Appendix-2 Hydrologic Study of Cañete 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 CAÑETE RIVER

Appendix-2

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HYDROLOGY OF MAXIMUM FLOODS IN CAÑETE RIVER

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I. INTRODUCTION

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

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 province of Cañete in the Department of Lima.

2.1.2 Geographic Location

The study area is located approximately at coordinates UTM at 345,250 and 444,750 in East Coordinates, and 8’543,750 and 8’676,000 in North Coordinates (Zone 18).

2.2 Background

As part of the project: "Protection of Rural Areas and Valleys and Flood Vulnerable", it requires a supporting technical document of the maximum flooding of the Cañete River, to define planning proposals hydrologic and hydraulic Cañete 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 Cañete River overflowed causing flooding of extensive crop areas and cities such as San Vicente de Cañete, Imperial, Pacarán, Socsi and Lunahuana, 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 Socsi Station. 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

Cañete 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 Cañete 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 Cañete River

3.1.1 General Description of the Basin

Politically, the Cañete River basin is part of the province of Cañete, department of Lima.

Its boundaries are: on the north by the Mantaro river basins, south to San Juan (Chincha) River Basin and the Pacific Ocean, on the east by the Mantaro River Basins and west to Mala River Basin and the Pacific Ocean.

It has a total area of 6,068.5 km2 and its waters drain into the Pacific Ocean with a tour of the main course predominantly southwesterly.

Cañete Valley, an area affected by the floods, is located in the lower basin between latitudes 11º58’19” – 13º18’55” South and longitude 75º30’26” – 76º30’46” West. Politically it belongs to the province of Cañete, department of Lima.

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

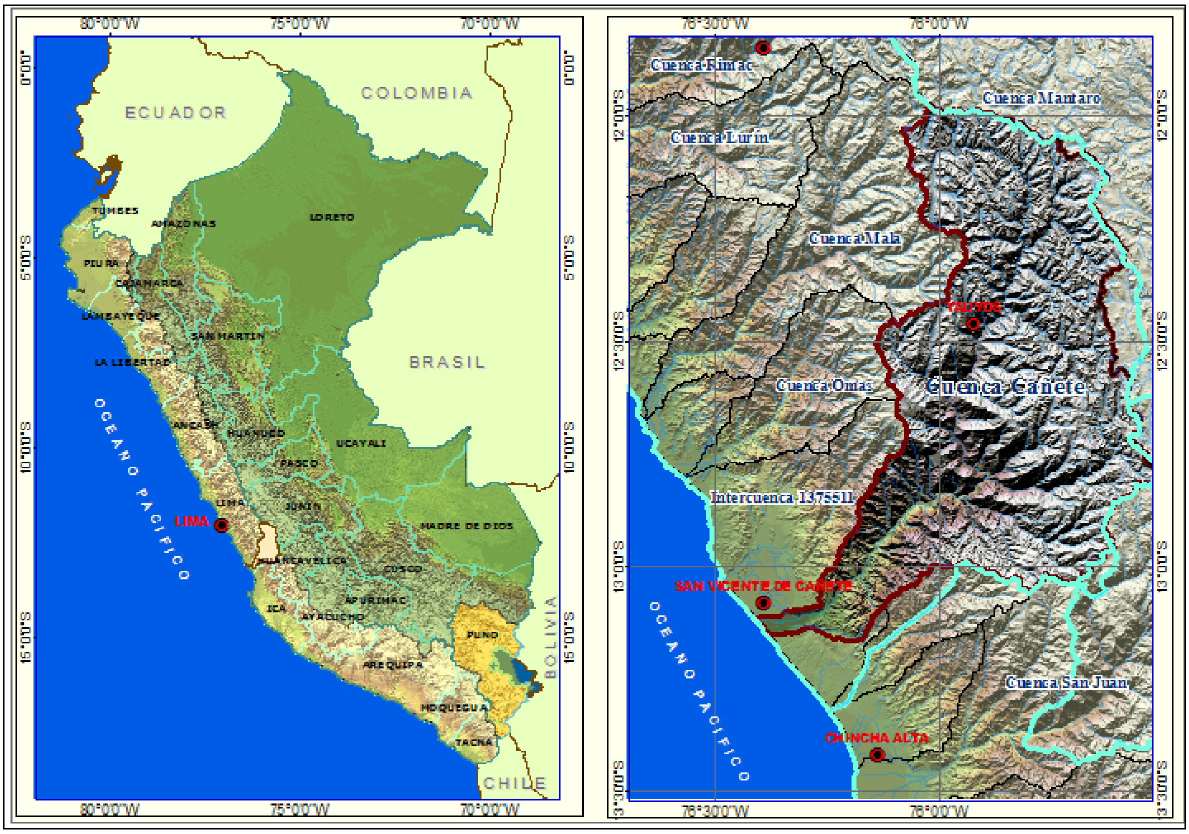


Figure Nº 3.1. Location Map of the Cañete River Basin

3.1.2 Hydrography of the Cañete 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. Cañete River is one of them, being located in the central region of this side.

Cañete River has an intermittent regimen and torrential character, its discharges are presented in the months of January to April. The maximum monthly discharge has been appraised of 900.00 m³/s (February-1972) and a low of 5.20 m³/s (September), with a mean annual discharge of 52.16 m³/s equivalent to an average annual volume of 1629.36 MMC.

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

3.2 Climatology

3.2.1 Rainfall

The rainfall, as a main parameter of the runoff generation is analyzed considering the available information of the stations located in the interior of the Cañete Basin, and in the neighboring Mala, Mantaro and San Juan (Chincha).

Rainfall information is available from 13 pluviometric stations located in the vicinity of the study area; these are located in the Cañete River Basin and surrounding basins. These stations are operated and maintained by the Peruvian

National Service of Meteorology and Hydrology (SENAMHI by their initials in Spanish)

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

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

CODE	STATION	DEPARTMENT	LONGITUDE	LATITUDE	ENTITY
636	YAUYOS	LIMA	75° 54'38.2	12° 29'31.4	SENAMHI
155450	YAURICOCHA	LIMA	75° 43'22.5	12° 19'0	SENAMHI
155169	TOMAS	LIMA	75° 45'1	12° 14'1	SENAMHI
156106	TANTA	LIMA	76° 01'1	12° 07'1	SENAMHI
6230	SOCSI CAÑETE	LIMA	76° 11'40	13° 01'42	SENAMHI
638	PACARAN	LIMA	76° 03'18.3	12° 51'43.4	SENAMHI
6641	NICOLAS FRANCO SILVERA	LIMA	76° 05'17	12° 53'57	SENAMHI
156112	HUANTAN	LIMA	75° 49'1	12° 27'1	SENAMHI
156110	HUANGASCAR	LIMA	75° 50'2.2	12° 53'55.8	SENAMHI
156107	COLONIA	LIMA	75° 53'1	12° 38'1	SENAMHI
156109	CARANIA	LIMA	75° 52'20.7	12° 20'40.8	SENAMHI
156104	AYAVIRI	LIMA	76° 08'1	12° 23'1	SENAMHI
489	COSMOS	JUNIN	75° 34'1	12° 09'1	SENAMHI

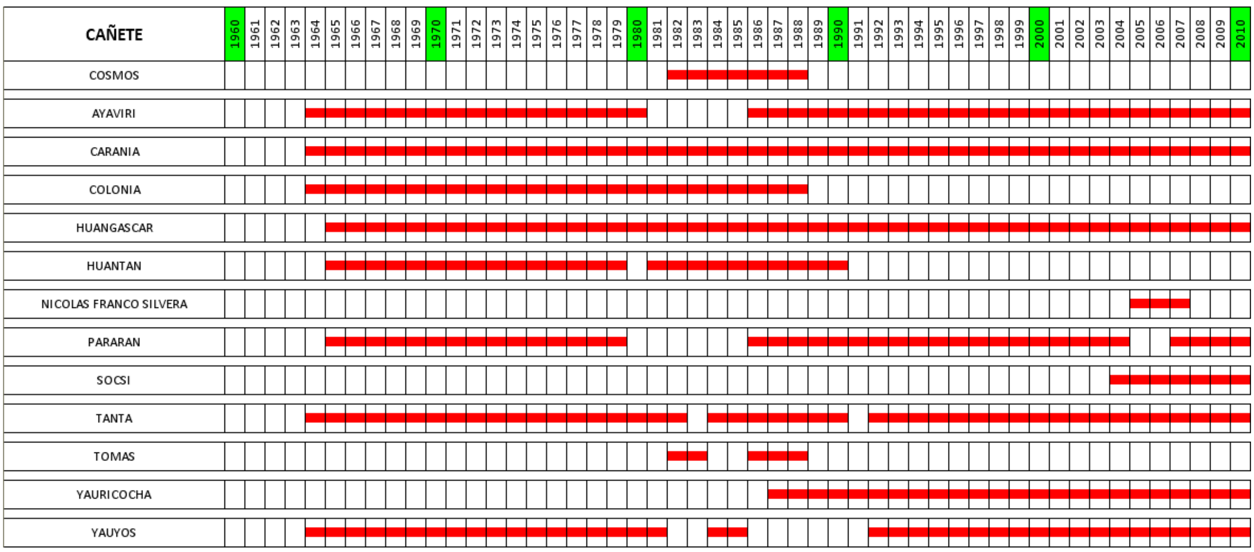


Figure Nº 3.2. Period and longitude of the available information of the rainfall stations

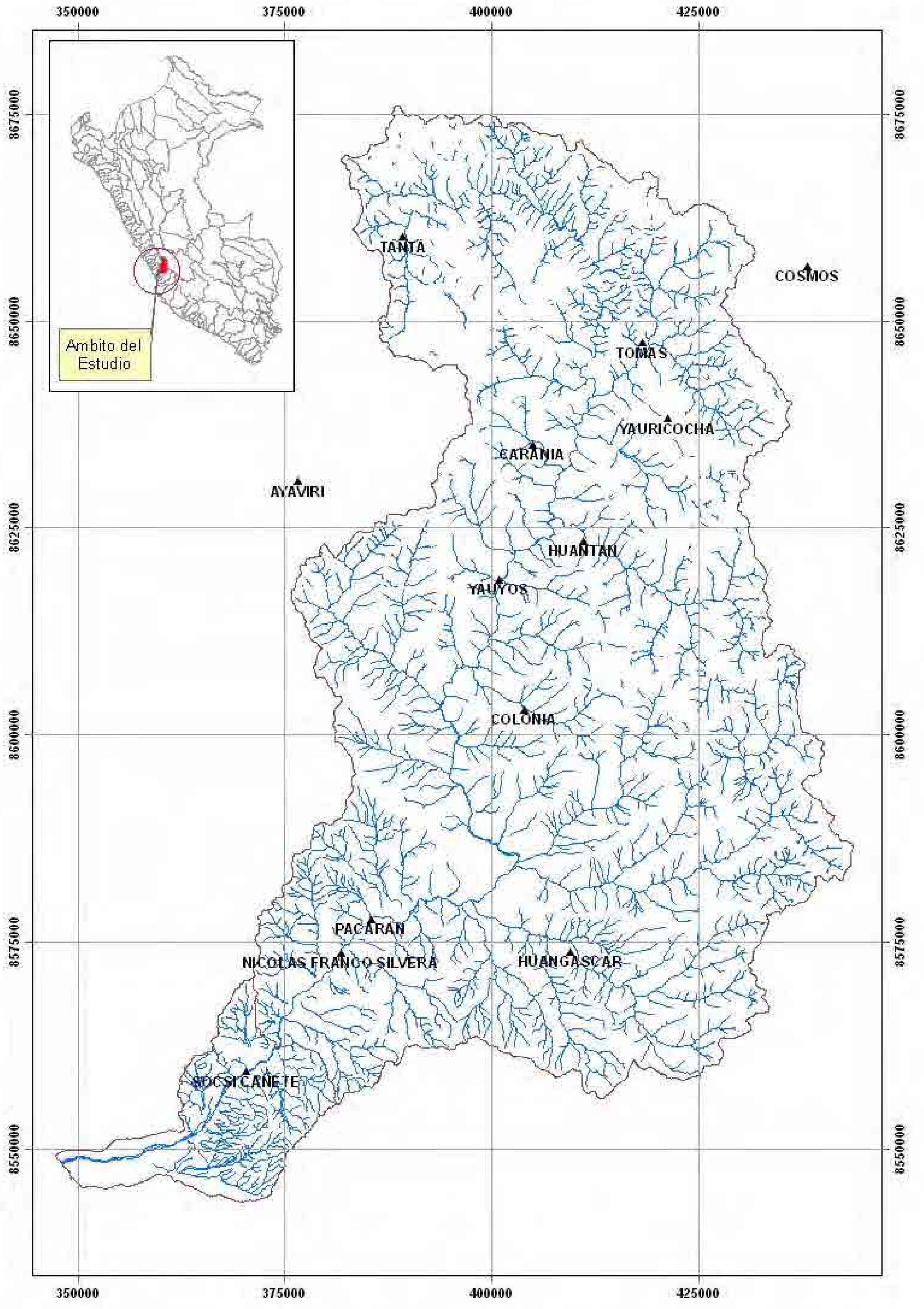


Figure Nº 3.3. Location of the Rainfall Stations in Cañete River Basin and Adjacent Basins

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

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

STATION	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
YAUYOS	71.36	83.70	83.26	20.35	3.36	0.52	0.15	0.92	3.10	12.94	19.68	44.46	343.80
YAURICOCHA	178.17	168.19	169.94	92.76	20.76	9.40	10.52	20.85	37.28	88.02	81.24	138.64	1,015.78
TOMAS	128.45	119.02	100.86	67.50	21.93	17.36	11.13	14.36	35.34	44.19	55.36	86.90	702.39
TANTA	151.80	157.83	162.22	91.07	25.07	7.23	5.52	11.23	29.59	60.70	78.74	110.98	891.99
SOCSI CAÑETE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	0.00	1.47
PACARAN	4.21	4.70	3.83	0.29	0.10	0.04	0.01	0.07	0.09	0.41	0.41	1.93	16.09
NICOLAS FRANCO SILVERA	1.80	4.57	2.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	2.33	11.50
HUANTAN	195.68	236.82	196.02	72.60	7.82	1.09	1.77	2.17	2.61	50.73	62.07	98.77	928.15
HUANGASCAR	59.94	72.77	85.06	9.93	0.63	0.20	0.03	0.25	0.43	2.23	6.45	24.95	262.87
COLONIA	84.62	109.69	127.22	27.47	3.15	0.35	0.79	0.56	3.81	15.23	21.41	64.96	459.25
CARANIA	118.12	118.97	126.34	43.37	12.69	3.80	3.19	4.98	11.01	27.60	32.47	79.56	582.10
AYAVIRI	119.80	137.90	151.32	46.06	5.25	0.02	0.28	0.83	1.93	10.36	17.37	56.67	547.80
COSMOS	110.38	99.85	110.09	53.48	24.93	4.10	7.03	13.01	32.87	49.44	52.59	95.53	653.29

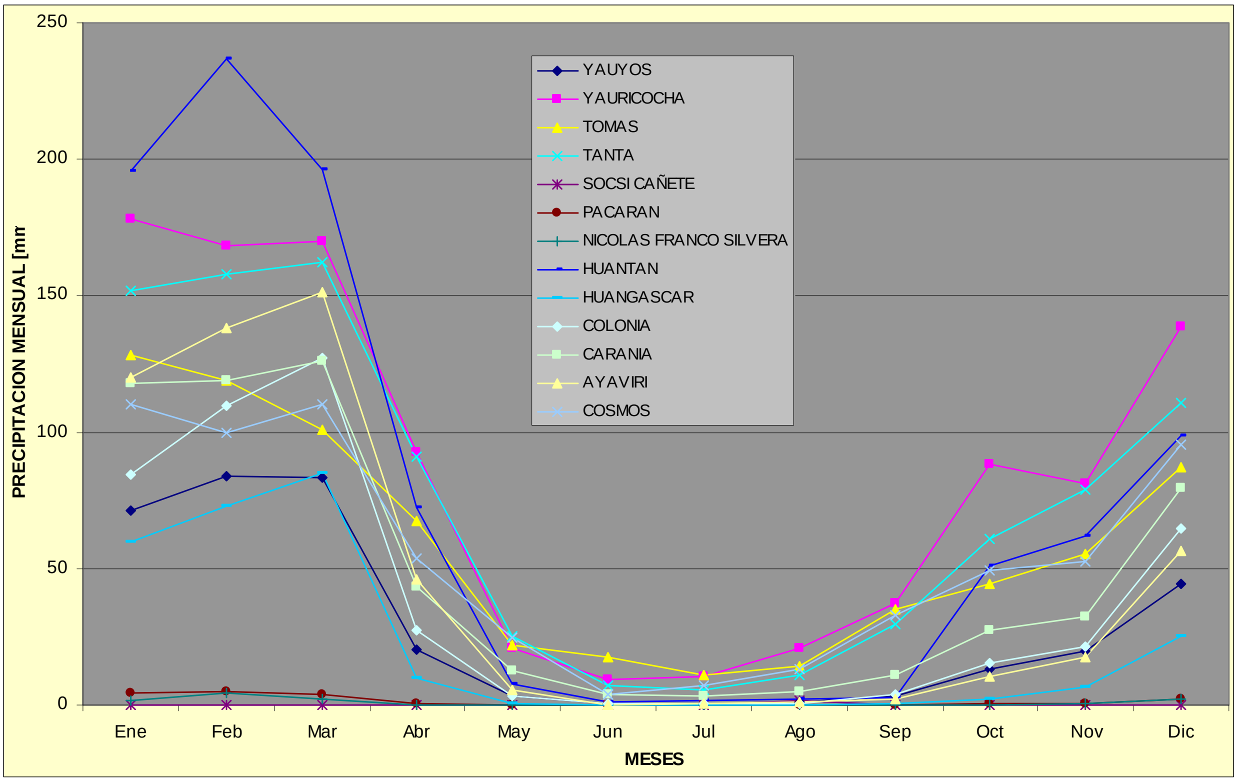


Figure Nº 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope

Table N° 3.2 and Figure N° 3.4 show that heaviest rainfalls are from October to April, and east rainfalls are from May to September. In addition, annual rainfall in the Cañete River Basin is noted to vary from 1,016 mm (Yauricocha Station) to 1.47 mm (Socsi 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 Huangascar and Carania with 46 years of record through 2009, we established a linear equation: P = mt + b, where P is annual rainfall and t is time in years, m and b are the variables that provide the best fit in a linear equation. The results are presented in Table 3.3, giving the following values of the trends:

Table Nº 3.3.Results of the linear fit equation of Carania and Huangascar station

Station	**m**	**b**	R^2
Carania	2.3017	525.70	0.0287
Huangascar	-1.6105	304.75	0.0228

The value of the regression coefficients (R2) is very low. For Carania Station would be a very weak upward trend and for Huangascar Station a seasonally weak downward 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° 3.2 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 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 Cañete River Basin varies between 1,000 mm and 200 mm, as shown in Figure N° 3.18.

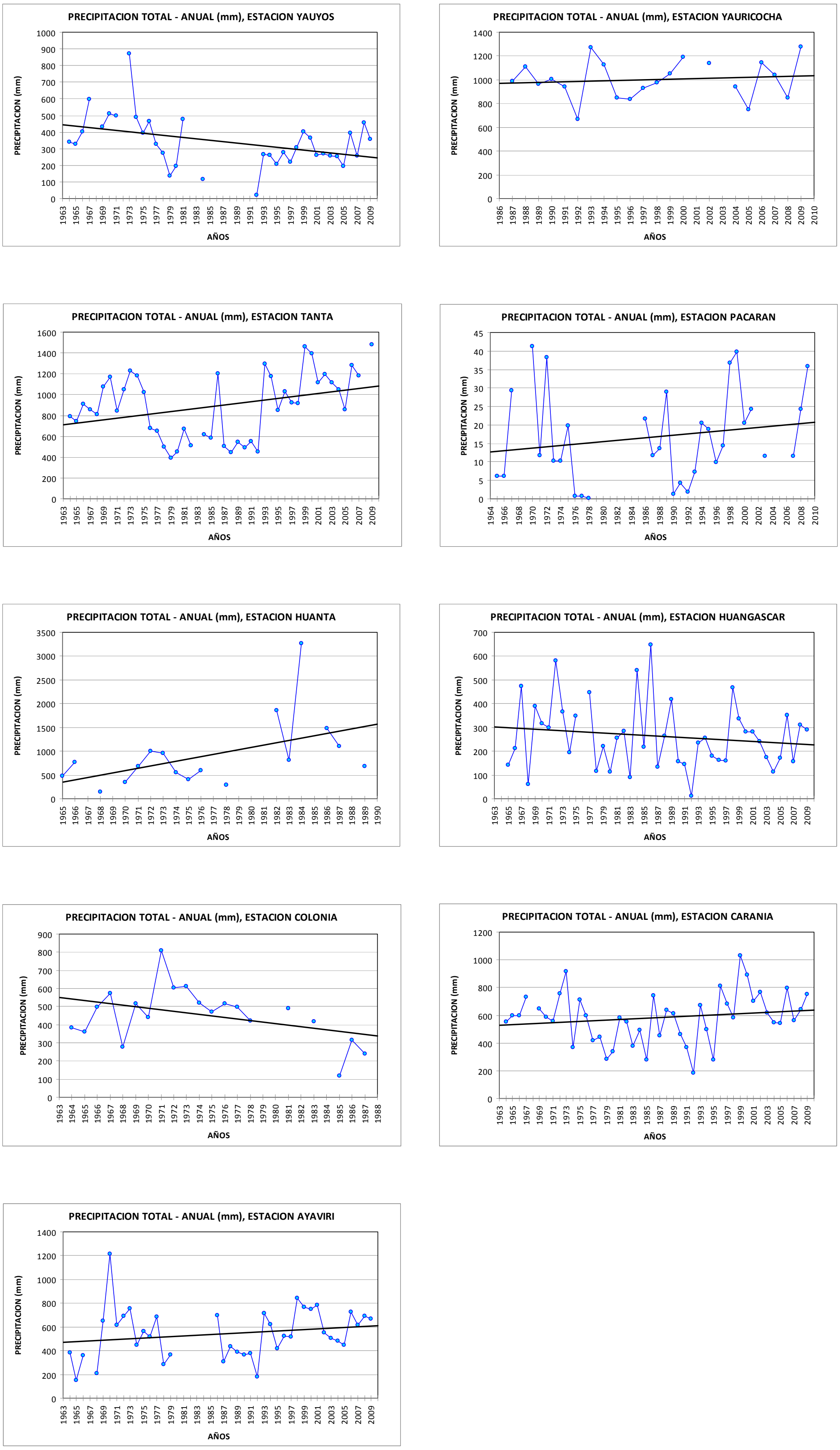


Figure Nº 3.5. Annual Rainfall Trends at the Stations considered within the Study Scope

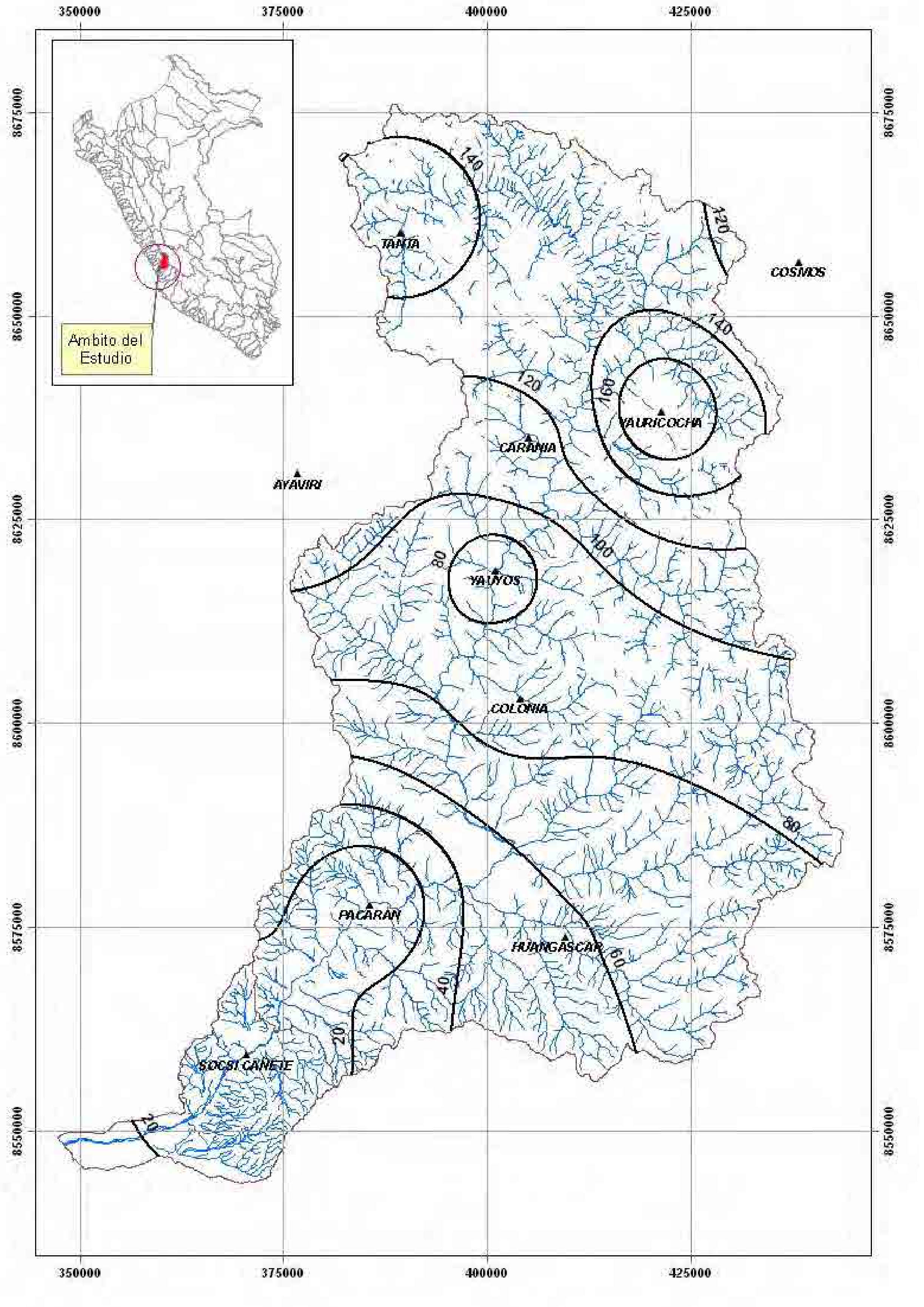


Figure Nº 3.6. Isohyets for Mean Monthly Rainfall in the Cañete Basin, in January

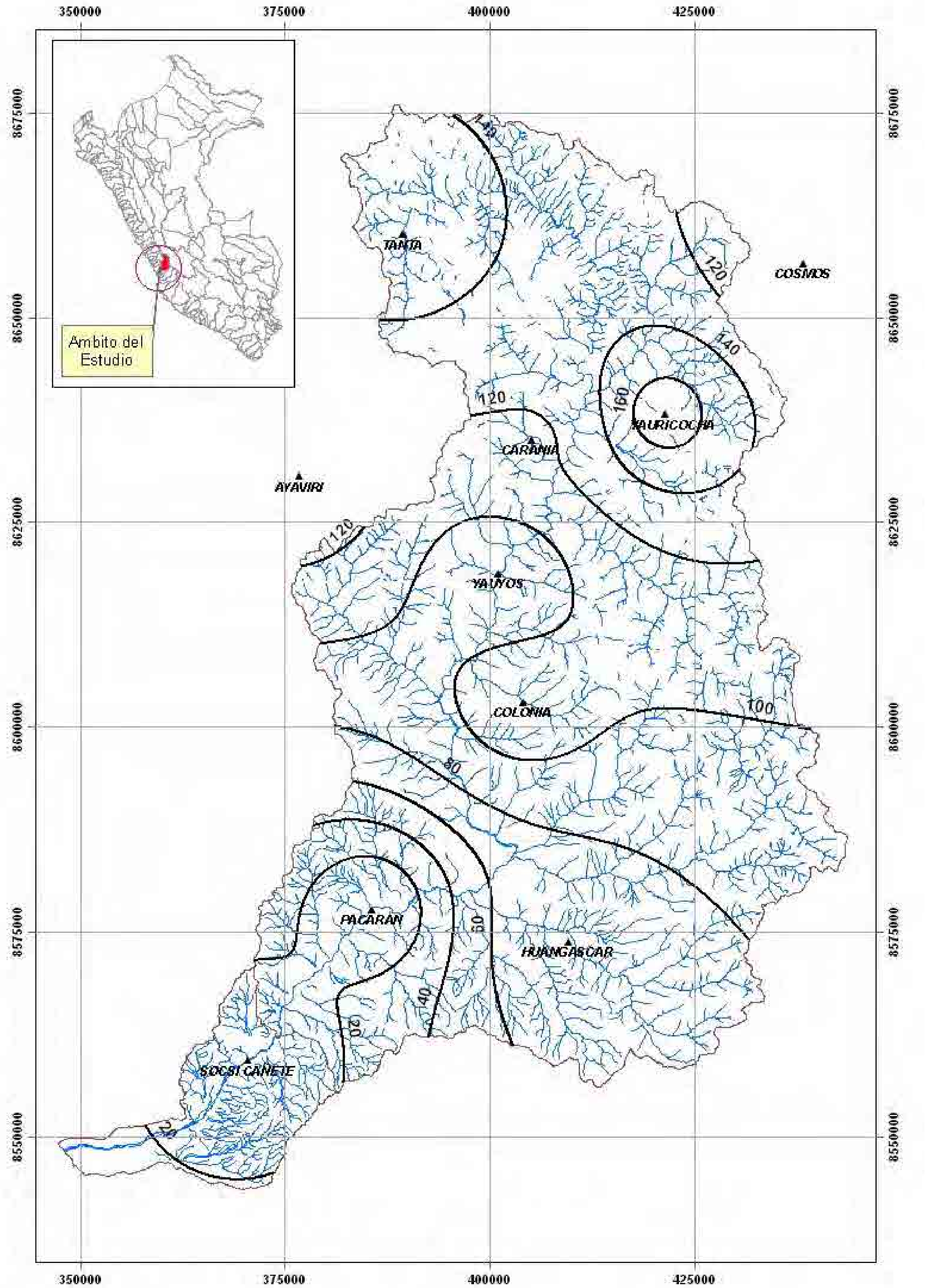


Figure Nº 3.7. Isohyets for Mean Monthly Rainfall in the Cañete Basin, in February

