00	0,00	0,00	54,3
02-Feb-10	21:00	0,00	0,00	0,00	41,6
02-Feb-10	22:00	0,00	0,00	0,00	31,6
02-Feb-10	23:00	0,00	0,00	0,00	24,0
03-Feb-10	00:00	0,00	0,00	0,00	18,3
03-Feb-10	01:00	0,00	0,00	0,00	13,9
03-Feb-10	02:00	0,00	0,00	0,00	10,6

03-Feb-10	03:00	0,00	0,00	0,00	8,1
03-Feb-10	04:00	0,00	0,00	0,00	6,2
03-Feb-10	05:00	0,00	0,00	0,00	4,8
03-Feb-10	06:00	0,00	0,00	0,00	3,7
03-Feb-10	07:00	0,00	0,00	0,00	2,8
03-Feb-10	08:00	0,00	0,00	0,00	2,2
03-Feb-10	09:00	0,00	0,00	0,00	1,6
03-Feb-10	10:00	0,00	0,00	0,00	1,0
03-Feb-10	11:00	0,00	0,00	0,00	0,6
03-Feb-10	12:00	0,00	0,00	0,00	0,3

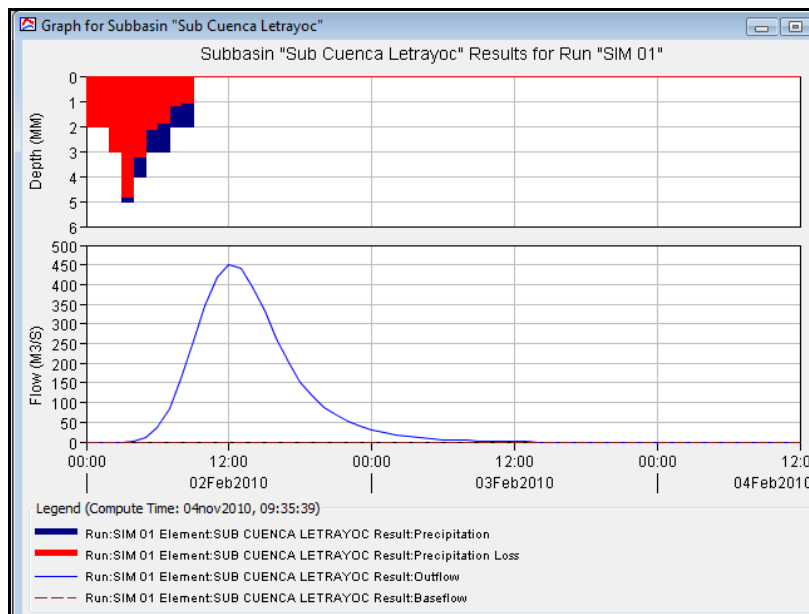


Figure N° 4.14. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period of 10 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 24 hours after it got started.

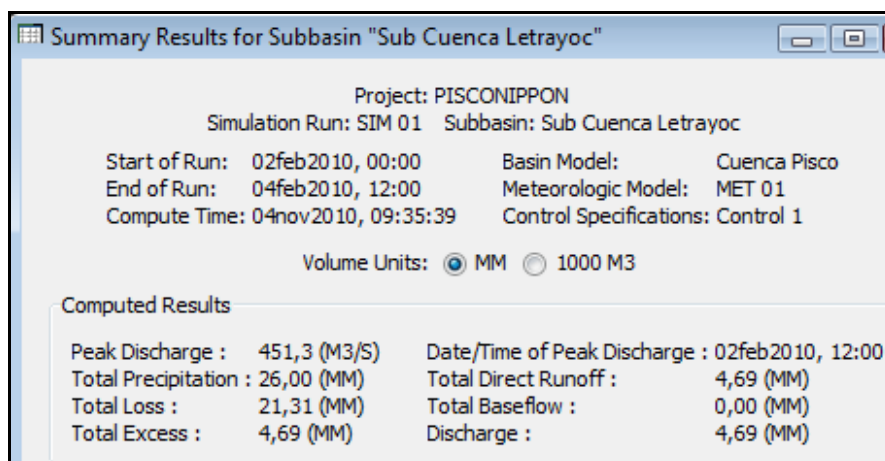


Figure N° 4.15. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 10 years

In Figure N° 4.15 is the maximum flow is calculated for a return period of 10 years of 451.3 m³/s. The maximum discharge spends

approximately 12 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 N° 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	2,00	2,00	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	4,81	0,19	1,6
02-Feb-10	05:00	4,00	3,24	0,76	11,0
02-Feb-10	06:00	3,00	2,12	0,88	35,8
02-Feb-10	07:00	3,00	1,90	1,10	85,1
02-Feb-10	08:00	2,00	1,16	0,84	160,9
02-Feb-10	09:00	2,00	1,09	0,91	254,8
02-Feb-10	10:00	0,00	0,00	0,00	347,0
02-Feb-10	11:00	0,00	0,00	0,00	417,2
02-Feb-10	12:00	0,00	0,00	0,00	451,3
02-Feb-10	13:00	0,00	0,00	0,00	440,5
02-Feb-10	14:00	0,00	0,00	0,00	394,8
02-Feb-10	15:00	0,00	0,00	0,00	331,6
02-Feb-10	16:00	0,00	0,00	0,00	264,0
02-Feb-10	17:00	0,00	0,00	0,00	202,9
02-Feb-10	18:00	0,00	0,00	0,00	152,0
02-Feb-10	19:00	0,00	0,00	0,00	115,7
02-Feb-10	20:00	0,00	0,00	0,00	88,5
02-Feb-10	21:00	0,00	0,00	0,00	67,9
02-Feb-10	22:00	0,00	0,00	0,00	51,6
02-Feb-10	23:00	0,00	0,00	0,00	39,2
03-Feb-10	00:00	0,00	0,00	0,00	29,9
03-Feb-10	01:00	0,00	0,00	0,00	22,7
03-Feb-10	02:00	0,00	0,00	0,00	17,3
03-Feb-10	03:00	0,00	0,00	0,00	13,3
03-Feb-10	04:00	0,00	0,00	0,00	10,2
03-Feb-10	05:00	0,00	0,00	0,00	7,8
03-Feb-10	06:00	0,00	0,00	0,00	6,0
03-Feb-10	07:00	0,00	0,00	0,00	4,6
03-Feb-10	08:00	0,00	0,00	0,00	3,5
03-Feb-10	09:00	0,00	0,00	0,00	2,6
03-Feb-10	10:00	0,00	0,00	0,00	1,7
03-Feb-10	11:00	0,00	0,00	0,00	1,0
03-Feb-10	12:00	0,00	0,00	0,00	0,5
03-Feb-10	13:00	0,00	0,00	0,00	0,2
03-Feb-10	14:00	0,00	0,00	0,00	0,0

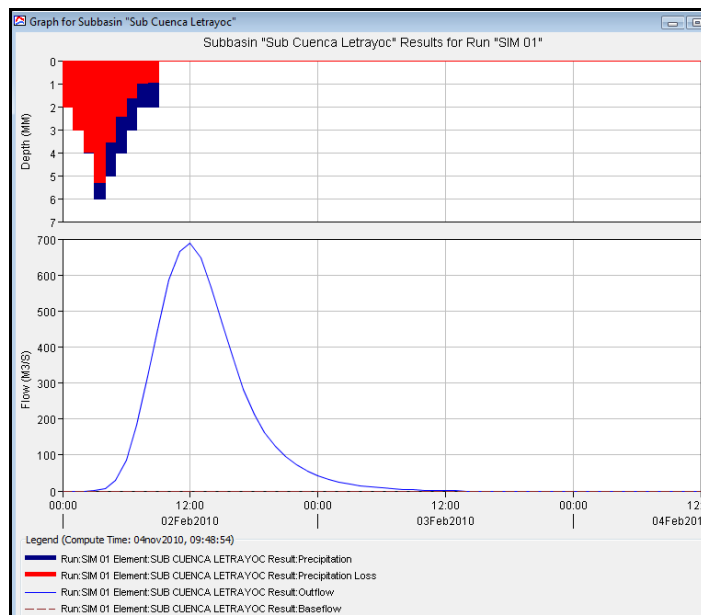


Figure N° 4.16. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period 25 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 24 hours after it got started.

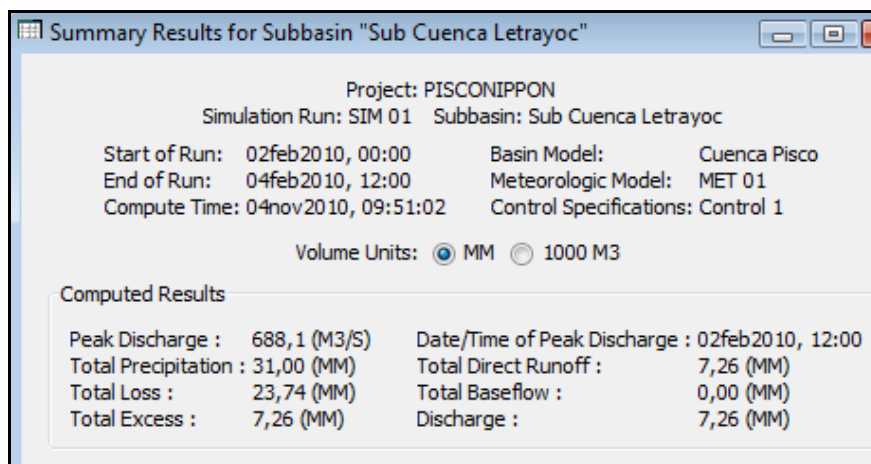


Figure N° 4.17. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 25 years

In Figure N° 4.17 is the maximum flow is calculated for a return period of 25 years of 688.1 m³/s. The maximum discharge spends approximately 12 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 N° 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	5,28	0,72	5,9
02-Feb-10	05:00	5,00	3,54	1,46	29,7
02-Feb-10	06:00	4,00	2,40	1,60	85,4
02-Feb-10	07:00	3,00	1,60	1,40	183,8
02-Feb-10	08:00	2,00	0,99	1,01	317,0
02-Feb-10	09:00	2,00	0,93	1,07	462,1
02-Feb-10	10:00	0,00	0,00	0,00	585,9
02-Feb-10	11:00	0,00	0,00	0,00	665,1
02-Feb-10	12:00	0,00	0,00	0,00	688,1
02-Feb-10	13:00	0,00	0,00	0,00	648,7
02-Feb-10	14:00	0,00	0,00	0,00	566,4
02-Feb-10	15:00	0,00	0,00	0,00	466,6
02-Feb-10	16:00	0,00	0,00	0,00	368,5
02-Feb-10	17:00	0,00	0,00	0,00	282,9
02-Feb-10	18:00	0,00	0,00	0,00	212,8
02-Feb-10	19:00	0,00	0,00	0,00	162,1
02-Feb-10	20:00	0,00	0,00	0,00	123,9
02-Feb-10	21:00	0,00	0,00	0,00	94,9
02-Feb-10	22:00	0,00	0,00	0,00	72,1
02-Feb-10	23:00	0,00	0,00	0,00	54,8
03-Feb-10	00:00	0,00	0,00	0,00	41,8
03-Feb-10	01:00	0,00	0,00	0,00	31,8
03-Feb-10	02:00	0,00	0,00	0,00	24,2
03-Feb-10	03:00	0,00	0,00	0,00	18,6
03-Feb-10	04:00	0,00	0,00	0,00	14,2
03-Feb-10	05:00	0,00	0,00	0,00	10,9
03-Feb-10	06:00	0,00	0,00	0,00	8,4
03-Feb-10	07:00	0,00	0,00	0,00	6,4
03-Feb-10	08:00	0,00	0,00	0,00	4,8
03-Feb-10	09:00	0,00	0,00	0,00	3,4
03-Feb-10	10:00	0,00	0,00	0,00	2,1
03-Feb-10	11:00	0,00	0,00	0,00	1,2
03-Feb-10	12:00	0,00	0,00	0,00	0,6
03-Feb-10	13:00	0,00	0,00	0,00	0,2
03-Feb-10	14:00	0,00	0,00	0,00	0,0

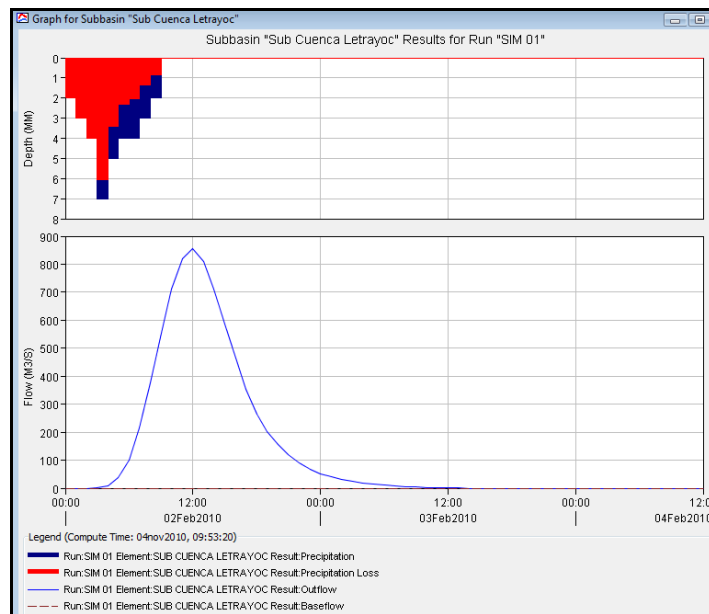


Figure N° 4.18. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period 50 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 22 hours after it got started.

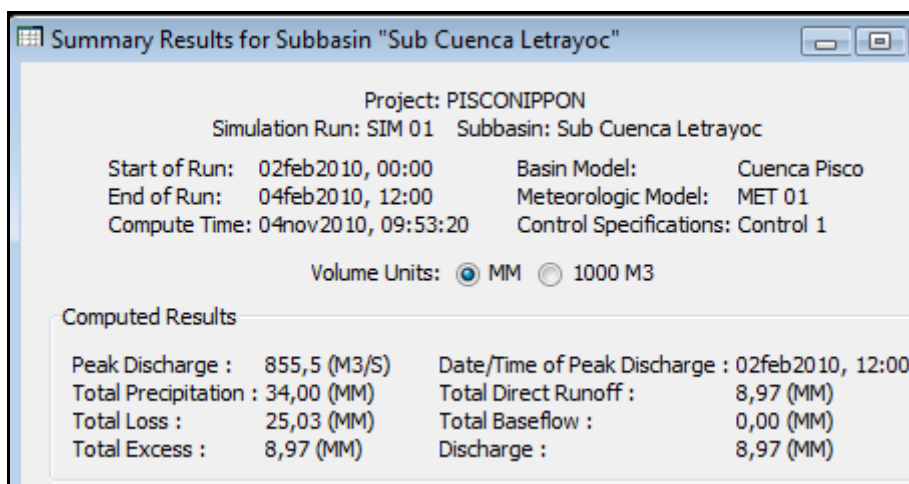


Figure N° 4.19. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 50 years

In Figure N° 4.19 is the maximum flow is calculated for a return period of 50 years of 855.5 m³/s. The maximum discharge spends approximately 12 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 N° 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	4,00	4,00	0,00	0,0
02-Feb-10	04:00	7,00	6,05	0,95	7,9
02-Feb-10	05:00	5,00	3,41	1,59	36,7
02-Feb-10	06:00	4,00	2,32	1,68	101,3
02-Feb-10	07:00	4,00	2,04	1,96	216,6
02-Feb-10	08:00	3,00	1,37	1,63	375,1
02-Feb-10	09:00	2,00	0,85	1,15	552,0
02-Feb-10	10:00	0,00	0,00	0,00	712,0
02-Feb-10	11:00	0,00	0,00	0,00	820,8
02-Feb-10	12:00	0,00	0,00	0,00	855,5
02-Feb-10	13:00	0,00	0,00	0,00	810,0
02-Feb-10	14:00	0,00	0,00	0,00	710,6
02-Feb-10	15:00	0,00	0,00	0,00	587,7
02-Feb-10	16:00	0,00	0,00	0,00	463,2
02-Feb-10	17:00	0,00	0,00	0,00	353,6
02-Feb-10	18:00	0,00	0,00	0,00	265,9
02-Feb-10	19:00	0,00	0,00	0,00	202,8
02-Feb-10	20:00	0,00	0,00	0,00	155,2
02-Feb-10	21:00	0,00	0,00	0,00	118,8
02-Feb-10	22:00	0,00	0,00	0,00	90,3
02-Feb-10	23:00	0,00	0,00	0,00	68,7
03-Feb-10	00:00	0,00	0,00	0,00	52,2
03-Feb-10	01:00	0,00	0,00	0,00	39,8
03-Feb-10	02:00	0,00	0,00	0,00	30,4
03-Feb-10	03:00	0,00	0,00	0,00	23,3
03-Feb-10	04:00	0,00	0,00	0,00	17,8
03-Feb-10	05:00	0,00	0,00	0,00	13,7
03-Feb-10	06:00	0,00	0,00	0,00	10,5
03-Feb-10	07:00	0,00	0,00	0,00	8,1
03-Feb-10	08:00	0,00	0,00	0,00	6,1
03-Feb-10	09:00	0,00	0,00	0,00	4,3
03-Feb-10	10:00	0,00	0,00	0,00	2,7
03-Feb-10	11:00	0,00	0,00	0,00	1,6
03-Feb-10	12:00	0,00	0,00	0,00	0,7
03-Feb-10	13:00	0,00	0,00	0,00	0,2
03-Feb-10	14:00	0,00	0,00	0,00	0,0

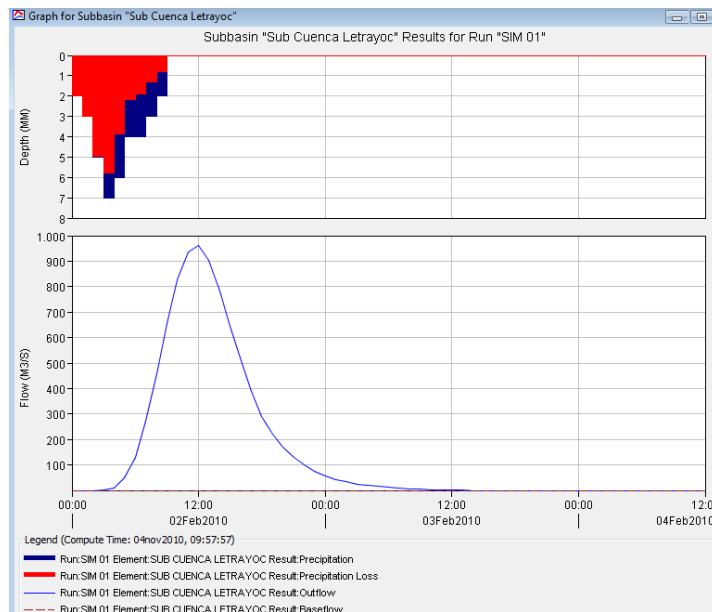


Figure N° 4.20. Hydrograph Rainfall – Runoff models of the Pisco River basin, Return Period 100 years

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 22 hours after it got started.