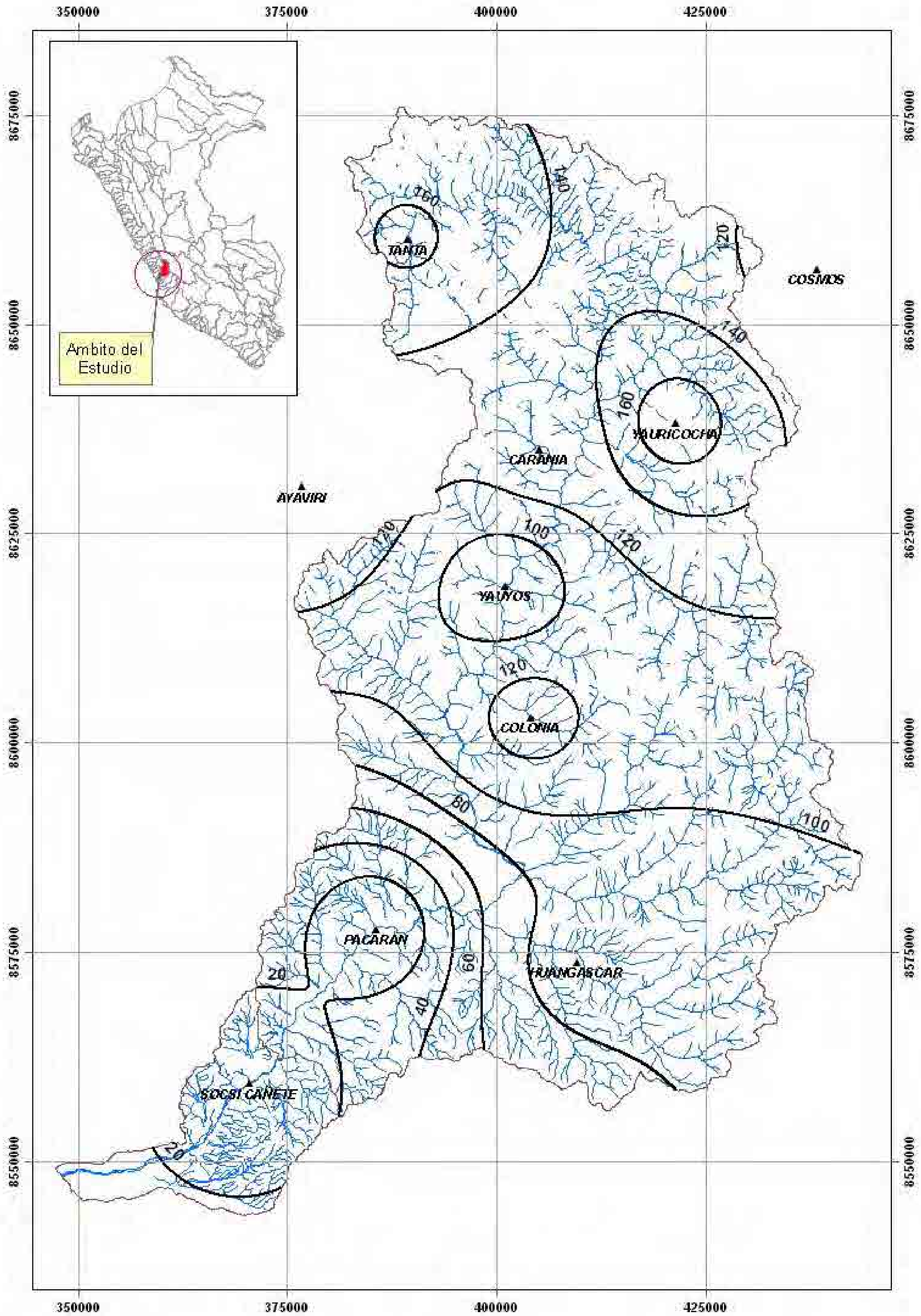


Figure Nº 3.8. Isohyets Mean Monthly Rainfall in the Cañete Basin, in March

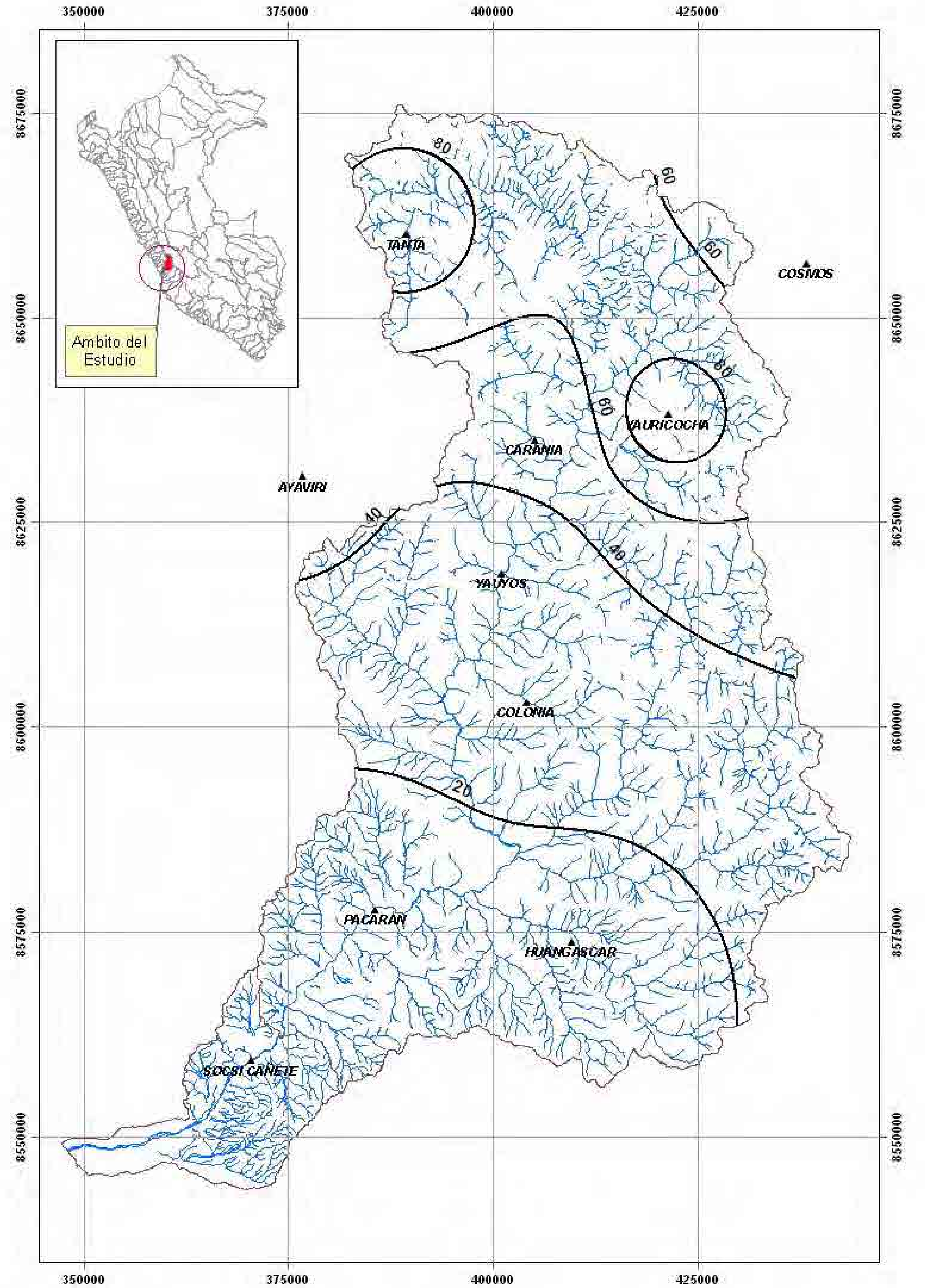


Figure Nº 3.9. Isohyets Mean Monthly Rainfall in the Cañete Basin, in April

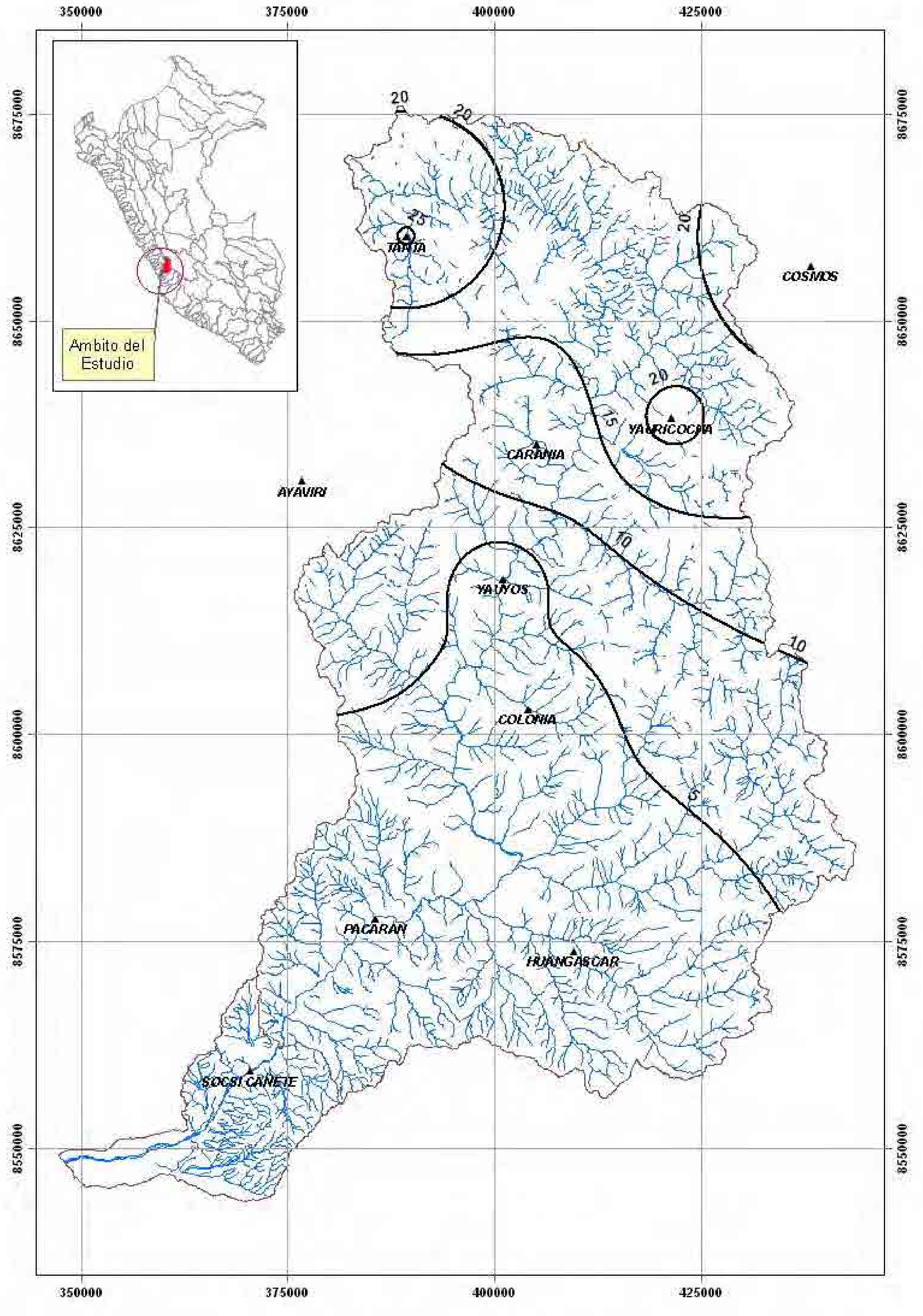


Figure Nº 3.10. Isohyets Mean Monthly Rainfall in the Cañete Basin, in May

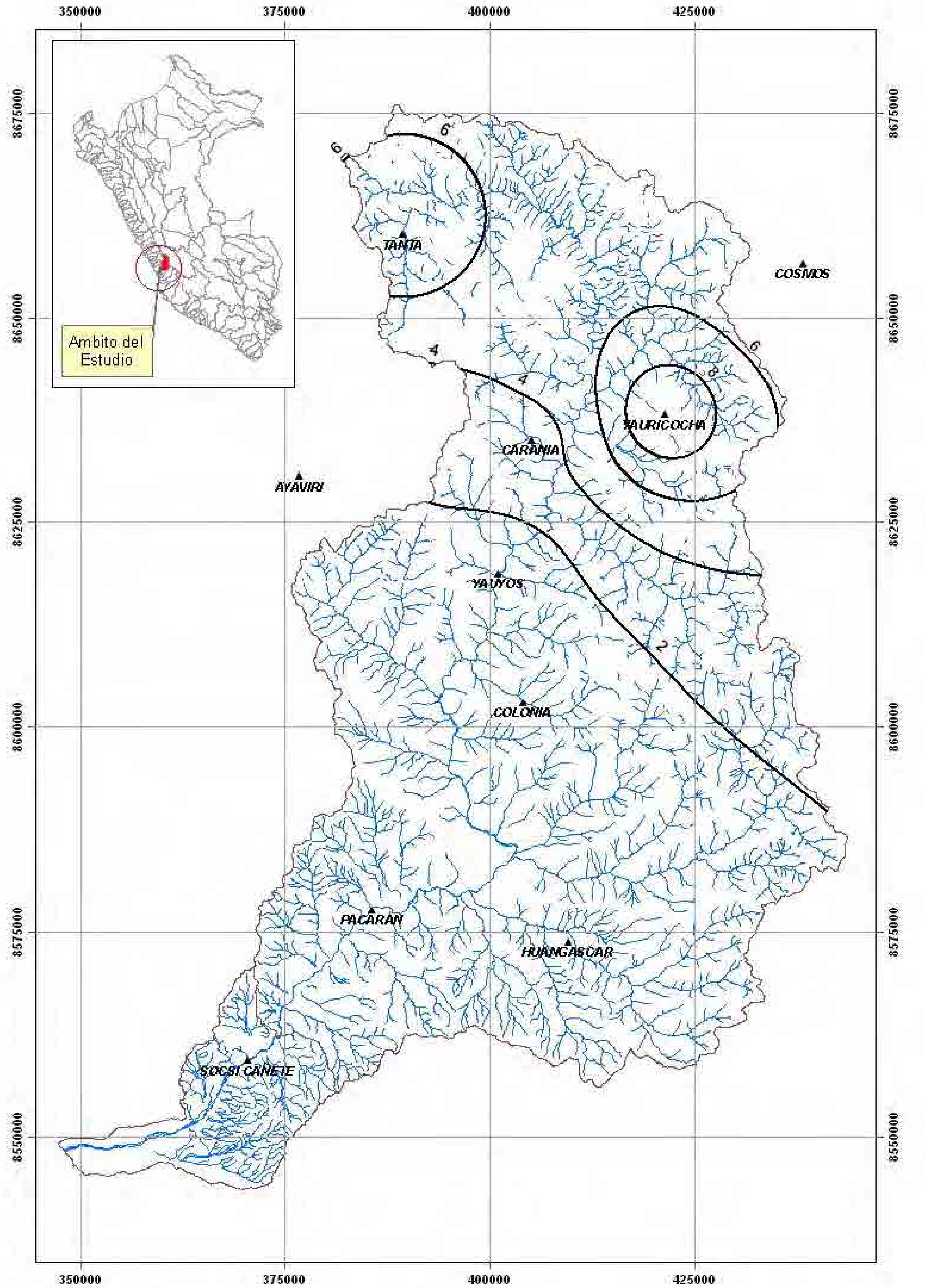


Figure Nº 3.11. Isohyets Mean Monthly Rainfall in the Cañete Basin, in June

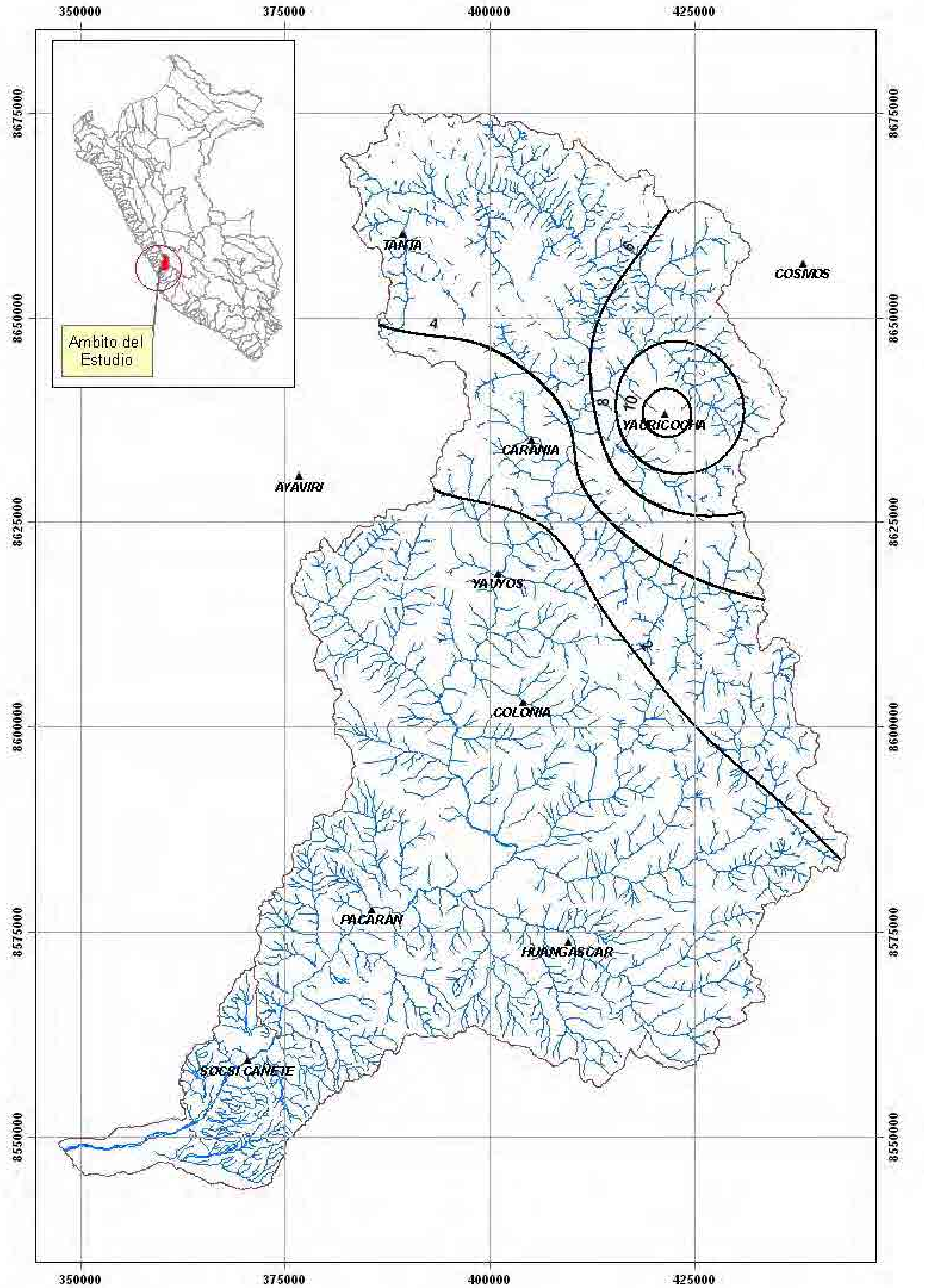


Figure Nº 3.12. Isohyets Mean Monthly Rainfall in the Cañete Basin, in July

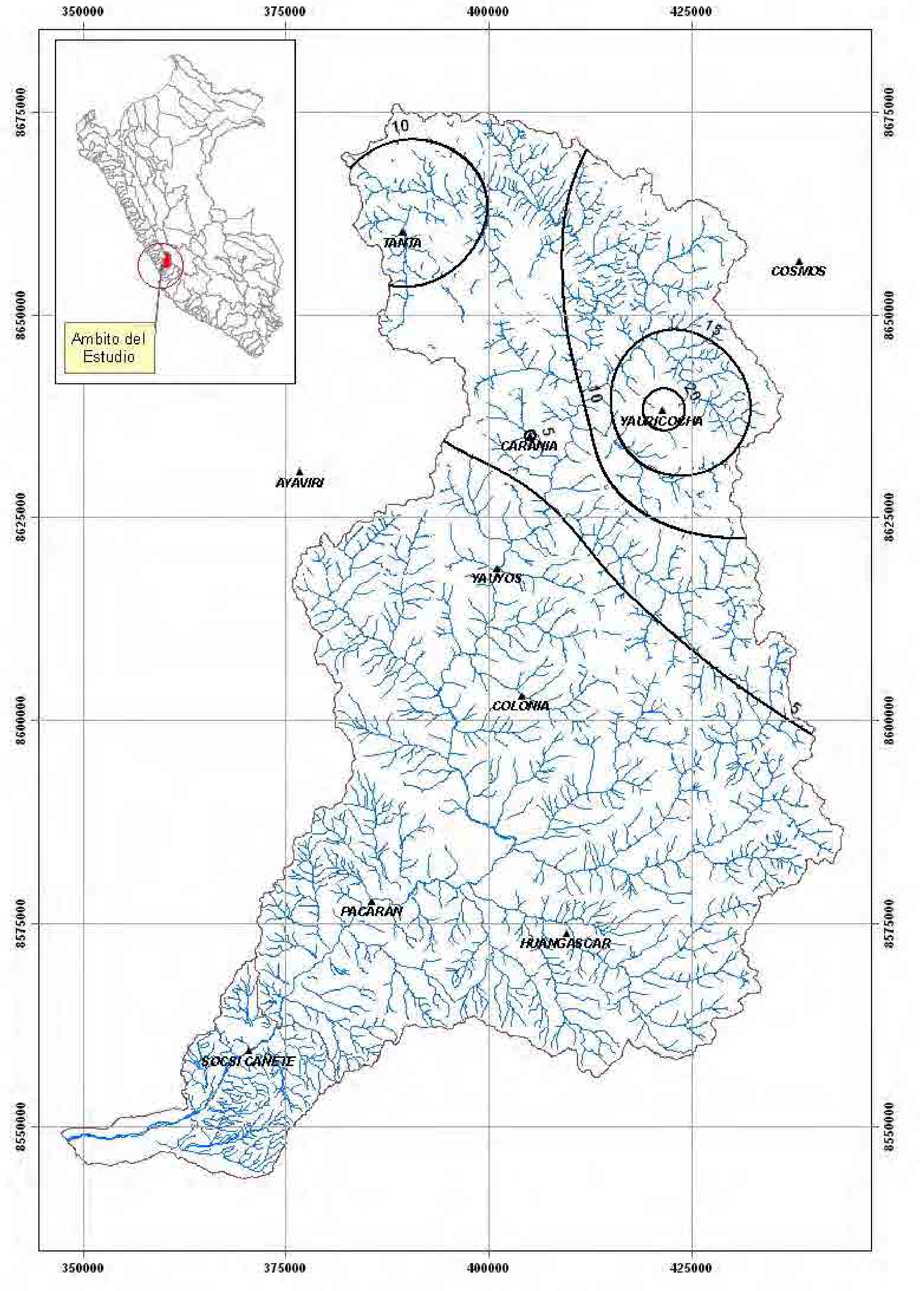


Figure Nº 3.13. Isohyets Mean Monthly Rainfall in the Cañete Basin, in August

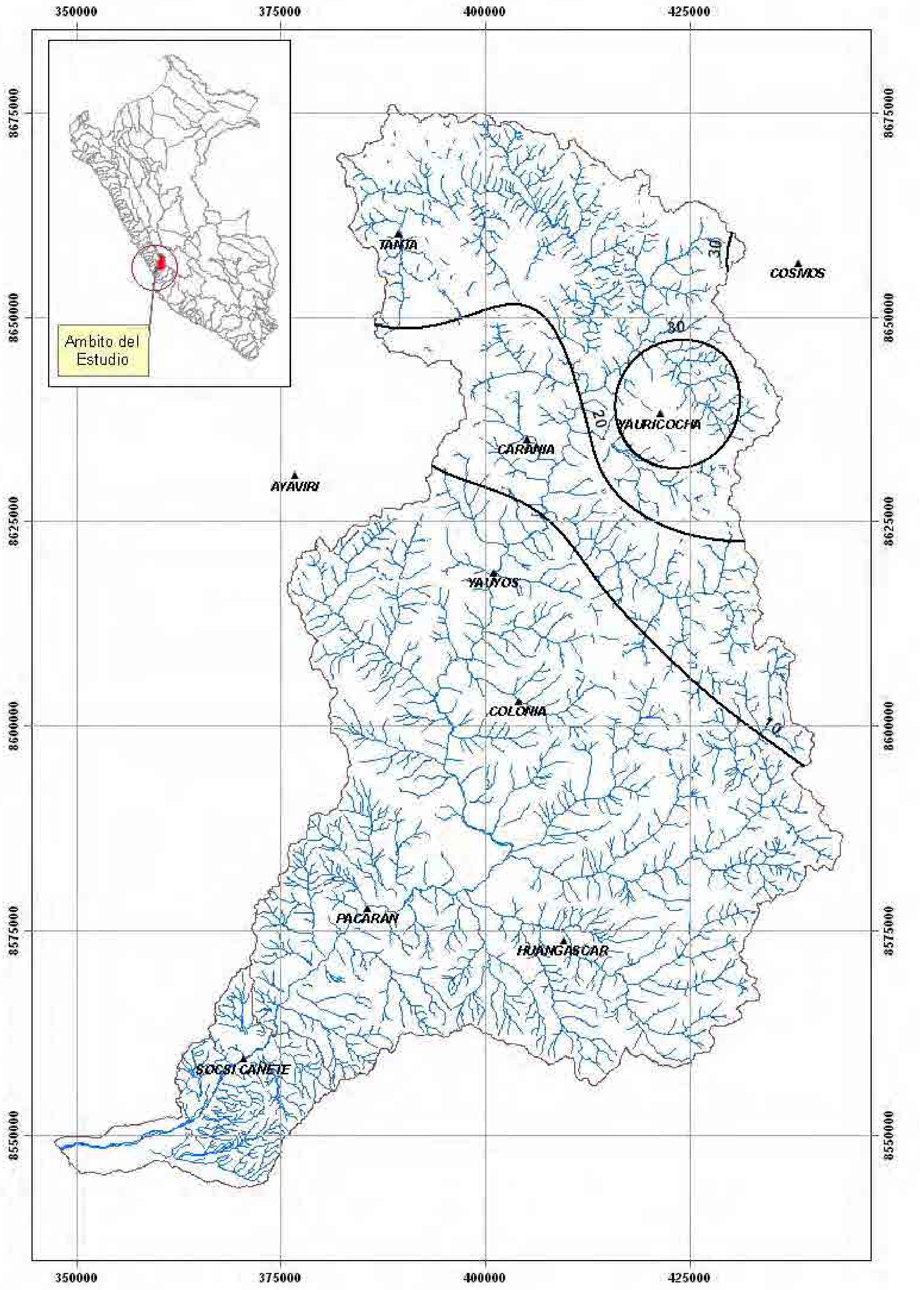


Figure Nº 3.14. Isohyets Mean Monthly Rainfall in the Cañete Basin, in September

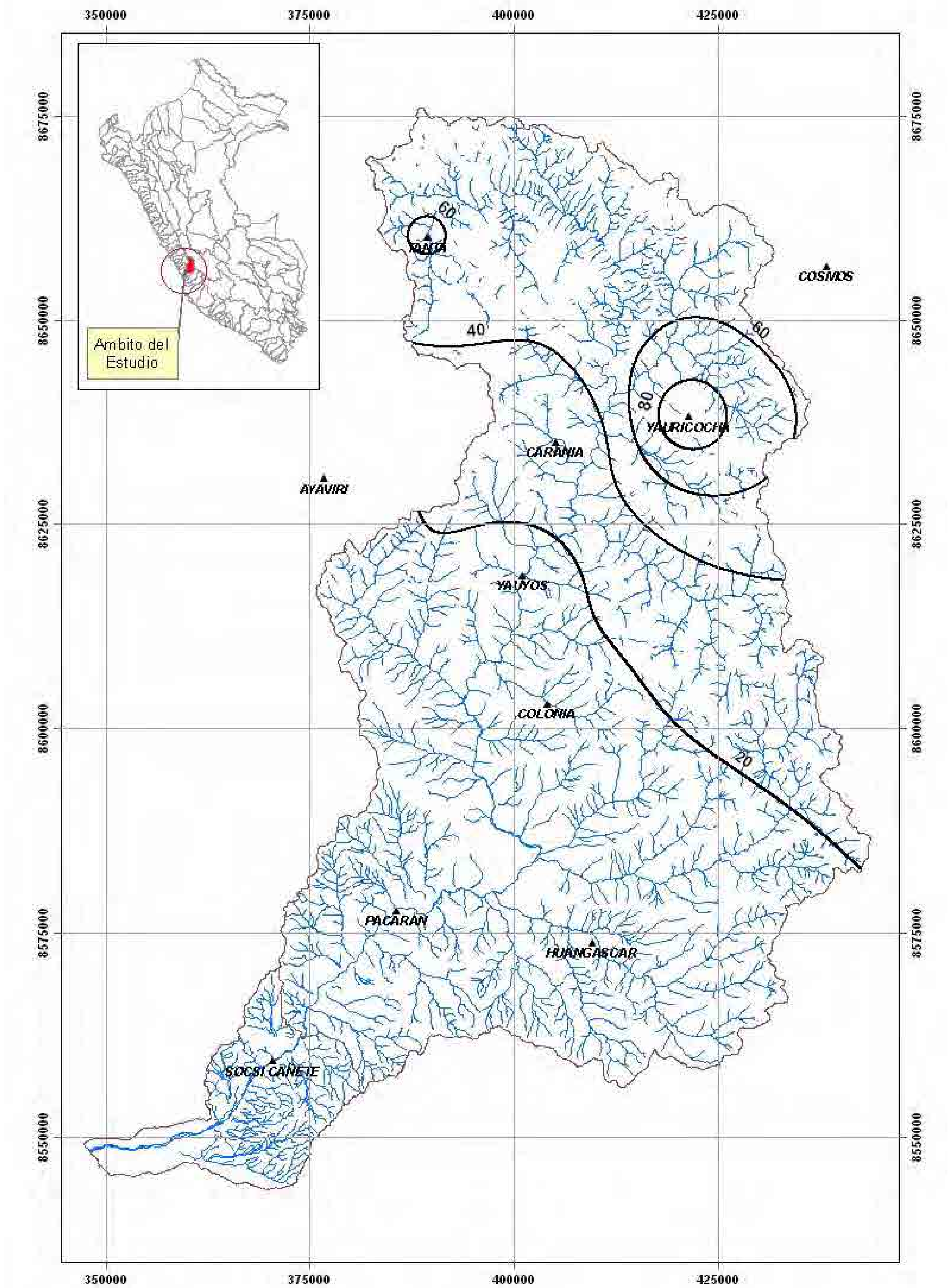


Figure Nº 3.15. Isohyets Mean Monthly Rainfall in the Cañete Basin, in October

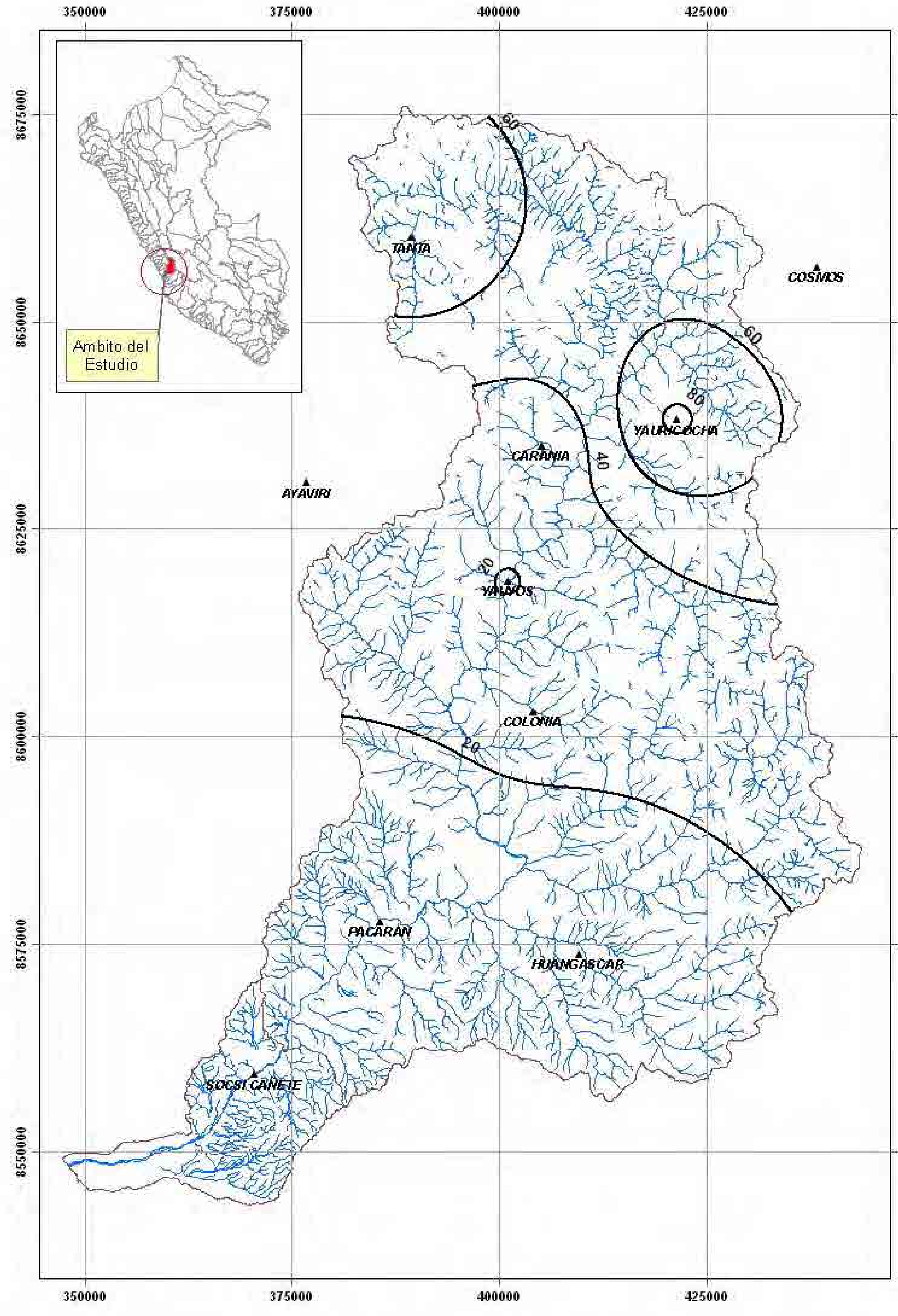


Figure Nº 3.16. Isohyets Mean Monthly Rainfall in the Cañete Basin, in November

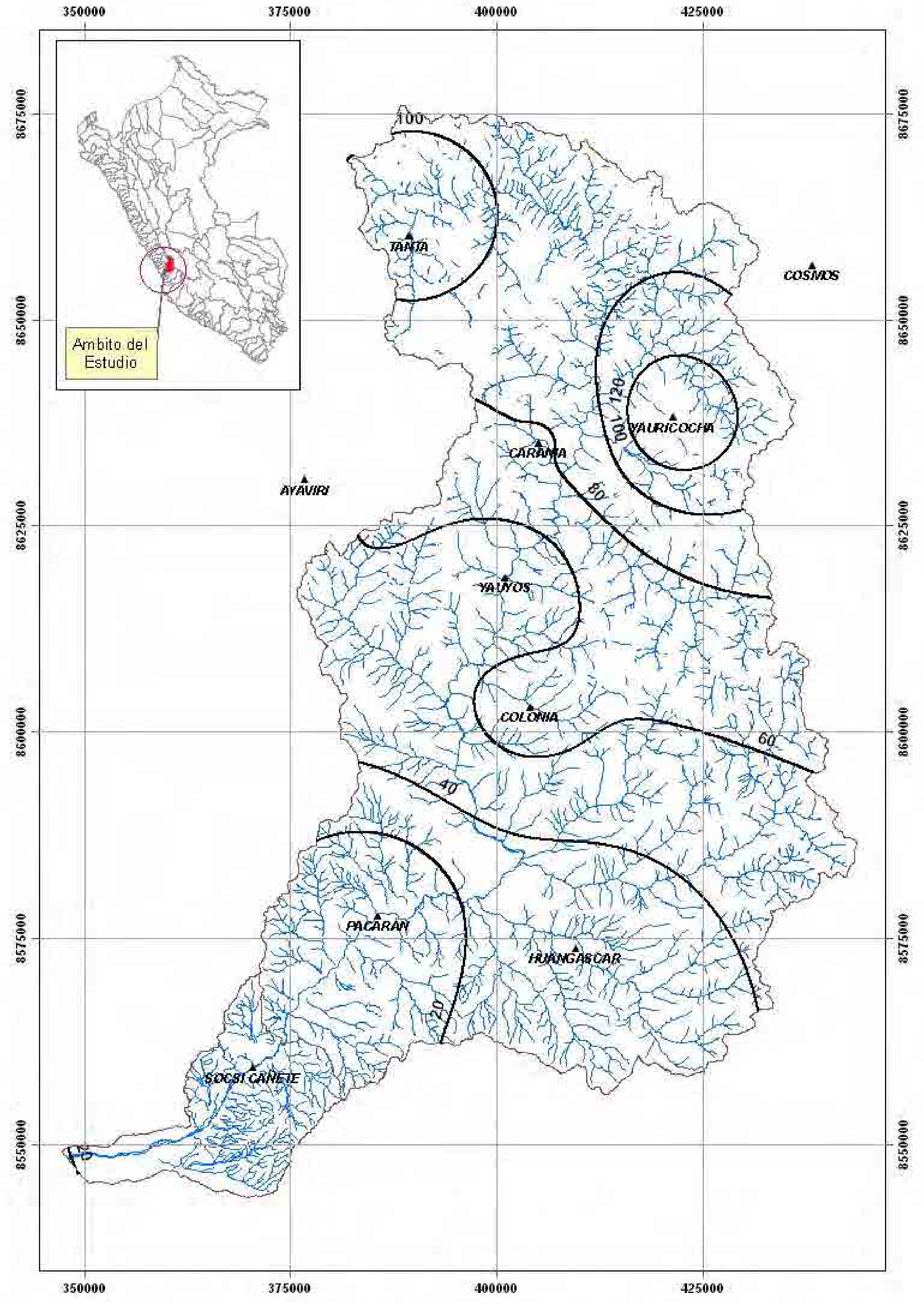


Figure Nº 3.17. Isohyets Mean Monthly Rainfall in the Cañete Basin, in December

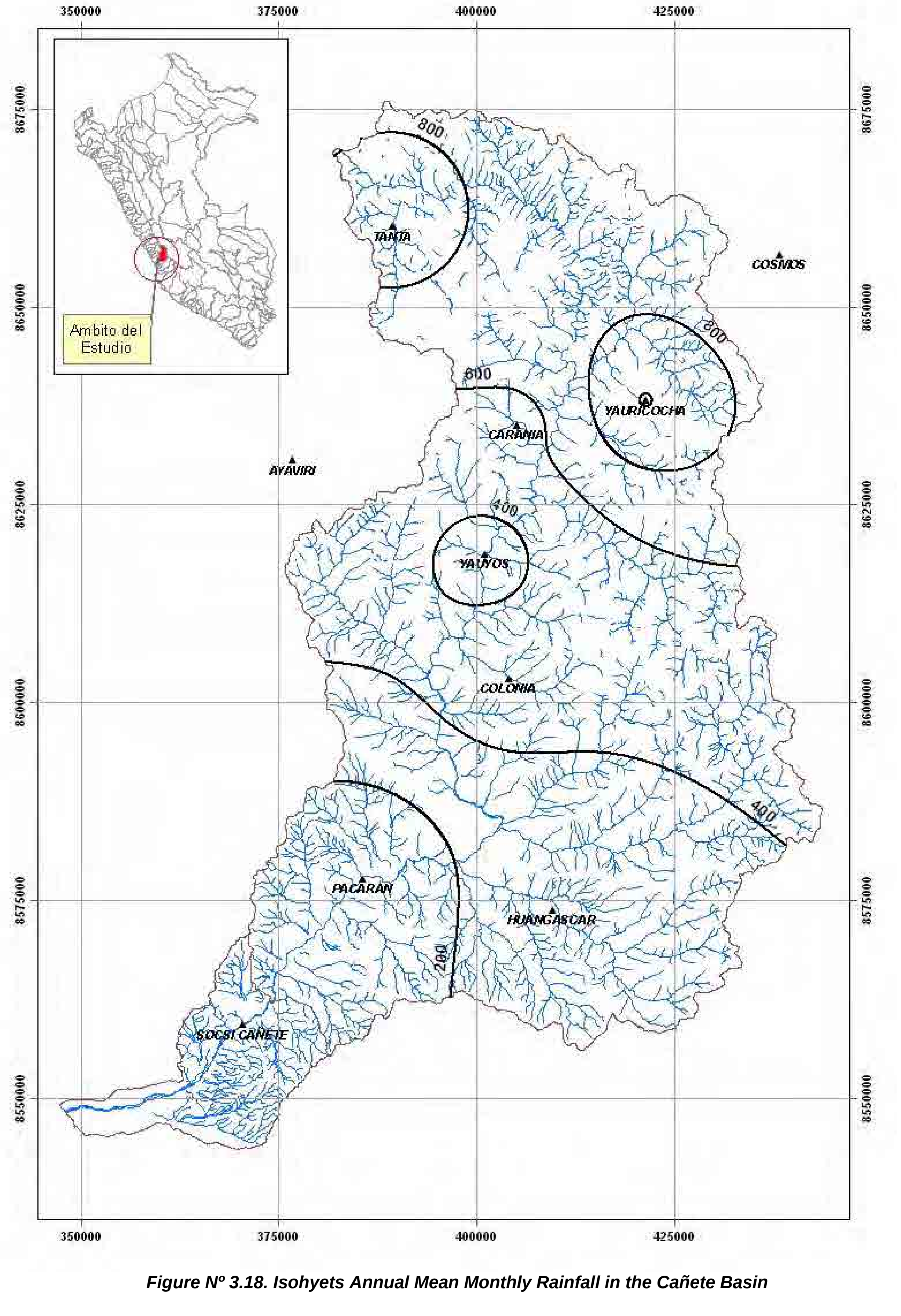


Figure Nº 3.18. Isohyets Annual Mean Monthly Rainfall in the Cañete Basin

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 Cañete Basin, the climate variable is measured by a network of meteorological stations, of Cañete, Pacarán and Yauyos, which are summarized in No. 3.4. This shows the historical averages of monthly mean temperature of the stations.

As shown in Table No. 3.4 and Figure No. 3.19, there is not great variability in the values given by Pacarán stations and Cañete, having both an annual monthly average of 20.7 and 20.0 º C. Yauyos station located at an altitude of 2290 meters, recorded a lower annual monthly average of 17.6 º C.

As you can see the annual distribution of monthly mean temperature is similar to Pacarán stations and Cañete, with temperatures with highs in the months from January to April, while the distribution at higher altitudes, controlled by the station Yauyos shows opposite behavior, is higher values of the temperature in the months of September to November.

In the valley of Cañete monthly average maximum temperature occurs in January and April, and is about 28 ° C. The monthly average minimum temperature usually occurs from July to September, with values averaging 14 ° C. Historical extreme values that have been presented for both maximum to minimum temperature are 33 º C (February) and 11.6 º C (September) respectively.

Figure N° 3.19 shows the distribution of the monthly average temperature from weather stations located in the Cañete Basin.

Table Nº 3.4. Monthly Half Temperature (C°) of the Stations of the Cañete River Basin and Adjacent Basins

ESTACION :	YAUYOS									ALTITUD : 2,290 msnm			
Año	**Ene**	**Feb**	**Mar**	**Abr**	**May**	**Jun**	**Jul**	**Ago**	**Set**	**Oct**	**Nov**	**Dic**	**MEDIA**
Máx	18.6	18.9	18.3	18.7	18.6	17.9	18.7	18.3	17.9	18.6	18.8	18.8	18.2
Mín	15.6	16.5	16.6	16.9	17.1	16.6	16.9	17.5	17.3	17.1	17.1	17.3	17.1
Prom.Mes	**17.1**	**17.4**	**17.5**	**17.5**	**17.7**	**17.1**	**17.5**	**17.8**	**17.7**	**18.1**	**17.9**	**17.8**	**17.6**
ESTACION :	PACARAN									ALTITUD : 700 msnm			
Máx	24.2	25.0	25.0	23.8	20.9	19.5	19.2	19.0	20.0	20.5	20.9	22.8	21.2
Mín	21.8	22.9	23.2	22.2	19.9	16.5	16.0	17.0	18.6	19.5	19.7	21.5	20.2
Prom.Mes	**22.8**	**23.7**	**23.9**	**22.9**	**20.3**	**17.9**	**17.3**	**17.6**	**19.1**	**20.0**	**20.5**	**22.0**	**20.7**
ESTACION :	CAÑETE									ALTITUD : 150 msnm			
Máx	23.4	24.1	24.0	22.8	21.9	22.1	21.4	21.0	21.0	20.7	22.0	24.7	22.3
Mín	22.6	23.6	23.4	21.2	18.4	15.8	15.6	16.2	16.6	17.6	18.3	21.1	19.2
Prom.Mes	**23.4**	**24.1**	**24.1**	**22.4**	**18.0**	**17.0**	**16.7**	**16.7**	**17.3**	**18.3**	**19.8**	**21.8**	**20.0**

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

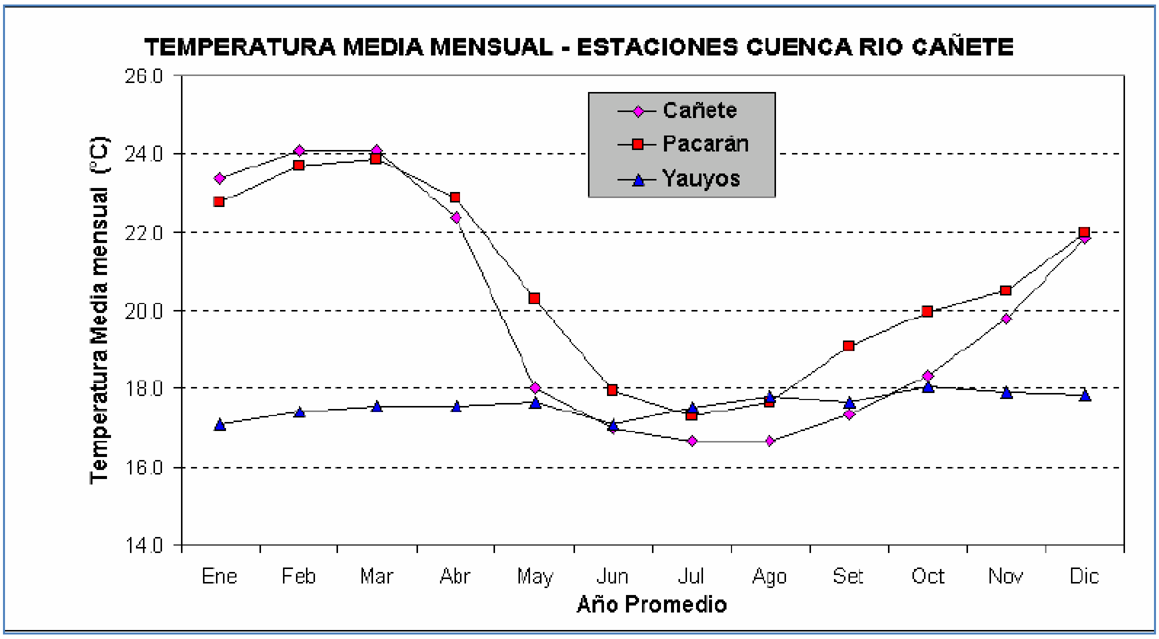


Figure Nº 3.19. Distribution of the Monthly Half Temperature of the Weather Stations Located in the Cañete River Basin

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

3.3 Hydrometry

There are 4 hydrometric stations located along the River Cañete catchment and surrounding basins. These stations are operated and maintained by the Peruvian National Service of Meteorology and Hydrology (SENAMHI by their initials in Spanish).

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

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

CODE	STATION NAME	CATEGORY*	CATCHMENT	DEPARTAMENT	PROVINCE	DISTRICT	LONGITUDE	LATITUDE	ELEVATION	CONDITION	WORKING PERIOD	
											START	END
203301	TOMA IMPERIAL	HLM	CAÑETE	LIMA	CAÑETE	LUNAHUANA	76° 13'1	13° 00'1	918	Closed	1926-01	1971-02
203302	SOCSI	HLM	CAÑETE	LIMA	CAÑETE	LUNAHUANA	76° 11'41.3	13° 01'42.9	312	Operating	1965-01	1994-08
203303	PACARAN	HLM	CAÑETE	LIMA	CAÑETE	PACARAN	76° 03'17	12° 51'58	694	Operating	Not Available	
203305	CATAPALLA	HLG	CAÑETE	LIMA	CAÑETE	LUNAHUANA	76° 06'34.7	12° 55'27.3	575	Closed	Not Available	

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.

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

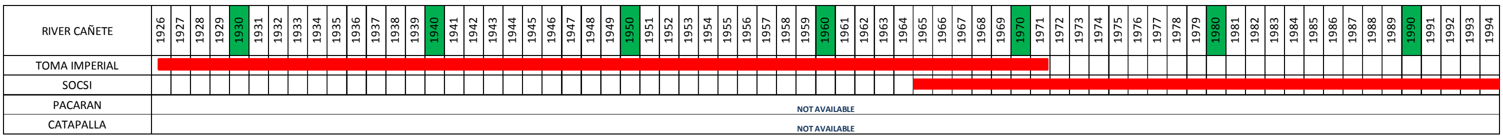


Figure Nº 3.20. Period and longitude of the available information of the Hydrometric Stations

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

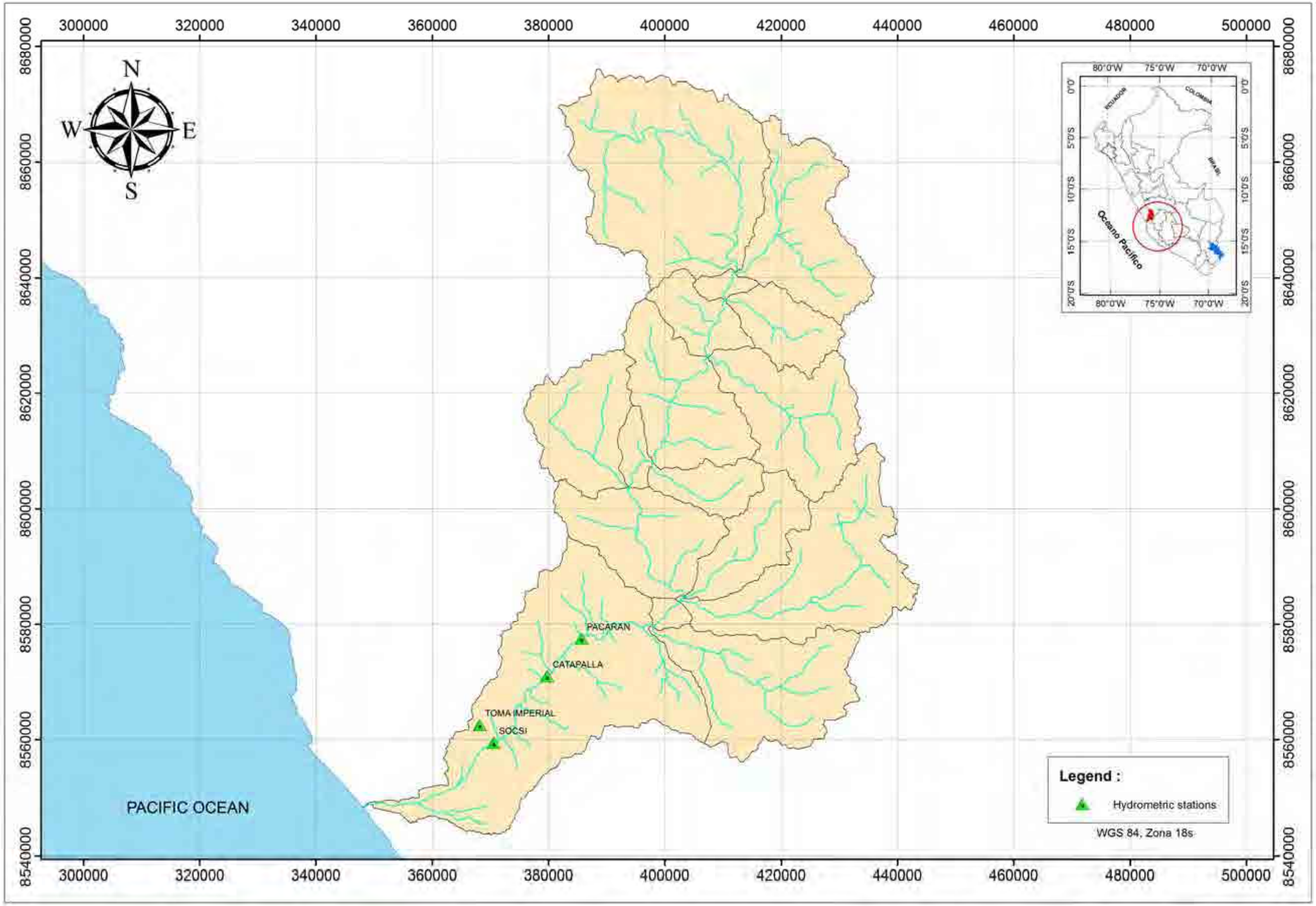


Figure Nº 3.21. Location of the hydrometric station Socsi in Cañete River basin

3.4 Comments on the hydrologic and meteorologic network in the Cañete 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, 8 stations have data until year 2010, 01 station has data until 2007, 01 station has data until 1990 and 03 stations have data until 1988.

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 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 4 stations, 1 station has data until year 1994, 1 station has data until 1971, the data from the remaining two stations was not available.

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

$$Q = aH^b$$

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

3.4.3 Recommendations

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

On the Equipment

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

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

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

.

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

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

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

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

On the Operation and Maintenance of the Equipments

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

On the Quality of the Measured Data

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

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

It is necessary to mention that there is currently an agreement between Peru's National Water Authority (ANA) and SENAMHI to provide equipment to SENAMHI weather stations financed by an external source, it is recommended that action be taken in order to include Cañete 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 in the so-called Base Point (point of interest, Socsi 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 Socsi station.

Field Reconnaissance:

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

Methodology and Procedures:

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

- Identification and delimitation of the sub – watershed to the point of interest (Hydrometric Station Socsi), 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 24 – hour maximum rainfall.

- 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 the entire basin inputs to the discharge) through the Dick and Peschke model.

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

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

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

4.2 Hydrology characterization, analysis of rainfall and river information

4.2.1 Hydrology Characterization

The geomorphological characteristics of the basis point watershed (Socsi Station) shown in Table Nº 4.1.

Table Nº 4.1. Geomorphological Characteristics of the Basis Point Watershed (Socsi Station)

Caracteristics	Value
Catchment Area (km2)	5,676.120
Major water course length (km)	187.000
Maximum Altitude (msnm)	4,760.000
Minimum Altitude (msnm)	405.000
Average Slope (m/m)	0.023

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

From the information shown in Table No. 4.2 and observing the Figure No. 3.3 and No. 3.4 in the following analysis will not consider the information from the stations Thomas and Nicolas Franco Silvera because the information was a few years and the station Huantan having information inconsistent with neighboring stations.

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

Year	Pluviometric Stations												
	YAUYOS	YAURICOCHA	TOMAS	TANTA	SOCSI CAÑETE	PACARAN	NICOLAS FRANCO SILVERA	HUANTAN	HUANGASCAR	COLONIA	CARANIA	AYAVIRI	COSMOS
1960													
1961													
1962													
1963													
1964	19.50			25.40						14.20	28.40	12.00	
1965	31.40			34.50		2.10		41.60	15.00	43.50	44.30	13.00	
1966	23.30			26.60		2.51		20.00	25.10	34.40	25.00	28.50	
1967	23.60			28.00		8.80			35.30	62.80	18.60		
1968				23.70				17.70	12.90	18.10		19.70	
1969	17.40			33.00					21.30	17.20	29.30	33.50	
1970	26.80			37.90		20.30		21.20	28.00	24.20	16.60	29.90	
1971	33.00			24.50		6.30		18.50	19.60	31.50	18.00	22.70	
1972				26.10		4.80		29.30	70.50	16.30	20.10	33.00	
1973	28.20			18.20		6.00		30.20	27.20	15.80	22.60	37.60	
1974	21.50			19.30		2.40		20.00	12.70	15.70	16.80	30.50	
1975	19.00			15.10		3.30		40.10	34.60	14.10	16.00	34.80	
1976	20.00			17.50		0.40		32.40		23.20	19.30	16.10	
1977	14.80			16.40		0.80			29.40	24.90	17.40	34.40	
1978	20.10			16.30		0.20		22.00	49.80	25.20	16.10	33.40	
1979	16.90			11.70					18.10		15.10	11.20	
1980	15.50			14.40					8.50		17.10		
1981	22.80			13.10					21.00	17.60	17.50		
1982			16.80	13.30				61.20	17.20		15.60		19.30
1983			9.80					33.60	9.70	21.50	16.60		15.50
1984	10.00			11.30				53.40	14.90		14.20		27.00
1985				12.40					13.80	8.00	12.90		
1986			17.50	18.00		3.51		36.20	19.00	26.50	20.00	32.70	33.70
1987		37.60	13.10	16.80		4.80		35.50	13.10	12.50	20.90	31.90	29.30
1988		28.80	13.60	13.80		3.30			20.40		33.10	23.80	
1989		26.10		13.90		6.00		27.70	20.00		24.40	39.40	
1990		30.80		15.80		1.20			20.00		26.00	25.60	
1991		24.00		11.50		1.50			19.00		12.40	27.40	
1992	6.30	21.50		16.00		1.21			5.00		15.10	29.90	
1993	17.30	40.50		41.60		3.00			20.00		16.00	29.70	
1994	31.50	21.80		26.40		9.00			24.00		14.10	30.20	
1995	12.20	20.20		27.00		6.20			30.00		13.50	30.20	
1996	24.30	16.60		31.70		2.60			23.00		16.10	24.60	
1997	18.80	28.20		27.40		3.60			25.30		14.60	46.20	
1998	14.70	27.60		41.80		5.50			33.80		14.10	32.40	
1999	19.90	24.40		24.50		11.20			24.30		15.60	23.10	
2000	12.90	58.60		28.90		3.80			30.60		27.00	35.40	
2001	13.30	20.60		22.70		5.60			12.80		14.90	24.00	
2002	11.60	25.80		28.20					24.80		17.70	28.70	
2003	14.40	60.40		28.00		4.40			15.00		18.90	18.20	
2004	14.20	41.30		32.90					17.70		21.40	29.20	
2005	13.60	30.40		22.00	0.00		6.40		13.00		20.50	21.00	
2006	20.60	26.20		29.50	0.00		3.00		25.10		30.10	26.50	
2007	19.80	29.00		33.60	0.00	2.30			14.60		23.40	34.20	
2008	19.90	15.40			0.00	2.60			24.00		21.90	30.40	
2009	15.10	26.90		69.20	8.00	6.00			14.80		20.50	27.30	
2010													

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

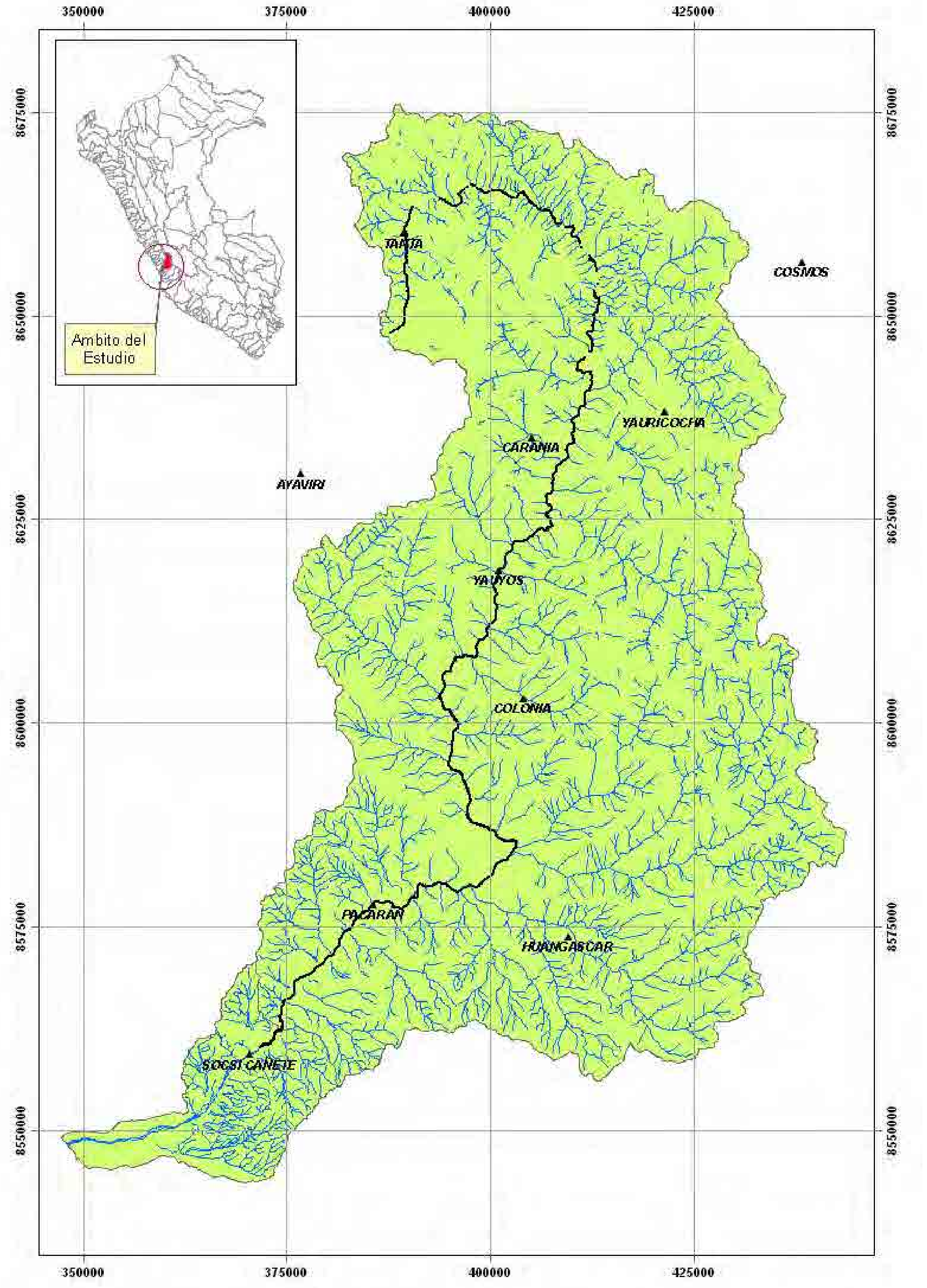


Figure Nº 4.1. Rainfall Stations considered for HEC - HMS Software application

Each maximum annual rainfall series for all ten (10) selected rainfall stations will be adjusted to a specific distribution type. In this sense, most common distribution functions are described, as applied to the extreme event hydrological studies.

4.2.2.1 Distribution Functions

The following describes the distribution functions:

1. Distribution Normal or Gaussiana

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

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

   To $-\infty < x < \infty$

   Where:

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

   x = Independent Variable.

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

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

   EXP = Exponential function with base e of natural logarithms.

2. Two-Parameter Log-normal Distribution

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

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

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

Where:

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

3. Log–Normal Distribution of Three Parameters

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

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

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

To $x_o \leq x < \infty$

Where:

xo = Positional parameter in the domain x

μ_y, = Scale parameter in the domain x.

σ_y^2 = Shape parameter in the domain x

4. Two-Parameter Gamma Distribution

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

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

To:

$0 \leq x < \infty$

$0 < y < \infty$

$0 < \beta < \infty$

As:

γ = Shape parameter (+)

β = Scale Parameter (+)

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

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

5. Three- Parameter Gamma Distribution or Pearson Type III

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

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

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

To

$x_o \leq x < \infty$

$-\infty < x_o < \infty$

$0 < \beta < \infty$

$0 < \gamma < \infty$

4.2.2.2 Calculation of Adjustment and Return Period for Maximum 24 Hours Rainfal.l

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

Based on the analysis carried out with CHAC software, data are found to fit the Generalized Extreme Value (GEV), as the distribution coefficient, see Table No. 4.3. The values for each rainfall station for each return period are shown in Table No 4.4

Table No. 4.3. Determination coefficient for each distribution function and for each rainfall station

Station	Determination Coeffcient for Each Distribution Function				
	Log Pearson III	GEV	SQRT	Gumbel	Log-Normal
AYAVIRI	0.95	0.95	0.92	0.92	0.91
CARANIA	0.91	0.92	0.91	0.91	0.89
COLONIA	0.95	0.96	0.93	0.93	0.91
COSMOS	0.92	0.93	0.91	0.90	0.90
HUANGASCAR	0.93	0.95	0.92	0.93	0.91
PACARAN		0.93	0.92	0.93	0.92
SOCSI CAÑETE		0.94		0.90	0.91
TANTA	0.90	0.92	0.91	0.92	0.90
YAURICOCHA	0.92	0.94	0.93	0.92	0.89
YAUYOS	0.96	0.97	0.95	0.95	0.92

Table N° 4.4. Maximum 24-hours rainfall of each Rainfall Station for each Return Period

STATION NAME	RETURN PERIOD T [YEARS]						
	PT_2	PT_5	PT_10	PT_25	PT_50	PT_100	PT_200
AYAVIRI	29.0	35.0	37.0	39.0	40.0	41.0	42.0
CARANIA	18.0	23.0	27.0	33.0	39.0	45.0	52.0
COLONIA	21.0	30.0	37.0	48.0	56.0	66.0	77.0
COSMOS	23.0	31.0	35.0	40.0	43.0	45.0	47.0
HUANGASCAR	20.0	29.0	35.0	44.0	51.0	59.0	67.0
HUANTAN	30.0	40.0	48.0	58.0	66.0	75.0	84.0
PACARAN	4.0	7.0	9.0	12.0	15.0	18.0	21.0
SOCSI CAÑETE	0.0	1.0	2.0	4.0	7.0	12.0	21.0
TANTA	23.0	32.0	38.0	46.0	52.0	58.0	65.0
TOMAS	14.0	18.0	20.0	21.0	22.0	23.0	24.0
YAURICOCHA	27.0	36.0	43.0	54.0	64.0	75.0	88.0
YAUYOS	18.0	23.0	27.0	31.0	34.0	37.0	40.0

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 generating spatial rainfall distribution for each return period.

The Surface Analysis' Contour tools in the ArcGIS Software Spatial Analyst module have allowed generating the isohyets maps for each return period. Its results are shown in Figures N° 4.2 to N° 4.7.

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

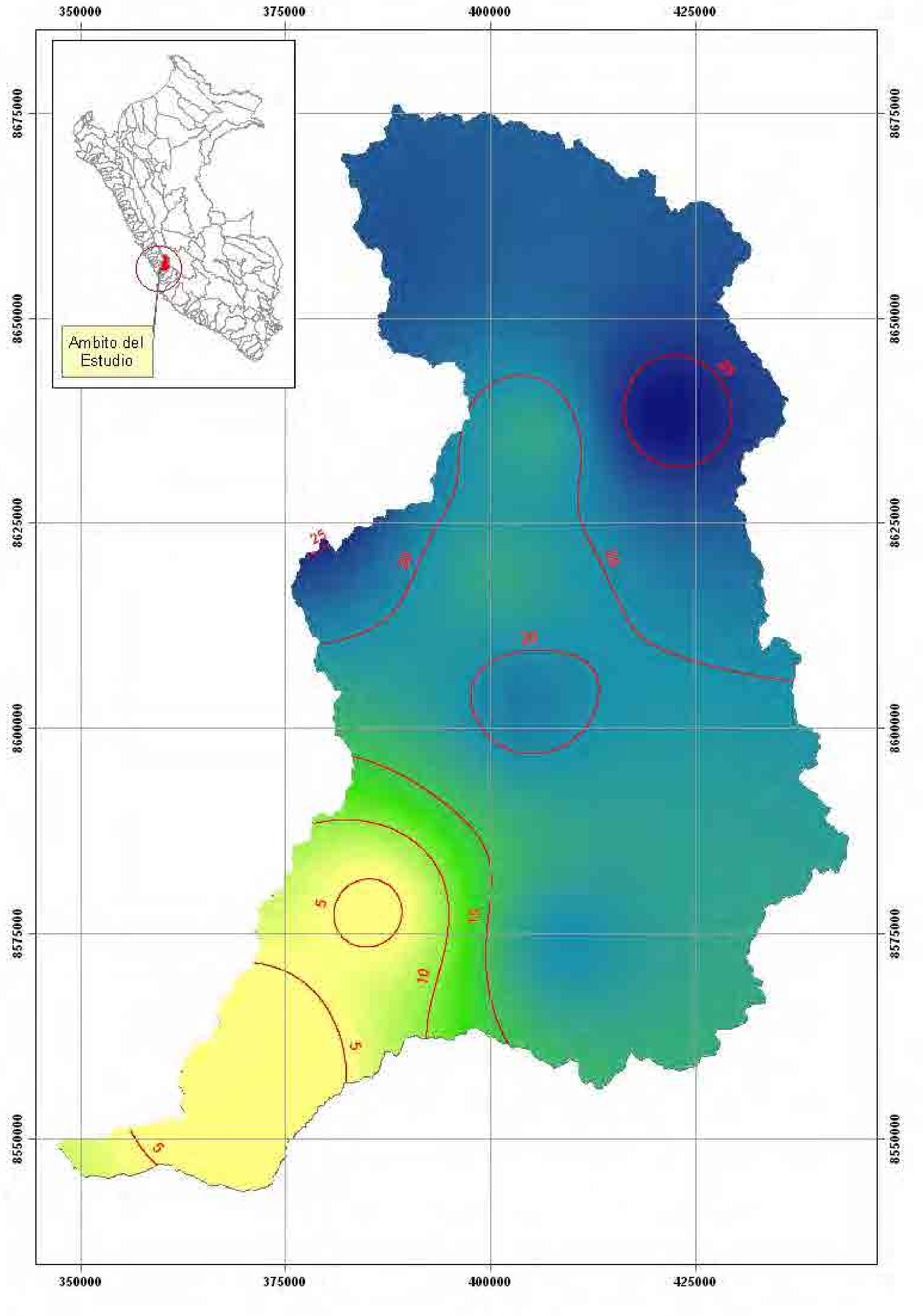


Figure Nº 4.2. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

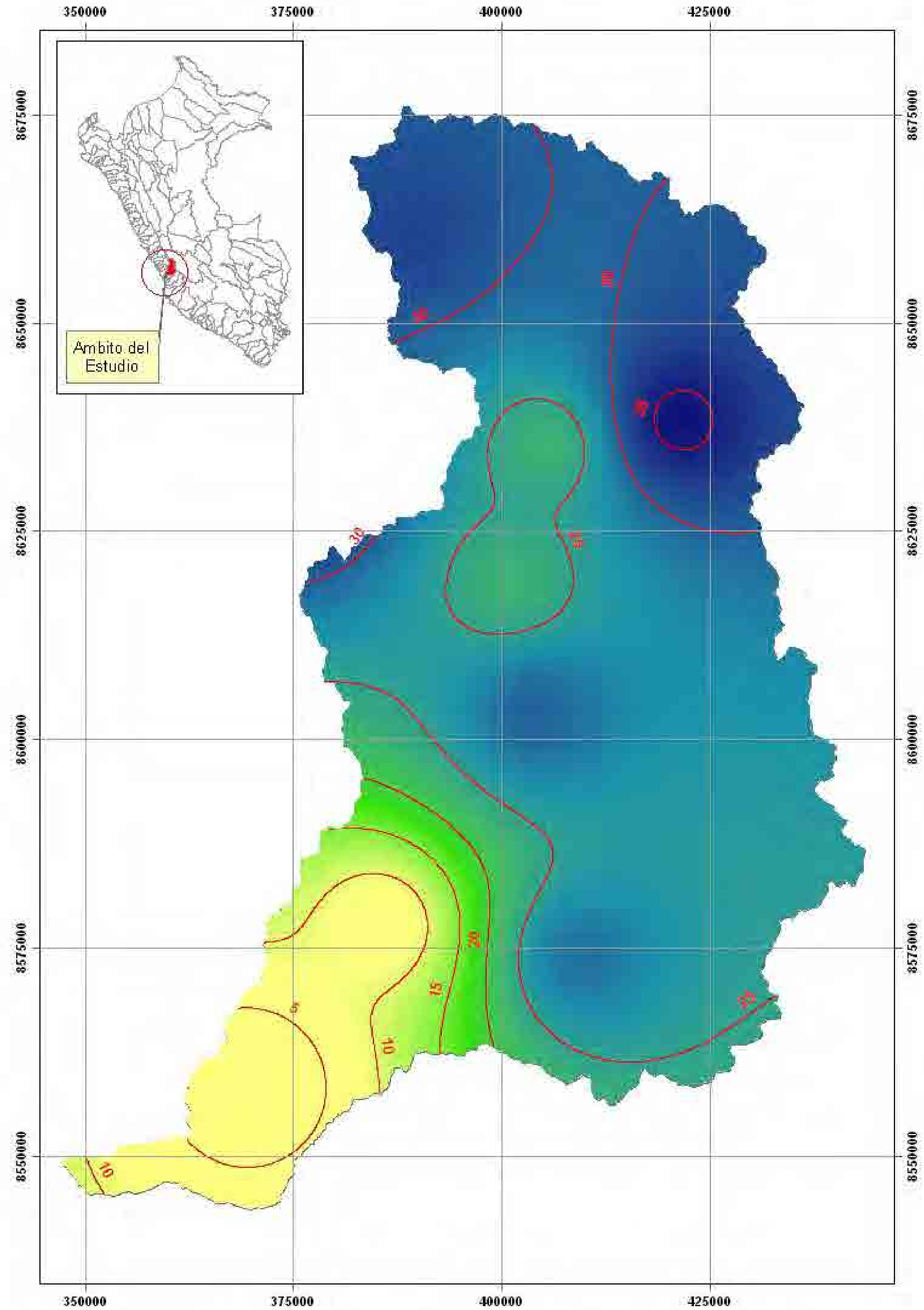


Figure Nº 4.3. Isohyets for the 5 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

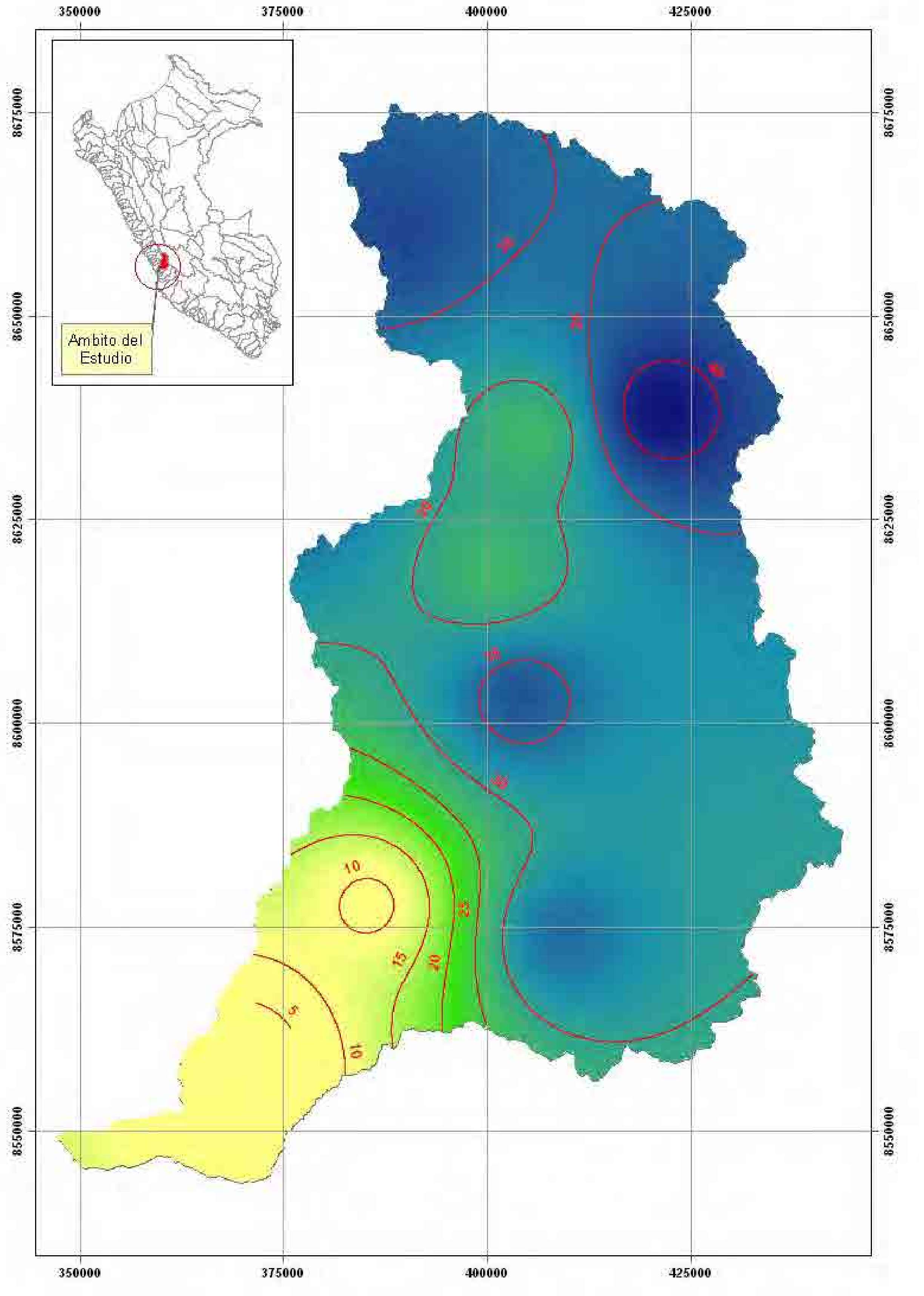


Figure Nº 4.4. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

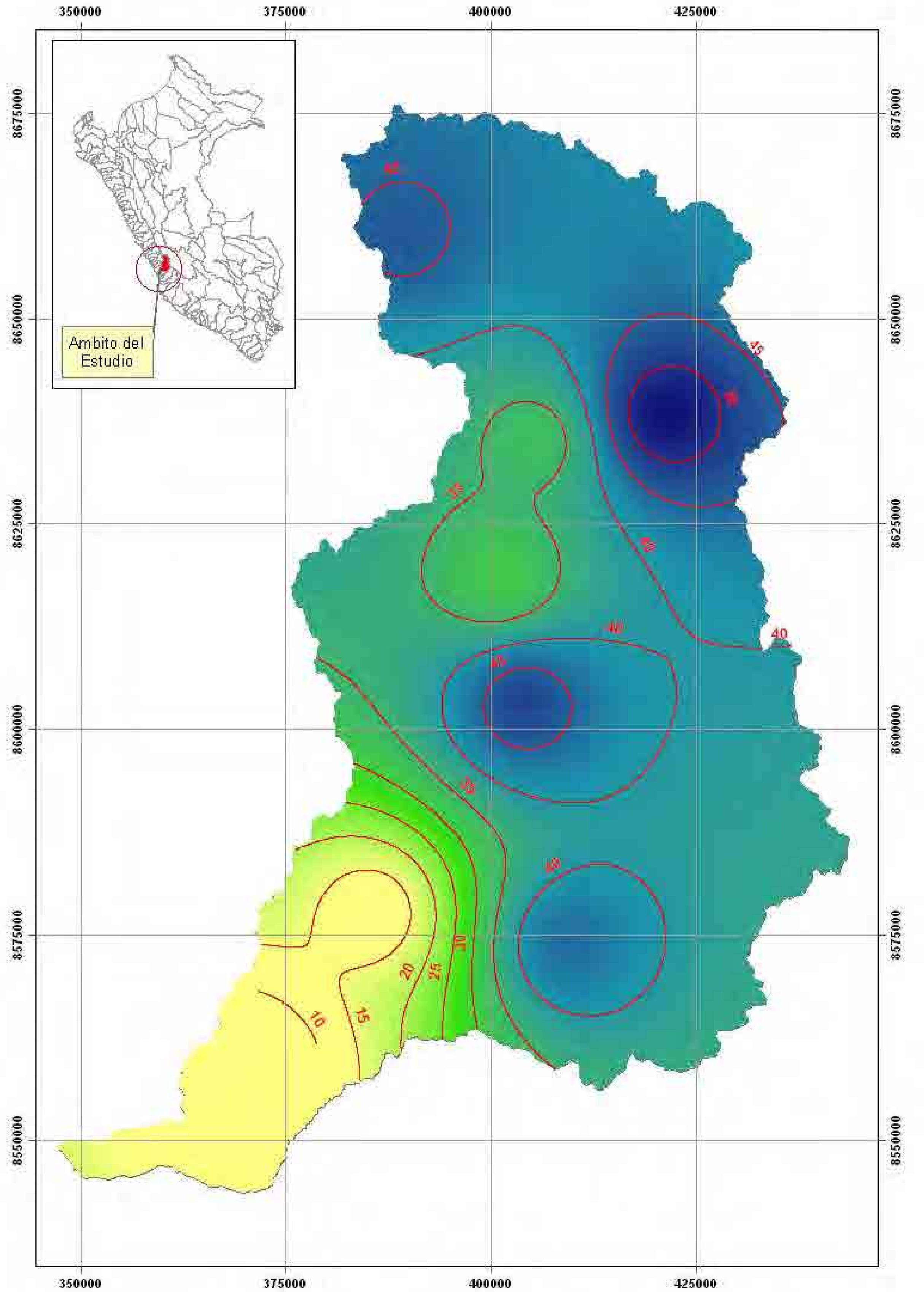


Figure Nº 4.5. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

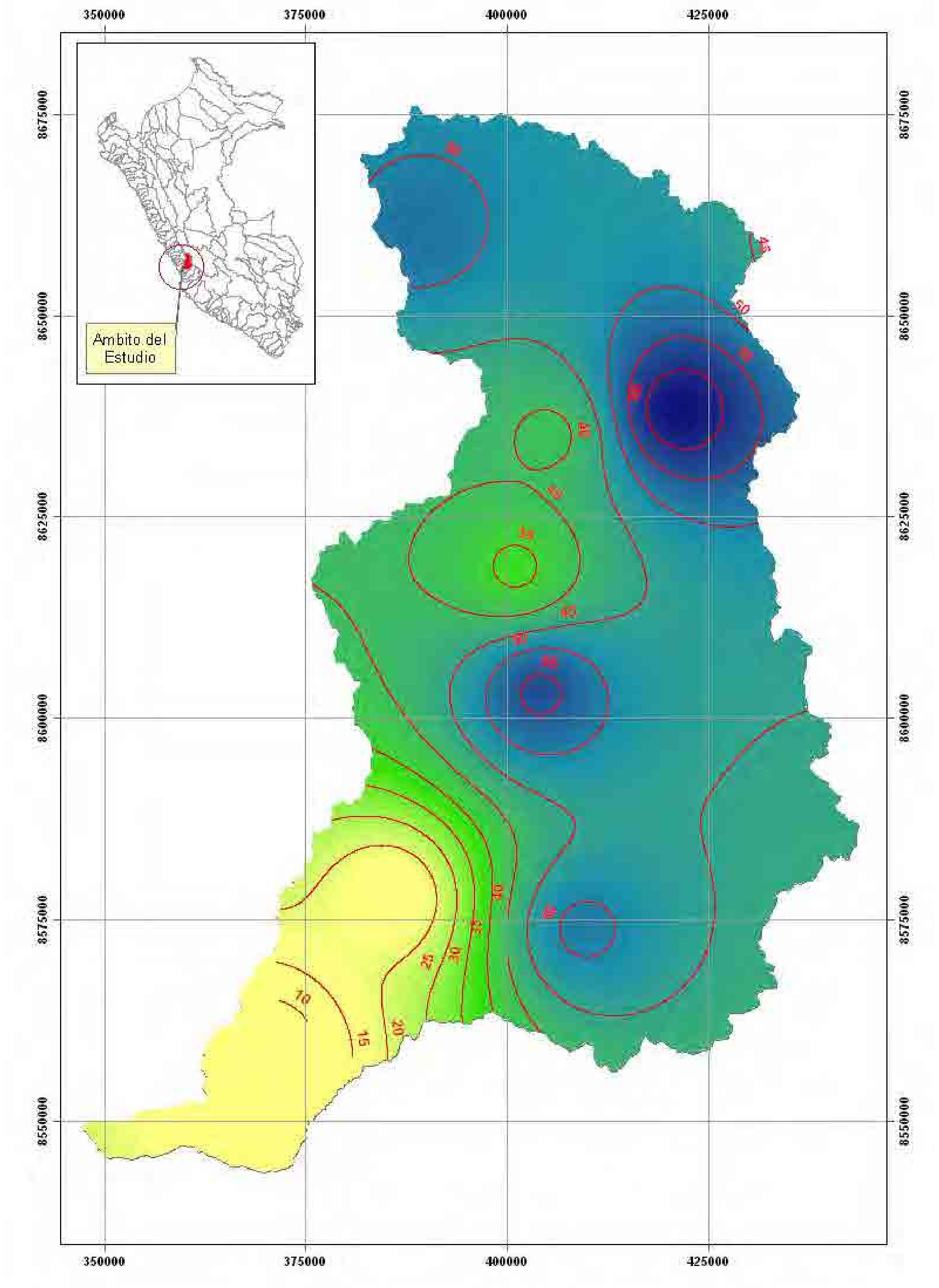


Figure Nº 4.6. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

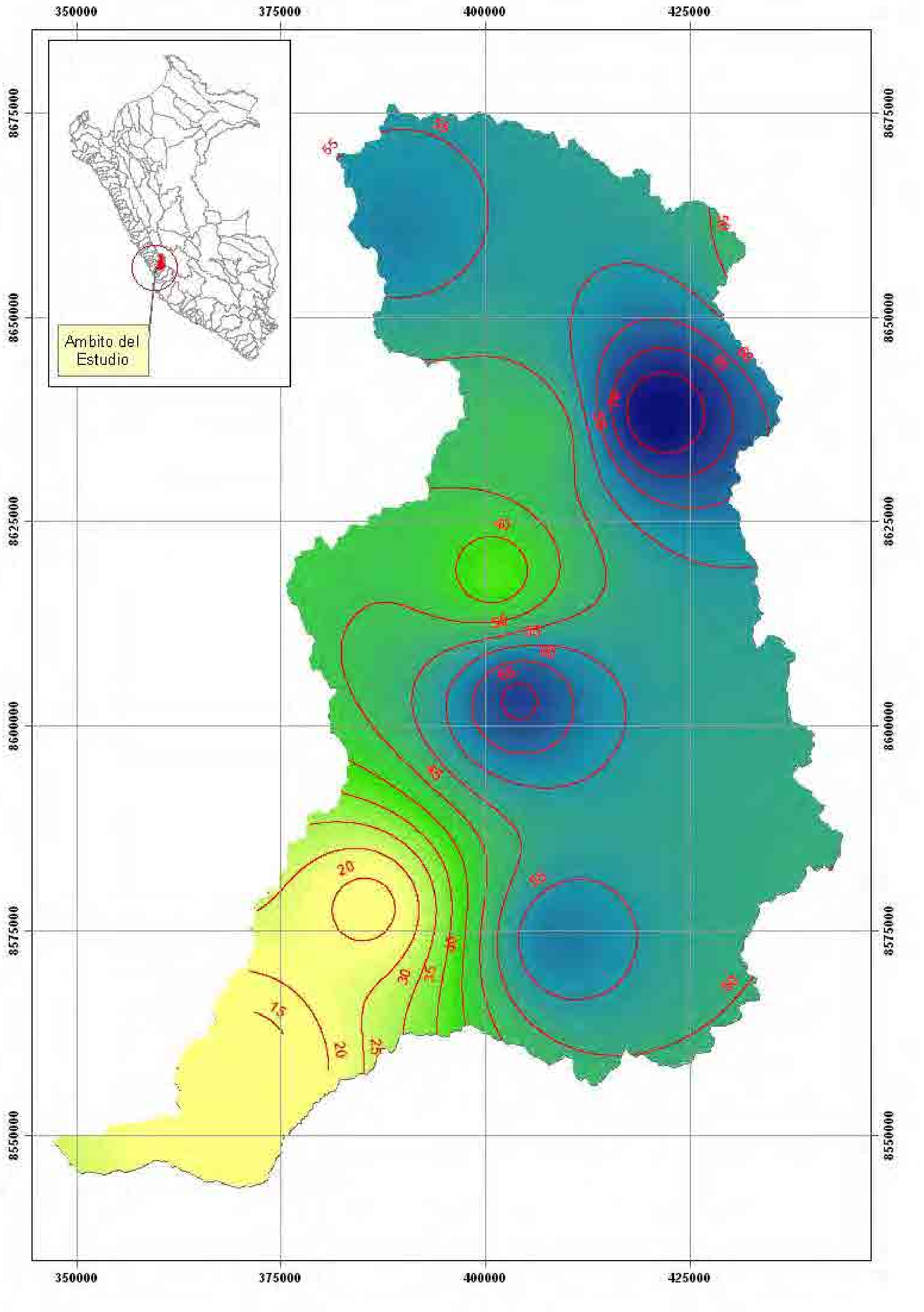


Figure Nº 4.7. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

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

Table Nº 4.5. Maximum Areal 24 – Hours Rainfall at the Base Point (Socsi Station) for each Return Period