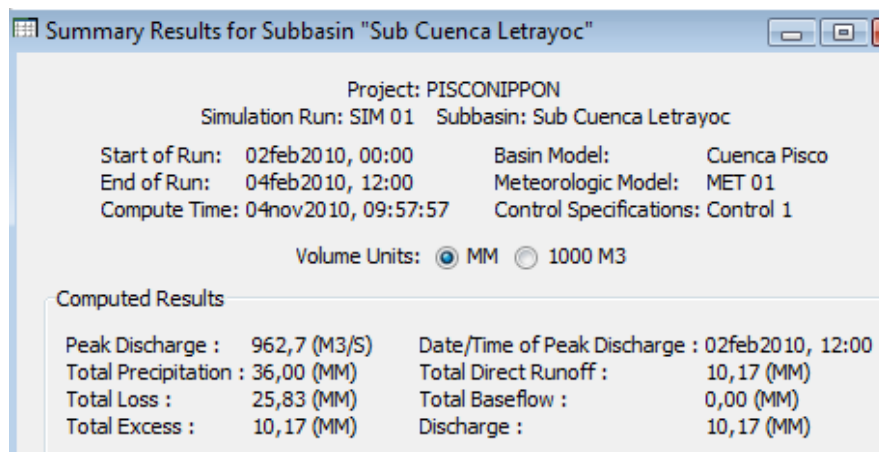


Figure N° 4.21. Results Model Simulation of Rainfall – Runoff Pisco River, Return Period of 100 years

In Figure N° 4.21 is the maximum flow is calculated for a return period of 100 years of 962.7 m³/s. The maximum discharge spends approximately 12 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 N° 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	3,00	3,00	0,00	0,0
02-Feb-10	03:00	5,00	4,98	0,02	0,2
02-Feb-10	04:00	7,00	5,80	1,20	10,4
02-Feb-10	05:00	6,00	3,87	2,13	48,3
02-Feb-10	06:00	4,00	2,17	1,83	129,9
02-Feb-10	07:00	4,00	1,91	2,09	270,6
02-Feb-10	08:00	3,00	1,29	1,71	457,6
02-Feb-10	09:00	2,00	0,80	1,20	655,8
02-Feb-10	10:00	0,00	0,00	0,00	826,8
02-Feb-10	11:00	0,00	0,00	0,00	936,2
02-Feb-10	12:00	0,00	0,00	0,00	962,7
02-Feb-10	13:00	0,00	0,00	0,00	902,0
02-Feb-10	14:00	0,00	0,00	0,00	784,4
02-Feb-10	15:00	0,00	0,00	0,00	645,6
02-Feb-10	16:00	0,00	0,00	0,00	507,9
02-Feb-10	17:00	0,00	0,00	0,00	387,9
02-Feb-10	18:00	0,00	0,00	0,00	291,9
02-Feb-10	19:00	0,00	0,00	0,00	222,6
02-Feb-10	20:00	0,00	0,00	0,00	170,4
02-Feb-10	21:00	0,00	0,00	0,00	130,3
02-Feb-10	22:00	0,00	0,00	0,00	99,1
02-Feb-10	23:00	0,00	0,00	0,00	75,4
03-Feb-10	00:00	0,00	0,00	0,00	57,3
03-Feb-10	01:00	0,00	0,00	0,00	43,7
03-Feb-10	02:00	0,00	0,00	0,00	33,3
03-Feb-10	03:00	0,00	0,00	0,00	25,5
03-Feb-10	04:00	0,00	0,00	0,00	19,6
03-Feb-10	05:00	0,00	0,00	0,00	15,0
03-Feb-10	06:00	0,00	0,00	0,00	11,6
03-Feb-10	07:00	0,00	0,00	0,00	8,8
03-Feb-10	08:00	0,00	0,00	0,00	6,6
03-Feb-10	09:00	0,00	0,00	0,00	4,6
03-Feb-10	10:00	0,00	0,00	0,00	2,9
03-Feb-10	11:00	0,00	0,00	0,00	1,6
03-Feb-10	12:00	0,00	0,00	0,00	0,7
03-Feb-10	13:00	0,00	0,00	0,00	0,2
03-Feb-10	14:00	0,00	0,00	0,00	0,0

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 Pisco river basin for the location of hydrometric station Letrayoc.

Table N° 4.21. Summary of Peak Flows at the Base Point for each Return Period

T [Años]	Q [m ³ /s]
2	213.0
5	287.4
10	451.3
25	688.1
50	855.5
100	962.7

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 84).

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.
- 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 of Technical References of HEC-HMS Software”, 2000.

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

December 2012



HYDROLOGY OF MAXIMUM FLOODS IN CHIRA RIVER

CONTENTS

1	INTRODUCTION	1
2	GENERAL ASPECTS	1
2.1	Location	1
2.1.1	Political Location	1
2.1.2	Geographic Location	1
2.2	Background	2
2.3	Justification of the Project	2
2.4	Objectives of the Study	2
3	PROJECT DESCRIPTION	3
3.1	Hydrographic System of Chira River	3
3.1.1	General Description of the Basin	3
3.1.2	Hydrography of the Chira River Basin	4
3.2	Climatology	5
3.2.1	Rainfall	5
3.2.2	Temperature	25
3.3	Hydrometry	26
3.4	Comments on the pluviometric and hydrometric network in the Chira River Catchment.	30
3.4.1	On Pluviometric Stations.	30
3.4.2	On Hydrometric Stations.	30
3.4.3	Recommendations	31
4	HYDROLOGY OF MAXIMUM FLOOD	33
4.1	Preliminary Considerations	33
4.2	Hydrologic Modeling	36
4.2.1	Basin Outlining	36
4.2.2	Design Rainfall	36
4.2.3	Distribution Functions	36
4.2.3.1	Calculation of Maximum 24 hours Rainfall for Different Return Periods	39
4.2.3.2	Map of Isohyets	40

4.2.3.3	Determination of Maximum 24-Hhours Rainfall for Different Return Periods in the Chira River Subwatershed	43
4.2.3.4	Storm Distribution	46
4.2.4	Maximum Daily Discharge Analysis	47
4.2.5	Simulation Model, Application of HEC-HMS Software	49
4.2.5.1	Hydrological Model	49
4.2.5.2	HEC – HMS Modeling	51
4.2.5.3	Results of the Simulation, Peak Flows in the Base Point	54
5	REFERENCES	55
	ANNEXES	56

HYDROLOGY OF MAXIMUM FLOODS IN CHIRA RIVER

LIST OF TABLES

<i>Table N° 3.1. Period and longitude of the available information of the Rainfall stations</i>	6
<i>Table N° 3.2. Characteristics of Rainfall Stations in the Cañete River Basin and Surrounding Basins</i>	9
<i>Table N° 3.3. Results of the linear fit equation of Montero, Pananga and Santo Domingo Stations</i>	10
<i>Table N° 3.4. Characteristics of Hydrometric Stations in the Chira River Basin and Surrounding Basins</i>	27
<i>Table N° 4.1. Characteristics of the Chira River Topographic Basins</i>	36
<i>Table N° 4.2a. Maximum 24 Hours Rainfall (mm) for Different Return Periods</i>	40
<i>Table N° 4.2b. Maximum 24-Hours Rainfalls for Different Return Periods in each river Basin of Chira</i>	44
<i>Table N° 4.3. Time Distribution of 24 Hour Rainfall. Type IA Was Used in this Simulation</i>	46
<i>Table N° 4.4. Maximum Daily Discharge of station Puente Sullana and Ardilla, Chira River (m³/s)</i>	47
<i>Table N° 4.5. Maximum Discharges for each Return Period at Station Puente Sullana and Ardilla, Chira River (m³/s)</i>	48
<i>Table N° 4.6. Characteristics of the Chira River Topographic Basins</i>	49
<i>Table N° 4.7. Sub-Basins of the Chira Major Basins</i>	49
<i>Table N° 4.8. Maximum 24-Hour Rainfall for Sub-Basins of the Chira River Catchment</i>	50
<i>Table N° 4.9. Curve Numbers for Major Basins</i>	51
<i>Table N° 4.10. Adopted Base Flows for Major Basins</i>	52
<i>Table N° 4.11. Summary of Peak Flows (m³/s) at the Base Points for each Return Period</i>	54

HYDROLOGY OF MAXIMUM FLOODS IN CHIRA RIVER

LIST OF FIGURES

<i>Figure N° 3.1. Location Map of the Chira River Basin</i>	4
<i>Figure N° 3.2. Period and longitude of the available information of the rainfall stations</i>	7
<i>Figure N° 3.3. Location of the rainfall stations in Chira River basin and adjacent basins</i>	8
<i>Figure N° 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope</i>	9
<i>Figure N° 3.5. Annual Rainfall Trends at the Stations considered within the Study Scop</i>	11
<i>Figure N° 3.6. Isohyets for Mean Monthly Rainfall in the Chira Basin, in January</i>	12
<i>Figure N° 3.7. Isohyets for Mean Monthly Rainfall in the Chira Basin, in February</i>	13
<i>Figure N° 3.8. Isohyets Mean Monthly Rainfall in the Chira Basin, in March</i>	14
<i>Figure N° 3.9. Isohyets Mean Monthly Rainfall in the Chira Basin, in April</i>	15
<i>Figure N° 3.10. Isohyets Mean Monthly Rainfall in the Chira Basin, in May</i>	16
<i>Figure N° 3.11. Isohyets Mean Monthly Rainfall in the Chira Basin, in June</i>	17
<i>Figure N° 3.12. Isohyets Mean Monthly Rainfall in the Chira Basin, in July</i>	18
<i>Figure N° 3.13. Isohyets Mean Monthly Rainfall in the Chira Basin, in August</i>	19
<i>Figure N° 3.14. Isohyets Mean Monthly Rainfall in the Chira Basin, in September</i>	20
<i>Figure N° 3.15. Isohyets Mean Monthly Rainfall in the Chira Basin, in October</i>	21
<i>Figure N° 3.16. Isohyets Mean Monthly Rainfall in the Chira Basin, in November</i>	22
<i>Figure N° 3.17. Isohyets Mean Monthly Rainfall in the Chira Basin, in December</i>	23
<i>Figure N° 3.18. Isohyets Annual Mean Monthly Rainfall in the Chira Basin</i>	24
<i>Figura N° 3.19. Average monthly temperature for La Esperanza, Chilaco and Mallares Stations</i>	25
<i>Figura N° 3.20. Average monthly temperature for La Toma Catamayo, Vilcabamba, Malacatos and Quinara Stations</i>	26
<i>Figura N° 3.21. Average monthly temperature for Zapotillo, Macara and Sausal de Culucan Statios</i>	26
<i>Figure N° 3.22. Period and longitude of the available information of the Hydrometric Stations</i>	27
<i>Figure N° 3.23. Location of the hydrometric stations in Chira River Basin and Adjacent Basins</i>	29
<i>Figure N° 4.1. Relative Position of Hydrological Stations in the Study Area</i>	35
<i>Figure N° 4.2a. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin</i>	40

<i>Figure N° 4.2b. Isohyets for the 5- Years Return Period Maximum 24-Hours Rainfall in the Chira Basin</i>	41
<i>Figure N° 4.2c. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin</i>	41
<i>Figure N° 4.2d. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin</i>	42
<i>Figure N° 4.2e. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin</i>	42
<i>Figure N° 4.2f. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin</i>	43
<i>Figure N° 4.3. Chira River Subbasin</i>	44
<i>Figure N° 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</i>	47
<i>Figure N° 4.5. Watershed considered by HEC-HMS model for the simulation.</i>	54

HYDROLOGY OF MAXIMUM FLOODS IN CHIRA RIVER

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 03°40'28 "and 05°07'06" of south latitude and the meridians 80°46'11 "and 79°07'52"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 km² are within Ecuadorian territory and 11.933 km² within Peruvian territory. Its watershed is approximately 9.500 km²

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 N° 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 km², of which 7.162 km² (37.51%) is in Ecuadorian territory and 11.933 km² 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 Pilaes 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 N° 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 N° 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

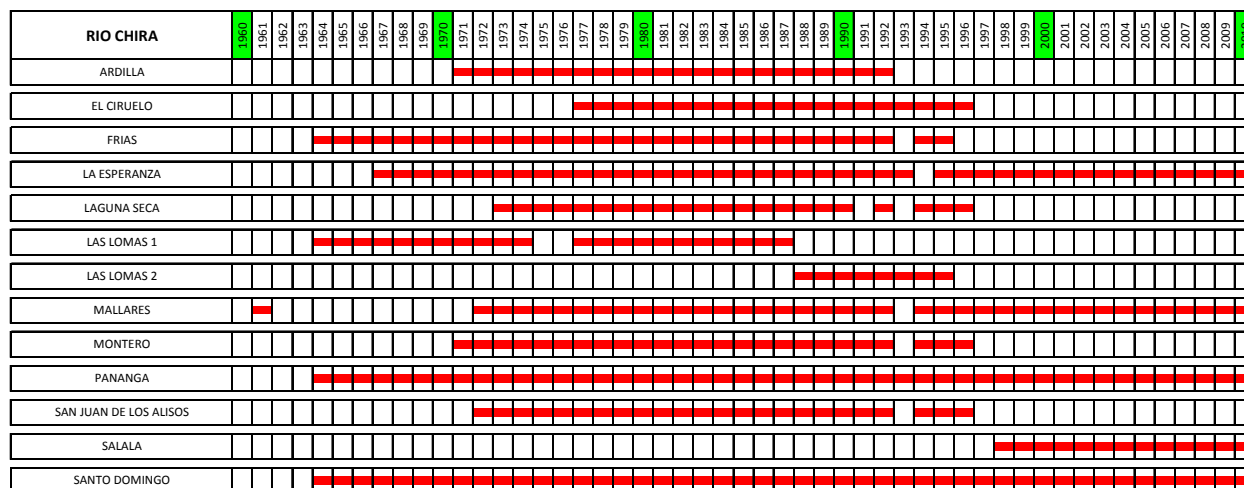


Figure N° 3.2. Period and longitude of the available information of the rainfall stations