Return Period "T" [Years]	Maximum Areal 24 Hours Rainfall [mm]
2	18.6
5	25.5
10	30.3
25	37.3
50	43.1
100	49.4

4.2.2.5 Determination of Maximum 24-Hours Rainfalsl for Different Return Period in the Cañete River Subwatersheds

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

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

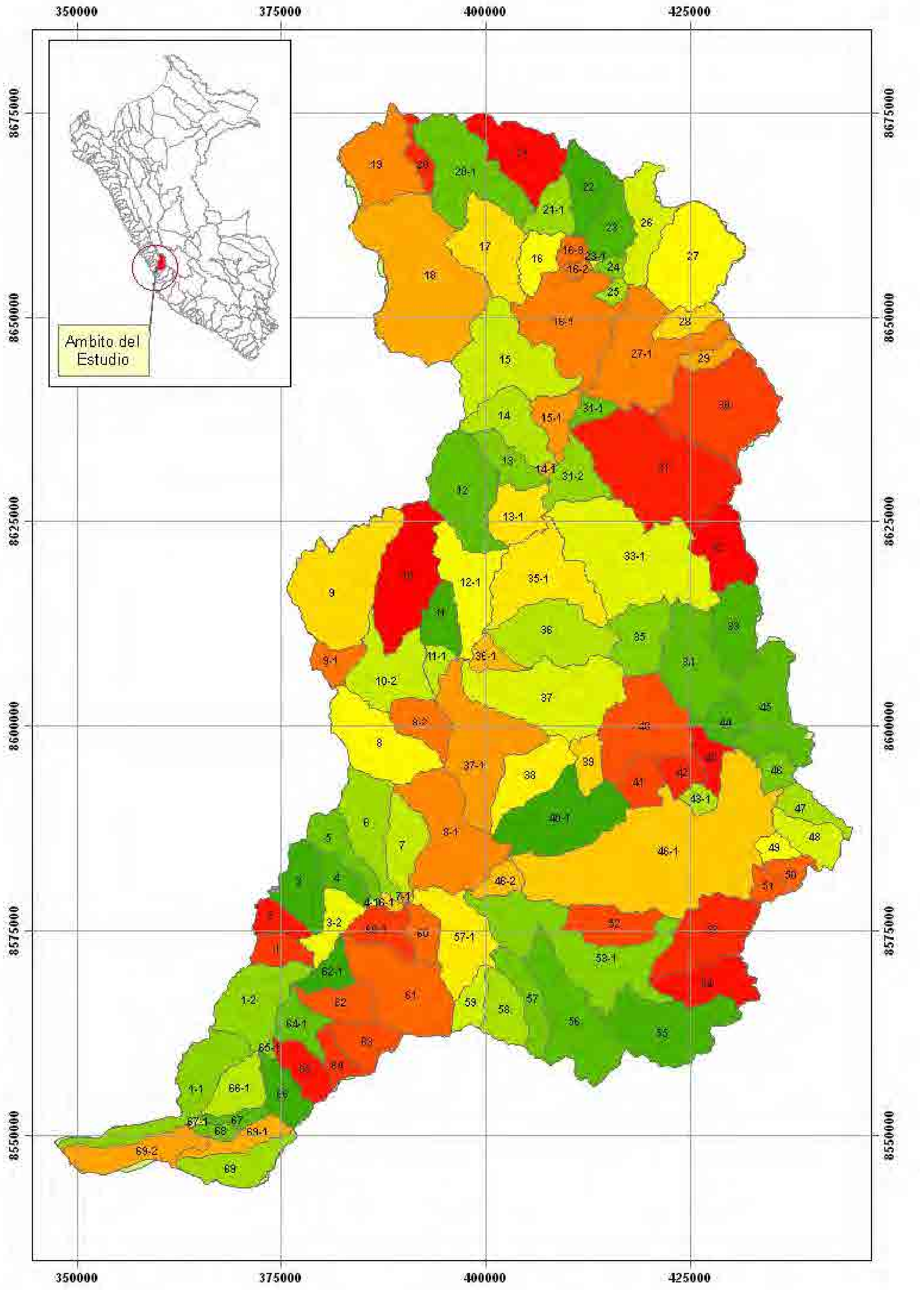


Figure Nº 4.8. The Cañete River Subbasin

Table Nº 4.6. Rainfall for Different Return Periods in each of Cañete River's Sub – Basins

SUBCUENCA	AREA [m²]	PERIODO DE RETORNO T [AÑOS]					
		PT_2	PT_5	PT_10	PT_25	PT_50	PT_100
1	23,147,500	5.6	8.8	11.0	14.5	18.0	22.3
10	99,153,800	20.1	26.1	30.3	35.6	39.8	44.3
10-2	70,237,800	18.9	25.4	30.1	36.6	41.7	47.5
11	31,142,000	19.2	25.4	30.0	35.9	40.5	45.6
1-1	78,972,200	2.3	4.1	5.5	8.1	11.4	16.4
11-1	13,827,500	19.4	26.3	31.5	38.8	44.4	50.9
12	89,313,800	19.5	25.2	29.3	34.8	39.4	44.2
1-2	72,163,700	2.6	4.6	6.1	8.8	12.1	16.9
12-1	70,463,200	18.7	24.3	28.6	33.6	37.4	41.5
13	31,367,400	18.7	24.1	28.3	34.3	40.1	45.9
13-1	42,137,500	19.0	24.6	28.9	34.3	39.0	43.9
14	54,650,700	18.7	24.0	28.2	34.3	40.2	46.1
14-1	2,579,850	18.8	24.3	28.5	34.7	40.6	46.7
15	110,794,000	20.6	27.0	31.7	38.3	44.2	50.3
15-1	29,864,500	19.3	25.0	29.4	35.9	42.1	48.5
16	28,933,500	22.1	29.6	34.7	41.8	47.7	53.8
16-1	115,763,000	22.1	29.2	34.4	41.8	48.3	55.1
16-2	5,852,460	22.3	29.7	34.8	42.0	48.1	54.4
16-3	11,163,600	22.3	29.7	34.8	42.0	47.9	54.1
17	76,294,400	22.3	30.2	35.6	42.9	48.7	54.6
18	211,788,000	22.5	30.7	36.1	43.5	49.2	54.9
19	64,858,300	22.7	31.2	36.9	44.4	50.2	56.0
2	21,011,000	6.5	9.9	12.3	16.0	19.5	23.7
20	14,588,700	22.6	31.1	36.7	44.2	50.0	55.8
20-1	104,300,000	22.5	30.7	36.2	43.6	49.3	55.1
21	67,786,400	22.3	30.1	35.3	42.4	48.0	53.8
21-1	30,166,600	22.2	29.9	35.0	42.1	47.8	53.7
22	43,677,300	22.3	29.8	34.9	41.9	47.5	53.2
23	35,324,400	22.4	30.0	35.0	42.1	47.9	53.8
23-1	893,202	22.4	29.9	35.0	42.3	48.4	54.6
24	7,548,340	22.6	30.1	35.2	42.6	48.7	55.1
25	8,179,220	22.8	30.3	35.5	43.2	49.7	56.4
26	47,884,700	22.6	30.2	35.2	42.2	47.8	53.5
27	104,899,000	23.0	30.8	35.6	42.3	47.5	52.6
27-1	124,017,000	24.5	32.6	38.5	47.5	55.5	64.1
28	23,403,400	23.9	31.8	37.3	45.3	52.1	59.2
29	15,008,000	24.6	32.8	38.6	47.3	54.9	62.9
3	47,658,400	6.7	10.4	12.9	16.6	20.1	24.0
30	128,021,000	25.0	33.3	39.5	48.8	56.9	65.7
31	180,056,000	23.9	31.7	37.6	46.5	54.5	63.2
31-1	13,039,600	22.3	29.3	34.6	42.7	50.0	57.9
31-2	39,773,800	20.1	26.2	30.9	37.6	43.8	50.3
32	52,009,900	21.9	29.2	34.6	42.4	49.0	56.2
3-2	31,314,700	5.0	8.2	10.4	13.7	17.0	20.4
33	52,648,100	20.5	27.7	32.8	40.3	46.4	53.2
33-1	185,838,000	20.7	27.5	32.5	39.6	45.6	52.1
34	84,179,000	20.0	27.1	32.3	39.9	45.9	52.7
35	52,094,800	20.0	27.1	32.4	40.0	46.0	52.8
35-1	99,091,900	18.9	24.7	29.2	34.7	39.0	43.6
36	88,427,000	19.7	26.8	32.1	39.7	45.5	52.2
36-1	16,706,700	20.0	27.6	33.5	42.1	48.4	56.1
37	134,150,000	20.3	28.6	34.9	44.5	51.7	60.4
37-1	118,354,000	19.0	26.8	32.6	41.5	48.2	56.2
38	55,311,100	18.9	26.7	32.5	41.3	47.9	56.0
39	21,906,100	19.3	27.1	32.8	41.5	48.1	55.9
4	21,422,100	5.4	8.8	11.0	14.4	17.7	21.1
40	97,596,400	19.5	26.9	32.4	40.5	46.7	54.0
40-1	103,460,000	18.1	25.6	31.0	39.0	45.3	52.5
41	25,810,500	18.9	26.3	31.7	39.7	45.9	53.1
4-1	960,631	4.1	7.1	9.1	12.1	15.1	18.1
42	21,371,300	19.0	26.3	31.6	39.3	45.4	52.4
43	19,427,800	19.1	26.4	31.6	39.2	45.2	52.1
43-1	11,757,600	18.8	26.1	31.3	38.9	44.9	51.9
44	25,792,000	19.5	26.6	31.8	39.3	45.3	52.1
45	87,978,100	19.7	26.8	31.9	39.3	45.2	51.9
46	17,937,900	19.1	26.2	31.3	38.7	44.6	51.2
46-1	333,392,000	18.6	26.2	31.5	39.3	45.5	52.6
46-2	17,979,500	16.0	23.1	27.9	35.2	41.0	47.6
47	18,444,100	18.9	26.0	31.0	38.3	44.1	50.7
48	33,608,200	18.7	25.7	30.7	38.0	43.8	50.4
49	12,810,600	18.5	25.7	30.7	38.1	44.0	50.7
5	34,390,600	7.6	11.5	14.2	18.1	21.8	25.7
50	15,473,600	18.4	25.6	30.5	37.9	43.7	50.4
51	13,740,700	18.3	25.5	30.5	37.9	43.8	50.6
52	45,403,700	19.2	27.7	33.4	42.0	48.7	56.4
53	77,545,100	18.2	25.7	30.9	38.6	44.7	51.7
53-1	147,352,000	18.6	26.8	32.4	40.7	47.2	54.6

54	50,099,700	17.9	25.3	30.5	38.1	44.1	51.0
55	96,938,800	17.6	25.1	30.3	37.9	43.9	50.9
56	99,022,600	17.9	25.8	31.2	39.2	45.5	52.7
57	37,032,300	17.4	25.1	30.3	38.1	44.4	51.5
57-1	72,431,600	12.1	17.8	21.7	27.5	32.4	37.9
57-2	540,355	6.2	9.9	12.3	16.0	19.5	23.2
58	38,487,100	15.9	23.0	27.8	35.0	40.8	47.5
59	21,680,700	13.7	19.9	24.2	30.5	35.8	41.8
6	63,213,200	9.8	14.4	17.5	22.2	26.2	30.7
60	23,807,900	7.9	12.1	15.0	19.3	23.1	27.4
60-1	33,284,000	5.1	8.4	10.6	14.0	17.2	20.6
61	99,516,800	8.3	12.5	15.5	19.9	23.9	28.4
6-1	4,236,010	4.6	7.8	9.9	13.1	16.3	19.5
62	34,471,000	5.9	9.1	11.4	15.0	18.6	23.1
62-1	22,790,000	5.6	8.8	11.0	14.5	18.0	22.1
63	33,513,100	6.6	10.0	12.5	16.4	20.2	25.0
64	17,449,300	4.7	7.4	9.4	12.7	16.3	21.2
64-1	30,391,000	3.1	5.2	6.9	9.7	13.0	17.9
65	30,594,300	2.4	4.3	5.8	8.5	11.8	16.8
65-1	2,586,310	0.6	1.8	2.9	5.0	8.1	13.1
66	32,456,400	1.7	3.3	4.7	7.1	10.3	15.3
66-1	36,758,000	0.7	2.0	3.1	5.3	8.4	13.4
67	11,483,200	1.8	3.4	4.8	7.2	10.4	15.5
67-1	1,476,050	2.5	4.3	5.8	8.5	11.8	16.8
68	9,270,090	2.5	4.3	5.9	8.5	11.8	16.8
69	42,492,200	4.0	6.4	8.2	11.3	14.7	19.8
69-1	26,182,700	2.9	4.9	6.5	9.2	12.6	17.6
69-2	50,858,000	5.2	7.9	9.9	13.2	16.8	21.9
7	42,214,200	9.5	14.1	17.2	21.9	26.0	30.6
7-1	1,125,050	5.8	9.3	11.7	15.2	18.6	22.2
8	85,368,700	16.4	22.6	27.0	33.4	38.4	44.3
8-1	114,221,000	13.5	19.4	23.5	29.7	34.7	40.5
8-2	35,785,400	18.3	25.3	30.5	38.1	43.9	50.8
9	132,743,000	22.0	28.1	31.8	36.6	40.2	44.2
9-1	22,038,200	19.1	25.3	29.5	35.2	39.7	44.8

4.2.3 Maximum Daily Discharge Analysis

For the analysis of Maximum Daily Discharges of River Cañete, the information of the hydrometric station Socsi has been used. This station has a contribution area of 5676 km^2. Figure 3.21 shows its location in the river Cañete catchment.

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

Table Nº 4.7.Maximum Daily Discharge from Socsi Station, Cañete River (m3/s)

AÑO	CAUDAL MAXIMO (m3/seg.)	
	SENAMHI	JUNTA DE USUARIOS
1926	-	455.00
1927	-	120.00
1928	-	198.00
1929	-	342.00
1930	-	263.00
1931	-	148.60
1932	-	850.00
1933	-	176.00
1934	-	305.00

1935	-	386.00
1936	-	265.00
1937	-	283.76
1938	-	401.99
1939	-	308.53
1940	-	141.28
1941	-	301.13
1942	-	319.22
1943	-	324.13
1944	-	396.65
1945	-	350.00
1946	-	354.00
1947	-	353.00
1948	-	279.00
1949	-	198.00
1950	-	244.74
1951	-	485.00
1952	-	360.00
1953	-	555.00
1954	-	657.00
1955	-	700.00
1956	-	470.00
1957	-	228.32
1958	-	270.40
1959	-	700.00
1960	-	488.75
1961	-	597.62
1962	-	566.24
1963	-	242.37
1964	-	153.06
1965	214.70	214.70
1966	207.00	201.00
1967	343.00	343.00
1968	154.00	154.00
1969	316.00	316.00
1970	408.00	408.00
1971	430.00	430.00
1972	900.00	900.00
1973	484.20	450.10
1974	-	326.00
1975	-	298.00
1976	294.92	332.00
1977	-	249.00
1978	-	216.00
1979	-	182.80
1980	-	100.10
1981	-	257.10
1982	-	120.00
1983	-	228.00
1984	-	425.50
1985	-	165.60
1986	-	370.50
1987	-	487.30
1988	206.00	420.30

1989	-	377.00
1990	-	189.00
1991	-	372.00
1992	-	164.30
1993	-	390.00
1994	-	550.00
1995	-	500.00
1996	-	310.00
1997	-	350.00
1998	-	348.00
1999	-	420.00
2000	-	350.00
2001	-	255.00
2002	-	204.00
2003	-	215.00
2004	-	196.00
2005	-	167.00
2006	-	250.00

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

Table Nº 4.8. Maximum Discharges for each Return Period at the Socsi Station, Cañete River (m3/s)

Periodo de Retorno (Años)	Caudal Máximo
2	312.67
5	453.80
10	547.24
25	665.30
50	752.89
100	839.83

It is necessary to mention that from a hydraulic analysis of the discharge capacity of the section of river Cañete at the location of the hydrometric station Socsi, it was concluded that this station cannot measure discharges larger than 900 m^3/s. This value coincides with the maximum discharge recorded in 1972.

A similar hydraulic analysis of the discharge capacity of the section of river Cañete at the location of the bridge of the Pan-American Highway shows that a maximum value of 2800 m^3/s can be transported in the section. Water levels which produce river discharges larger than the reported by the hydrometric station Socsi have been observed by local people.

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

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

Where:

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

H = Head (m)

Tc = Concentration time (Hr)

Travel time = 0,6*Tc

Table Nº 4.9. Concentration and Travel Times for the Base Point (Socsi Station)

L =	187.00	Km
H =	4,355.00	Mts
Tc =	**15.87**	Hrs
Tv =	**9.52**	Hrs

Maximum Rain Storm Duration

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

This value is lower than the time of concentration of 15.87 hours calculated in the previous item, it indicates that the peak values to be estimated in the hydrometric station Socsi won´t correspond to the simultaneous contribution of runoff of the whole catchement of the river Cañete until the hydrometric station Socsi.

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 Socsi.

Dick and Peschke equation:

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

Where:

Pd = Maximum rainfall for a duration "d"

Pd_{24}= Maximum 24 – hours rainfall

Tc= Time of Concentration (minutes)

Table Nº 4.10. Maximum Rainfall for Store Durations of 10 hours (mm), according to Dick - Peschke

T [Años]	Pp Areal Max 24 Horas [mm]	Pp Max, [mm]
2	18.6	16.81
5	25.5	23.04
10	30.3	27.38
25	37.3	33.70
50	43.1	38.95
100	49.4	44.64

The maximum daily rainfall for return periods of 2, 5, 10, 25, 50, and 100 years are 19, 26, 30, 37, 43 and 49 mm, respectively, and for a duration of 10 hour storm are 17, 23, 27, 34, 39 y 45 mm, respectively.

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

Table Nº 4.11. Histogram for different Return Periods, 10-Hours Storm Duration

Return Period [Years]	Hour										Total Rainfall [mm]
	1	2	3	4	5	6	7	8	9	10	

2	1	2	2	3	2	2	2	1	1	1	16.81
5	1	2	3	4	3	3	2	2	1	1	23.04
10	1	2	4	5	4	3	3	2	2	1	27.38
25	2	3	4	6	5	4	3	3	2	1	33.70
50	2	4	5	7	5	5	4	3	2	2	38.95
100	2	4	6	8	6	5	4	4	3	2	44.64

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 hydrologic soil group and the land use description.

Group A: Deep sand, deep wind – deposited soils, aggregate silts.

Group B: Shallow wind – deposited soils, sandy marl.

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

Group D: Expansive soils, highly plastic clays.

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

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

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

The adopted curve number resulted from a process of calibration where its value was adjusted to produce peak discharges values similar to the estimated maximum daily discharge. Following this procedure a curve number of 79 was obtained, this value is similar to the curve numbers obtained in neighboring basins.

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").

Socsi 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 5676 Km² basin area is taken into account as basic information. Due to the small averages discharges generally observed in river Cañete it was assumed that there was no base flow previous to the occurrence of the flood flows.

Meteorological Model.- Based on calculation under Nº 3.2 Pluviometer Information Analysis and Frequency Law, hyetographs are introduced inthe meteorological l 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 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. Aproximating the Lag Time as 0.6 times the Concentration Time, a lag time of 9.52 hours and a minimum computational time of 2.76 hours are 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 a curve number which produce peak discharges values similar to the estimated maximum daily discharge. This procedure was applied for estimated discharges lower than 900 m^3/s, which, as was stated in section 4.2.3, is the maximum discharge that can be measured in hydrographic station Socsi. Following this procedure a curve number of 79 was obtained.

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

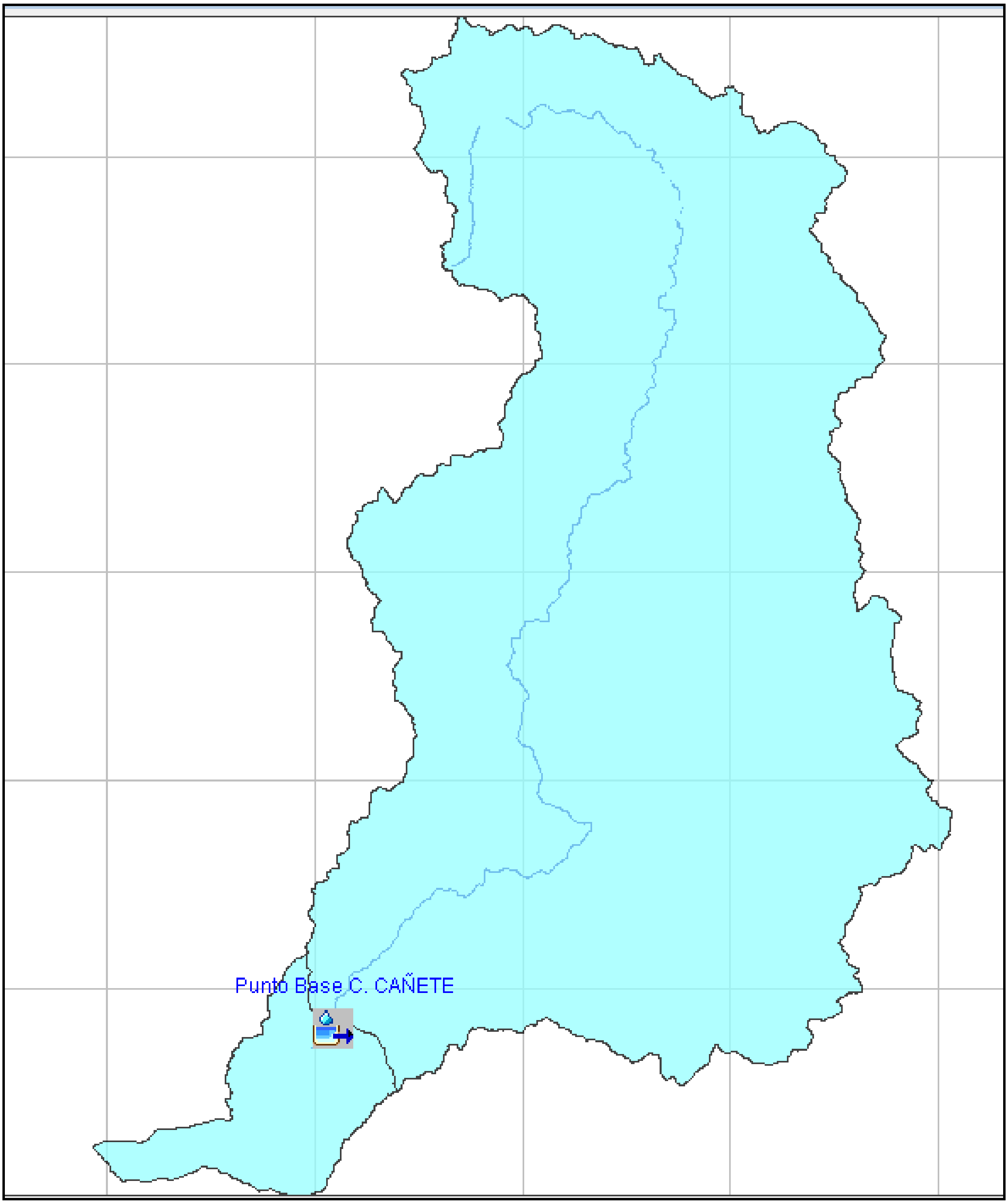


Figure Nº 4.9. Cañete River Basin Model in HEC-HMS Software

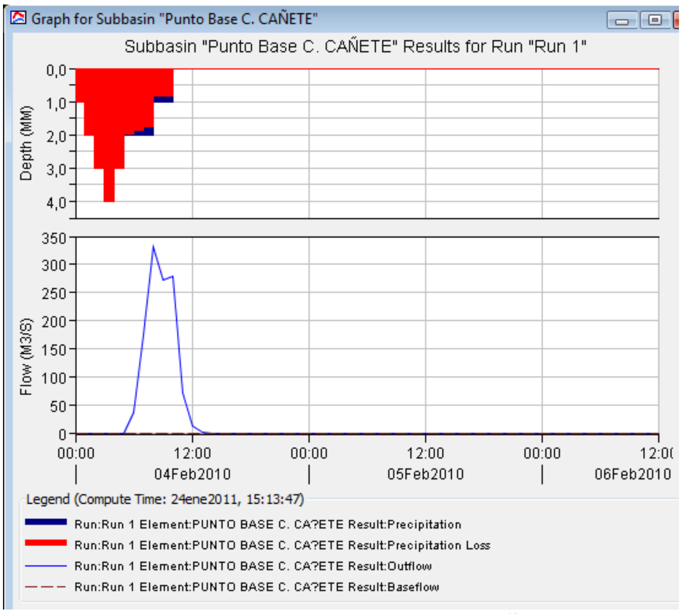


Figure Nº 4.10. Hydrograph Rainfall – Runoff models for the Cañete River basin, 2 -year Return Period

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 13 hours after it got started.

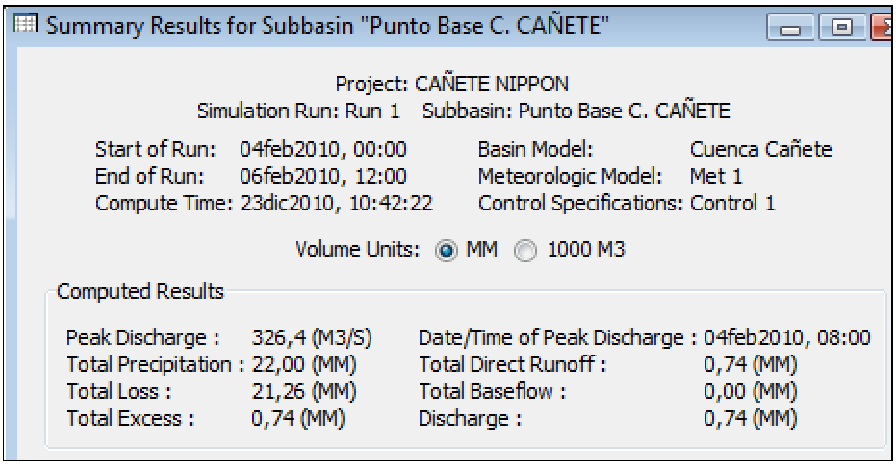


Figure Nº 4.11. Results of Rainfall – Runoff Model Simulation Cañete River, 5 – year Return Period

In Figure Nº 4.11 is the maximum flow is calculated for a return period of 2 years of 330.9 m^3/s. The maximum discharge spends approximately 8 hours after the storm started in the tax (for extreme conditions as defined above).

Table No. 4.13 shows the values of the hydrograph of the flood return period of 2 years.

Table Nº 4.13. 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)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	2,00	2,00	0,00	0,0
04-Feb-10	03:00	3,00	3,00	0,00	0,0
04-Feb-10	04:00	4,00	4,00	0,00	0,0
04-Feb-10	05:00	3,00	3,00	0,00	0,0
04-Feb-10	06:00	2,00	1,97	0,03	38,0
04-Feb-10	07:00	2,00	1,86	0,14	174,3
04-Feb-10	08:00	2,00	1,76	0,24	330,9
04-Feb-10	09:00	1,00	0,84	0,16	271,9
04-Feb-10	10:00	1,00	0,82	0,18	278,3
04-Feb-10	11:00	0,00	0,00	0,00	71,9
04-Feb-10	12:00	0,00	0,00	0,00	13,5
04-Feb-10	13:00	0,00	0,00	0,00	2,3
04-Feb-10	14:00	0,00	0,00	0,00	0,0

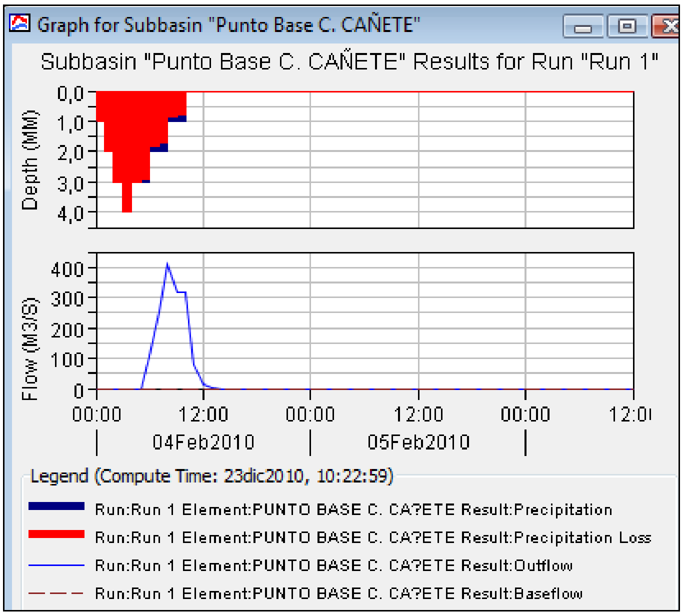


Figure Nº 4.12. Hydrograph Rainfall – Runoff models for the Cañete River basin, 5 -year Return Period

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 13 hours after it got started.

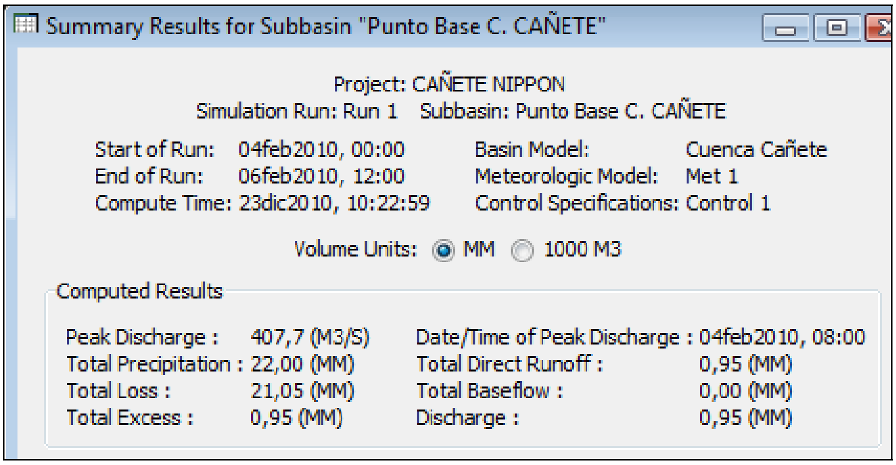


Figure Nº 4.13. Results of Rainfall – Runoff Model Simulation Cañete River, 5 – year Return Period

In Figure Nº 4.13 is the maximum flow is calculated for a return period of 5 years of 407.7 m^3/s. The maximum discharge spends approximately 08 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 5 years.

Table Nº 4.14. 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)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	2,00	2,00	0,00	0,0
04-Feb-10	03:00	3,00	3,00	0,00	0,0
04-Feb-10	04:00	4,00	4,00	0,00	0,0
04-Feb-10	05:00	3,00	3,00	0,00	0,0
04-Feb-10	06:00	3,00	2,91	0,09	104,2
04-Feb-10	07:00	2,00	1,81	0,19	253,8
04-Feb-10	08:00	2,00	1,71	0,29	407,7
04-Feb-10	09:00	1,00	0,82	0,18	318,0
04-Feb-10	10:00	1,00	0,80	0,20	314,7
04-Feb-10	11:00	0,00	0,00	0,00	81,0
04-Feb-10	12:00	0,00	0,00	0,00	15,2
04-Feb-10	13:00	0,00	0,00	0,00	2,6
04-Feb-10	14:00	0,00	0,00	0,00	0,0

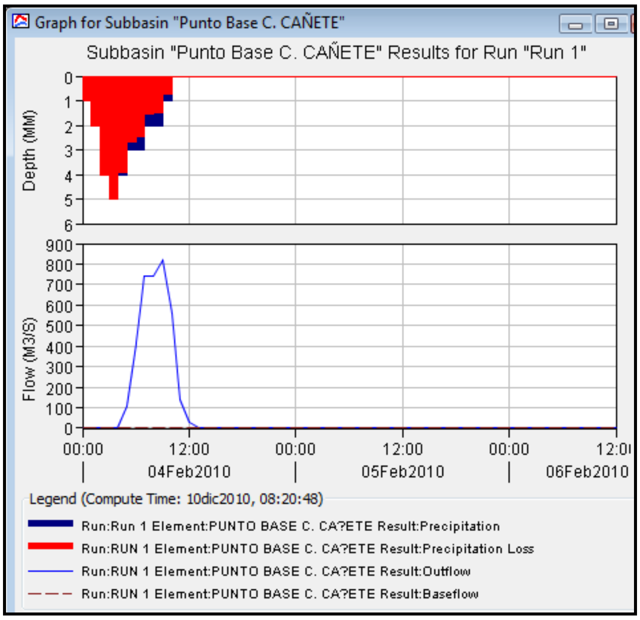


Figure N° 4.14. Hydrograph Rainfall – Runoff models for the Cañete River basin, 10 - year Return Period

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 13 hours after it got started.

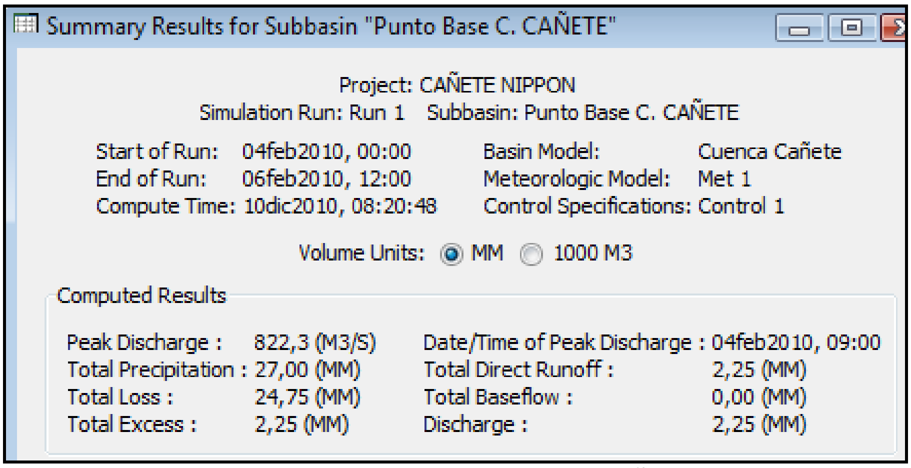


Figure N° 4.15. Results Rainfall – Runoff Model Simulation Cañete River, 10 – year Return Period

In Figure N° 4.15 is the maximum flow is calculated for a return period of 10 years of 822.3 m^3/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 10 years.

***Table Nº 4.15. 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)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	2,00	2,00	0,00	0,0
04-Feb-10	03:00	4,00	4,00	0,00	0,0
04-Feb-10	04:00	5,00	5,00	0,00	0,0
04-Feb-10	05:00	4,00	3,91	0,09	104,2
04-Feb-10	06:00	3,00	2,68	0,32	409,6
04-Feb-10	07:00	3,00	2,46	0,54	740,0
04-Feb-10	08:00	2,00	1,54	0,46	739,6
04-Feb-10	09:00	2,00	1,46	0,54	822,3
04-Feb-10	10:00	1,00	0,70	0,30	561,2
04-Feb-10	11:00	0,00	0,00	0,00	138,0
04-Feb-10	12:00	0,00	0,00	0,00	26,1
04-Feb-10	13:00	0,00	0,00	0,00	3,8
04-Feb-10	14:00	0,00	0,00	0,00	0,0

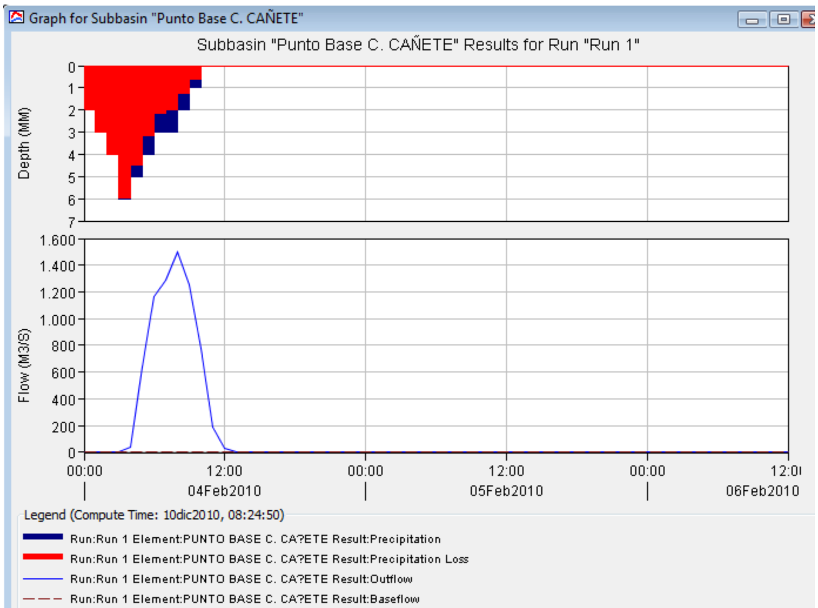


Figure Nº 4.16. Hydrograph Rainfall – Runoff model for the Cañete River basin, 25 – year Return Period

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 13 hours after it got started.

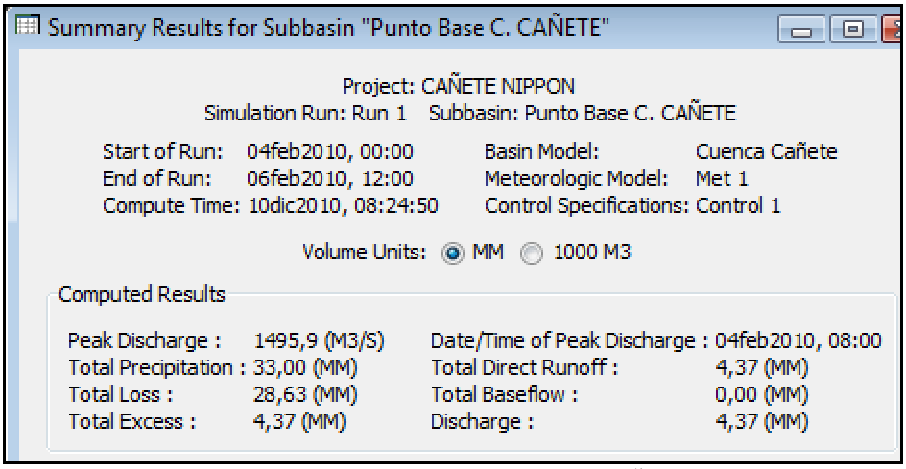


Figure Nº 4.17. Results Rainfall – Runoff Model Simulation Cañete River, 25 – year Return Period

In Figure Nº 4.17 is the maximum flow is calculated for a return period of 25 years of 1495.9 m^3/s. The maximum discharge spends approximately 08 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 25 years.

Table Nº 4.16. 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)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	2,00	2,00	0,00	0,0
04-Feb-10	02:00	3,00	3,00	0,00	0,0
04-Feb-10	03:00	4,00	4,00	0,00	0,0
04-Feb-10	04:00	6,00	5,97	0,03	38,0
04-Feb-10	05:00	5,00	4,46	0,54	640,5
04-Feb-10	06:00	4,00	3,16	0,84	1164,8
04-Feb-10	07:00	3,00	2,16	0,84	1290,7
04-Feb-10	08:00	3,00	2,01	0,99	1495,9
04-Feb-10	09:00	2,00	1,26	0,74	1254,5
04-Feb-10	10:00	1,00	0,61	0,39	774,7
04-Feb-10	11:00	0,00	0,00	0,00	188,5
04-Feb-10	12:00	0,00	0,00	0,00	34,7
04-Feb-10	13:00	0,00	0,00	0,00	5,0
04-Feb-10	14:00	0,00	0,00	0,00	0,0

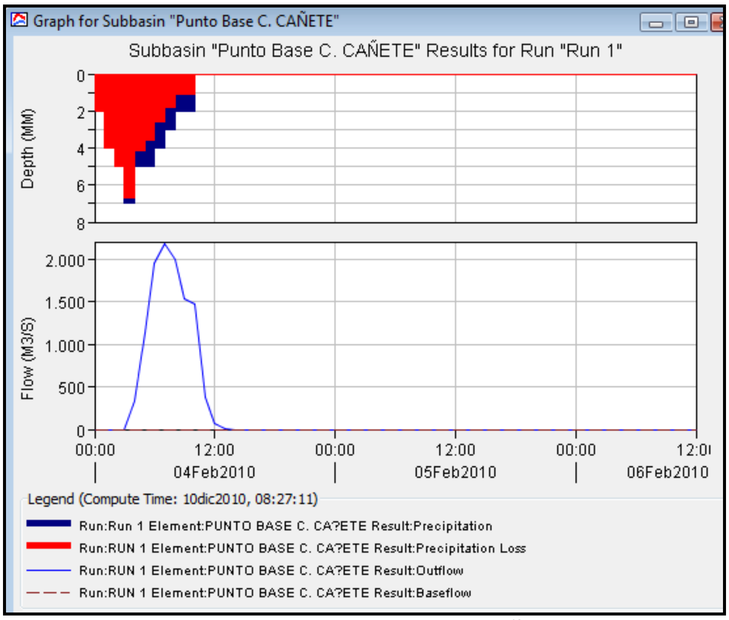


Figure Nº 4.18. Hydrograph Rainfall – Runoff model for the Cañete River basin, 50 – year Return Period

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 13 hours after it got started.

Summary Results for Subbasin "Punto Base C. CAÑETE"

Project: CAÑETE NIPPON

Simulation Run: Run 1 Subbasin: Punto Base C. CAÑETE

Start of Run:	04feb2010, 00:00	Basin Model:	Cuenca Cañete
End of Run:	06feb2010, 12:00	Meteorologic Model:	Met 1
Compute Time:	10dic2010, 08:27:11	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge :	2174,9 (M3/S)	Date/Time of Peak Discharge :	04feb2010, 07:00
Total Precipitation :	39,00 (MM)	Total Direct Runoff :	6,99 (MM)
Total Loss :	32,01 (MM)	Total Baseflow :	0,00 (MM)
Total Excess :	6,99 (MM)	Discharge :	6,99 (MM)

Figure Nº 4.19. Results Rainfall – Runoff Model Simulation Cañete River, 50 – year Return Period

In Figure Nº 4.19 is the maximum flow is calculated for a return period of 50 years of 2174.9 m^3/s. The maximum discharge spends approximately 08 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 50 years.

Table Nº 4.17. 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)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	2,00	2,00	0,00	0,0
04-Feb-10	02:00	4,00	4,00	0,00	0,0
04-Feb-10	03:00	5,00	5,00	0,00	0,0
04-Feb-10	04:00	7,00	6,72	0,28	328,8
04-Feb-10	05:00	5,00	4,11	0,89	1134,8
04-Feb-10	06:00	5,00	3,61	1,39	1939,8
04-Feb-10	07:00	4,00	2,58	1,42	2174,9
04-Feb-10	08:00	3,00	1,79	1,21	1987,0
04-Feb-10	09:00	2,00	1,13	0,87	1531,7
04-Feb-10	10:00	2,00	1,08	0,92	1464,5
04-Feb-10	11:00	0,00	0,00	0,00	374,7
04-Feb-10	12:00	0,00	0,00	0,00	70,7
04-Feb-10	13:00	0,00	0,00	0,00	11,9
04-Feb-10	14:00	0,00	0,00	0,00	0,0
04-Feb-10	15:00	0,00	0,00	0,00	0,0

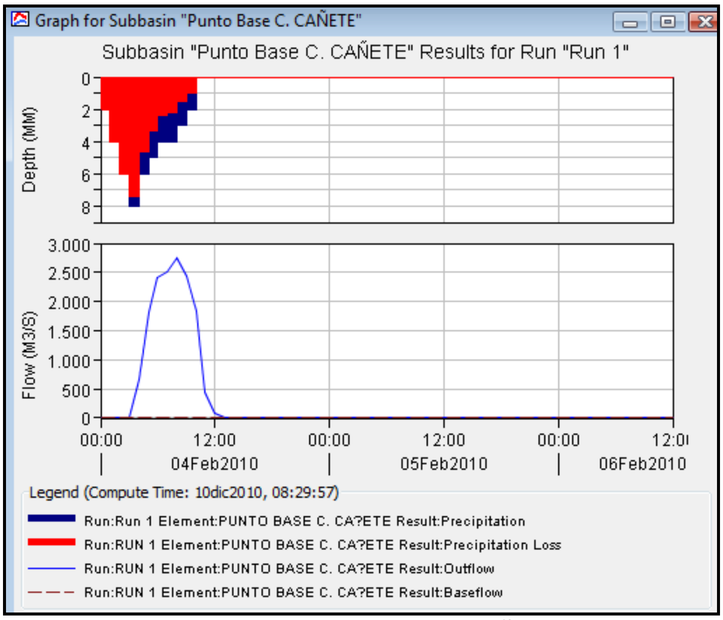
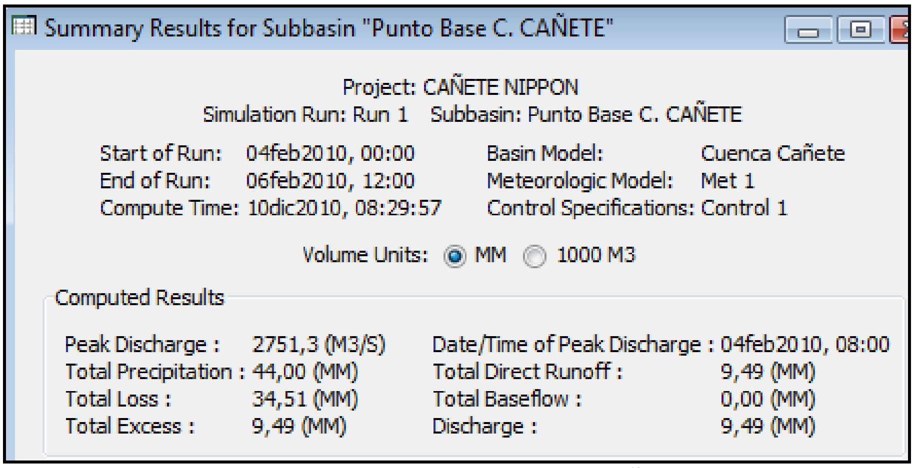


Figure Nº 4.20. Hydrograph Rainfall – Runoff model for the Cañete River basin, 100 – year Return Period

Storm that was analyzed, as rainfall after an infiltration process is transferred as runoff, and it ends around 13 hours after it got started.


Summary Results for Subbasin "Punto Base C. CAÑETE"

Project: CAÑETE NIPPON
Simulation Run: Run 1 Subbasin: Punto Base C. CAÑETE

Start of Run: 04feb2010, 00:00 Basin Model: Cuenca Cañete
End of Run: 06feb2010, 12:00 Meteorologic Model: Met 1
Compute Time: 10dic2010, 08:29:57 Control Specifications: Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge : 2751,3 (M3/S) Date/Time of Peak Discharge : 04feb2010, 08:00
Total Precipitation : 44,00 (MM) Total Direct Runoff : 9,49 (MM)
Total Loss : 34,51 (MM) Total Baseflow : 0,00 (MM)
Total Excess : 9,49 (MM) Discharge : 9,49 (MM)

Figure Nº 4.21. Results Rainfall – Runoff Model Simulation Cañete River, 100 – year Return Period

In Figure Nº 4.21 is the maximum flow is calculated for a return period of 100 years of 2751.3 m^3/s. The maximum discharge spends approximately 08 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 100 years.

Table Nº 4.18. 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)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	2,00	2,00	0,00	0,0
04-Feb-10	02:00	4,00	4,00	0,00	0,0
04-Feb-10	03:00	6,00	6,00	0,00	0,0
04-Feb-10	04:00	8,00	7,43	0,57	667,9
04-Feb-10	05:00	6,00	4,62	1,38	1805,1
04-Feb-10	06:00	5,00	3,35	1,65	2421,6
04-Feb-10	07:00	4,00	2,41	1,59	2500,2
04-Feb-10	08:00	4,00	2,20	1,80	2751,3
04-Feb-10	09:00	3,00	1,53	1,47	2433,6
04-Feb-10	10:00	2,00	0,97	1,03	1825,9
04-Feb-10	11:00	0,00	0,00	0,00	456,0
04-Feb-10	12:00	0,00	0,00	0,00	85,4
04-Feb-10	13:00	0,00	0,00	0,00	13,3
04-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 Cañete river basin for the location of hydrometric station Socsi.

Table Nº 4.19. Summary of Peak Flows at the Base Point for each Return Period

T [Años]	Q [m³/s]
2	331.0
5	407.7
10	822.3
25	1,495.9
50	2,174.9
100	2,751.3

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 79).

As it was considered in the calibration, peak discharges obtained with HEC-HMS model for low 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 Hydrologyl, 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-3 Hydrologic Study of Chincha River Basin

Japan International Cooperation Agency

PERÚ Ministerio de Agricultura

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

HYDROLOGY OF MAXIMUM FLOODS IN CHINCHA RIVER

Appendix-3

December 2012

Yachiyo Engineering Co., Ltd.

NIPPON KOEI CO.,LTD.

LATIN AMERICA - CARIBBEAN

NIPPON KOEI LAC CO., LTD.

Ingenieros Consultores

C

HYDROLOGY OF MAXIMUM FLOODS IN CHINCHA RIVER

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HYDROLOGY OF MAXIMUM FLOODS IN CHINCHA RIVER

I. INTRODUCTION

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

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 province of Chincha and Pisco in the Department of Ica and the province of Castrovirreyna in the Department of Huancavelica.

2.1.2 Geographic Location

The study area is located approximately at coordinates UTM at 366,306 y 463,710 in East Coordinates, and 8’492,815 y 8’586,315 in North Coordinates (Zone 18).

2.2 Background

As part of the project: "Protection of Rural Areas and Valleys and Flood Vulnerable", it requires a supporting technical document of the maximum flooding of the Chincha River, to define planning proposals hydrologic and hydraulic Chincha 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 Chincha River overflowed causing flooding of extensive crop areas and cities such as El Carmen, San Regis, Pedregal, San Francisco and Chincha Baja, 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 Conta. 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

Chincha 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 Chincha 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 Chincha River

3.1.1 General Description of the Basin

Politically, the Chincha River basin is part of the provinces of Chincha and Pisco and Castrovirreyna belonging to the departments of Ica and Huancavelica respectively.

Its boundaries are: on the north by the Mantaro river basins, and interbasin Topará Cañete, south to Pisco River Basin, on the east by the Mantaro River Basins and Pisco and west by the Pacific Ocean.

It has a total area of 4,388.63 km2 and its waters drain into the Pacific Ocean with a tour of the main course predominantly southwesterly.

Chincha Valley, an area affected by the floods, is located in the lower basin between latitudes 13º 12'- 13º 37' South and longitude 76º 00'- 76º 15' West. Politically it belongs to the province of Chincha and Ica. This basically consists of a range river 25 km wide at its center, extending from sea level to 2000 m elevation, covering an area of 25.73 km2 and was established as the most important agricultural area of the San River Basin Juan

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

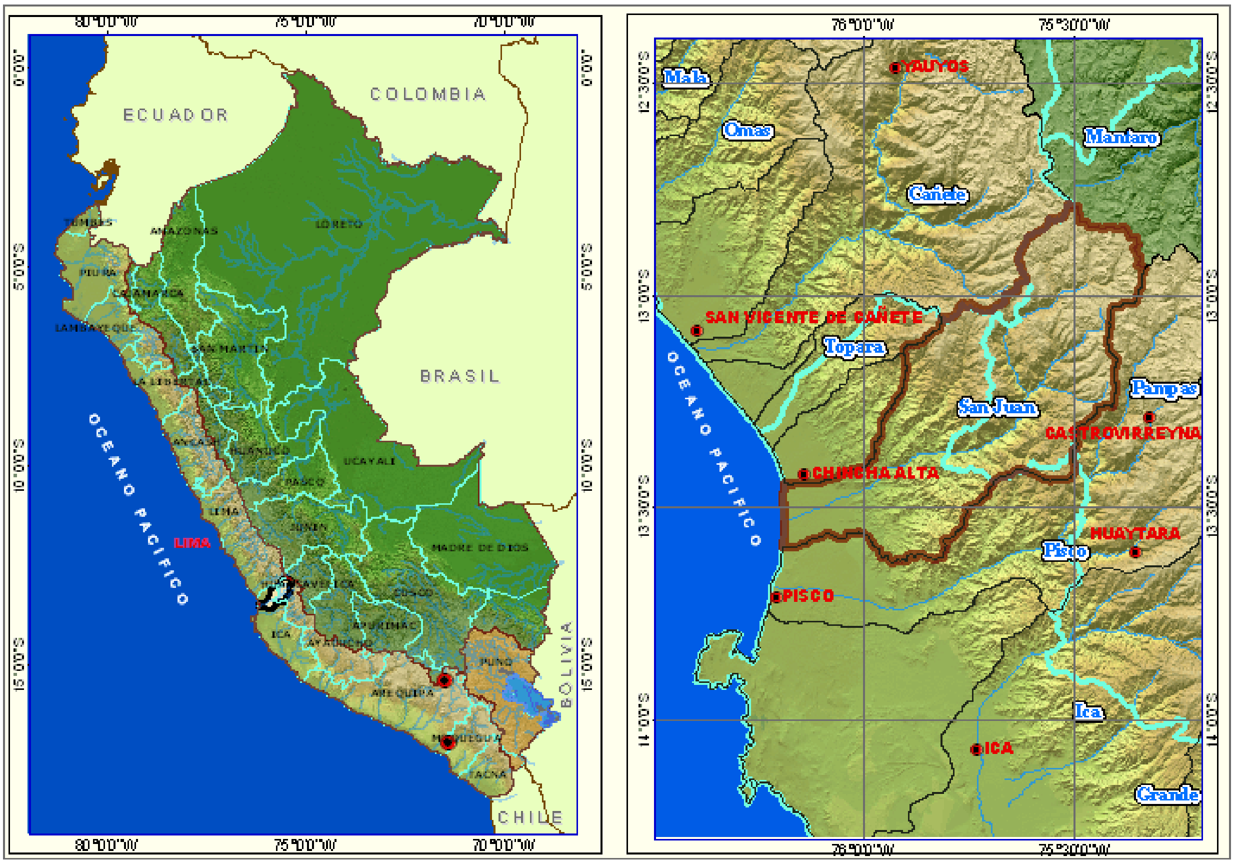


Figure Nº 3.1. Location Map of the Chincha River Basin

3.1.2 Hydrography of the Chincha 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. Chincha River is one of them, being located in the central region of this side.

Chincha River has an intermittent regimen and torrential character; its discharges are presented in the months of January to April. The maximum monthly discharge has been appraised of 494.19 m3 / s (February-1967) and a low of 0.00 m3 / s, with a mean annual discharge of 15.46 m3 / s equivalent to an average annual volume of 480.71 MMC. In the dry season the river is not carrying water for an average of three months

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

3.2 Climatology

3.2.1 Rainfall

The rainfall, as a main parameter of the runoff generation is analyzed considering the available information of the stations located in the interior of the Chincha Basin, and in the neighboring Cañete, Mantaro y Pisco.

Rainfall information is available from 10 pluviometric stations located in the vicinity of the study area, these are located in the Chincha 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 relationship of stations with their respective characteristics of code, type, location, etc. Historical records of monthly total rainfall and their histograms are presented in Annexes I and II respectively. Figure Nº 3.2, shows the period and the length of the data available from meteorological stations and Figure No. 3.3 shows the locations in the Chincha Basin and adjacent watersheds.

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

CODE	STATION	DEPARTAMENT	LONGITUDE	LATITUDE	ENTITY
156119	TOTORA	HUANCAVELICA	75° 19'1	13° 07'1	SENAMHI
156117	TICRAPO	HUANCAVELICA	75° 26'1	13° 23'1	SENAMHI
643	COCAS	HUANCAVELICA	75° 22'1	13° 16'1	SENAMHI
156115	SAN PEDRO DE HUACARPANA 2	ICA	75° 39'1	13° 03'1	SENAMHI
857	SAN PEDRO DE HUACARPANA	ICA	75° 39'39	13° 03'3	SENAMHI
156113	CHINCHA DE YANAC	ICA	75° 47'47	13° 13'13	SENAMHI
791	FONAGRO (CHINCHA)	ICA	76° 08'8	13° 28'28	SENAMHI
156219	CONTA	ICA	75° 58'0	13° 26'0	SENAMHI
641	VILLA DE ARMAS	HUANCAVELICA	75° 08'1	13° 08'1	SENAMHI
151503	HUACHOS	HUANCAVELICA	75° 32'32	13° 13'13	SENAMHI

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

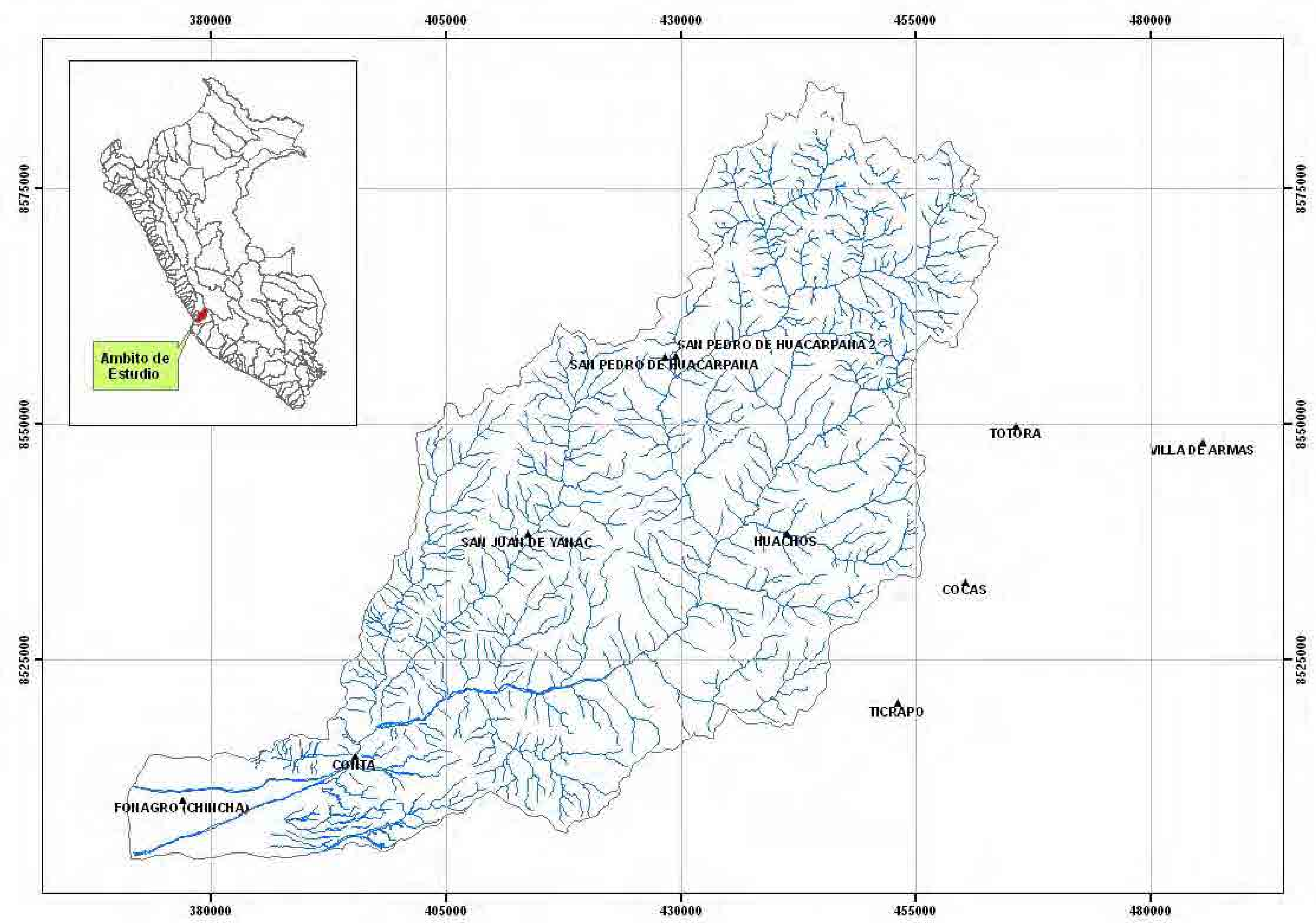


Figure Nº 3.3. Location of the Rainfall Stations in Chincha River Basin and Adjacent Basins

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

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

ESTACION	Mes												Total
	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic	
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
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
COCAS	94.93	111.50	138.93	29.87	5.31	0.26	0.36	1.54	6.70	11.83	16.61	40.73	458.57
SAN PEDRO DE HUACARPANA 2	114.93	137.80	161.96	50.64	5.30	0.38	0.23	2.25	5.51	17.68	30.93	58.94	586.56
SAN PEDRO DE HUACARPANA	121.19	136.68	139.80	34.99	2.64	0.00	0.04	2.53	7.24	12.94	27.45	64.52	550.02
CHINCHA DE YANAC	27.03	37.28	39.98	6.97	0.27	0.00	0.10	0.02	0.76	2.81	2.11	14.08	131.41
FONAGRO (CHINCHA)	0.42	1.08	0.34	0.07	0.48	1.23	1.34	0.83	0.68	0.38	0.21	0.56	7.60
CONTA	1.84	3.24	0.81	0.31	0.01	0.03	0.06	0.04	0.05	0.18	0.14	0.24	6.95
VILLA DE ARMAS	133.69	136.26	148.26	39.55	2.82	0.00	0.01	1.57	8.52	10.84	22.17	59.92	563.61
HUACHOS	98.45	120.27	119.57	29.42	1.90	0.23	0.25	1.01	1.73	6.74	15.33	57.08	451.98

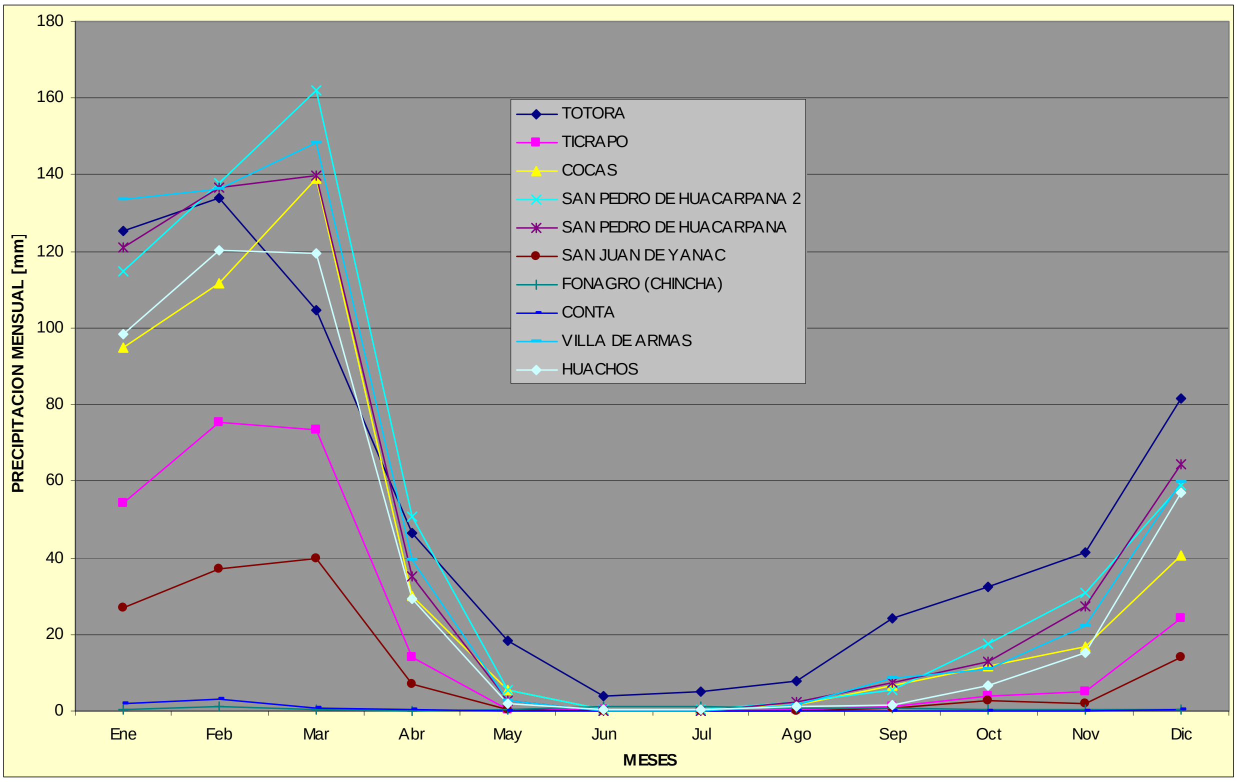


Figure Nº 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope

Table N° 3.2 and Figure N° 3.4 show that heaviest rainfalls are from October to April, and east rainfalls are from May to September. In addition, annual rainfall in the Chincha River Basin is noted to vary from 625.95mm (Totora Station) to 6.95 mm (Conta 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 Totora, Huacarpana and Huachos we established a linear equation: P = mt + b, where P is annual rainfall and t is time in years, m and b are the variables that provide the best fit in a linear equation. The results are presented in Table 3.3, giving the following values of the trends:

Table Nº 3.3.Results of the linear fit equationof Carania and Huangascar station

Estación	m	b	R2
Totora	-11.76	775.0	0.189
Huacarpana	-12.60	651.0	0.173
Huachos	3.53	431.7	0.052

The value of the regression coefficients (R^2) is very low. For Totora and Huacarpana Stations would be a seasonally weak downward trend and for Huachos 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° 3.2 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 Cañete River Basin varies between 1,000 mm and 200 mm, as shown in Figure N° 3.18.

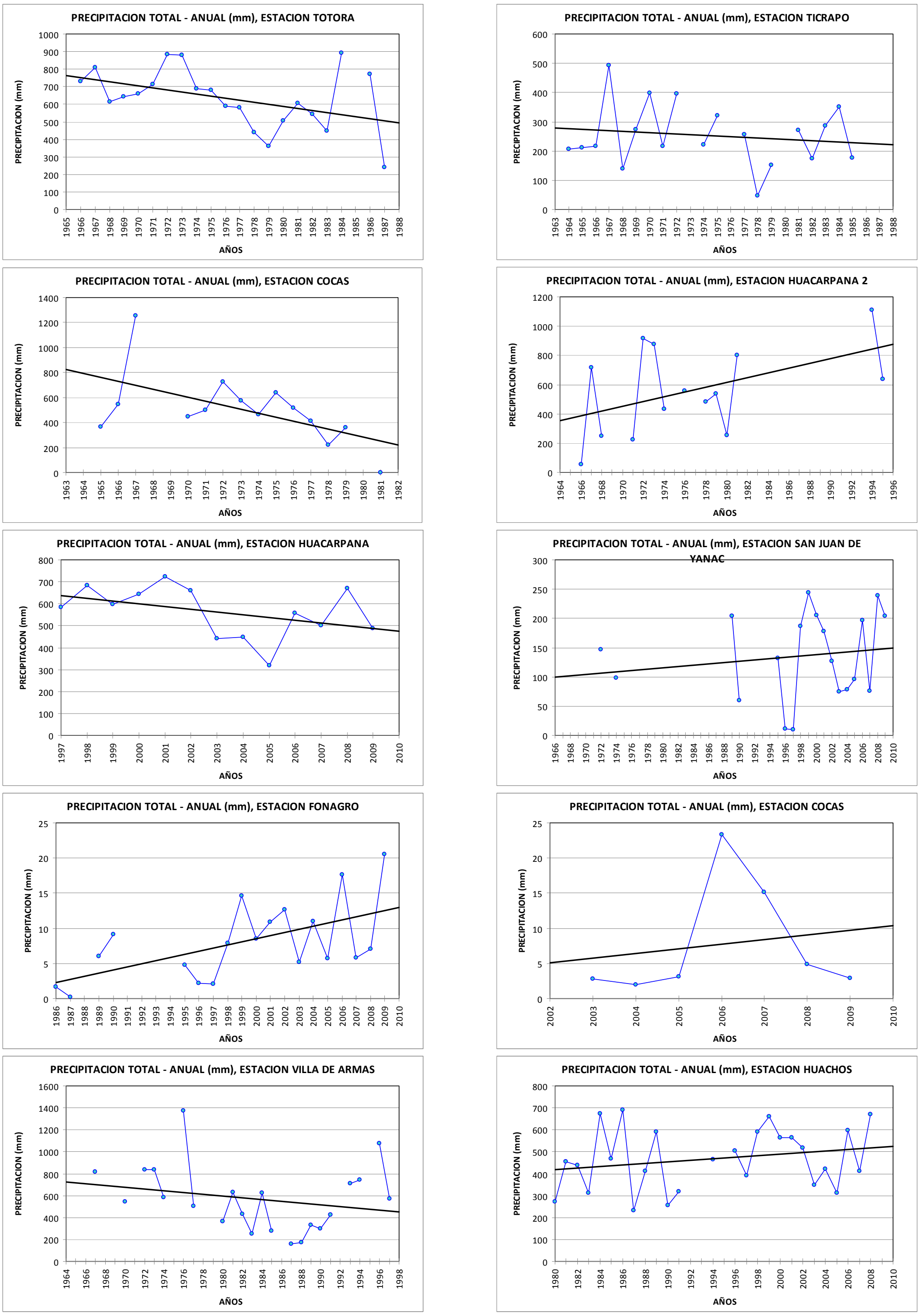


Figure Nº 3.5. Annual Rainfall Trends at the Stations considered within the Study Scope

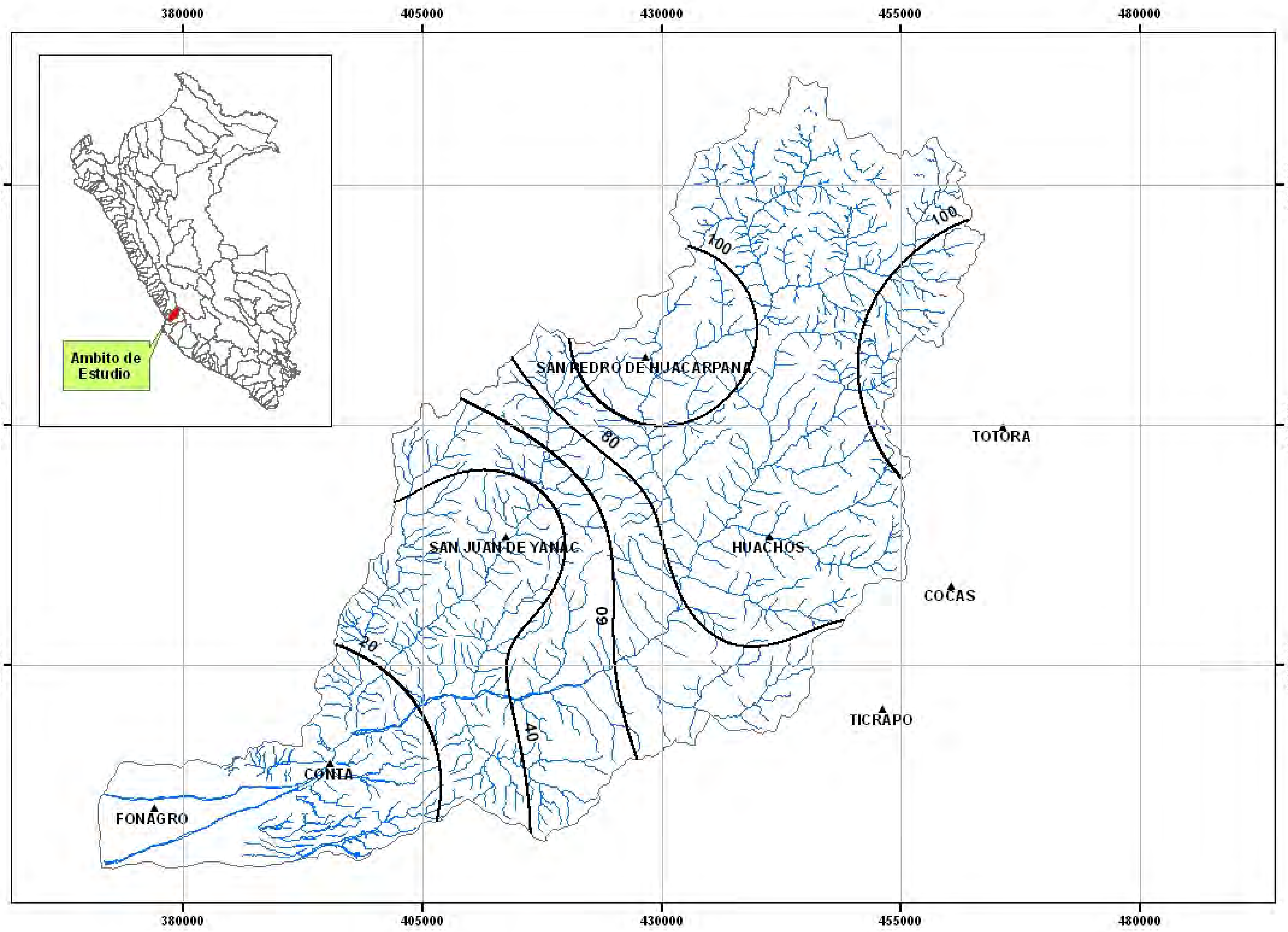


Figure Nº 3.6. Isohyets for Mean Monthly Rainfall in the Chincha Basin, in January