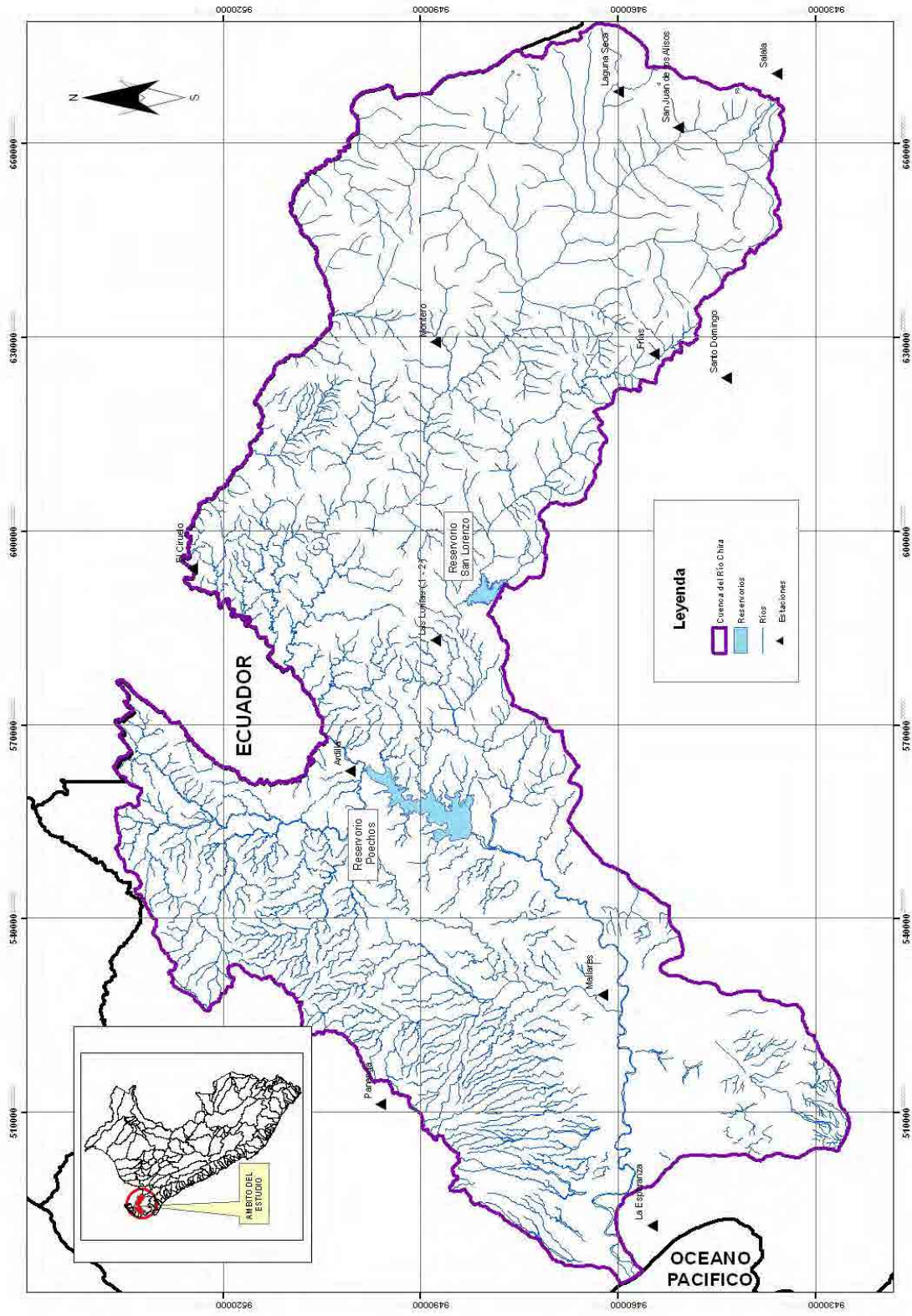


Figure N° 3.3. Location of the rainfall stations in Chira River basin and adjacent basins

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 N° 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

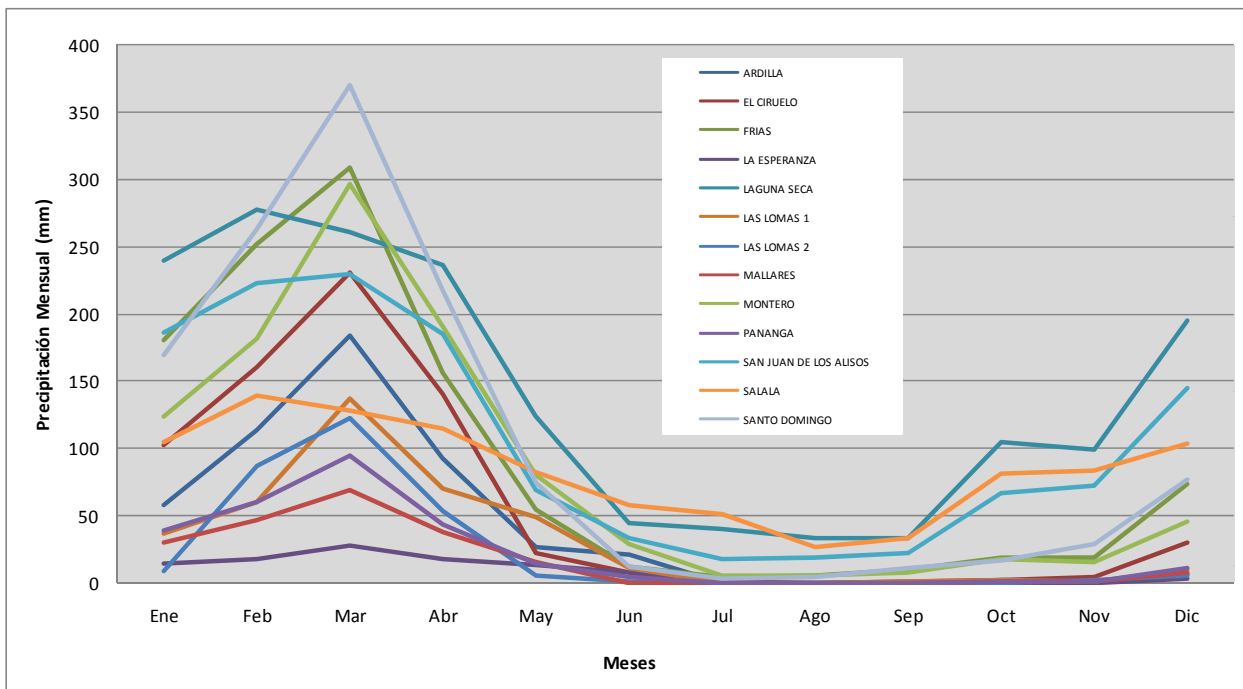


Figure N° 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope

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 N° 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 (R²) is very low. For Montero Station would be a seasonally downward trend and for Pananga and Santo Domingo Stations a vseasonally upward trend. R² 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.

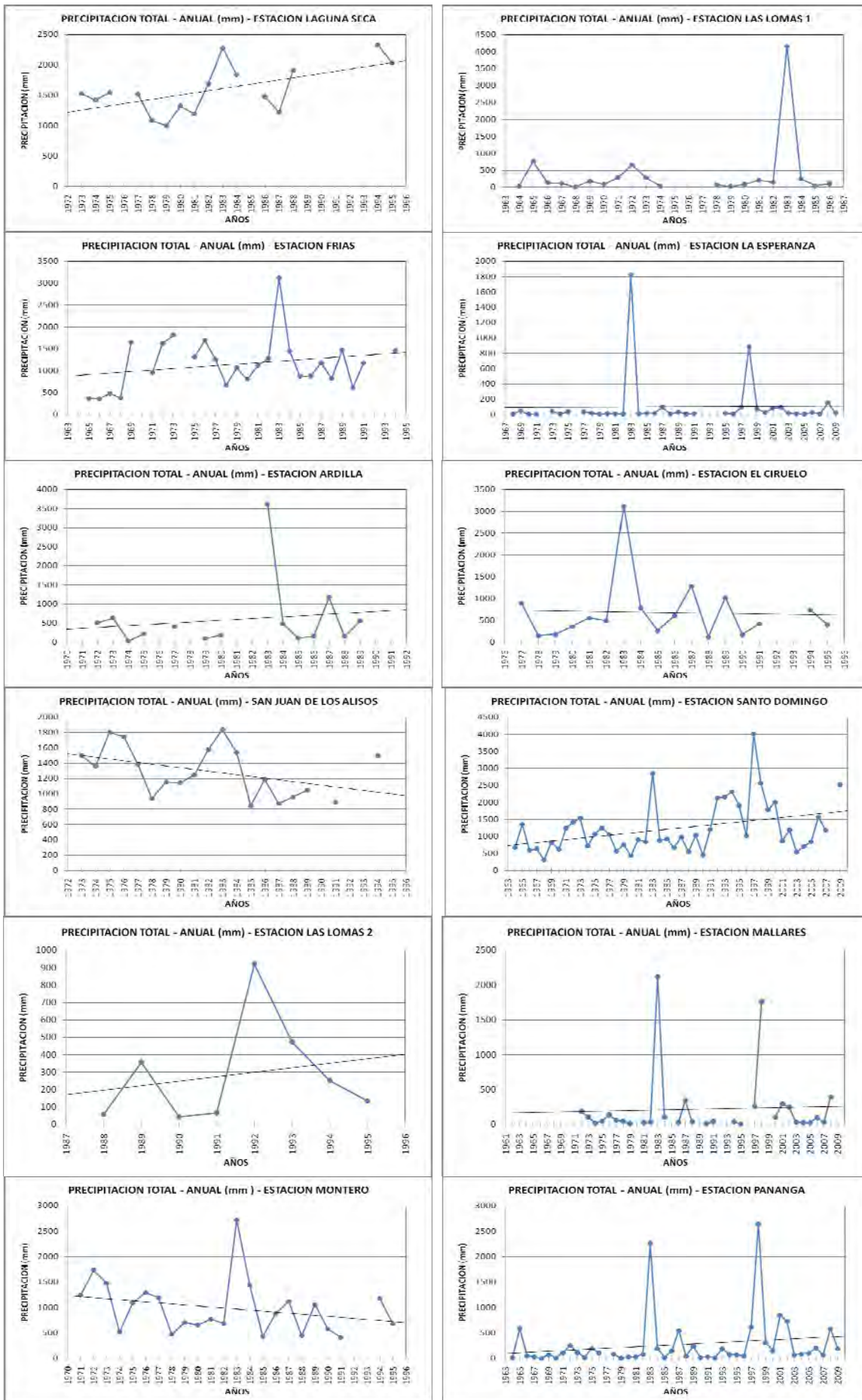


Figure N° 3.5. Annual Rainfall Trends at the Stations considered within the Study Scop

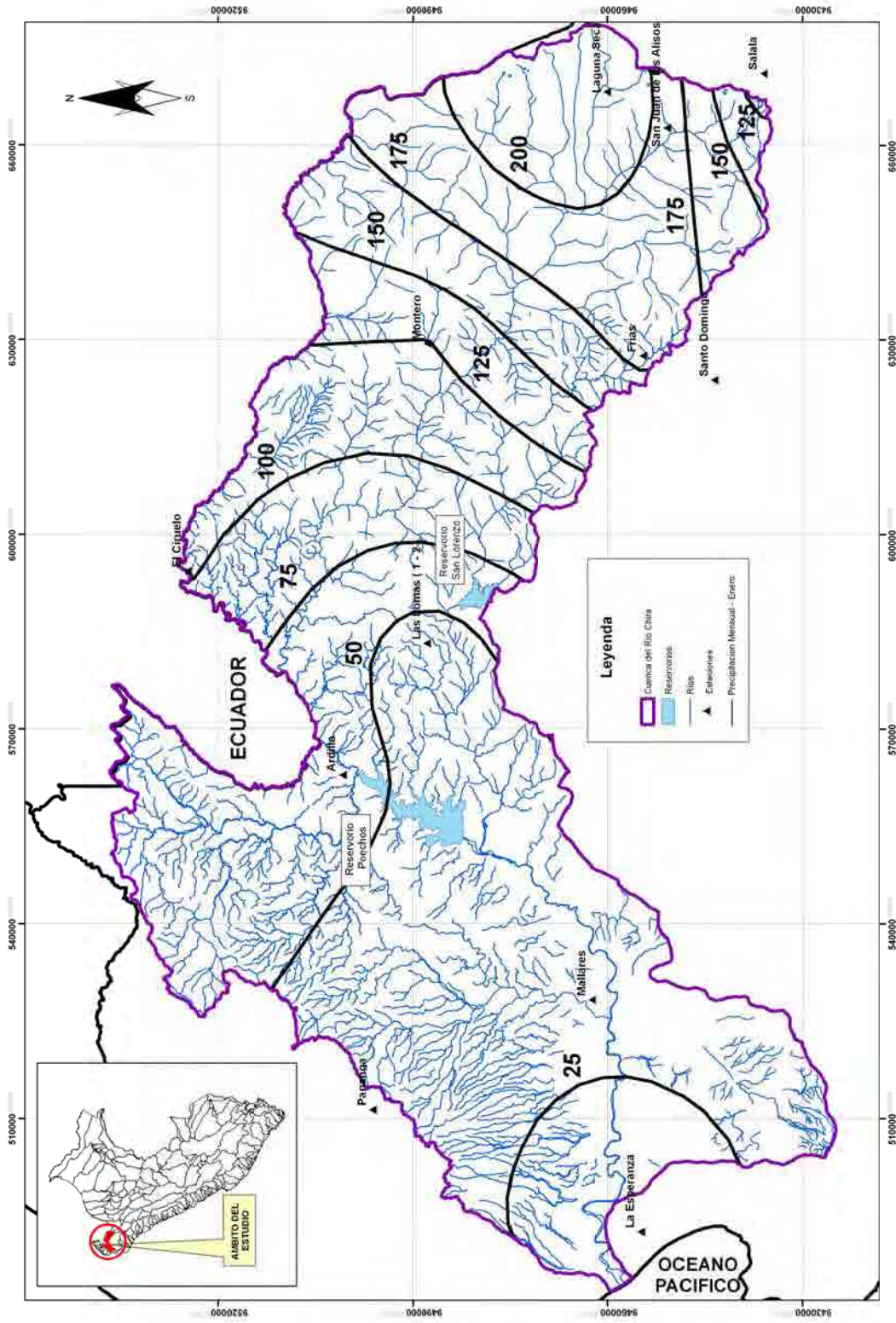


Figure N° 3.6. Isohyets for Mean Monthly Rainfall in the Chira Basin, in January

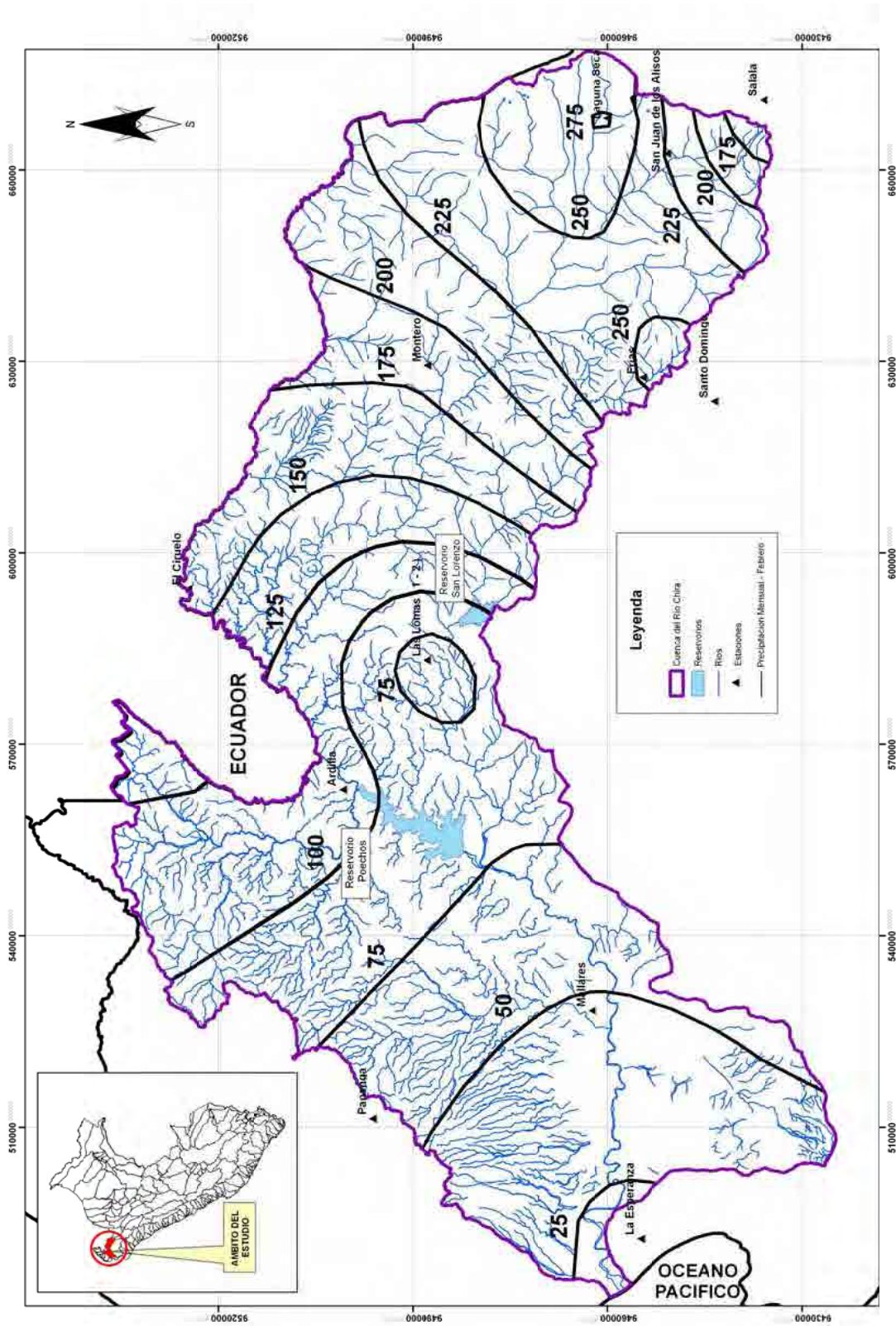


Figure N° 3.7. Isohyets for Mean Monthly Rainfall in the Chira Basin, in February