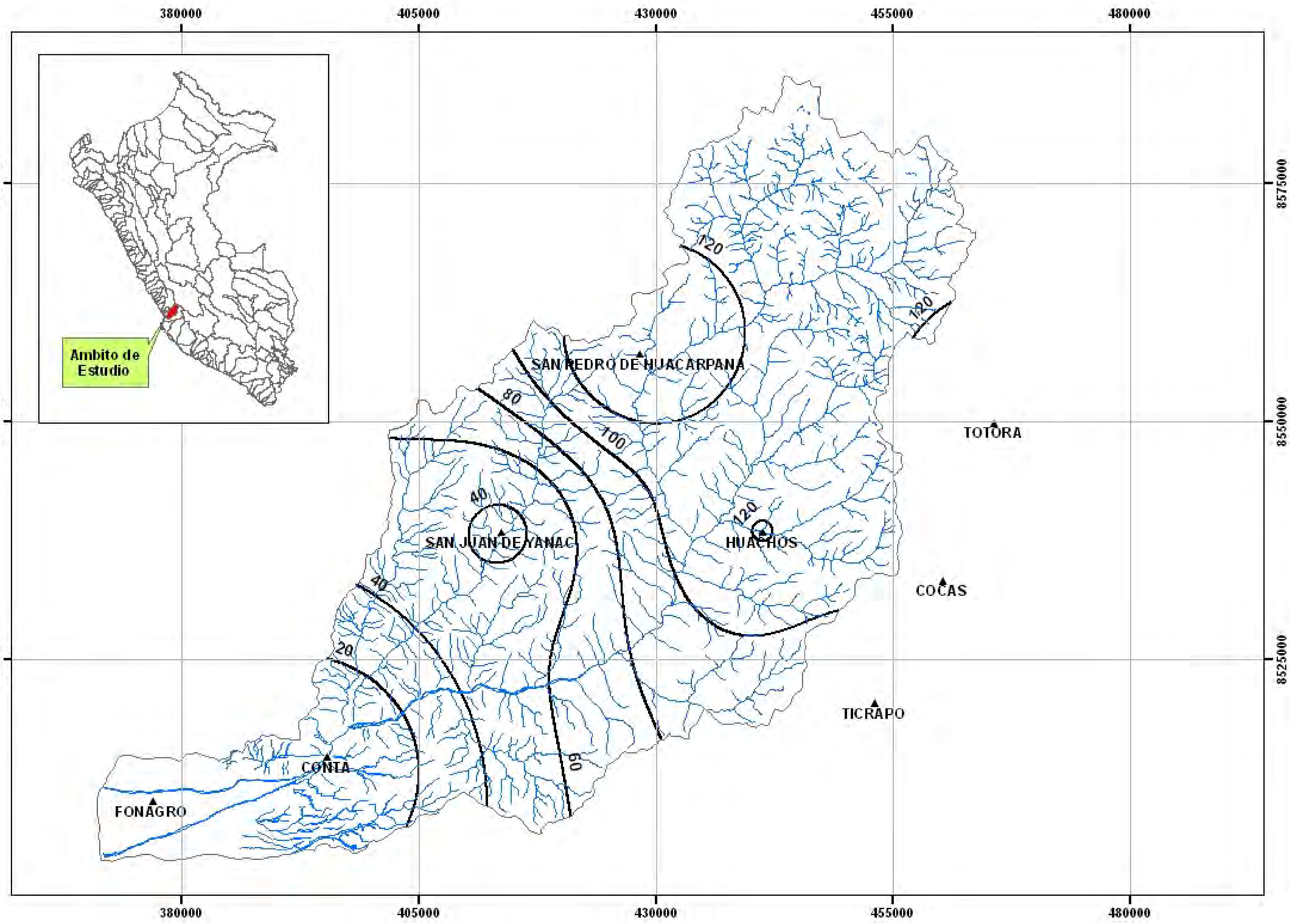


Figure Nº 3.7. Isohyets for Mean Monthly Rainfall in the Chincha Basin, in February

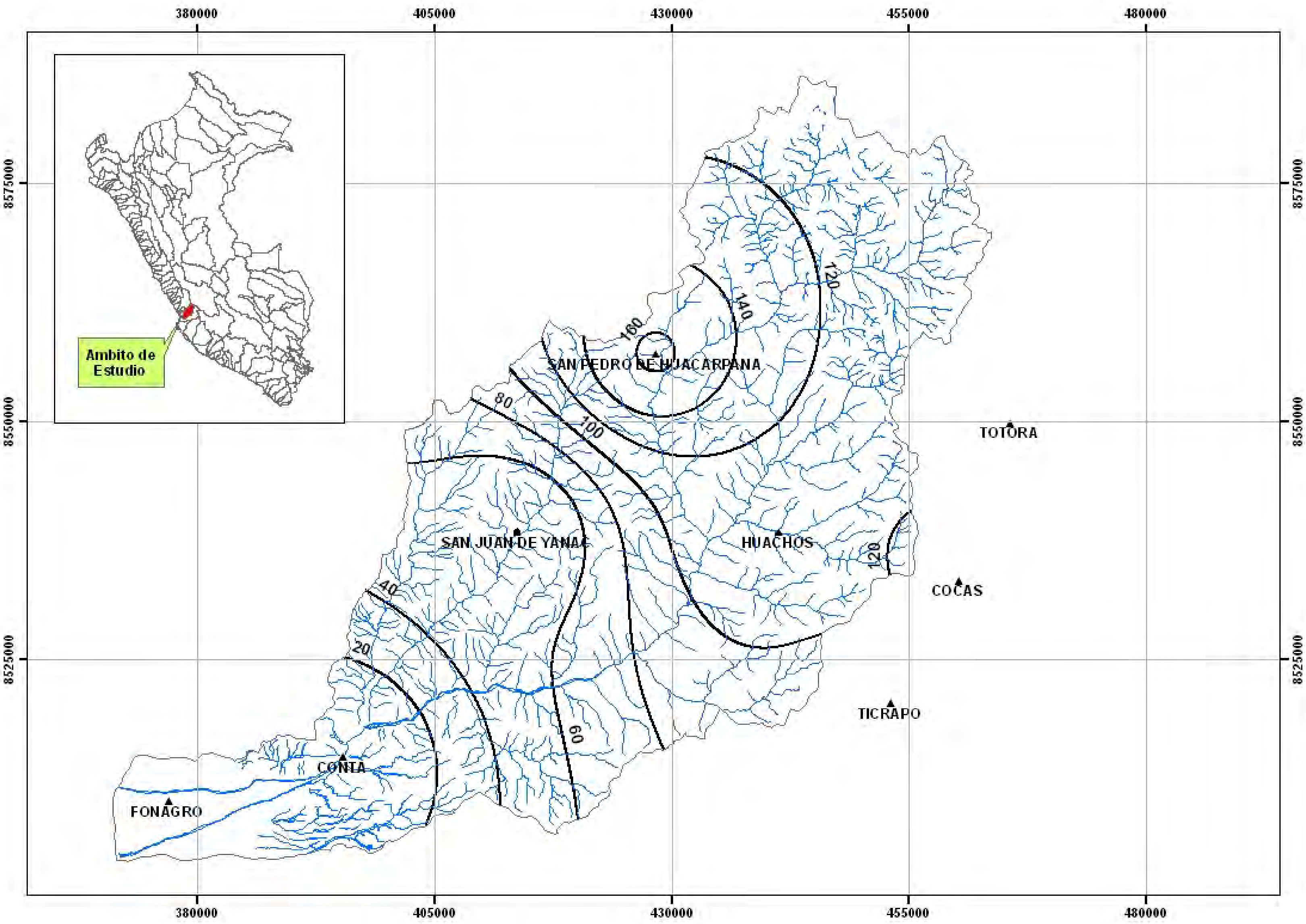


Figure Nº 3.8. Isohyets Mean Monthly Rainfall in the Chincha Basin, in March

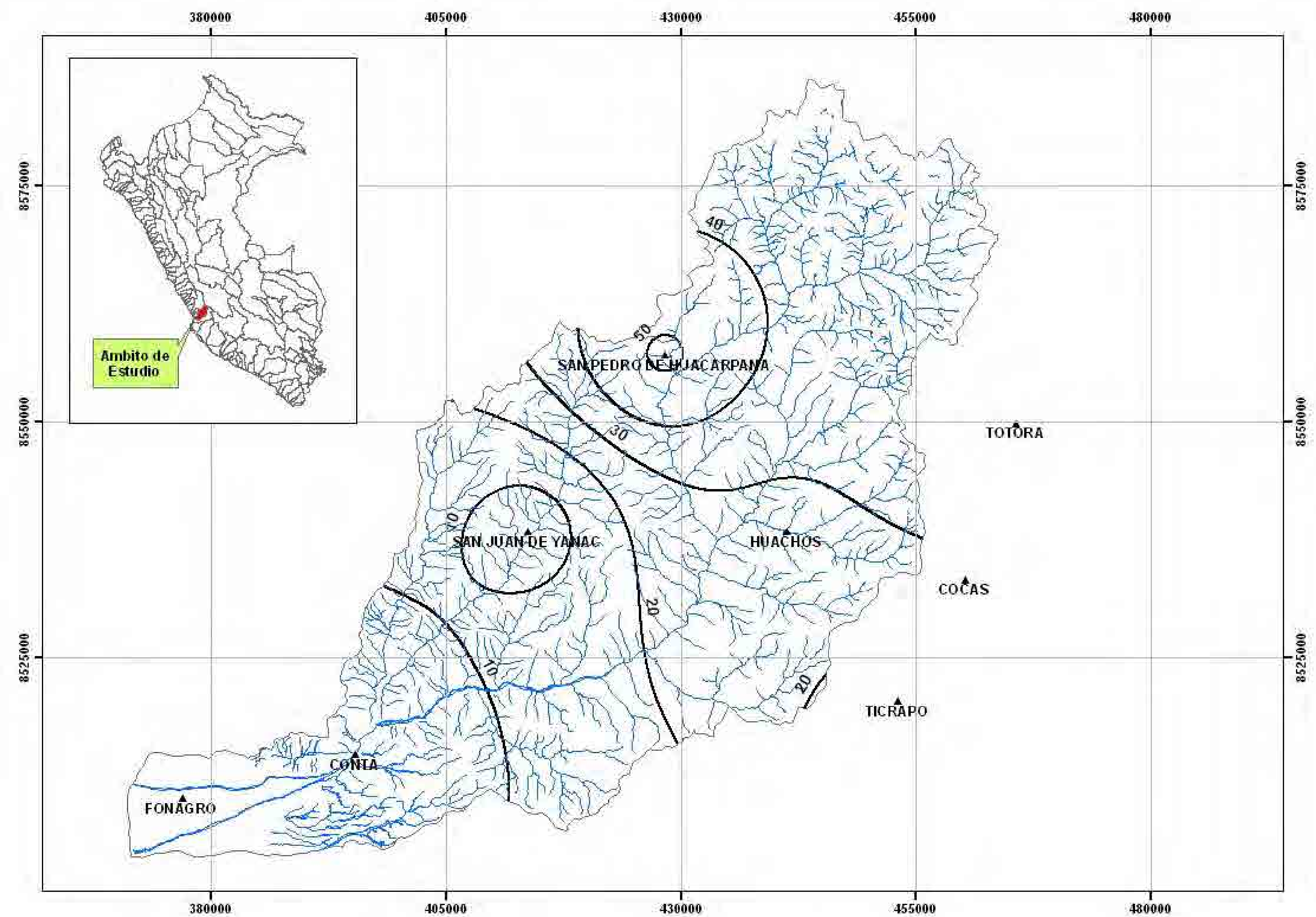


Figure Nº 3.9. Isohyets Mean Monthly Rainfall in the Chincha Basin, in April

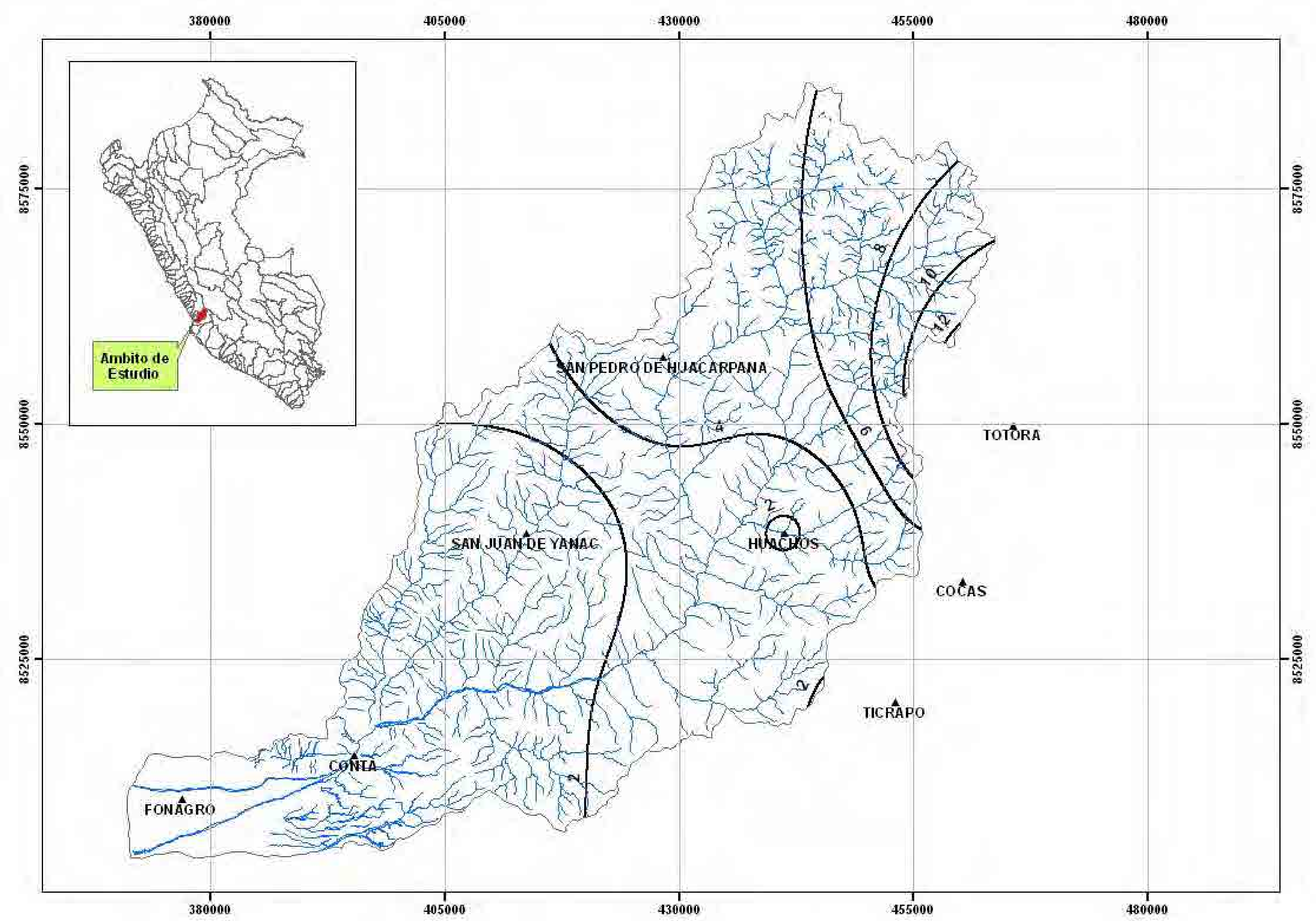


Figure Nº 3.10. Isohyets Mean Monthly Rainfall in the Chincha Basin, in May

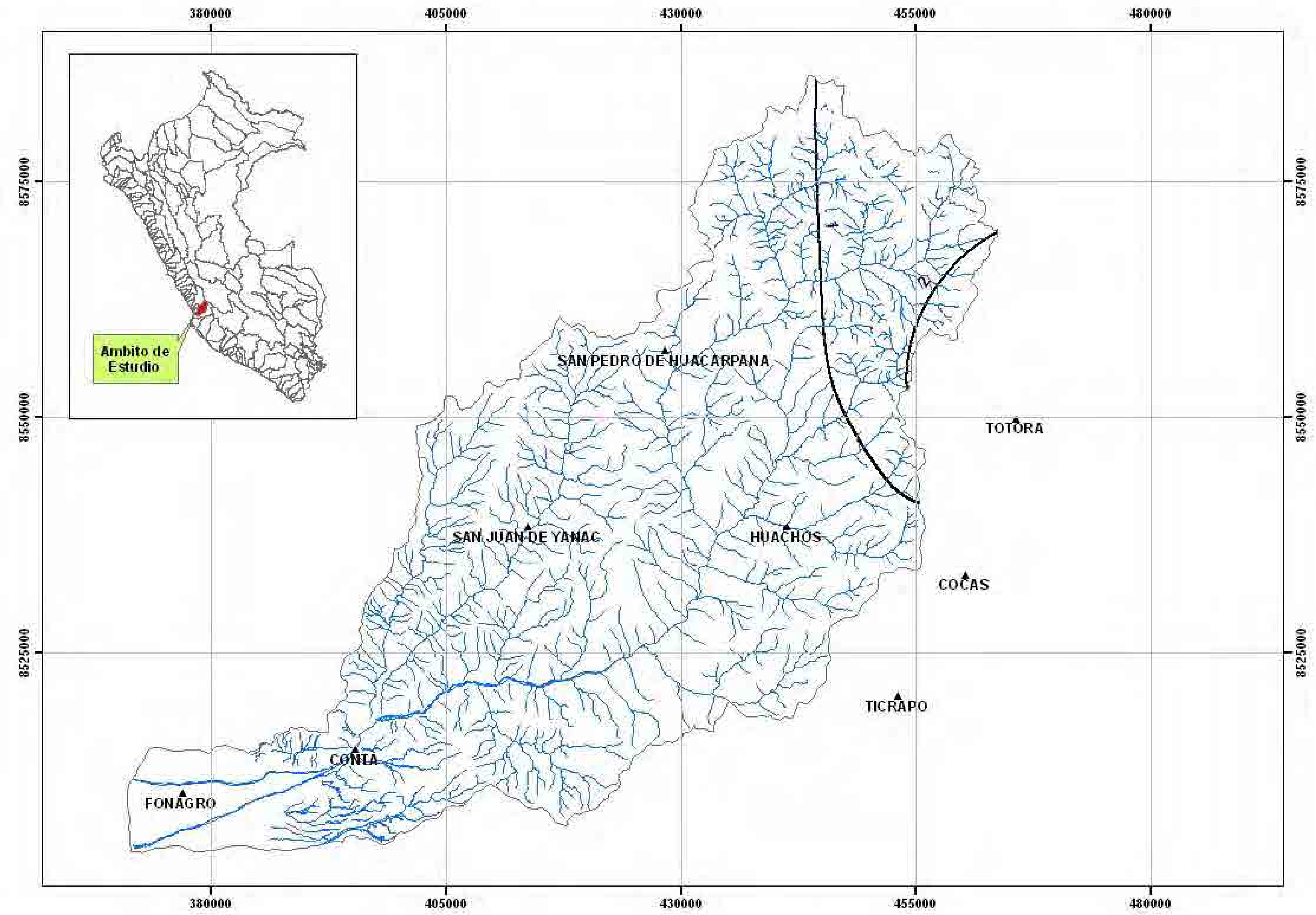


Figure Nº 3.11. Isohyets Mean Monthly Rainfall in the Chincha Basin, in June

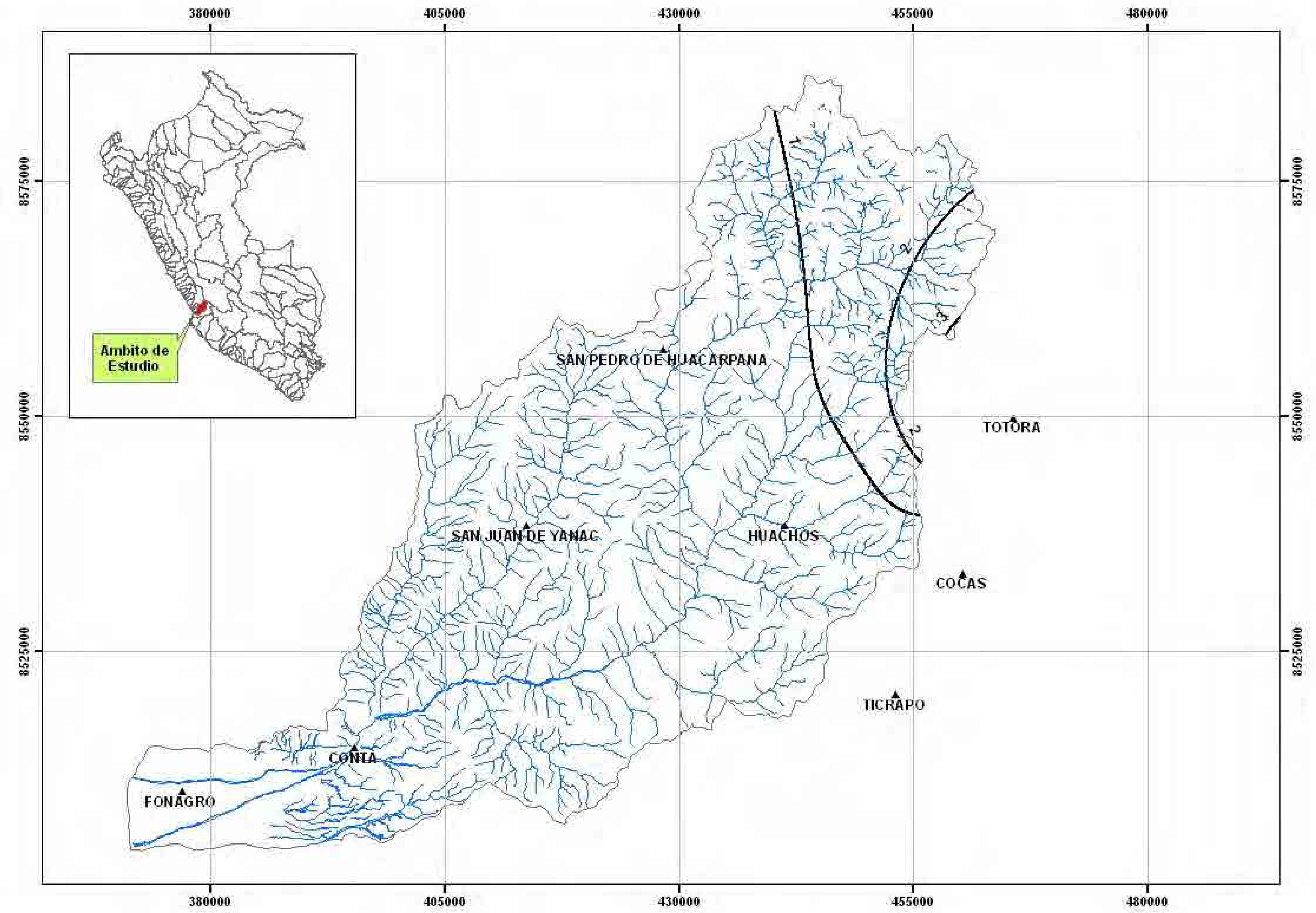


Figure Nº 3.12. Isohyets Mean Monthly Rainfall in the Chincha Basin, in July

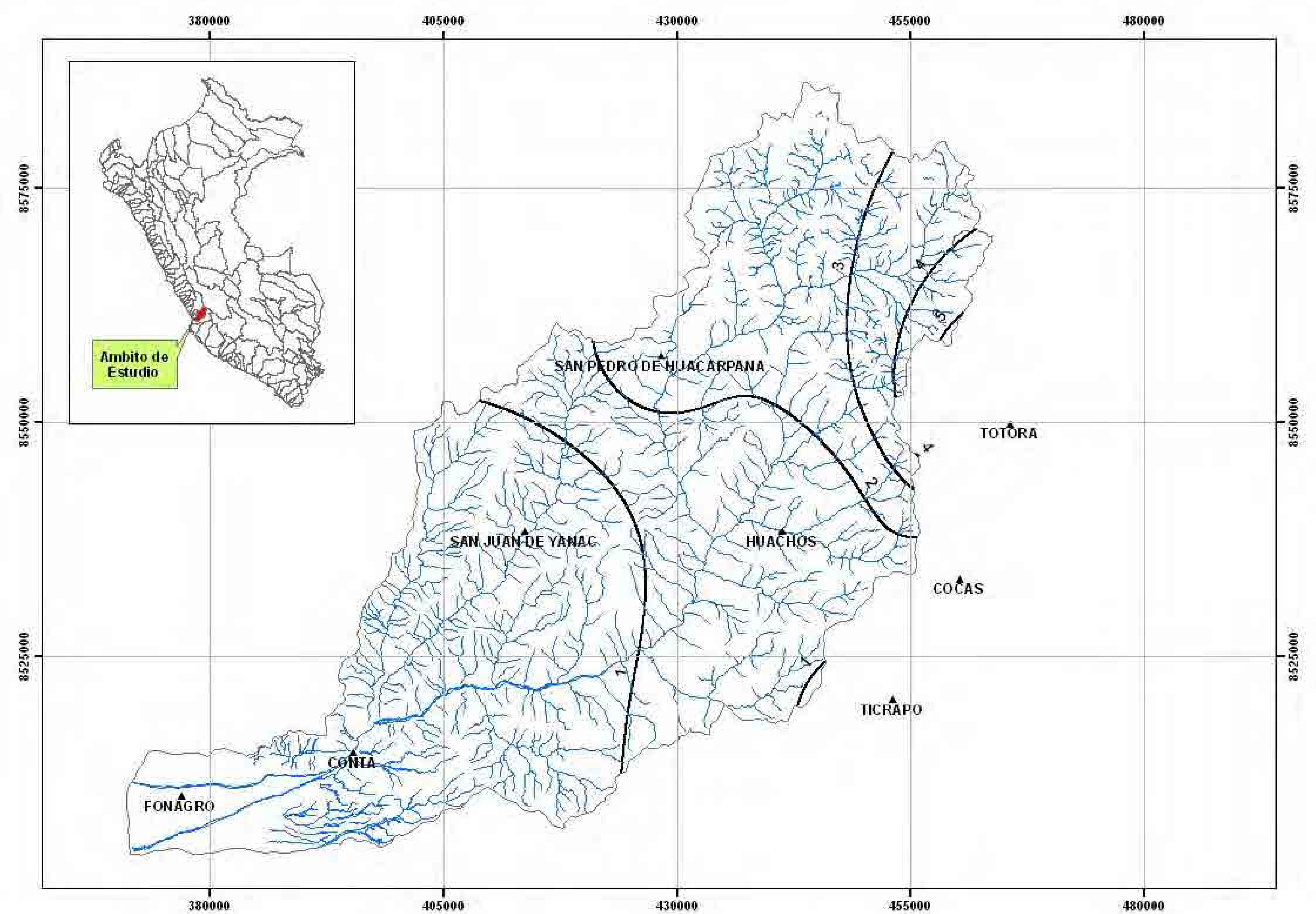


Figure Nº 3.13. Isohyets Mean Monthly Rainfall in the Chincha Basin, in August

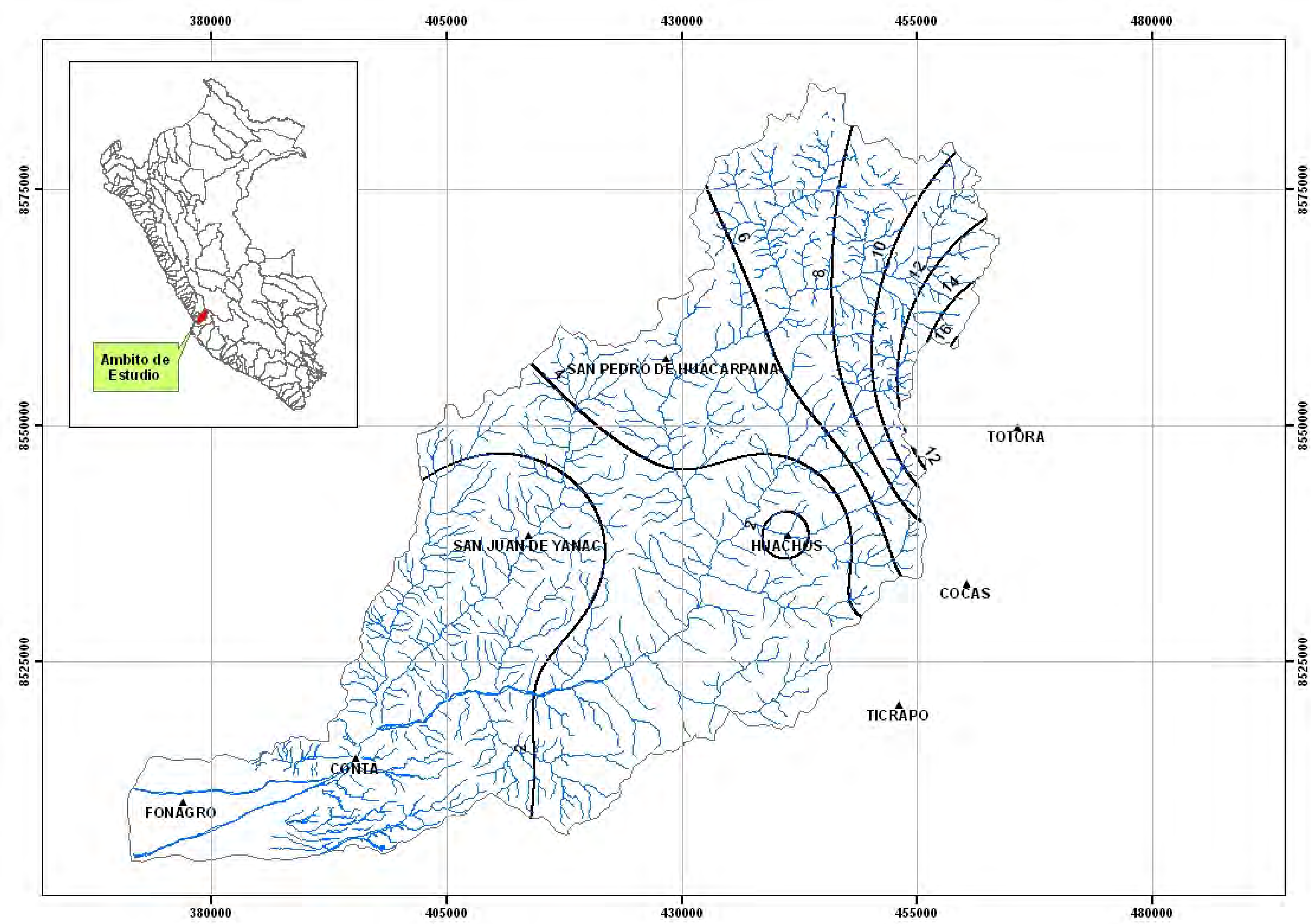


Figure Nº 3.14. Isohyets Mean Monthly Rainfall in the Chincha Basin, in September

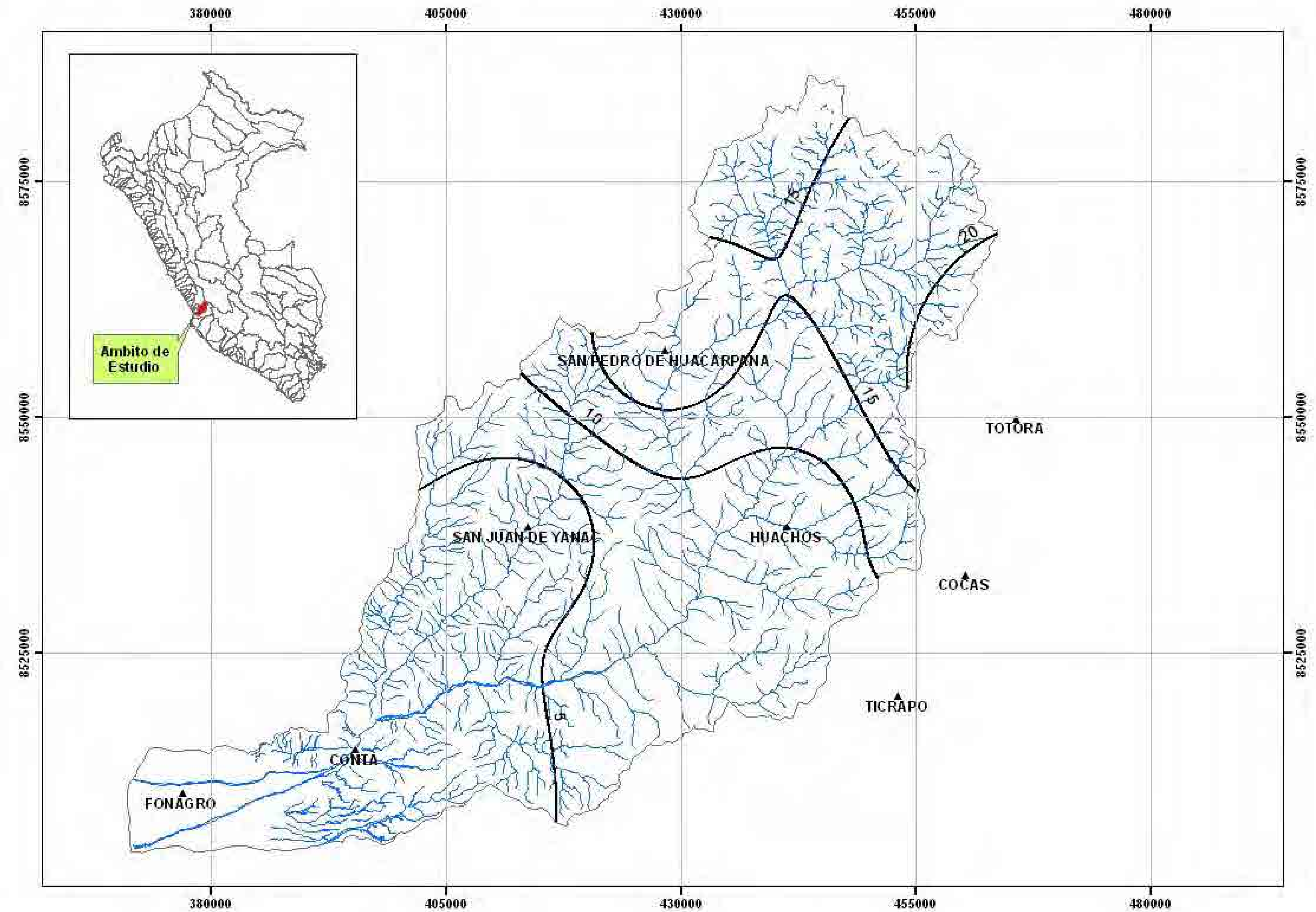


Figure Nº 3.15. Isohyets Mean Monthly Rainfall in the Chincha Basin, in October

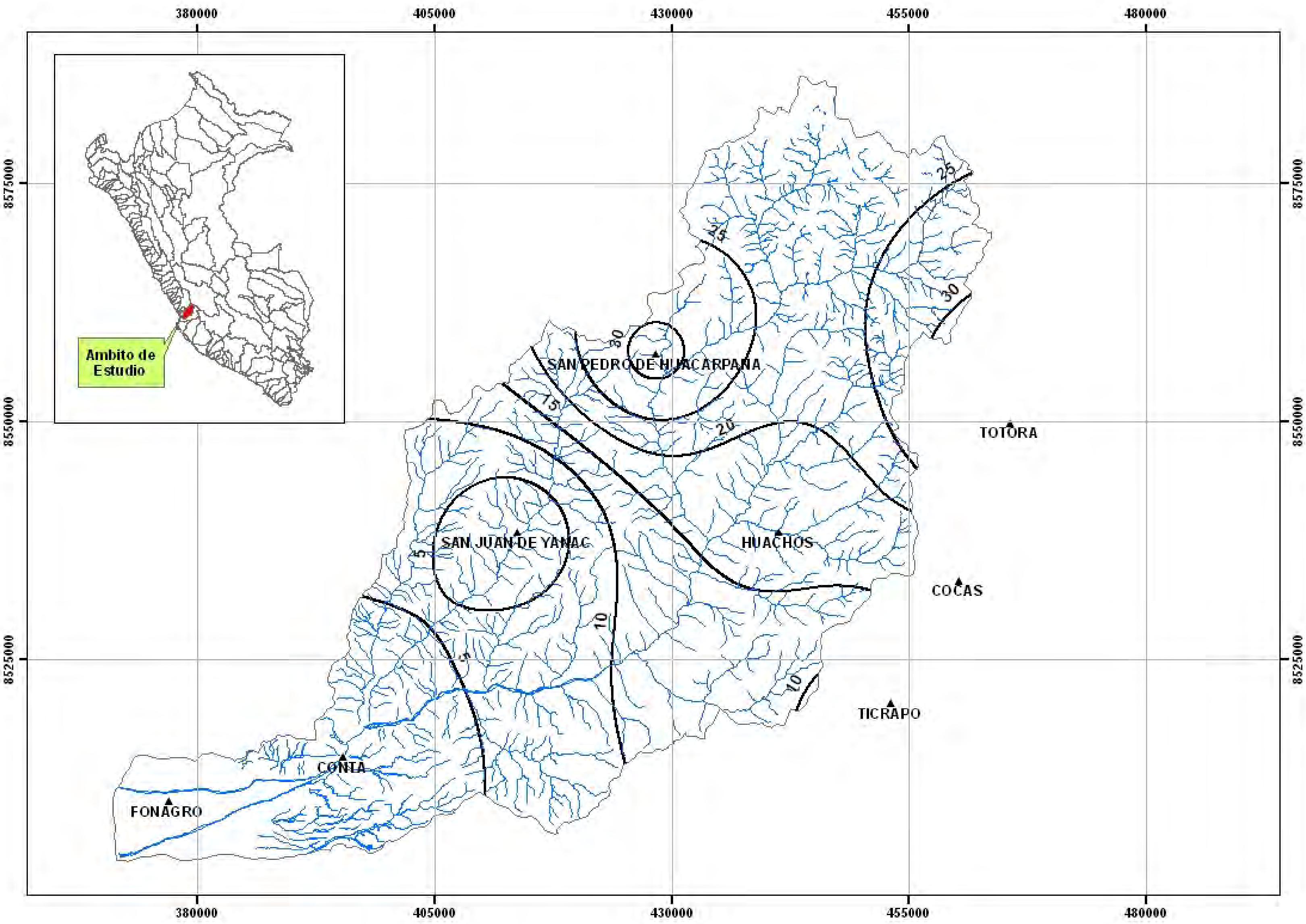


Figure Nº 3.16. Isohyets Mean Monthly Rainfall in the Chincha Basin, in November

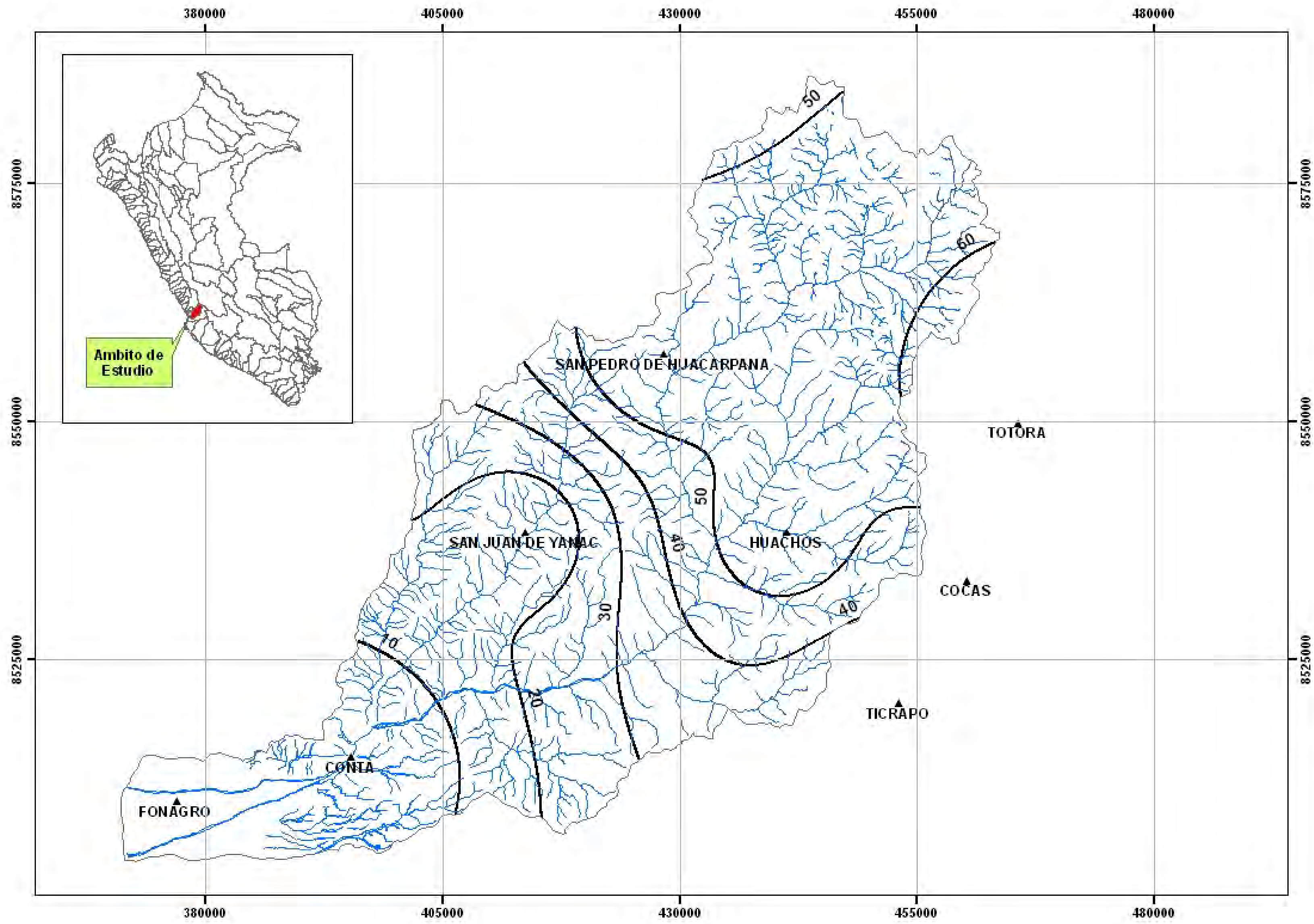


Figure Nº 3.17. Isohyets Mean Monthly Rainfall in the Chincha Basin, in December

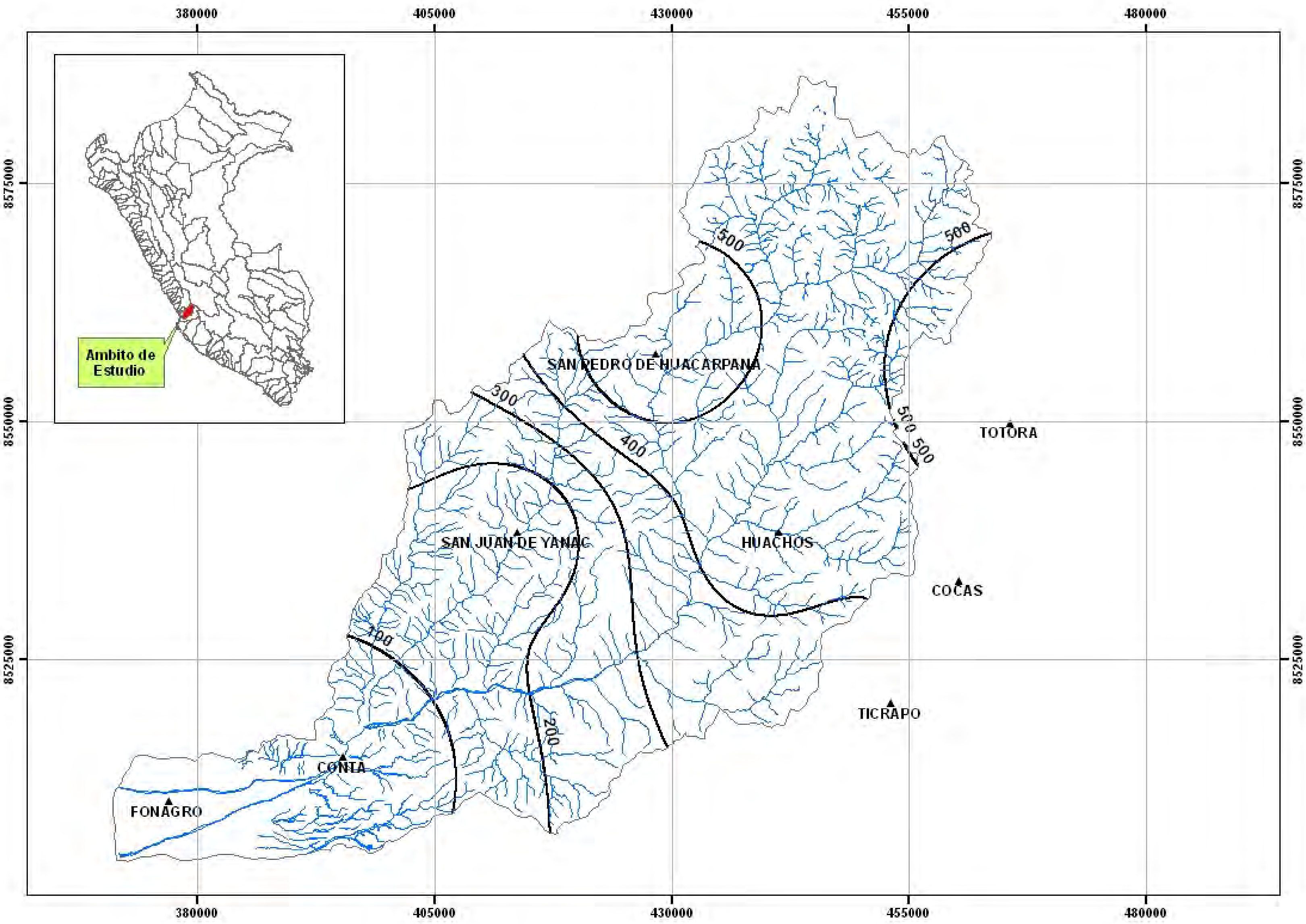


Figure Nº 3.18. Isohyets Annual Mean Monthly Rainfall in the Chincha Basin

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 Chincha Basin, the climate variable is measured by a network of meteorological stations, which are summarized in Table No. 3.2. This shows the historical averages of monthly mean temperature at stations of Fonagro, Chincha de Castrovirreyna, Chincha de Yanac, Villa de Arma y San Pedro de Huacarpana located within the basin, and Huáncano, Agnococha to neighboring basins of Pisco.

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 Fonagro stations (20, 3) and Huancano (20.6) and minima occur in the Acnococha stations (2.8).

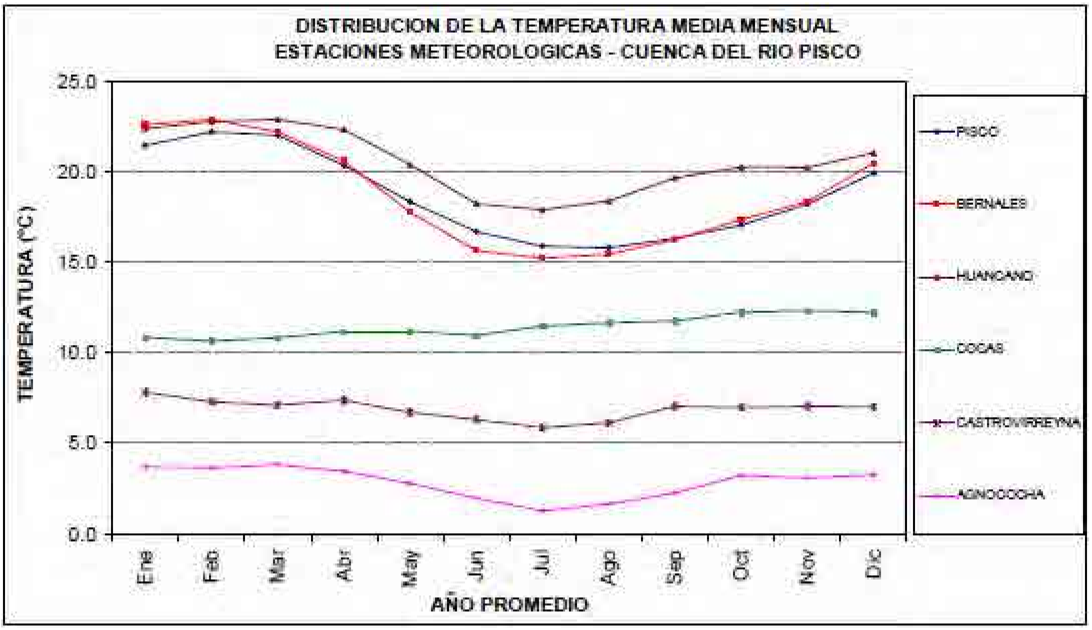
Figure N° 3.19 shows the distribution of the monthly average temperature from weather stations located in the Chincha Basin, where we note that the monthly average temperatures are higher in the station San Juan and the minimum occurs at the station Acnococha.

Table Nº 3.4. Monthly Half Temperature (C°) of the Stations of the Chincha River Basin and Adjacent Basins

ESTACION METEOROLOGICA	ALTITUD	AÑO PROMEDIO												MEDIA
	msnm	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Set	Oct	Nov	Dic	ANUAL
FONAGRO	50	23.6	24.3	23.8	22.3	19.9	17.9	17.4	17.4	17.5	18.4	19.4	21.6	20.3
HUANCANO (*)	1006	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
SAN JUAN DE CASTROVIRREYNA	2150	19.7	19.3	19.9	19.4	19.8	18.9	19.5	19.3	19.6	19.4	19.2	19.4	19.4
SAN JUAN DE YANAC	2400	14.8	14.9	15.0	14.9	15.9	15.5	15.5	16.1	15.8	15.8	15.4	16.1	15.5
HUACHOS	2680	15.1	14.7	14.7	14.7	15.2	15.2	14.9	15.9	15.8	15.8	15.1	16.0	15.2
VILLA DE ARMA	3280	11.8	10.4	11.3	12.0	12.6	12.3	13.0	12.6	13.2	12.8	11.7	11.4	12.1
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
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 Chincha River Basin. IRH-INRENA-MINAG, 2003

Figure Nº 3.19. Distribution of the Monthly Half Temperature of the Weather Stations Located in the Chincha River Basin



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

3.3 Hydrometry

Discharges information of river Pisco is available from the hydrometric station Conta located in the district of Alto Laran, province of Chincha and department of Ica. This station, operated and maintained by the Ministry of Agriculture, 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.

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

Table Nº 3.5. Location of Hydrometric Station Conta

CODE	STATION NAME	CATEGORY*	CATCHMENT	DEPARTAMENT	PROVINCE	DISTRICT	LONGITUDE	LATITUDE	ELEVATION	CONDITION	WORKING PERIOD	
											START	END
203501	CONTA	HLM	SAN JUAN	ICA	CHINCHA	ALTO LARAN	75° 59'59	13° 27'27	280	Operating	1922-09	2010-12

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.

Figure Nº 3.20, shows the period and length of the data available in Hydrometric Station Conta and Figure No. 3.21 shows its location in Chincha Basin.

Figure Nº 3.20. Period and longitude of the available information in Hydrometric Station Conta

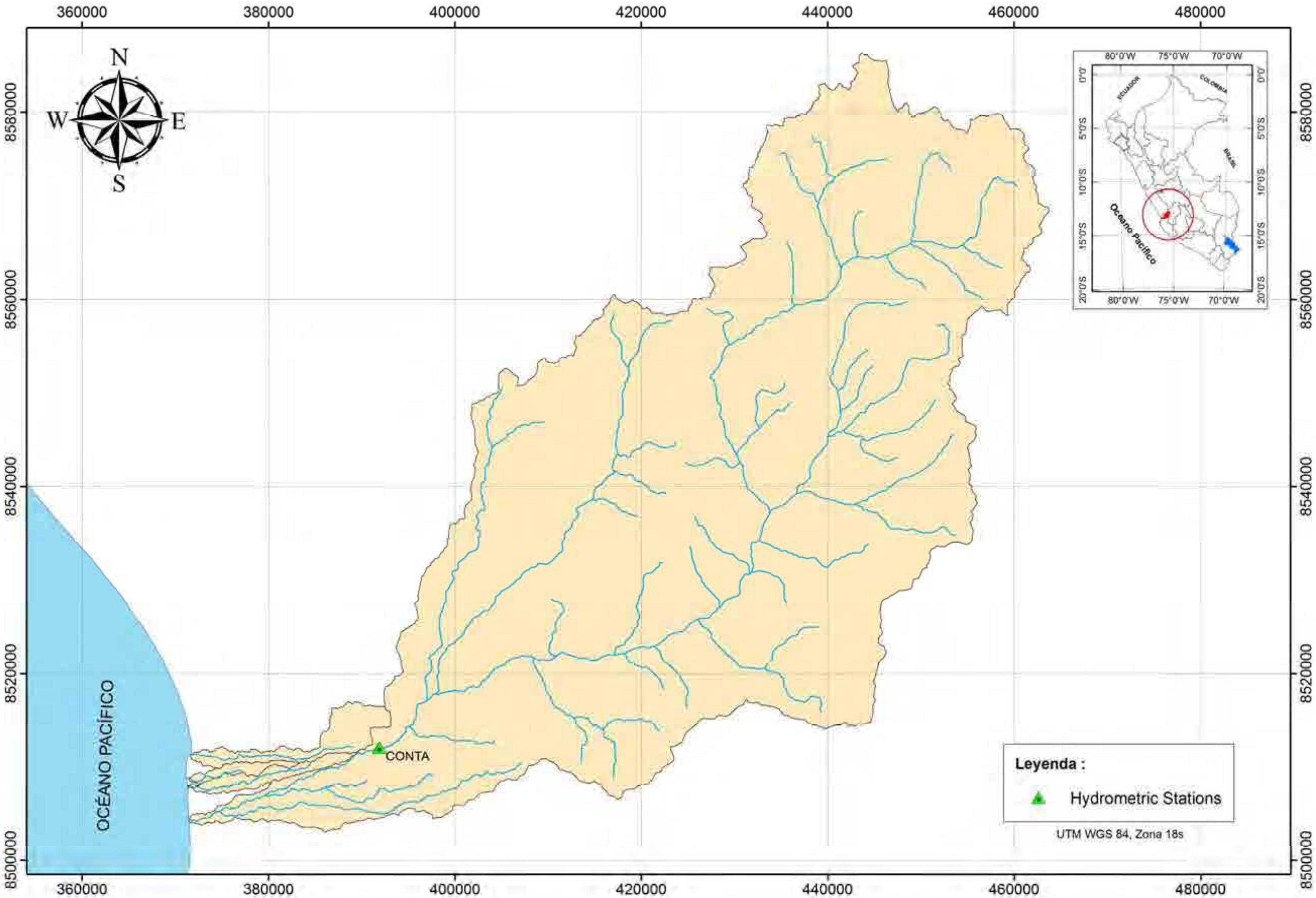


Figure N° 3.21. Location of the hydrometric station Conta in Chincha River basin

The information of the hydrometric station Conta 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.

3.4 Comments on the hydrologic and meteorologic network in the Chincha 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 10 stations, 5 stations have data until year 2010, 1 station has data until 1998, 1 station has data until 1996, 1 station has data until 1989, 1 station has data until 1988, and 1 station has data until 1981. The stations with information previously to 1999 are not operative anymore; the remaining stations are currently operative. Although the information coming from stations which have data until years previously to 1992 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. An exception has been done for Conta station which although having just 7 years of records has been considered because of the lack of other pluviometric station for describing the sector where it is located.

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 this station is 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.

The Conta station has a widespread data, the information is from 1922 to 2010.

In this station water levels are measured by reading the level in a staff gage (or ruler), lectures are transferred to a notebook and discharges are found using an equation of the type:

$$Q = aH^b$$

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

3.4.3 Recommendations

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

On the Equipment

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

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

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

.

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

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

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

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

On the Operation and Maintenance of the Equipments

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

On the Quality of the Measured Data

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

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

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

IV. HYDROLOGY OF MAXIMUM FLOOD

4.1 Preliminary Considerations

This chapter describes the methodology of work developed for the generation of flood flows in the so-called Base Point (point of interest, Conta 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 Conta.

Field Reconnaissance:

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

Methodology and Procedures:

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

- Identification and delimitation of the sub – watershed to the point of interest (Hydromeetric Station Conta), 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 24 – hour maximum rainfall.
- 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 the entire basin inputs to the discharge) through the Dick and Peschke model.

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

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

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

4.2 Hydrology characterization, analysis of rainfall and river information

4.2.1 Hydrology Characterization

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

Table Nº 4.1. Geomorphological Characteristics of the Basis Point Watershed (station Conta)

Caracteristica	Valor
Area de la Cuenca (km2)	2,981.000
Longitud Max. De Recorrido (km)	121.250
Cota Mayor (msnm)	4,725.000
Cota Menor (msnm)	323.000
Pendiente (m/m)	0.036

4.2.2 Maximum Rainfall in 24 Hour Analysis

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

From the information shown in Table No. 4.2 and Figure No.3.3 we conclude that the stations are distributed throughout the study area, except station of Villa Arma which is very far to the Chincha River Basin.

Table Nº 4.2. Maximum Rainfall in 24 Hours Annual for Stations located within the Study Scope

Year	Pluviometric Stations									
	TOTORA	TICRAPO	COCAS	SAN PEDRO DE HUACARPANA 2	SAN PEDRO DE HUACARPANA	CHINCHA DE YANAC	FONAGRO (CHINCHA)	CONTA	VILLA DE ARMAS	HUACHOS
1960										
1961										
1962										
1963										
1964		21.50	19.80							
1965	24.00	20.70	21.60	15.00						
1966	15.00	12.60	20.20	5.20						
1967	24.00	24.40	36.00	31.00					59.60	
1968	20.00	10.00		16.00						
1969	22.00	35.80		24.50						
1970	23.00	40.20	22.10	24.50					24.90	
1971	21.00	28.40	29.40	20.00					31.00	
1972	27.00	32.00	30.80	26.00		12.80			29.60	
1973	25.00	44.31	36.80	21.10					42.40	
1974	22.00	14.00	20.60	14.50		8.20			36.00	
1975	19.00	19.50	22.40	22.50		10.30			35.80	
1976	20.00	25.50	21.40	17.00					38.00	
1977	25.00	24.00	20.60	15.00					36.20	
1978	20.01	5.40	14.40	26.00					61.80	
1979	25.01	18.00	27.40	32.00					27.40	
1980	35.00	24.10		19.50					43.00	33.20
1981	29.00	33.00		32.00					35.20	20.80
1982	29.01	10.90		18.00					30.00	25.80
1983	24.01	30.00							11.80	19.90
1984	37.01	20.80							11.80	29.20
1985	30.00	18.00							20.80	25.50
1986	27.00	26.80		24.00			0.30		20.00	28.50
1987	13.01						0.20		19.00	20.10
1988	25.01			32.00			0.70		20.00	33.50
1989				27.00		6.80	3.00		10.80	19.80
1990				24.00		5.50	2.00		20.00	23.20
1991				33.00					28.00	24.30
1992										
1993				23.00					26.00	
1994				30.00					21.40	26.10
1995				25.00		10.30	2.30		28.40	23.10
1996				24.00		0.40	0.90		48.60	25.40
1997					23.60	2.50	0.80		30.40	16.20
1998					25.00	11.30	1.50			38.50
1999					28.00	15.90	6.00			41.60
2000					24.20	14.00	1.50			20.50
2001					24.20	9.70	1.10			23.80
2002					30.00	14.60	1.10			37.00
2003					20.60	9.51	0.50	0.60		15.20
2004					28.70	7.20	1.21	0.40		44.20
2005					16.00	16.50	0.91	1.00		28.60
2006					27.80	37.40	3.21	6.00		25.60
2007					16.00	14.20	1.00	4.00		20.50
2008					22.60	14.70	1.90	0.80		23.80
2009					16.40	15.90	2.20	0.30		
2010						23.80				

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

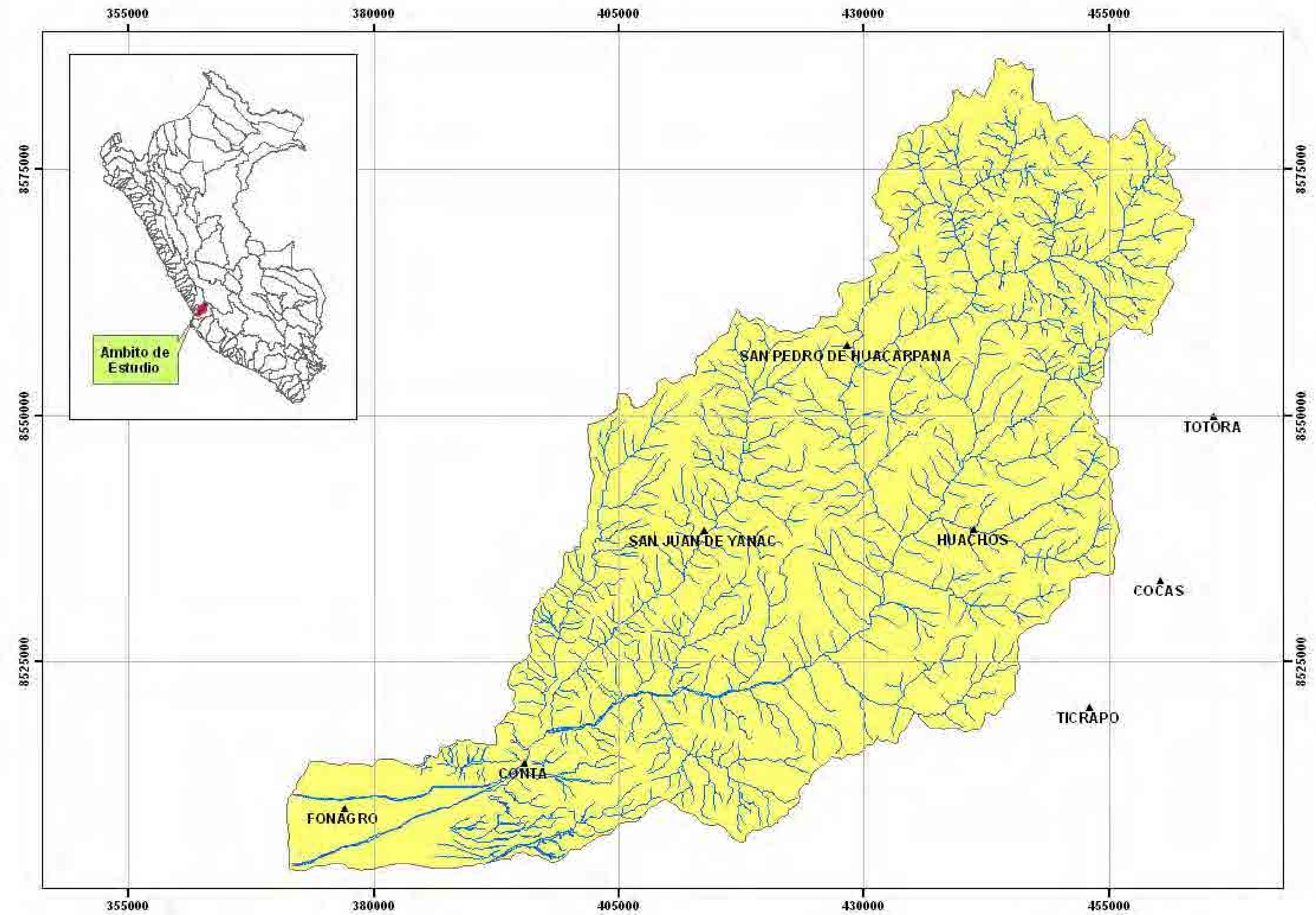


Figure Nº 4.1. Rainfall Stations considered for HEC - HMS Software application

Each maximum annual rainfall series for all eight (8) selected rainfall stations will be adjusted to a specific distribution type. In this sense, most common distribution functions are described, as applied to the extreme event hydrological studies.

4.2.2.1 Distribution Functions

The following describes the distribution functions:

1. Distribution Normal or Gaussiana

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

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

   To $-\infty < x < \infty$

   Where:

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

   x = Independent Variable.

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

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

   EXP = Exponential function with base e of natural logarithms.

2. Two-Parameter Log-normal Distribution

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

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

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

Where:

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

3. Log–Normal Distribution of Three Parameters

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

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

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

To $x_o \leq x < \infty$

Where:

xo = Positional parameter in the domain x

μ_y, = Scale parameter in the domain x.

σ_y^2 = Shape parameter in the domain x

4. Two-Parameter Gamma Distribution

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

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

To:

$0 \leq x < \infty$

$0 < y < \infty$

$0 < \beta < \infty$

As:

γ = Shape parameter (+)

β = Scale Parameter (+)

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

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

5. Three- Parameter Gamma Distribution or Pearson Type III

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

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

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

To

$x_o \leq x < \infty$

$-\infty < x_o < \infty$

$0 < \beta < \infty$

$0 < \gamma < \infty$

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

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

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

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

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

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

Station	Determination Coeffcient for Each Distribution Function				
	Log Pearson III	GEV	SQRT	Gumbel	Log-Normal
Totora	0.88	0.97	0.91	0.90	0.87
Ticrapo	0.80	0.95	0.88	0.90	0.93
Cocas	0.82	0.95	0.89	0.93	0.92
San Pedro de Huacarpana	0.89	0.95	0.91	0.90	0.93
San Juan de Yanac	0.93	0.94	0.92	0.92	0.91
Fonagro (Chincha)		0.95	0.93	0.93	0.92
Conta	0.93	0.95	0.92	0.92	0.89
Villa de Armas	0.90	0.92	0.89	0.90	0.92
Huachos	0.92	0.93	0.92	0.90	0.90

Table Nº 4.4. Maximum 24-hours rainfall 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
COCAS	22.0	30.0	34.0	38.0	40.0	42.0	43.0
CONTA	1.0	2.0	4.0	6.0	9.0	13.0	18.0
FONAGRO	1.0	2.0	3.0	4.0	5.0	7.0	8.0
HUACHOS	24.0	31.0	36.0	42.0	48.0	53.0	59.0
CHINCHA DE YANAC	11.0	18.0	23.0	30.0	34.0	39.0	44.0
SAN PEDRO DE HUACARPANA	23.0	29.0	32.0	35.0	36.0	37.0	38.0
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

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

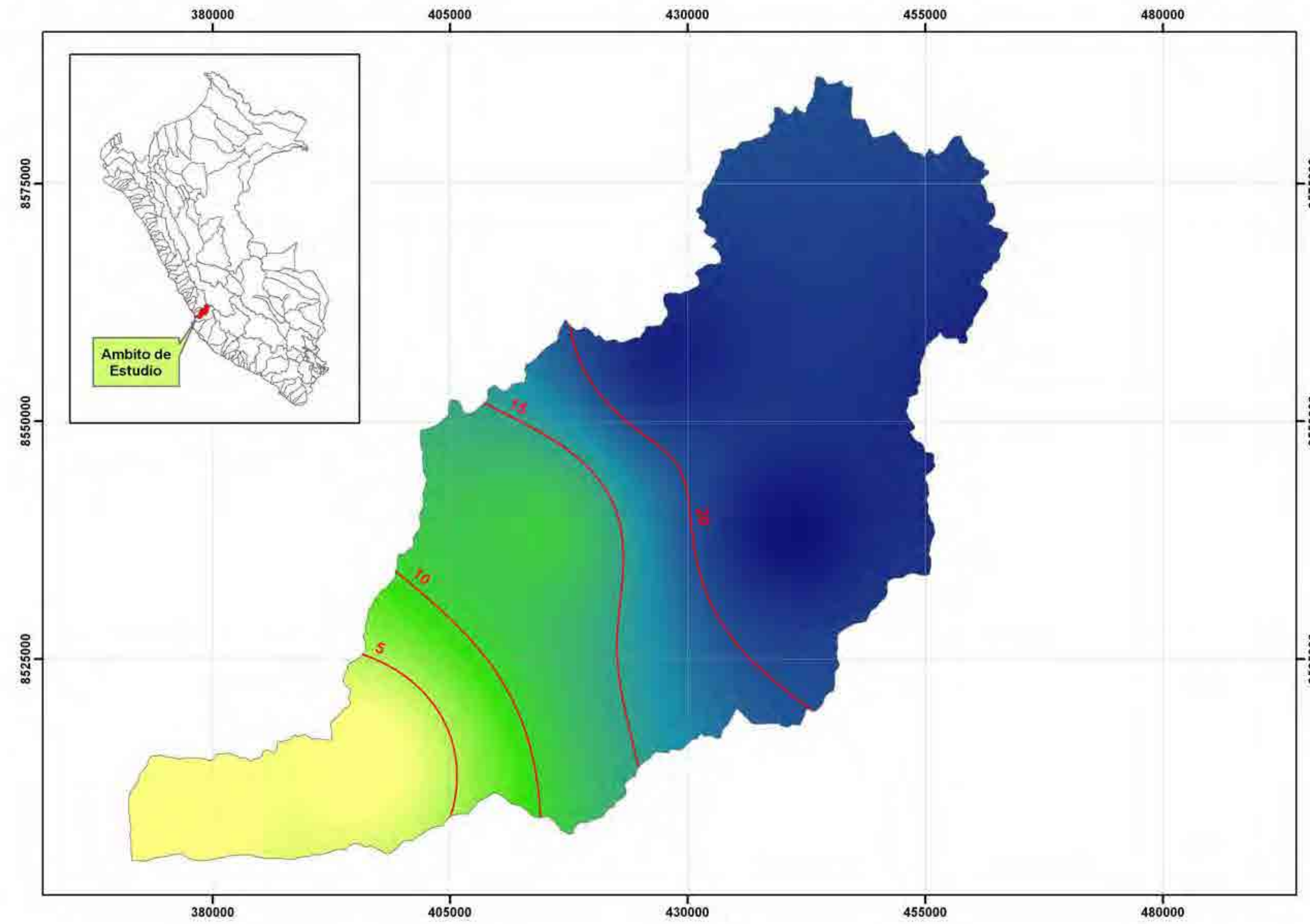


Figure Nº 4.2. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Chincha Basin

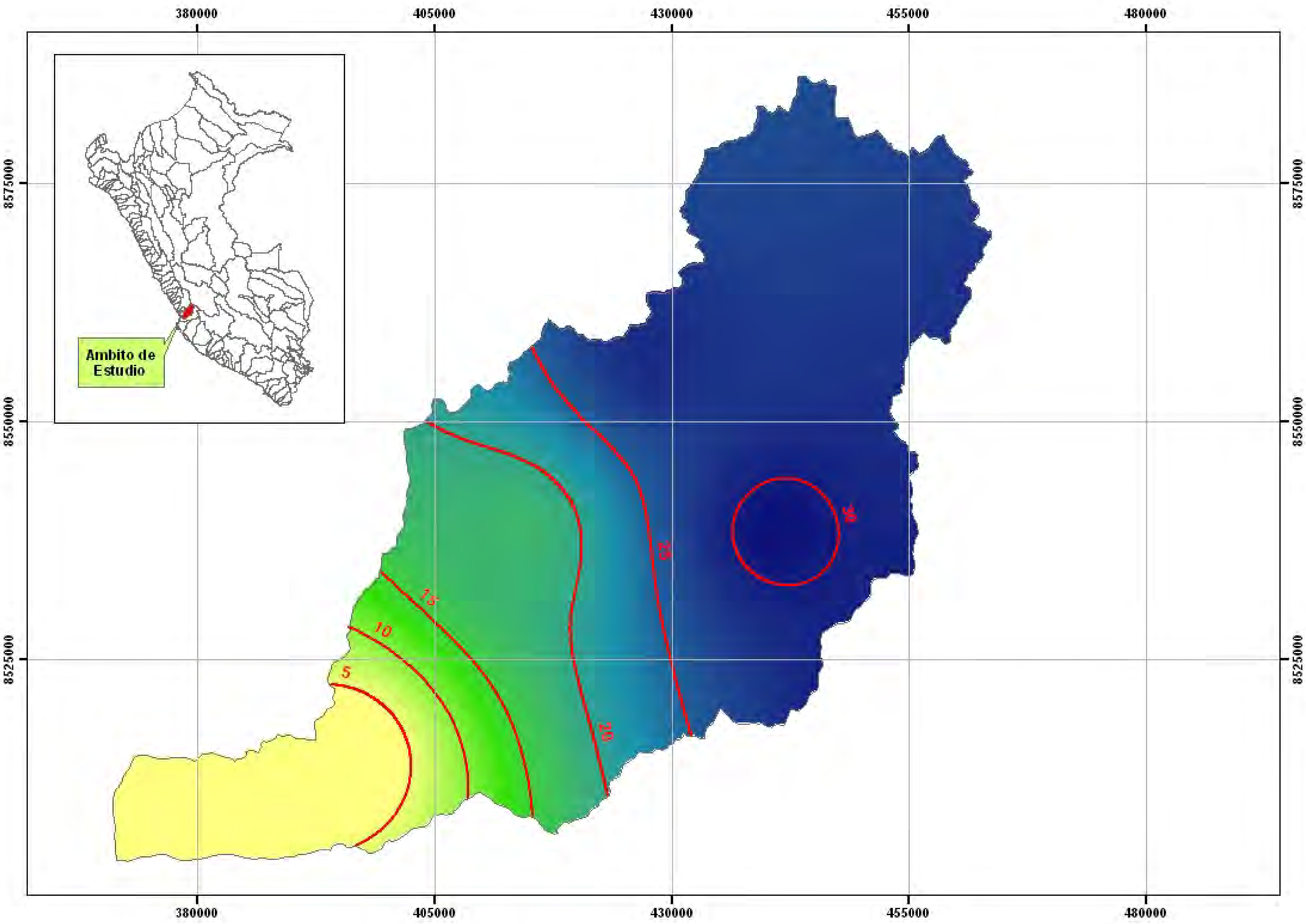


Figure Nº 4.4. Isohyets for the 5 - Years Return Period Maximum 24-Hours Rainfall in the Chincha Basin