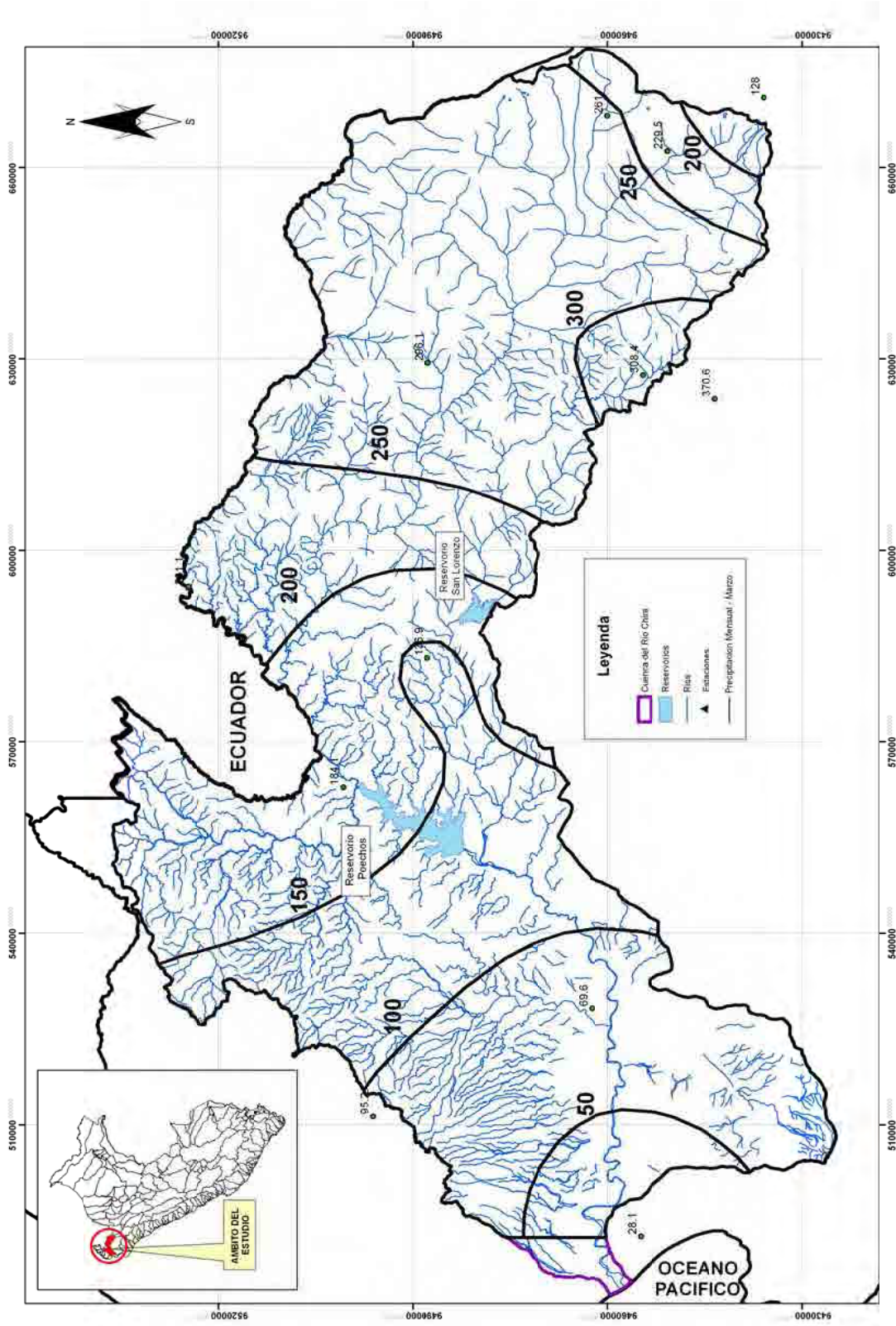


Figure N° 3.8. Isohyets Mean Monthly Rainfall in the Chira Basin, in March

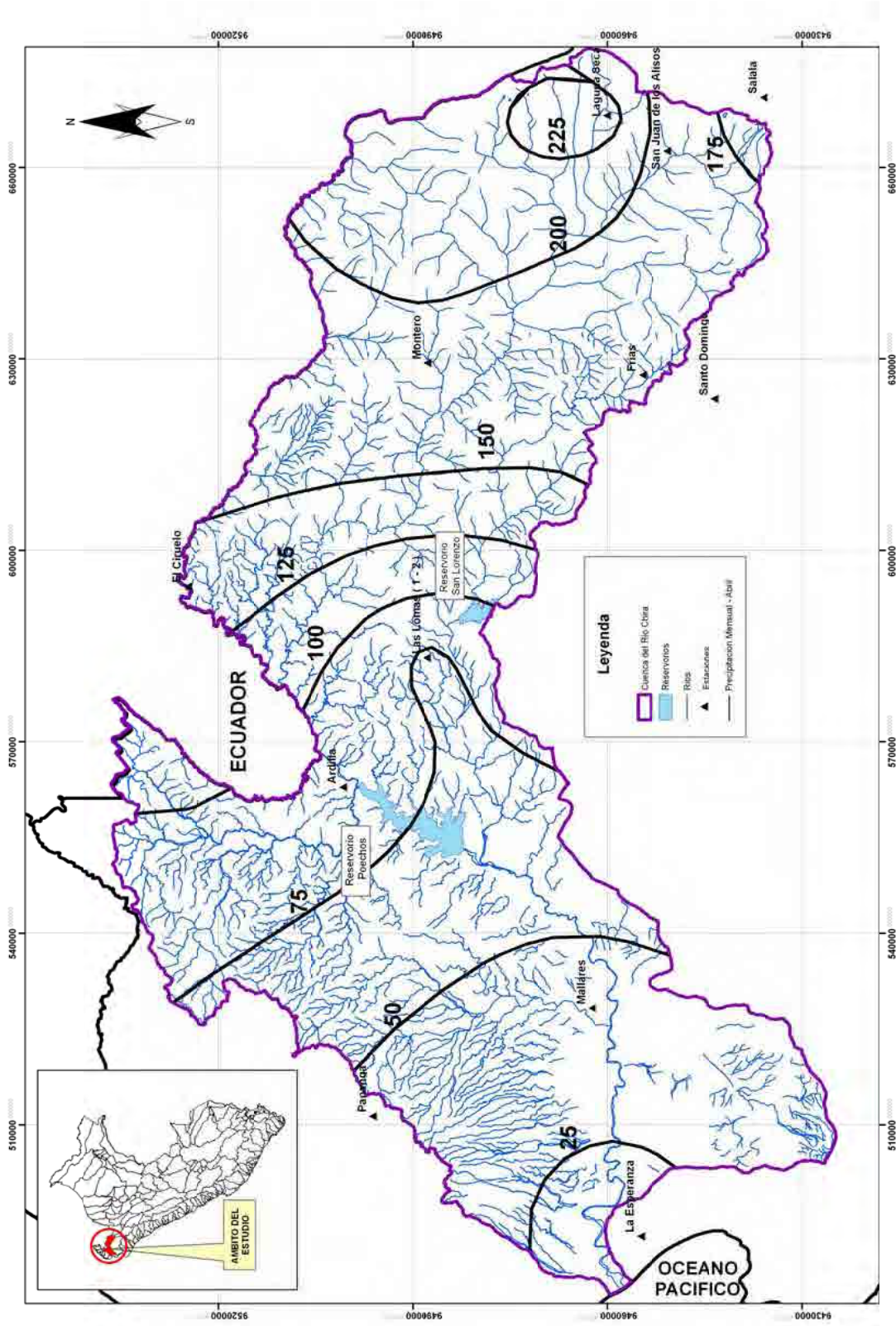


Figure N° 3.9. Isohyets Mean Monthly Rainfall in the Chira Basin, in April

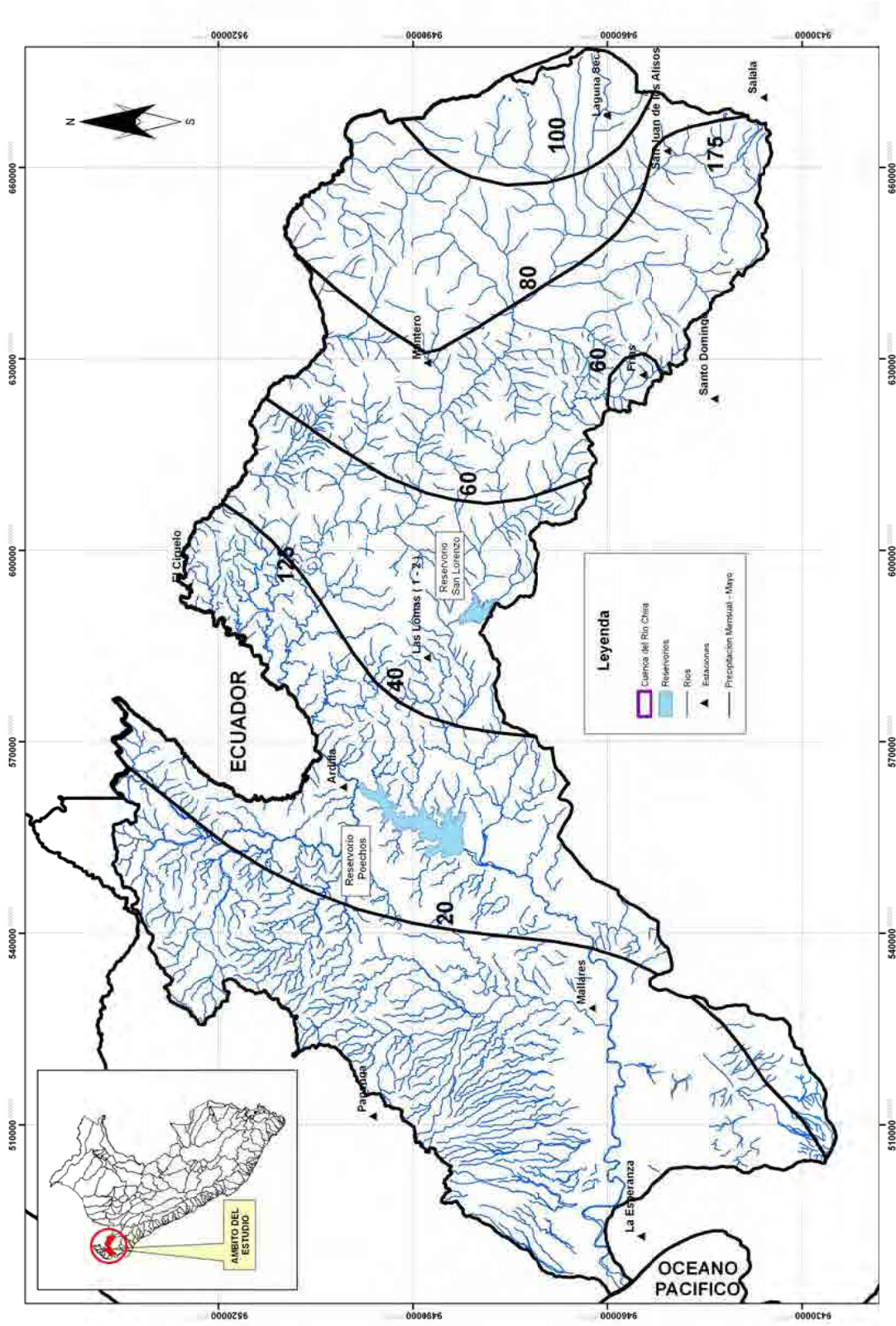


Figure N° 3.10. Isohyets Mean Monthly Rainfall in the Chira Basin, in May

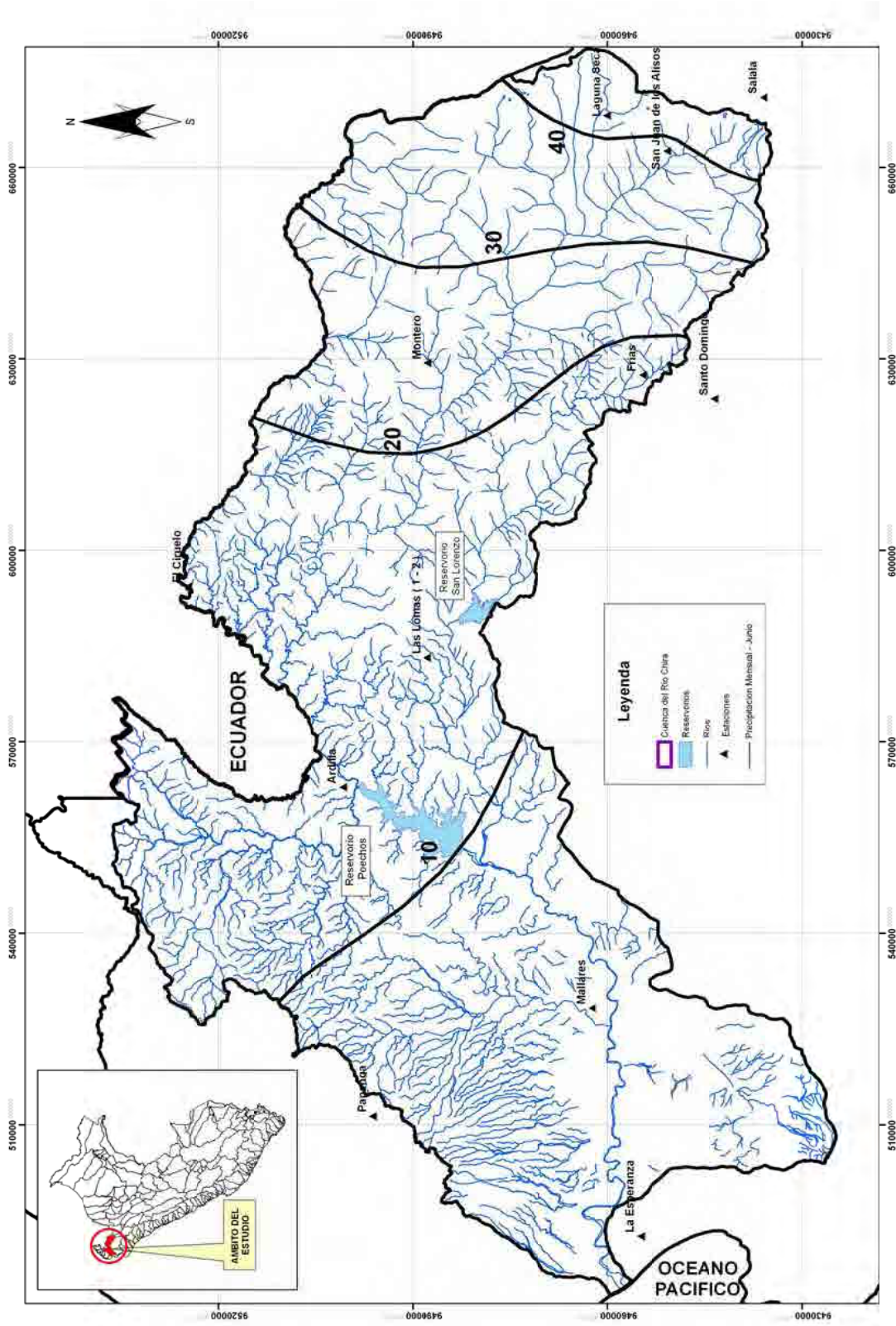


Figure N° 3.11. Isohyets Mean Monthly Rainfall in the Chira Basin, in June

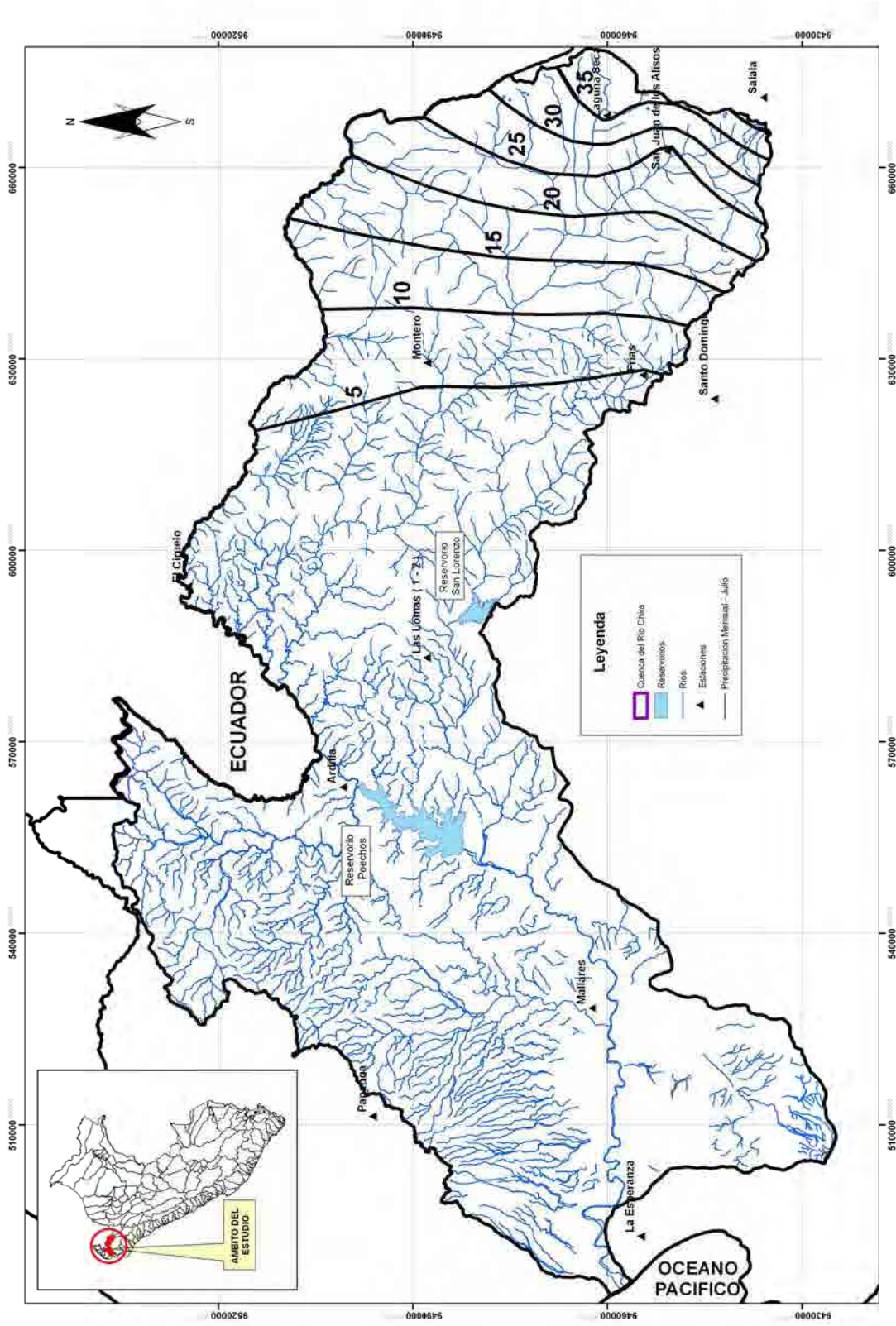


Figure N° 3.12. Isohyets Mean Monthly Rainfall in the Chira Basin, in July

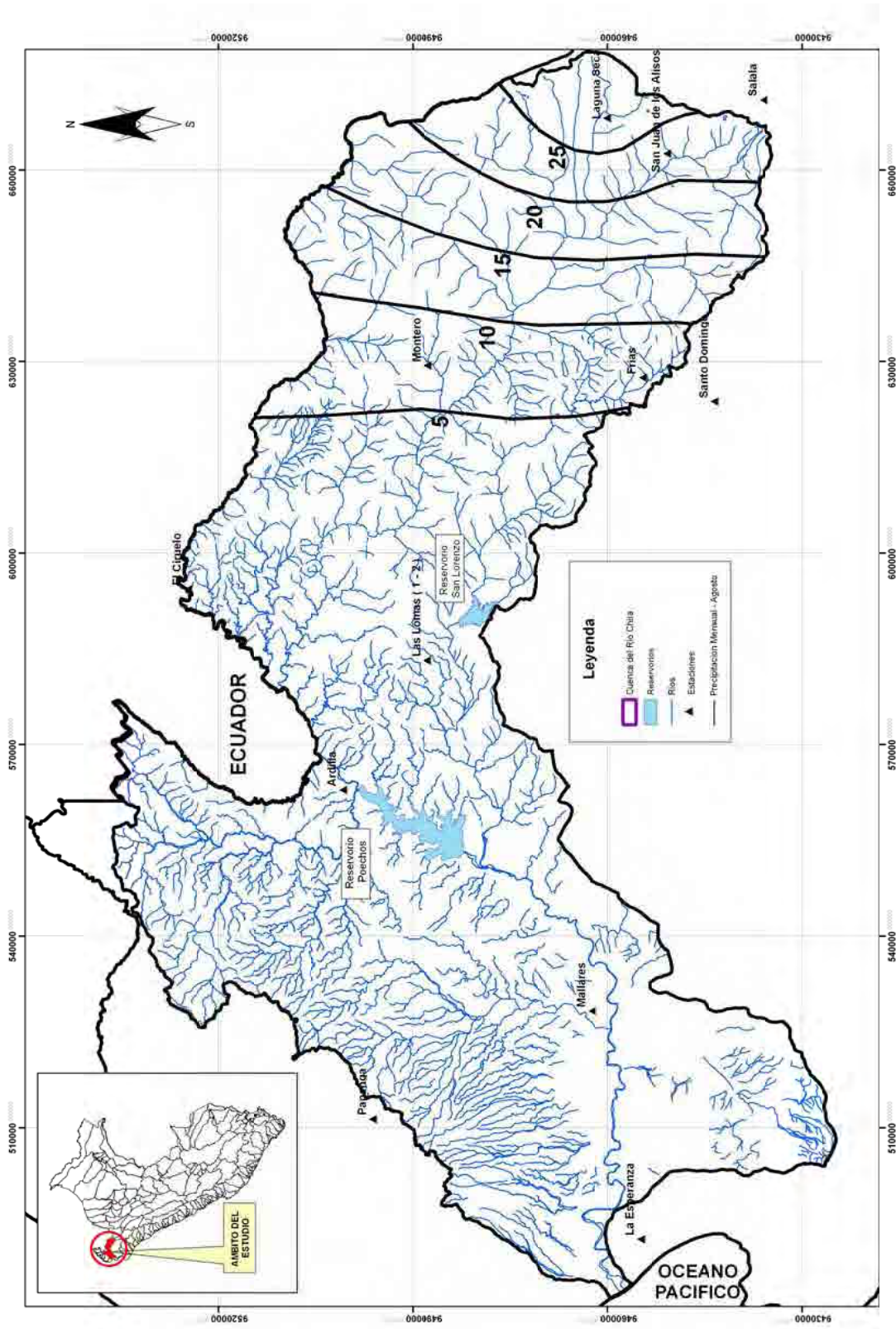


Figure N° 3.13. Isohyets Mean Monthly Rainfall in the Chira Basin, in August

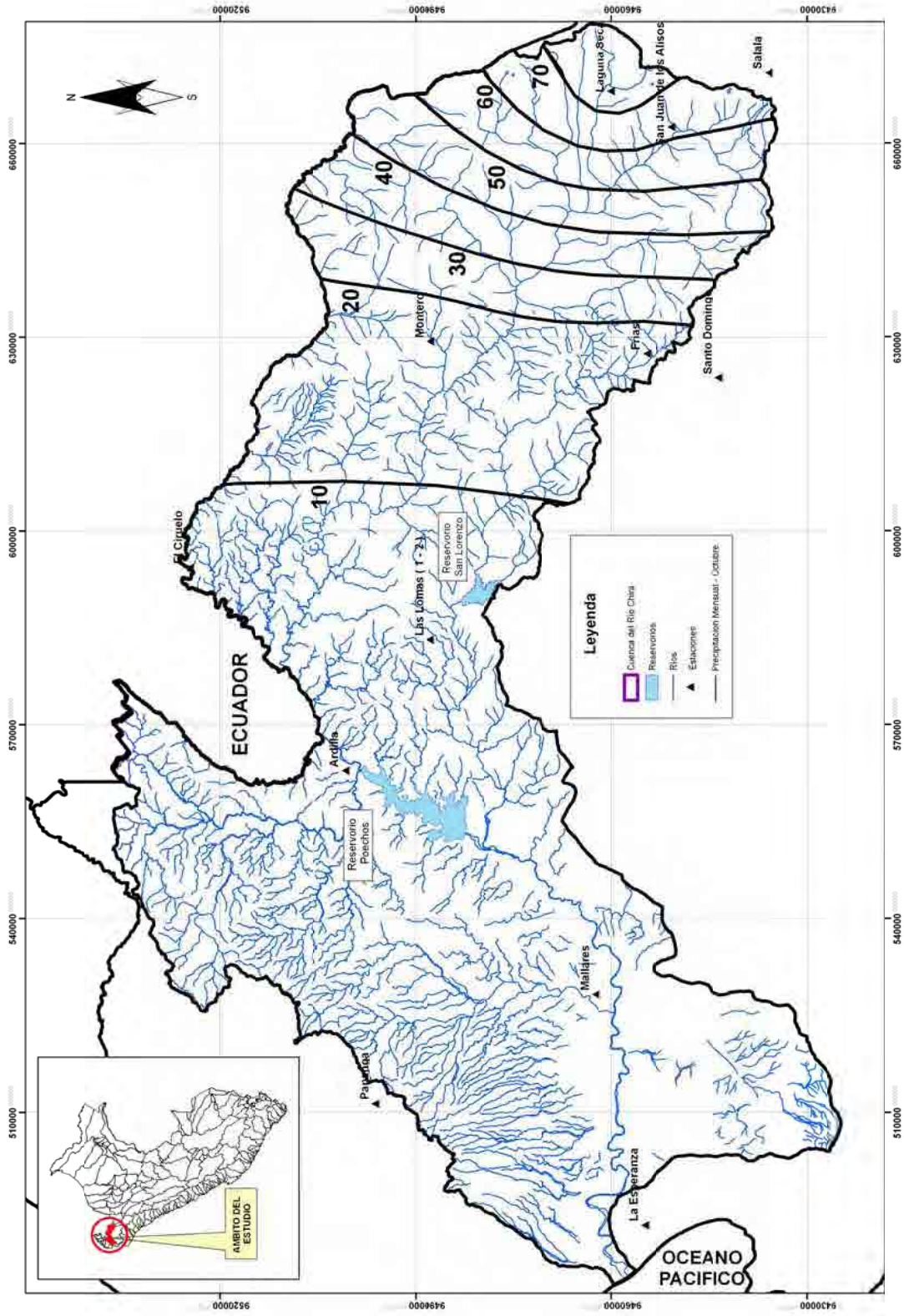


Figure N° 3.14. Isohyets Mean Monthly Rainfall in the Chira Basin, in September

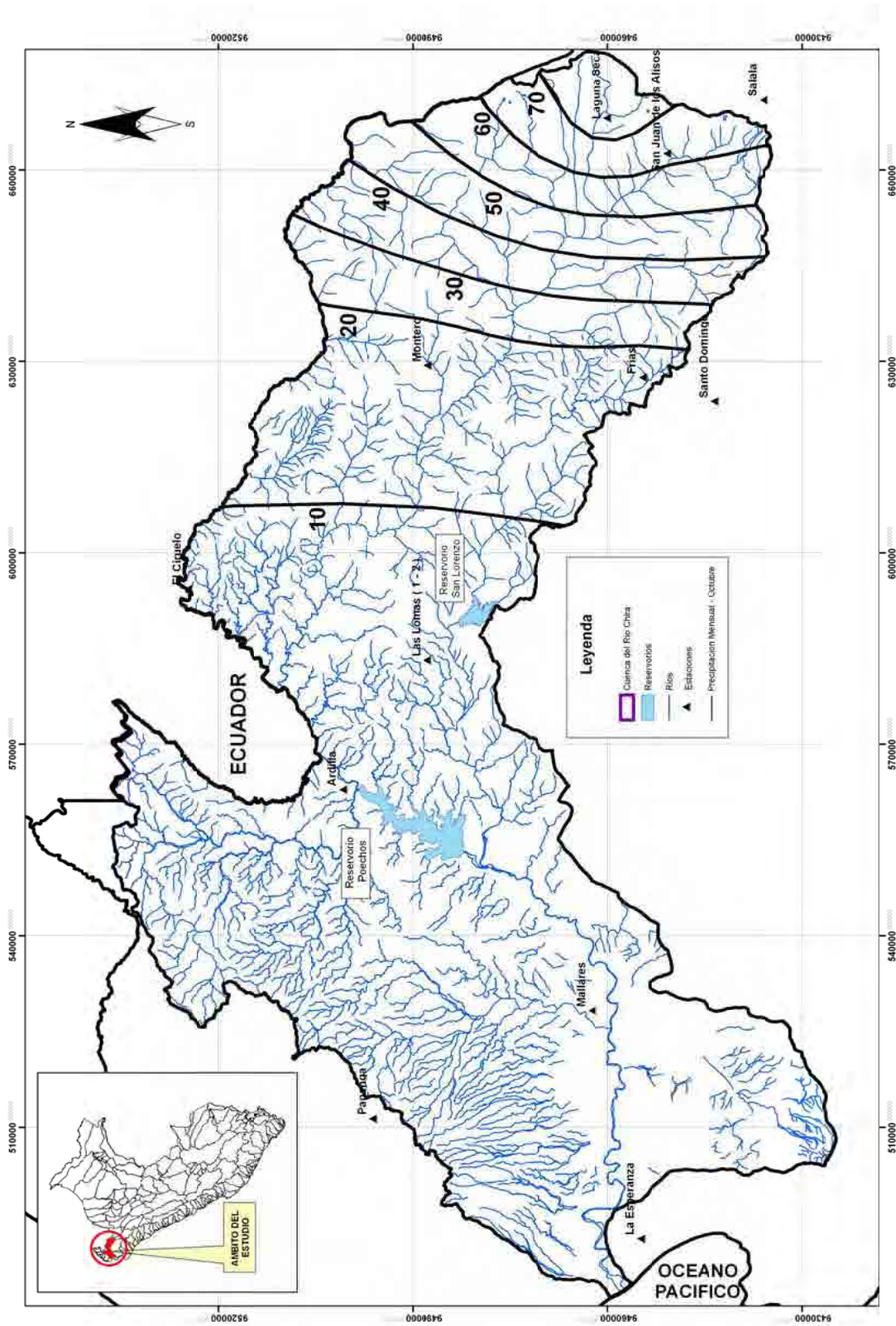


Figure N° 3.15. Isohyets Mean Monthly Rainfall in the Chira Basin, in October

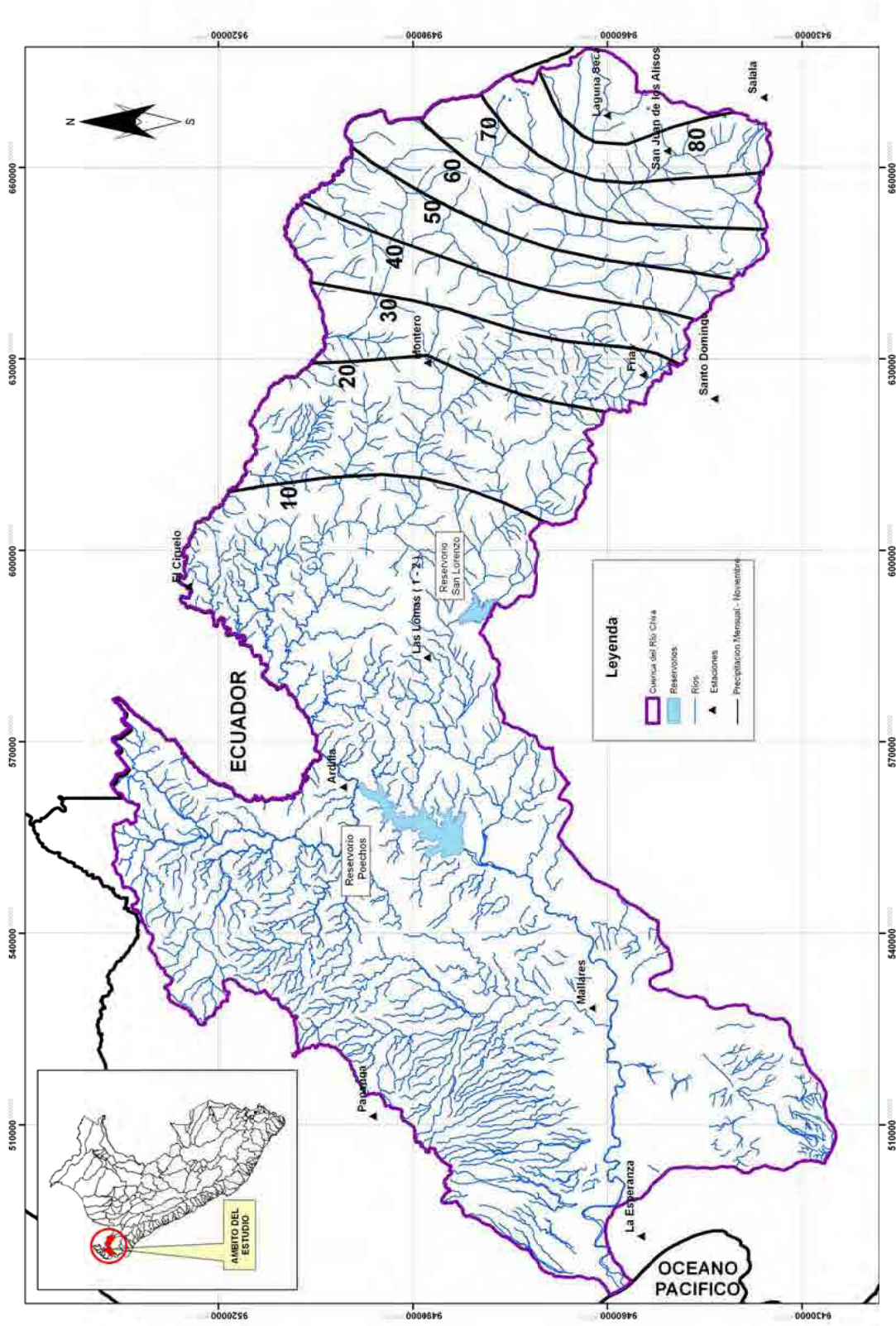


Figure N° 3.16. Isohyets Mean Monthly Rainfall in the Chira Basin, in November

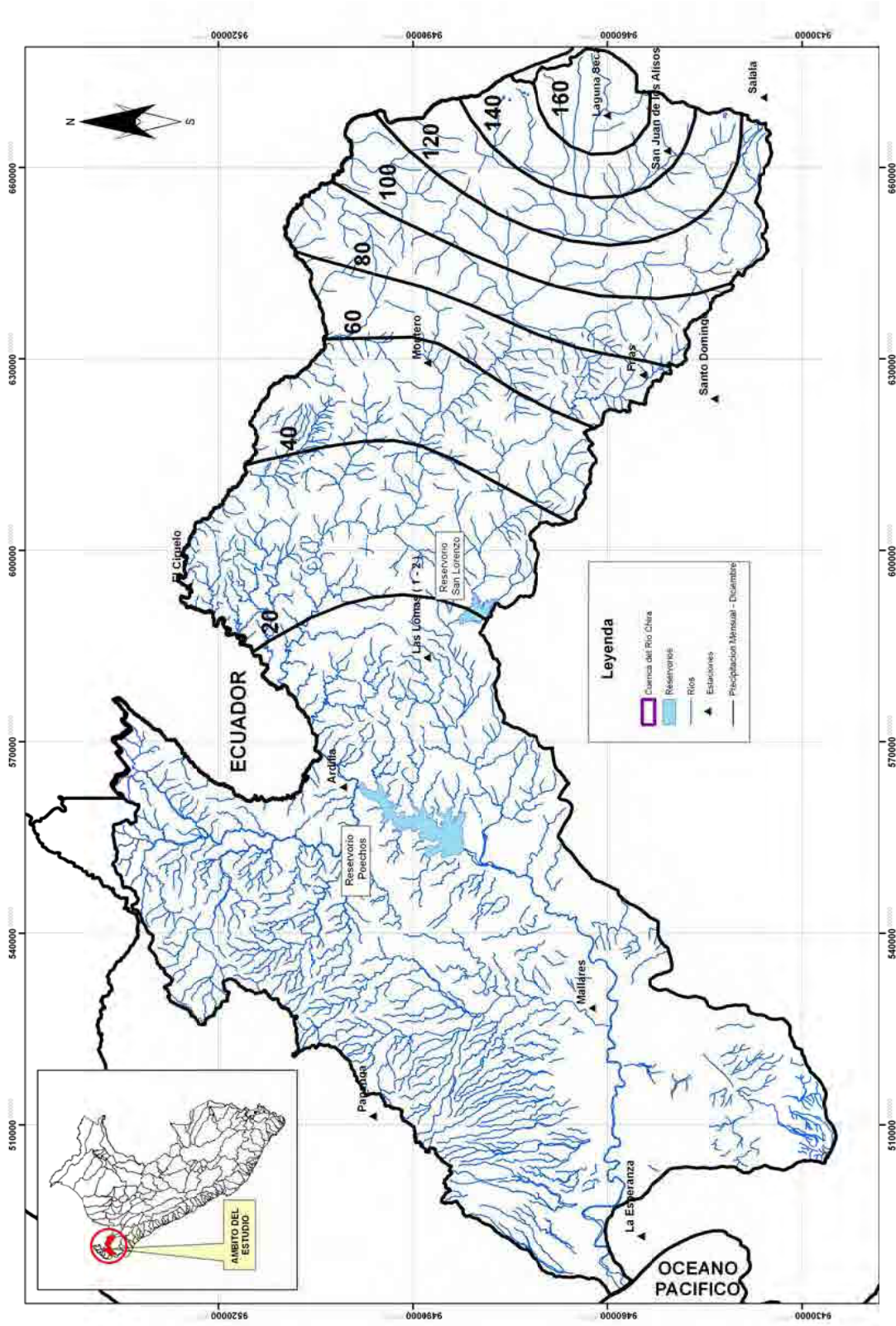


Figure N° 3.17. Isohyets Mean Monthly Rainfall in the Chira Basin, in December

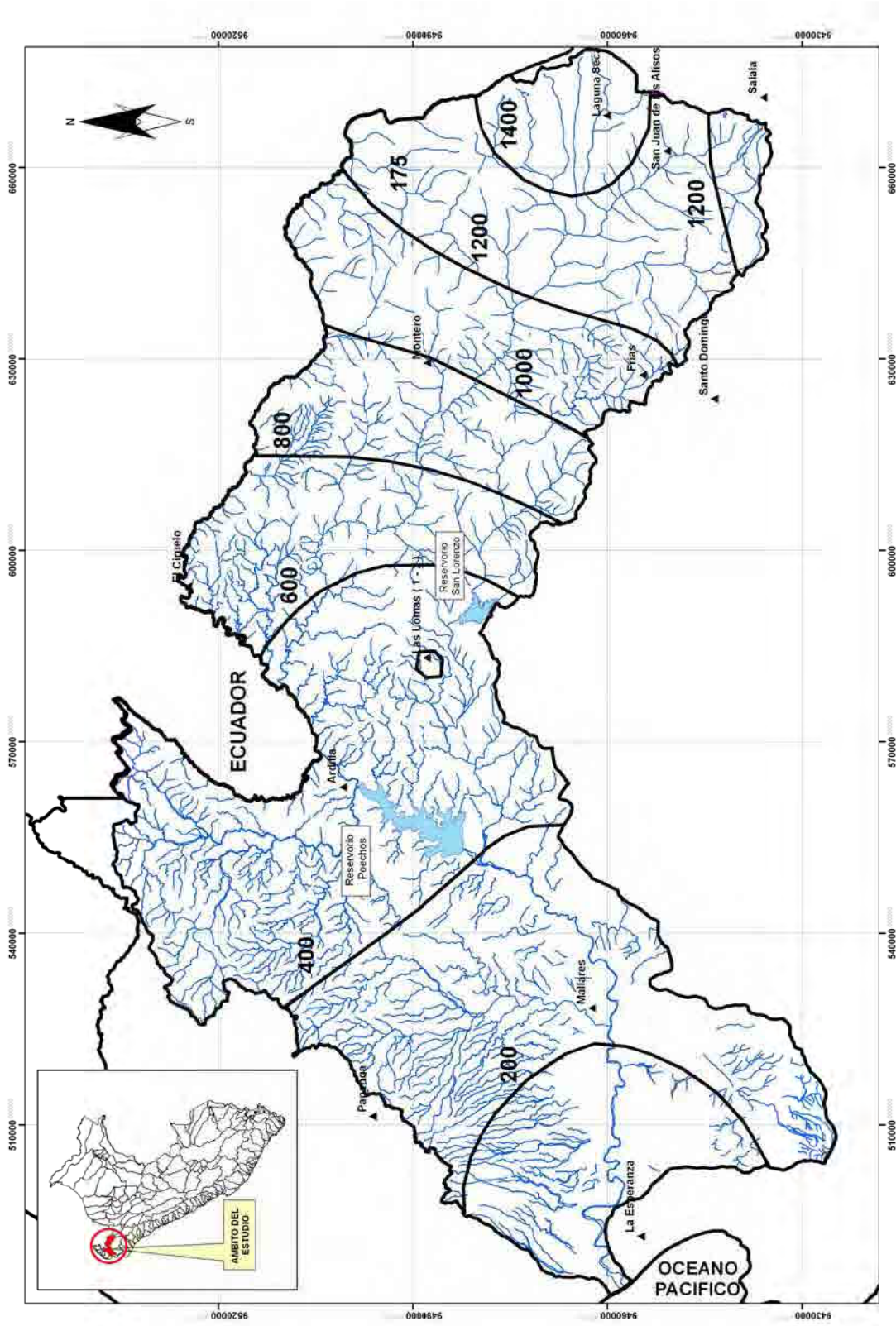


Figure N° 3.18. Isohyets Annual Mean Monthly Rainfall in the Chira Basin

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 ° C.

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

Minima occur in the months of June through August, reaching 15 ° C on the coast, down to 8 ° 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.

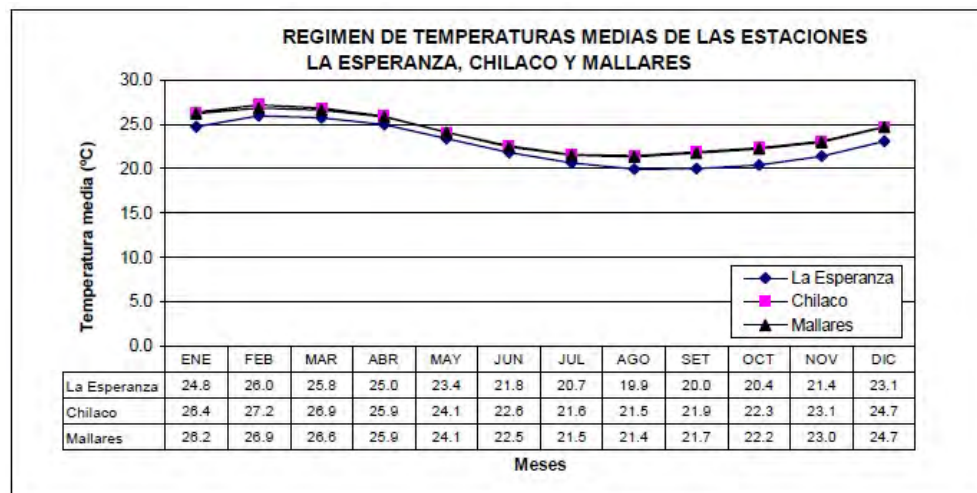


Figura N° 3.19. Average monthly temperature for La Esperanza, Chilaco and Mallares Stations
Fuente: Proyecto Binacional Catamayo - Chira

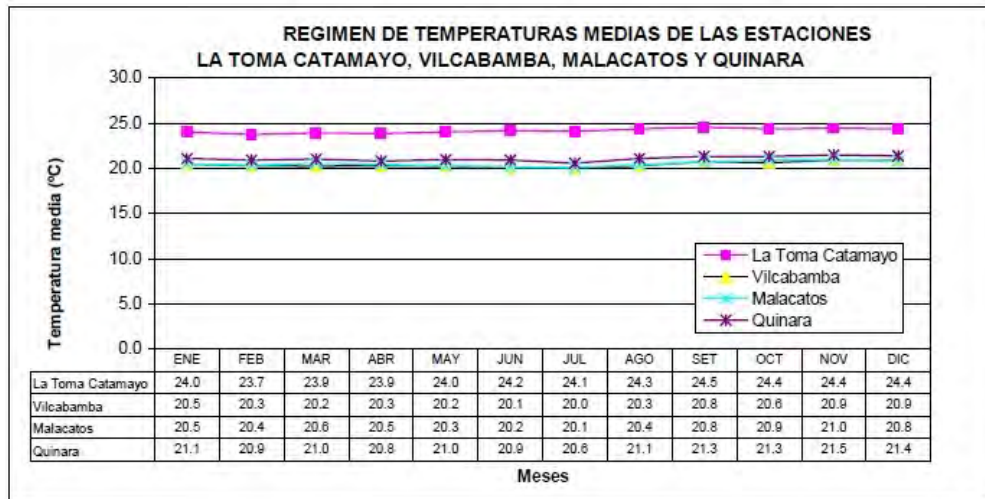


Figura N° 3.20. Average monthly temperature for La Toma Catamayo, Vilcabamba, Malacatos and Quinara Stations

Fuente: Proyecto Binacional Catamayo – Chira

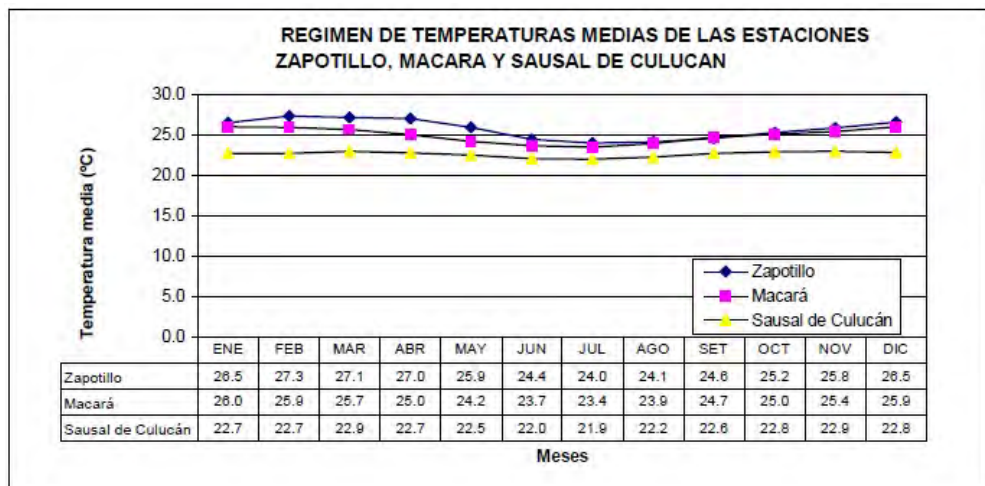


Figura N° 3.21. Average monthly temperature for Zapotillo, Macara and Sausal de Culucan Stations

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 N° 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	SAPILICA	80° 04'1	04° 44'1	472	Closed	Not Available	
200305	PUNTE 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	PUNTE INTERNACIONAL MACARA	HLM	CHIRA	PIURA	AYABACA	SUYO	79° 57'1	04° 24'1	415	Paralyzed	1991-03	1997-08
200311	CANAL CHIPILICO	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	PUNTE SULLANA	HLM	CHIRA	PIURA	SULLANA	SALITRAL	80° 41'1	04° 53'1	25	Paralyzed	1991-03	1998-01
200320	LAGARTERA	HLM	CHIRA	PIURA	AYABACA	SAPILICA	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	RESERVOIRIO 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	Operating	Not Available	
200426	SALIDA RESERVOIRIO 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
172606Operating	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 N° 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.

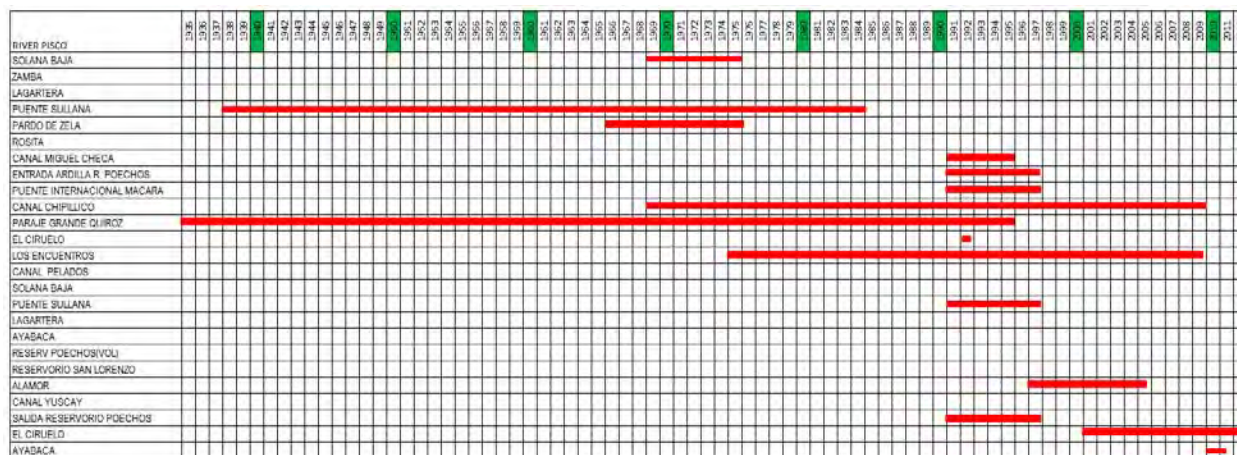


Figure N° 3.22. Period and longitude of the available information of the Hydrometric Stations

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.

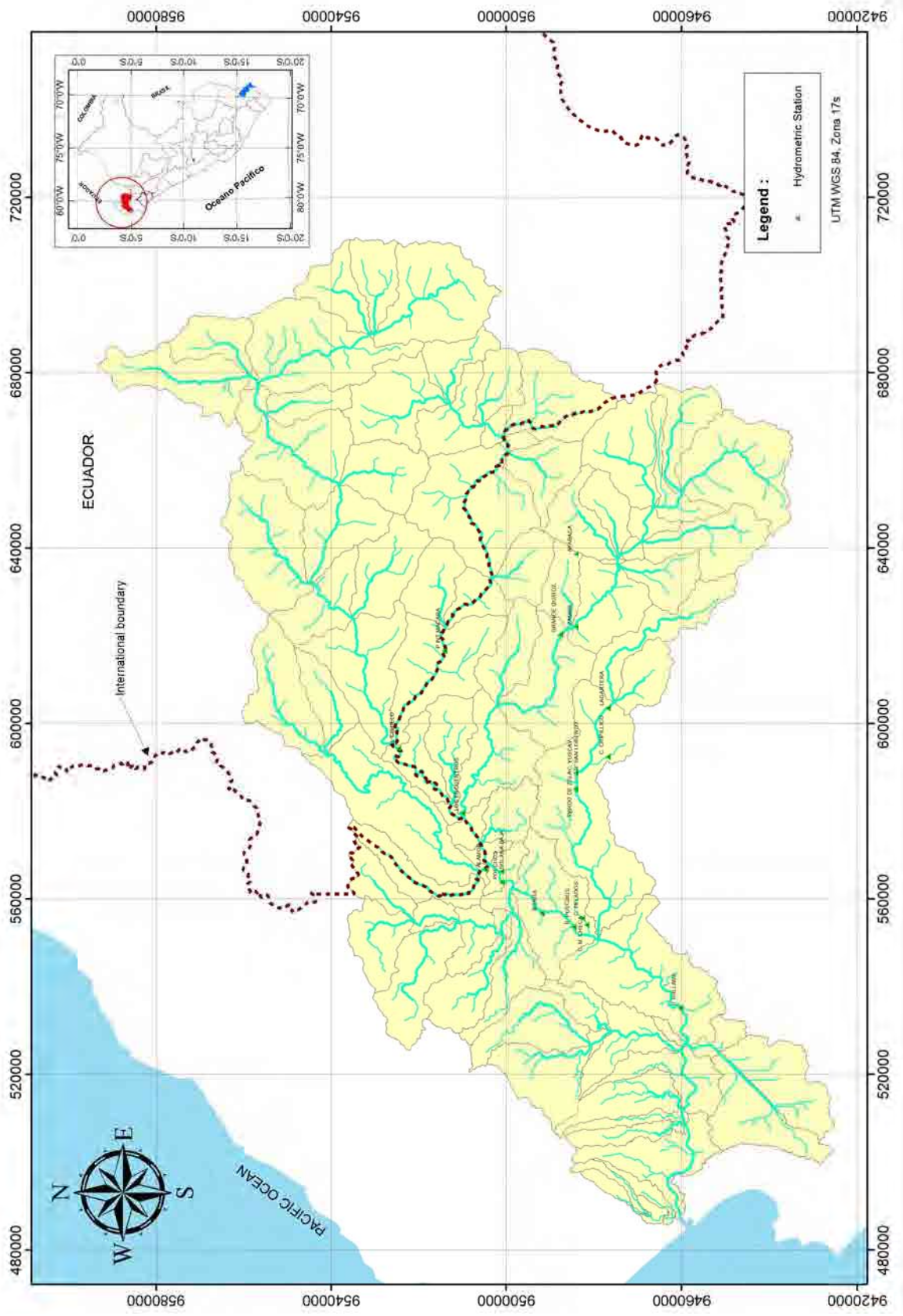


Figure N° 3.23. Location of the hydrometric stations in Chira River Basin and Adjacent Basins

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 m³/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, turbidity 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.

Field Reconnaissance:

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.

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 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.

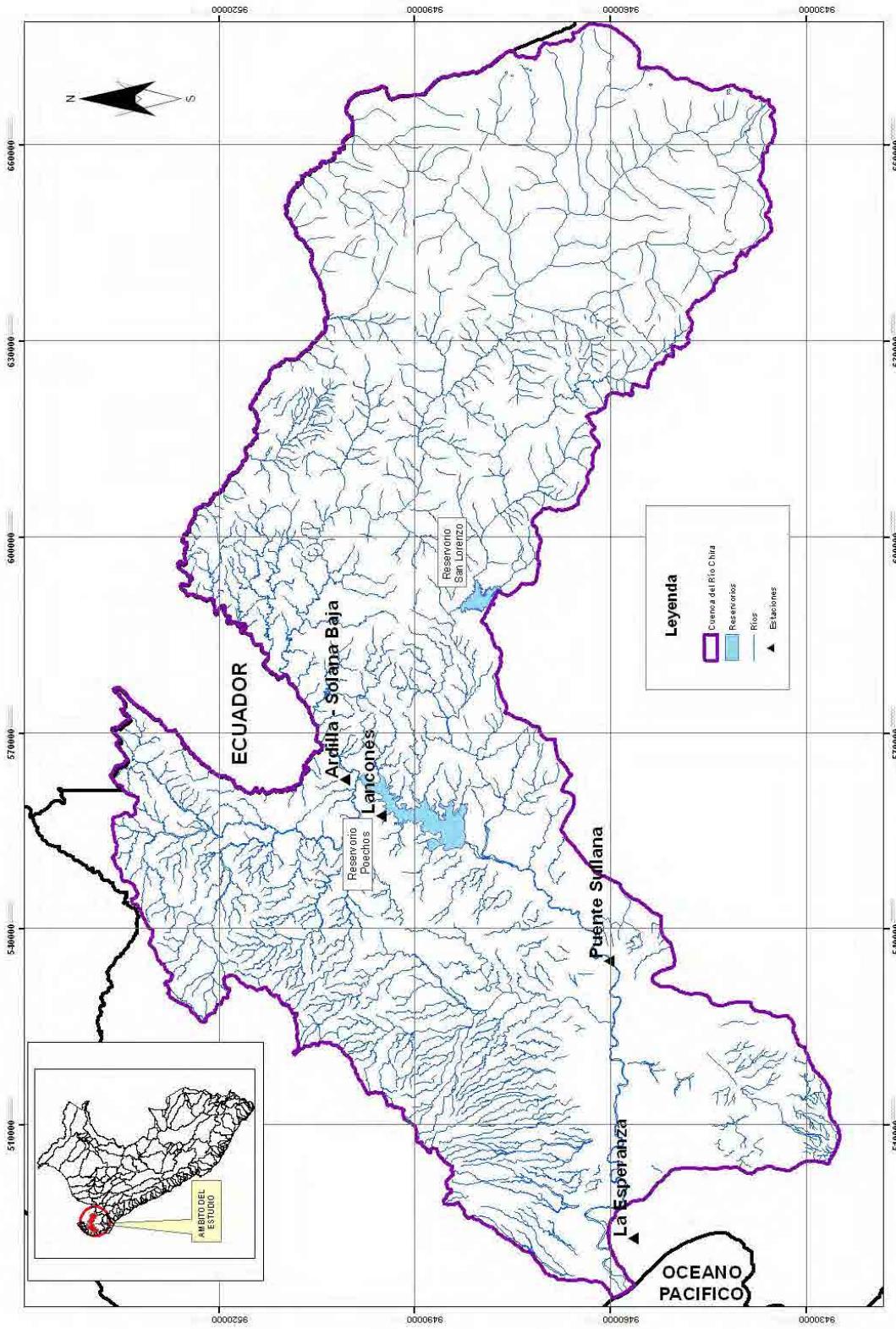


Figure N° 4.1. Relative Position of Hydrological Stations in the Study Area

4.2 Hydrologic Modeling

4.2.1 Basin Outlining

The area of Chira River catchment until the Bridge Simón Rodríguez is 17059 km², 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 N° 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,

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

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:

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

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

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 x_0 , before taking logarithms, we can get that is normally distributed.

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

$$f(x) = \frac{1}{(x - x_0)\sigma_y\sqrt{2\pi}} \text{EXP} \left\{ -\frac{1}{2} \left[\frac{\ln(x - x_0) - \mu_y}{\sigma_y} \right]^2 \right\}$$

To $x_0 \leq x < \infty$

Where:

x_0 = 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:

$0 \leq x < \infty$

$0 < \gamma < \infty$

$0 < \beta < \infty$

As:

γ = Shape parameter (+)

β = Scale Parameter (+)

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

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

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:

$$f(x) = \frac{(x - x_0)^{\gamma-1} e^{-\frac{x-x_0}{\beta}}}{\beta^{\gamma} \Gamma_{\gamma}}$$

To

$$x_0 \leq x < \infty$$

$$-\infty < x_0 < \infty$$

$$0 < \beta < \infty$$

$$0 < \gamma < \infty$$

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.

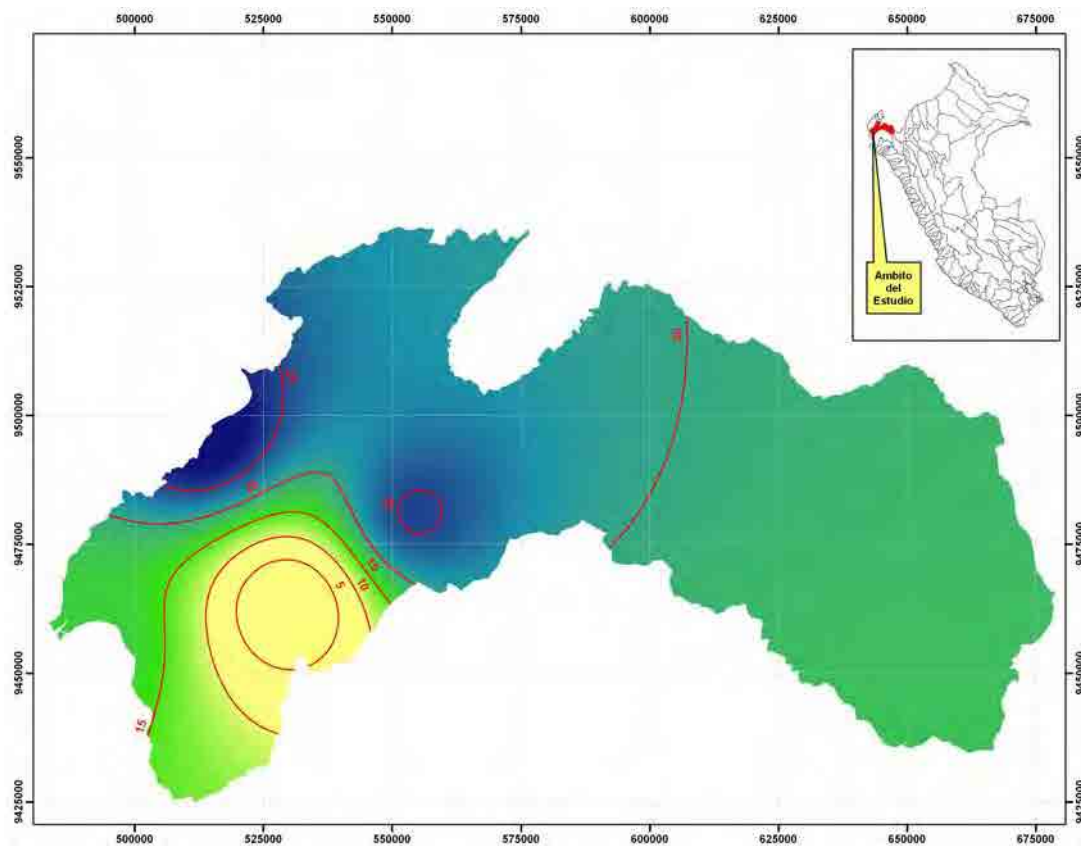


Figure N° 4.2a. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

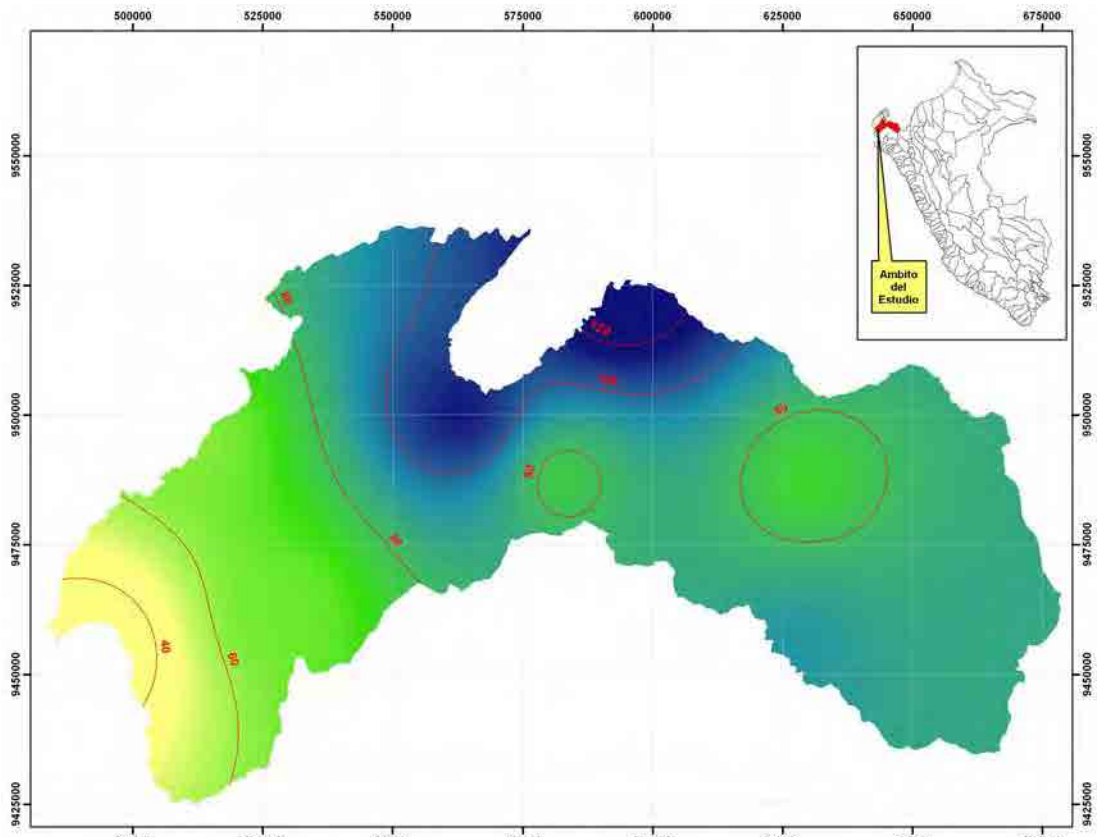


Figure N° 4.2b. Isohyets for the 5- Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

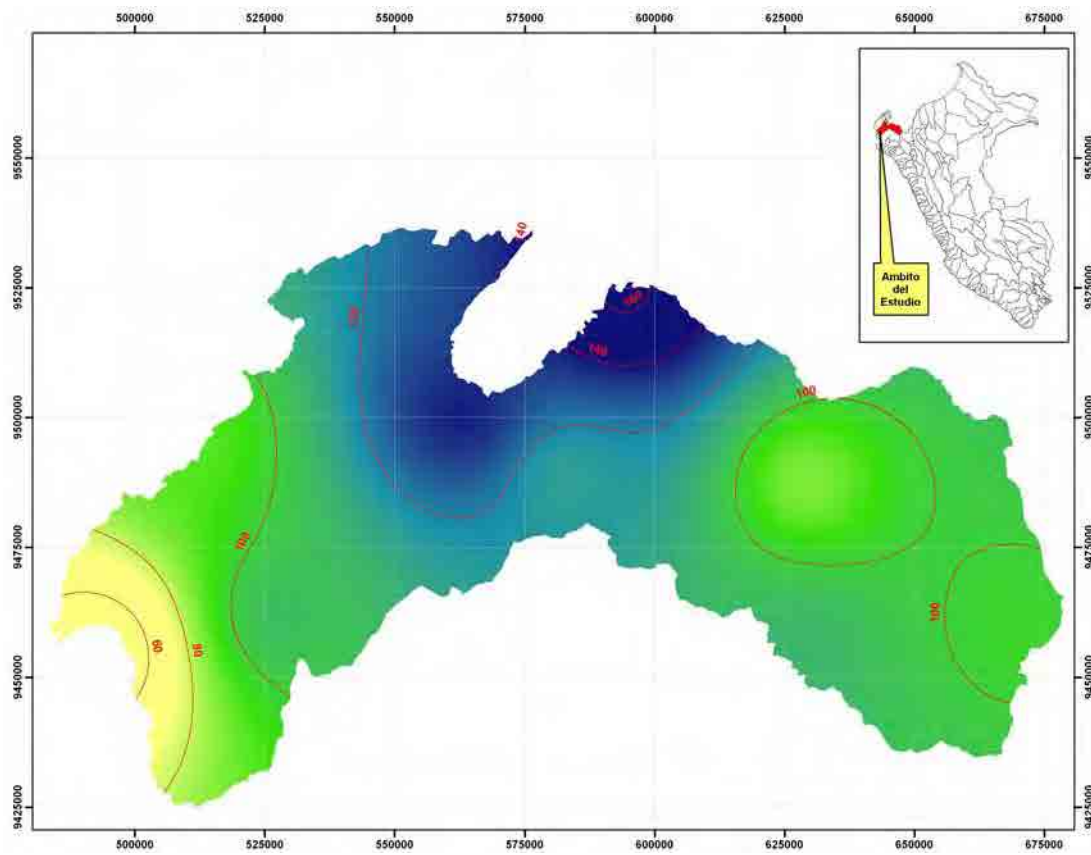


Figure N° 4.2c. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

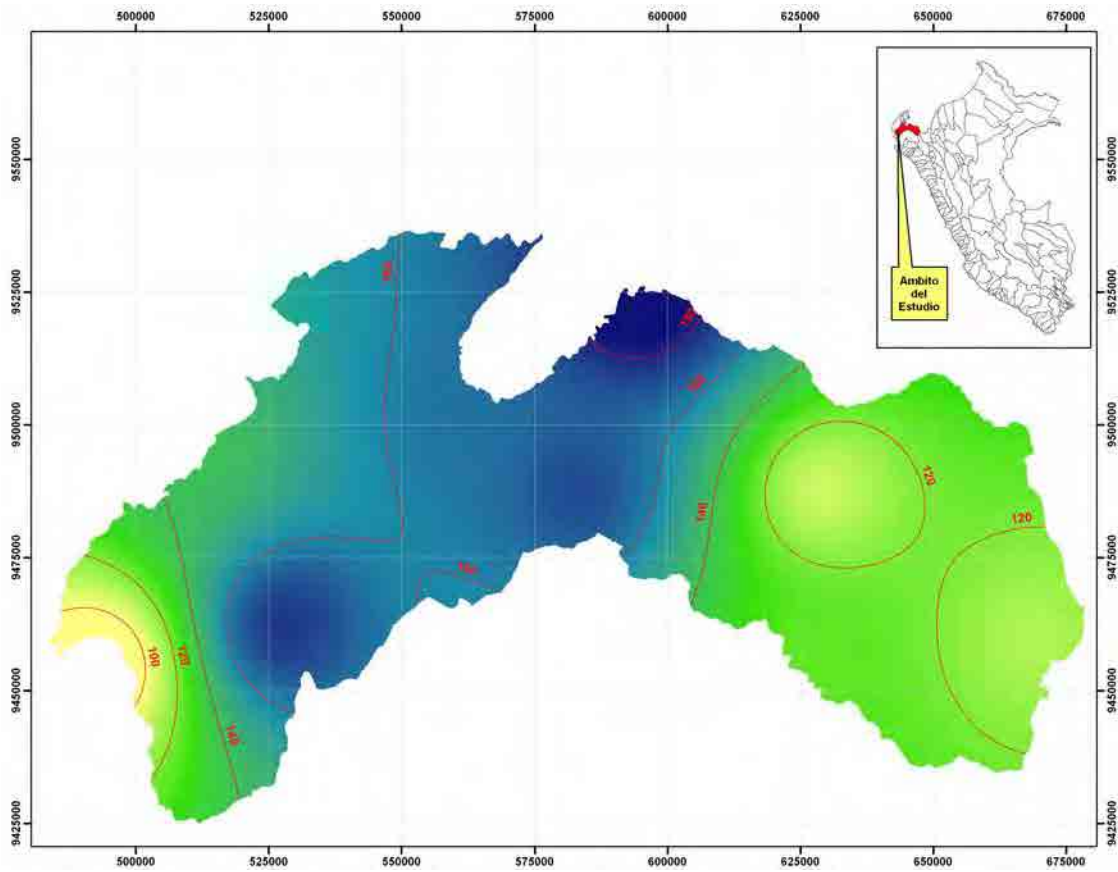


Figure N° 4.2d. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

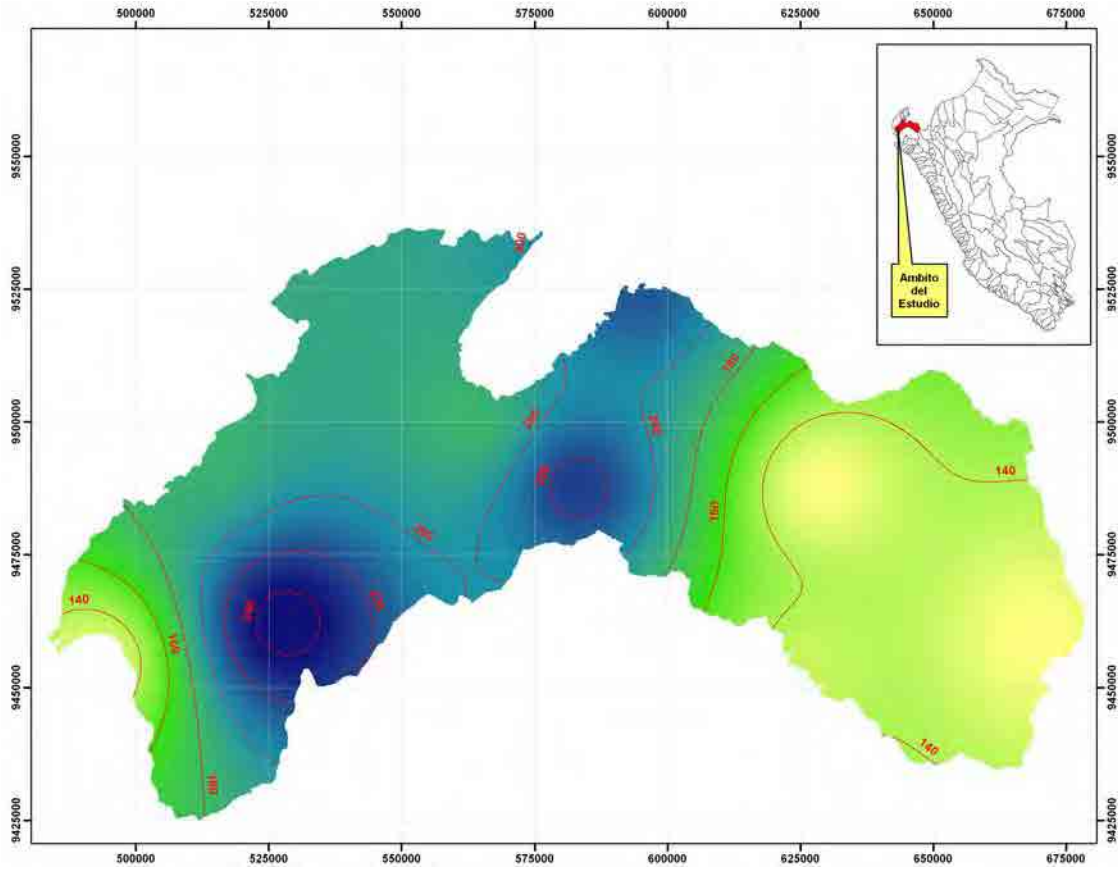


Figure N° 4.2e. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

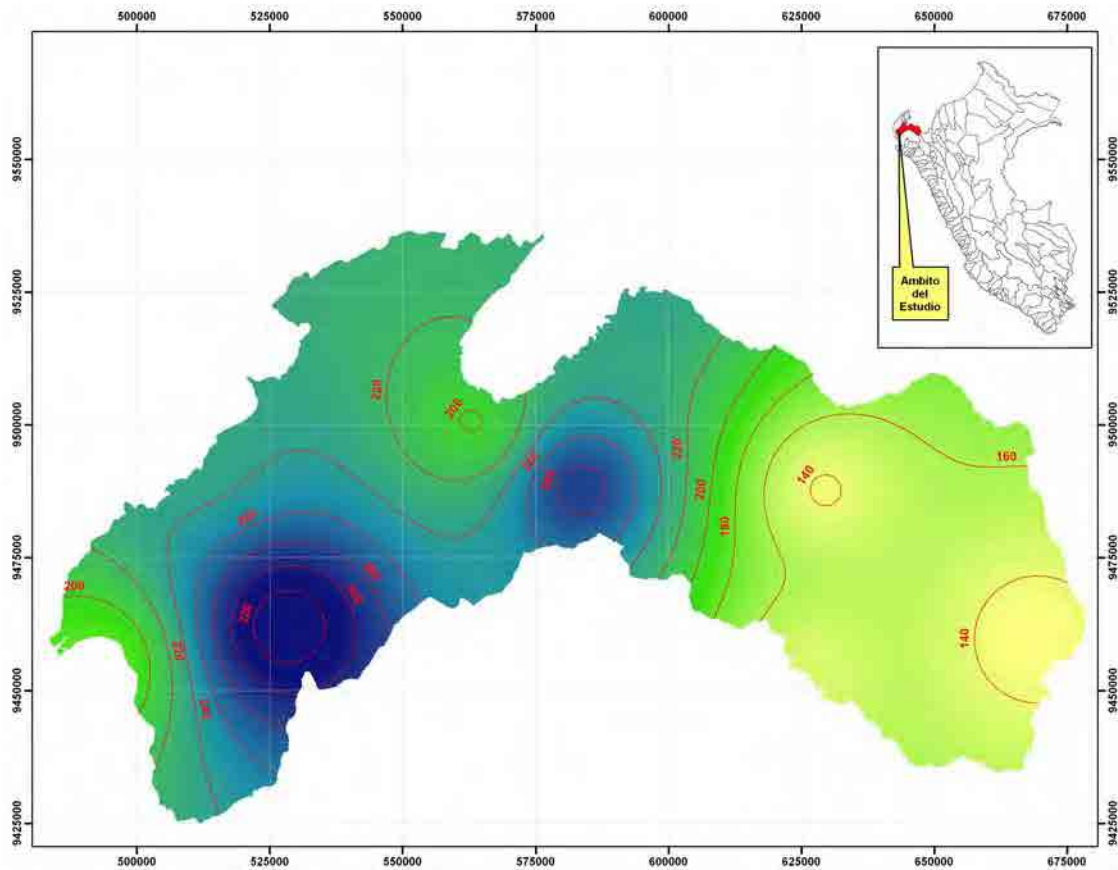


Figure N° 4.2f. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Chira Basin

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 N° 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 N° 4.2b are shown the values of maximum 24-hours rainfalls for each subbasin.

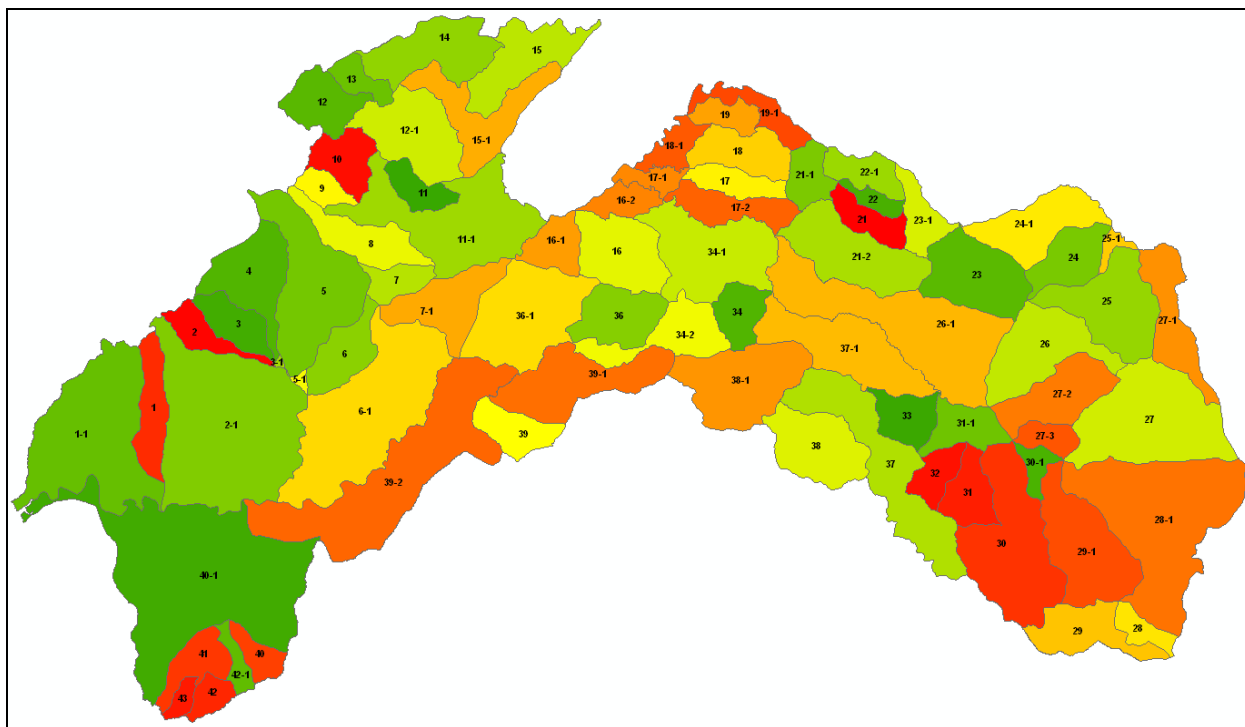


Figure N° 4.3. Chira River Subbasin

Table N° 4.2b. Maximum 24-Hours Rainfalls for Different Return Periods in each river Basin of Chira

SUBBASIN	AREA [m ²]	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 N° 4.3. Comparison of Time Distribution of the Extreme 24 Hour Rainfall Observed at El Tigre Station with Typical SCS Storm Distribution.

Time (hr)	t/24	24 hr precipitation temporal distribution			
		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

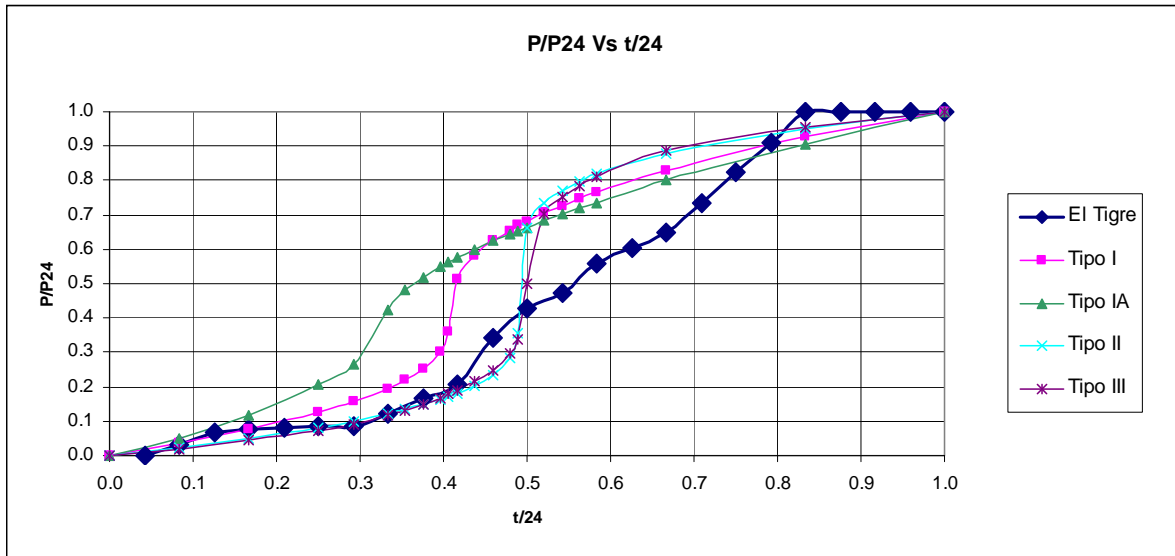


Figure N° 4.4. SCS 25-Hr Rainfall Distribution for the Type I, Type IA, Type II and Type III Rainfall Distributions. Compare to Data Registers at El Tigre Station

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 km². 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 N° 4.4

Table N° 4.4. Maximum Daily Discharge of station Puente Sullana and Ardilla, Chira River (m³/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 N° 4.5. Maximum Discharges for each Return Period at Station Puente Sullana and Ardilla, Chira River (m³/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):

$$t_p = 0.75C_t(L \cdot L_c)^{0.3}$$

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 N° 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 N° 4.7. Sub-Basins of the Chira Major Basins

Sub - Basin	Area (km ²)	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 N° 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 assumption 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 Numbers 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 N° 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 catchment until Puente Simón Rodríguez, of 17059 km² , 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 N° 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 N° 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 N° 4.5 shows the watershed considered by HEC-HMS model for the simulation.

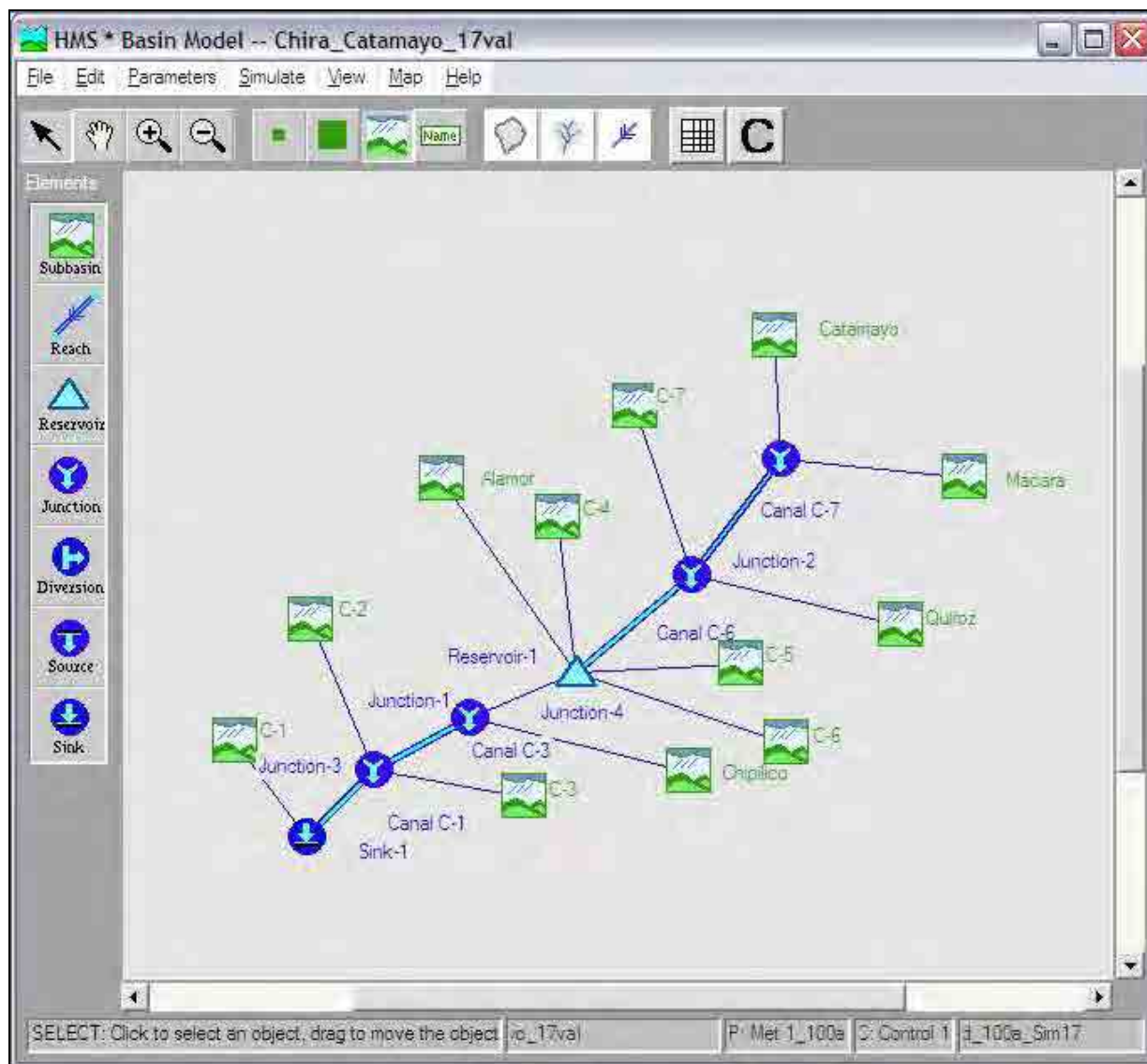


Figure N° 4.5. Watershed considered by HEC-HMS model for the simulation.

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

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 N° 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.