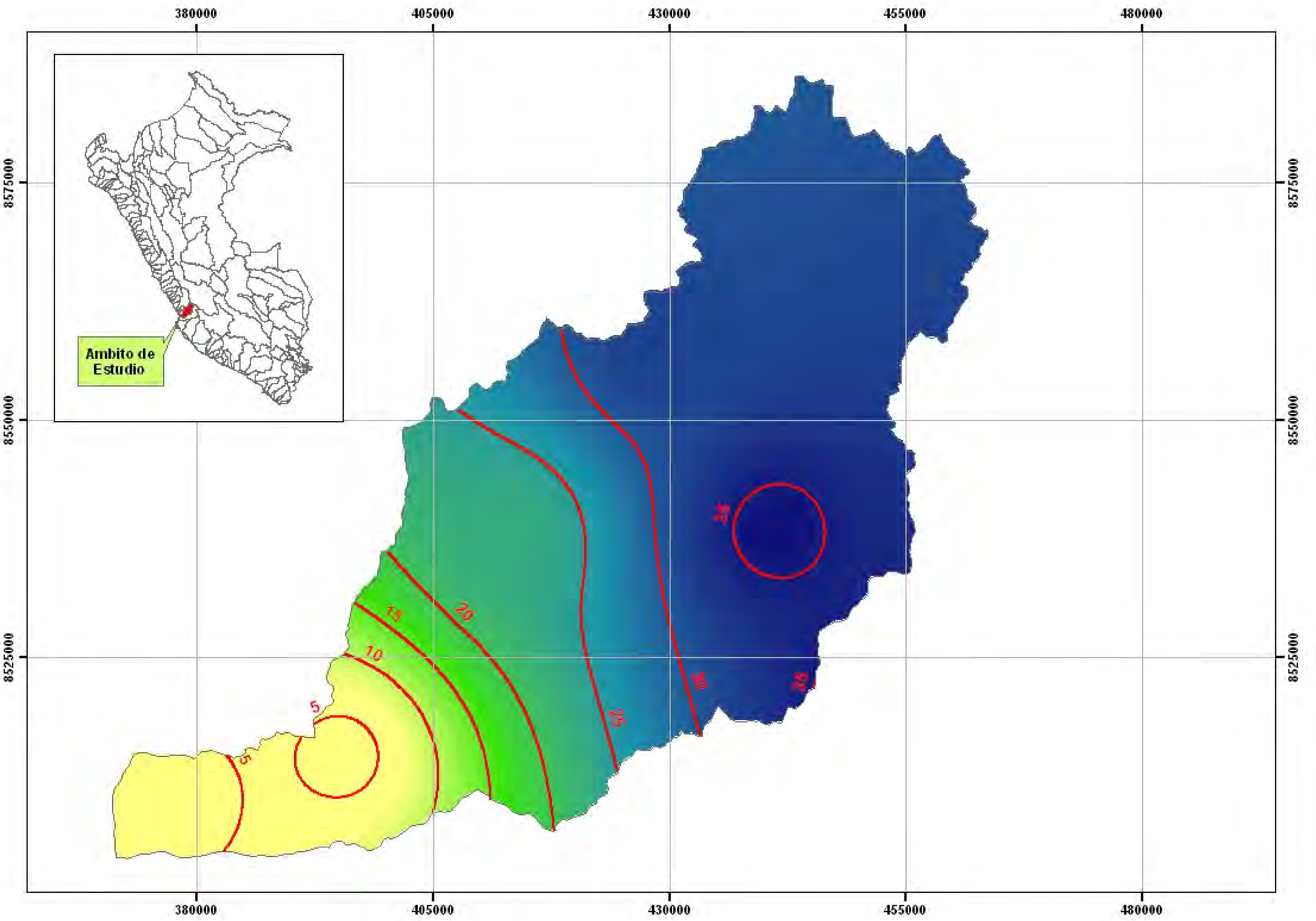


Figure Nº 4.5. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Chincha Basin

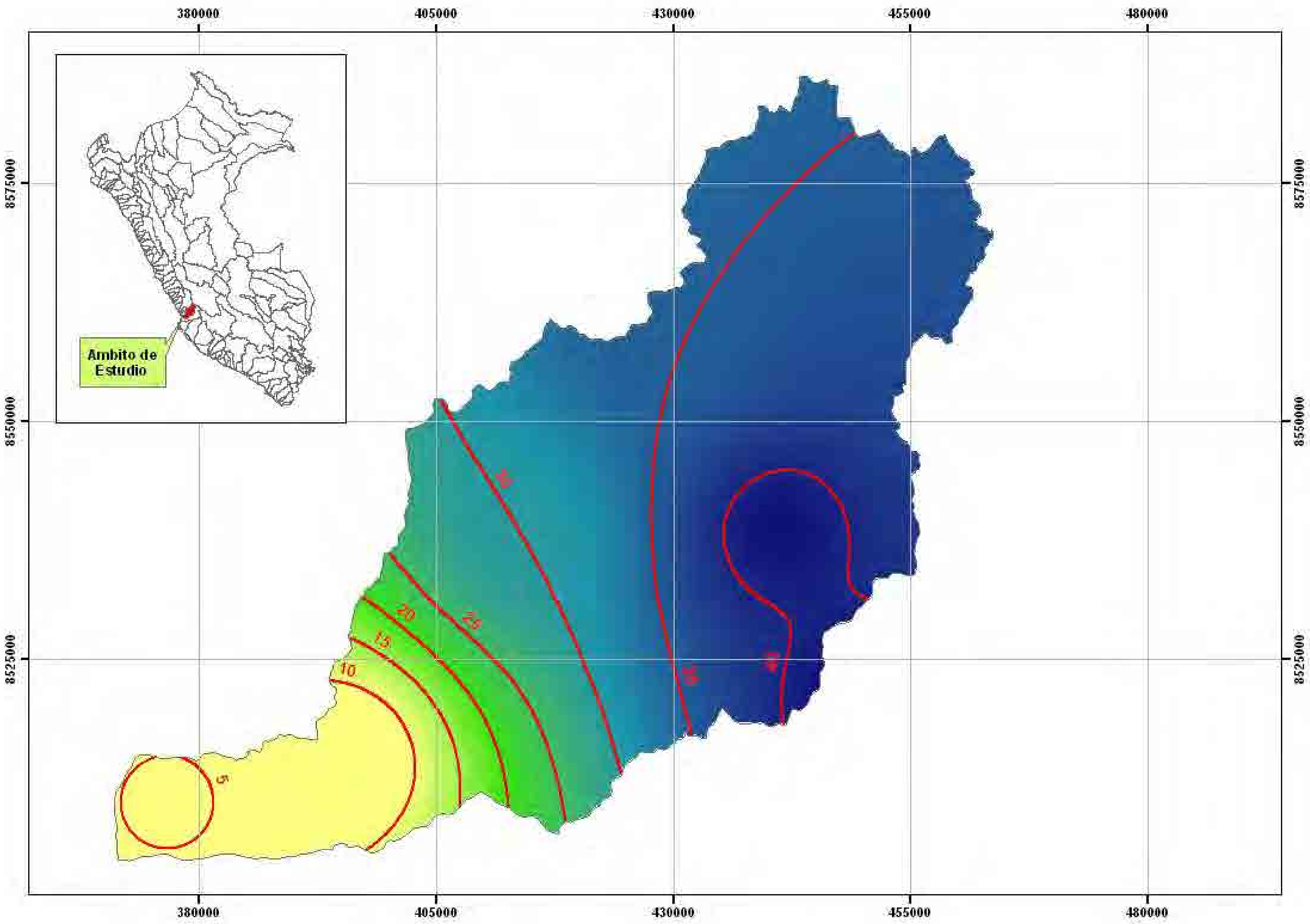


Figure Nº 4.6. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Chincha Basin

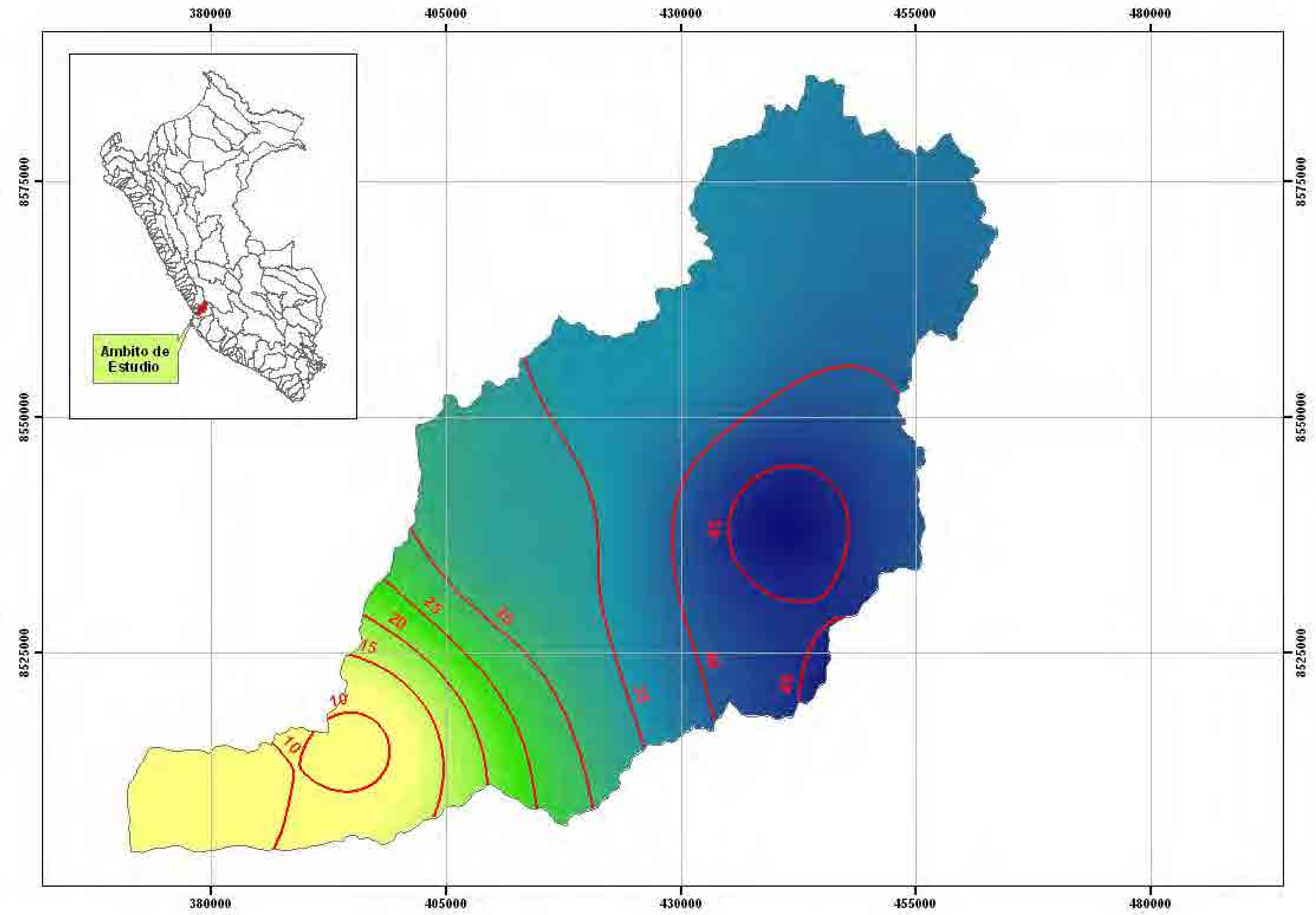


Figure Nº 4.7. Isohyets for the 510 - Years Return Period Maximum 24-Hours Rainfall in the Chincha Basin

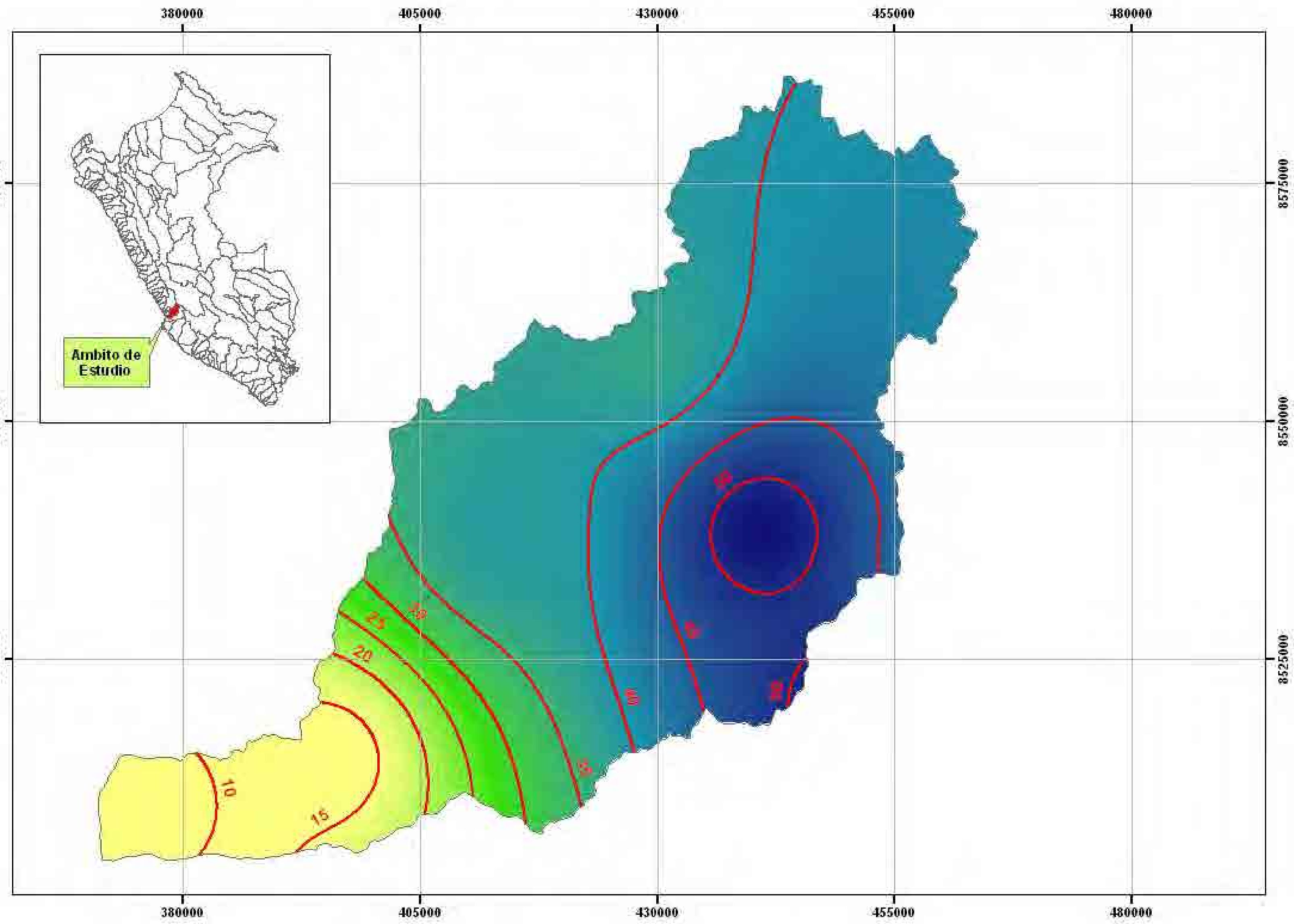


Figure Nº 4.8. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Chincha Basin

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

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

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

Return Period "T" [Years]	Maximum Areal 24 Hours Rainfall [mm]
2	17.00
5	23.40
10	27.39
25	32.22
50	35.56
100	39.06

4.2.2.5 Determination of Maximum 24-hours Rainfalls for Different Return Period in the Chincha River Subwatersheds

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

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

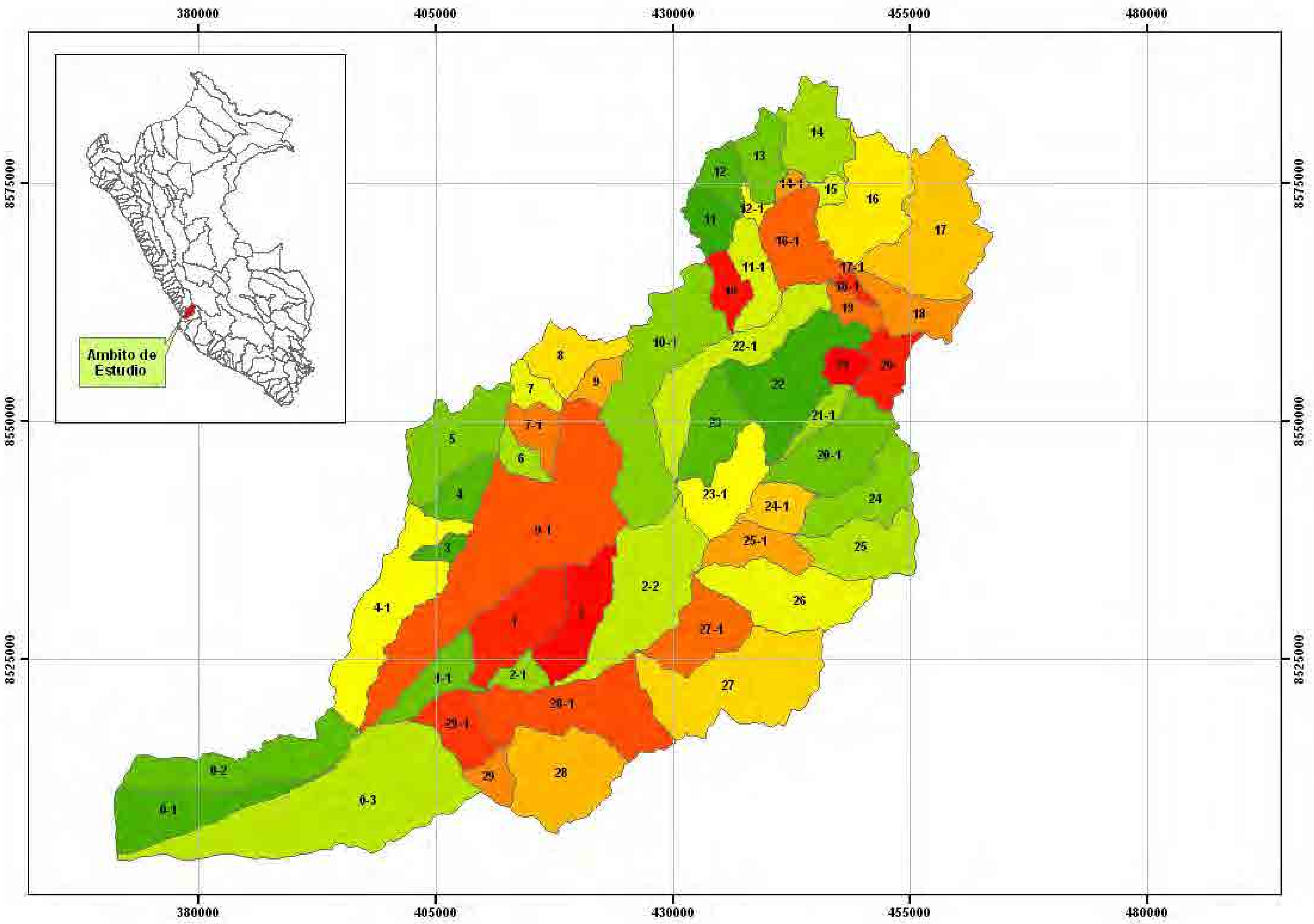


Figure Nº 4.8. Chincha River Subbasin

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

SUBCUENCA	AREA [m²]	PERIODO DE RETORNO T [AÑOS]				
		PT_5	PT_10	PT_25	PT_50	PT_100
0-1	72,853,800	2.6	3.9	5.1	6.5	8.8
0-2	95,339,100	2.8	4.4	6.1	8.1	11.1
0-3	241,533,000	4.4	6.4	8.6	11.2	14.7
1	73,531,600	17.8	22.1	27.8	31.5	35.9
10	22,517,800	27.9	31.3	35.1	37.1	39.0
10-1	158,721,000	27.3	30.9	34.8	36.8	38.9
11	26,871,500	27.2	30.7	34.7	36.9	39.1
1-1	39,902,900	10.8	13.9	17.7	20.9	24.8
11-1	38,959,800	27.7	31.2	35.2	37.5	39.7
12	24,616,300	26.8	30.4	34.6	37.0	39.4
12-1	6,292,700	27.1	30.7	34.9	37.3	39.7
13	35,532,500	26.7	30.4	34.7	37.2	39.8
14	61,041,700	26.7	30.4	34.8	37.5	40.2
14-1	6,477,230	27.0	30.7	35.0	37.6	40.1
15	8,361,510	27.1	30.8	35.2	37.9	40.6
16	89,357,900	27.3	31.0	35.5	38.2	40.9
16-1	61,093,700	27.4	31.1	35.4	37.9	40.5
17	129,350,000	27.7	31.4	35.9	38.6	41.3
17-1	19,473	27.7	31.4	35.9	38.6	41.3
18	41,751,000	28.2	31.8	36.3	39.0	41.6
18-1	7,304,390	27.8	31.6	36.0	38.8	41.5
19	16,081,300	28.0	31.7	36.2	39.0	41.7
2	60,158,900	20.2	24.6	30.3	34.1	38.4
20	34,374,300	28.4	32.2	36.8	39.7	42.5
20-1	78,404,600	29.2	33.6	38.7	42.8	46.4
21	16,100,800	28.3	32.2	36.8	39.9	42.8
2-1	16,088,800	17.1	21.0	25.9	29.4	33.5
21-1	16,247,300	28.7	32.9	37.9	41.6	45.0
22	102,595,000	28.3	32.2	36.8	39.9	42.8
2-2	127,871,000	24.3	28.7	34.3	38.3	42.4
22-1	86,095,700	28.0	31.5	35.5	37.6	39.8
23	53,727,200	28.1	31.9	36.4	39.3	42.1
23-1	58,386,900	28.9	33.4	38.8	43.3	47.4
24	61,672,300	29.6	33.9	39.1	43.1	46.7
24-1	30,060,500	30.6	35.5	41.3	47.0	51.8
25	63,550,100	29.8	34.3	39.6	43.5	47.2
25-1	39,100,800	30.2	35.1	40.9	46.5	51.2
26	90,912,100	29.5	34.3	40.1	44.9	49.2
27	145,480,000	27.1	31.8	37.7	42.0	46.1
27-1	59,892,800	26.7	31.3	37.0	41.3	45.5
28	99,243,900	17.2	20.9	25.3	28.7	32.6
28-1	115,811,000	19.3	23.3	28.2	31.8	35.8
29	18,457,100	12.1	15.2	18.8	22.0	25.8
29-1	39,563,500	10.3	13.2	16.7	19.8	23.7
3	10,377,500	17.7	22.2	28.3	31.9	36.5
4	29,705,300	18.7	23.3	29.5	33.2	37.8
4-1	113,323,000	12.3	15.7	20.0	23.3	27.3
5	77,743,400	20.0	24.2	29.8	33.2	37.2
6	16,818,500	20.1	24.6	30.7	34.2	38.5
7	18,266,100	23.8	27.7	32.4	35.1	38.2
7-1	26,661,000	22.0	26.2	31.6	34.8	38.5
8	43,345,000	26.3	29.8	33.8	35.8	38.0
9	17,234,000	27.2	30.6	34.3	36.1	38.0
9-1	279,704,000	18.0	22.3	28.0	31.5	35.8

4.2.3 Maximum Daily Discharge Analysis

For the analysis of Maximum Daily Discharges of River Chincha, the information of the hydrometric station Conta has been used. This station has a contribution area of 2981.5 km^2. Figure 3.21 shows its location in the river Chincha catchment.

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

Table Nº 4.7.Maximum Daily Discharge of station Conta, Chincha River (m3/s)

AÑO	SENAMHI	JUNTA DE USUARIOS			Combinados
	Total	Rio Chico	Rio Matagente	Total	
1950	155.43	-	-	-	155.43
1951	395.75	-	-	-	395.75
1952	354.00	-	-	-	354.00
1953	1,268.80	-	-	-	1,268.80
1954	664.40	-	-	-	664.40
1955	241.45	-	-	-	241.45
1956	227.83	-	-	-	227.83
1957	226.53	-	-	-	226.53
1958	88.36	35.34	53.02	88.36	88.36
1959	301.42	120.57	180.85	301.42	301.42
1960	245.17	98.07	147.10	245.17	245.17
1961	492.83	197.13	295.69	492.82	492.82
1962	395.06	158.02	237.03	395.05	395.05
1963	337.84	135.14	202.70	337.84	337.84
1964	66.95	26.78	40.17	66.95	66.95
1965	154.12	61.65	92.47	154.12	154.12
1966	139.13	55.65	83.48	139.13	139.13
1967	1,202.58	481.03	721.55	1,202.58	1,202.58
1968	43.92	17.57	26.35	43.92	43.92
1969	72.14	28.86	43.28	72.14	72.14
1970	271.57	108.63	162.94	271.57	271.57
1971	497.84	199.13	298.71	497.84	497.84
1972	784.16	313.66	470.50	784.16	784.16
1973	137.53	55.01	82.52	137.53	137.53
1974	215.66	86.26	129.40	215.66	215.66
1975	246.87	98.75	148.12	246.87	246.87
1976	311.13	124.45	186.68	311.13	311.13
1977	97.10	38.84	58.26	97.10	97.10
1978	33.00	13.20	19.80	33.00	33.00
1979	51.90	20.76	31.14	51.90	51.90
1980	33.70	13.48	20.22	33.70	33.70
1981	83.95	33.58	50.37	83.95	83.95
1982	183.60	73.44	110.16	183.60	183.60
1983	81.20	32.48	48.72	81.20	81.20
1984	292.87	117.15	175.72	292.87	292.87
1985	71.42	51.88	77.82	129.70	129.70
1986	106.26	46.00	69.00	115.00	115.00
1987	-	42.00	63.00	105.00	105.00
1988	-	28.51	42.76	71.27	71.27
1989	-	71.38	107.07	178.45	178.45
1990	24.34	9.74	14.60	24.34	24.34
1991	-	41.00	61.49	102.49	102.49
1992	-	5.95	8.92	14.87	14.87
1993	-	51.73	77.59	129.32	129.32
1994	-	75.61	113.41	189.02	189.02
1995	-	121.47	182.21	303.68	303.68
1996	-	49.85	74.77	124.62	124.62
1997	-	10.60	15.89	26.49	26.49
1998	-	112.00	168.00	280.00	280.00
1999	-	165.74	248.61	414.35	414.35
2000	-	114.93	172.39	287.32	287.32

2001	-	81.72	122.59	204.31	204.31
2002	-	47.65	71.48	119.13	119.13
2003	-	52.38	78.57	130.95	130.95
2004	-	63.73	95.60	159.33	159.33
2005	-	14.24	21.36	35.60	35.60
2006	-	62.48	93.72	156.20	156.20

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 Nº 4.8. Maximum Discharges for each Return Period at te Station Conta, Chincha River (m3/s)

Periodo de Retorno (Años)	Caudal Máximo
2	178.60
5	378.22
10	535.94
25	762.80
50	951.24
100	1,155.95

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

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

Where:

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

H = Head (m)

Tc = Concentration time (Hr)

Travel time (Tv)= 0,6*Tc

Table Nº 4.9. Concentration ans Travel Times for the Base Point (station Conta)

L =	121.25	Km
H =	4,402.00	Mts
Tc =	**9.58**	Hrs
Tv =	**5.75**	Hrs

Maximum Rain Storm Duration

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

This value exceeds the time of concentration of 9.58 hours calculated in the previous item, it indicates that the peak values to be estimated in the hydrometric station Conta will correspond to the simultaneous contribution of runoff of the the whole catchement of the river Pisco until the Conta hydrometric station.

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

Pd_{24}= 24 – hour maximum rainfall

Tc= Concentration time (minutes)

Table Nº 4.10. Maximum Rainfall according to Dick - Peschke

T [Años]	Pp Areal Max 24 Horas [mm]	Pp Max, dura-cion igual Tc [mm]
2	17.00	13.66
5	23.40	18.80
10	27.39	22.01
25	32.22	25.89
50	35.56	28.57
100	39.06	31.38

The maximum daily rainfall for return periods of 2, 5, 10, 25, 50, and 100 year are 17, 23, 27, 32, 36 and 39 mm, respectively, and rainfalls for a duration of 10 hours storm are 14, 19, 22, 26, 29, and 31 mm, respectively.

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

Table Nº 4.11. Hyetograph for different Return Period

Return Period [Years]	Hour										Total Rainfall [mm]
	1	2	3	4	5	6	7	8	9	10	
2	1	1	2	3	2	2	1	1	1	1	13.66
5	1	2	2	4	3	2	2	2	1	1	18.80
10	1	2	3	4	3	3	2	2	1	1	22.01
25	1	2	3	5	4	3	3	2	2	1	25.89
50	1	3	4	5	4	3	3	2	2	1	28.57
100	2	3	4	6	4	4	3	3	2	1	31.38

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.

Four hydrological soil groups have been defineds:

Group A: Deep sand, deep wind – deposited soils, aggregate silts.

Group B: Shallow wind – deposited soils, sandy marl.

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

Group D: Expansive soils, highly plastic clays.

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

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

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

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

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

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

Zonas Industriales		1.00	91.0
Zonas residensiales		5.00	81.0
Calles y carreteras	Pavimentadas con cunetas	1.00	98.0
	Grava	1.00	89.0
	Tierra	2.00	87.0
Curva de Numero de la Cuenca		101.00	**85.5**

After the process of calibration of the model HEC-HMS, this value was adjusted to 91.

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").

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

Meteorological Model.- Based on calculation under Nº 3.2 Pluviometer Information Analysis and Frequency Law, hyetographs are introduced inthe 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. Aproximating the Lag Time as 0.6 times the Concentration Time, a lag time of 5.75 hours and a minimum computational time of 1.67 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 produce peak discharges values similar to the estimated maximum daily discharge. Following this procedure a curve number of 91 was obtained.

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

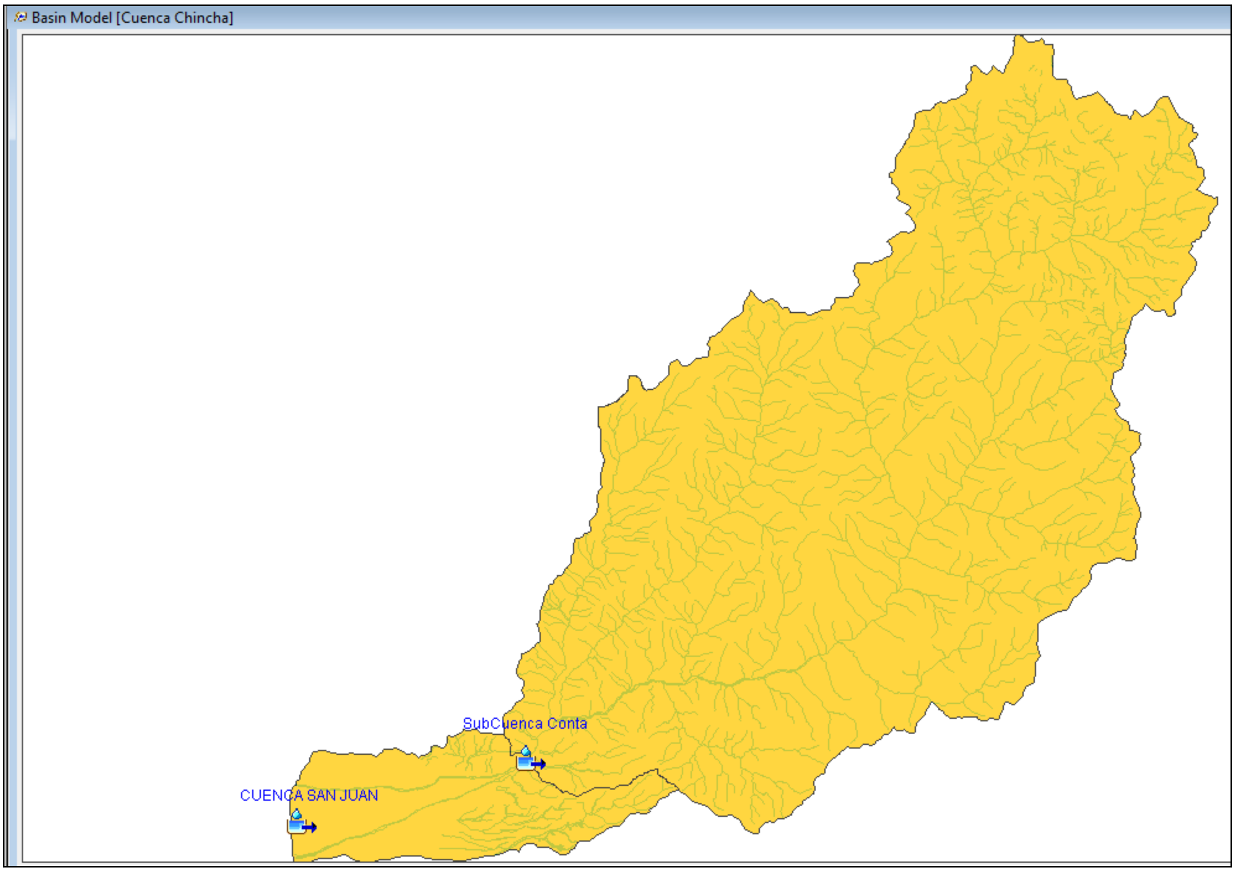


Figure N° 4.9. Model Chincha River Basin in the HEC-HMS Software

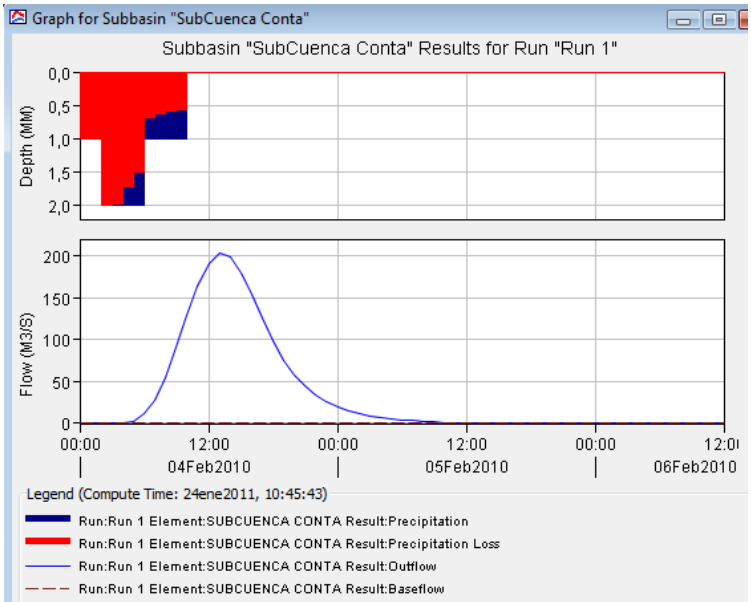


Figure N° 4.10. Hydrograph Rainfall – Runoff models of the Chincha River basin, Return Period of 5 years

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.

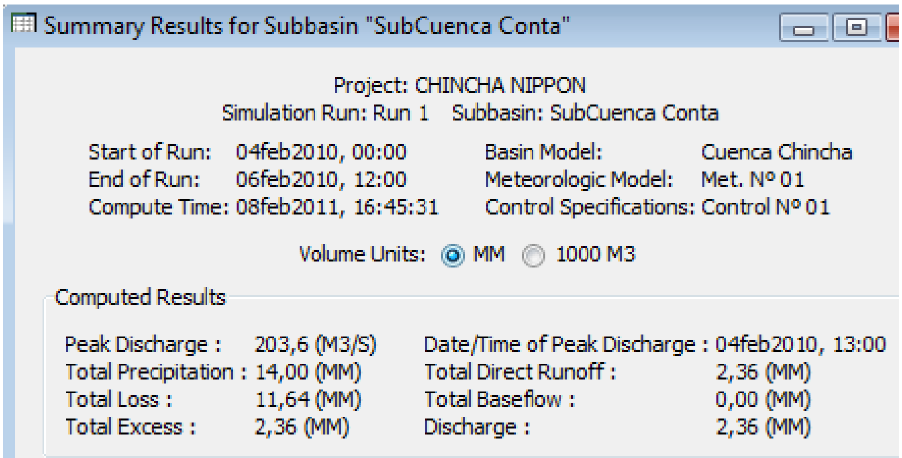


Figure Nº 4.11.Results Model Simulation of Rainfall – Runoff Chincha River, Return Period of 5 years

In Figure Nº 4.11 is the maximum flow is calculated for a return period of 2 years of 203.6 m^3/s. The maximum discharge spends approximately 13 hours after the storm started in the tax (for extreme conditions as defined above).

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

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

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	1,00	1,00	0,00	0,0
04-Feb-10	03:00	2,00	2,00	0,00	0,0
04-Feb-10	04:00	2,00	1,96	0,04	0,3
04-Feb-10	05:00	2,00	1,72	0,28	2,8
04-Feb-10	06:00	2,00	1,49	0,51	11,1
04-Feb-10	07:00	1,00	0,67	0,33	27,8
04-Feb-10	08:00	1,00	0,63	0,37	55,0
04-Feb-10	09:00	1,00	0,59	0,41	90,6
04-Feb-10	10:00	1,00	0,56	0,44	129,0
04-Feb-10	11:00	0,00	0,00	0,00	163,8
04-Feb-10	12:00	0,00	0,00	0,00	190,5
04-Feb-10	13:00	0,00	0,00	0,00	203,6
04-Feb-10	14:00	0,00	0,00	0,00	199,0
04-Feb-10	15:00	0,00	0,00	0,00	179,7
04-Feb-10	16:00	0,00	0,00	0,00	153,9
04-Feb-10	17:00	0,00	0,00	0,00	125,7
04-Feb-10	18:00	0,00	0,00	0,00	99,1
04-Feb-10	19:00	0,00	0,00	0,00	75,4
04-Feb-10	20:00	0,00	0,00	0,00	57,5
04-Feb-10	21:00	0,00	0,00	0,00	44,5
04-Feb-10	22:00	0,00	0,00	0,00	34,5
04-Feb-10	23:00	0,00	0,00	0,00	26,5

05-Feb-10	00:00	0,00	0,00	0,00	20,3
05-Feb-10	01:00	0,00	0,00	0,00	15,7
05-Feb-10	02:00	0,00	0,00	0,00	12,1
05-Feb-10	03:00	0,00	0,00	0,00	9,3
05-Feb-10	04:00	0,00	0,00	0,00	7,2
05-Feb-10	05:00	0,00	0,00	0,00	5,5
05-Feb-10	06:00	0,00	0,00	0,00	4,3
05-Feb-10	07:00	0,00	0,00	0,00	3,4
05-Feb-10	08:00	0,00	0,00	0,00	2,6
05-Feb-10	09:00	0,00	0,00	0,00	2,0
05-Feb-10	10:00	0,00	0,00	0,00	1,5
05-Feb-10	11:00	0,00	0,00	0,00	1,1
05-Feb-10	12:00	0,00	0,00	0,00	0,7
05-Feb-10	13:00	0,00	0,00	0,00	0,5
05-Feb-10	14:00	0,00	0,00	0,00	0,3
05-Feb-10	15:00	0,00	0,00	0,00	0,1
05-Feb-10	16:00	0,00	0,00	0,00	0,0

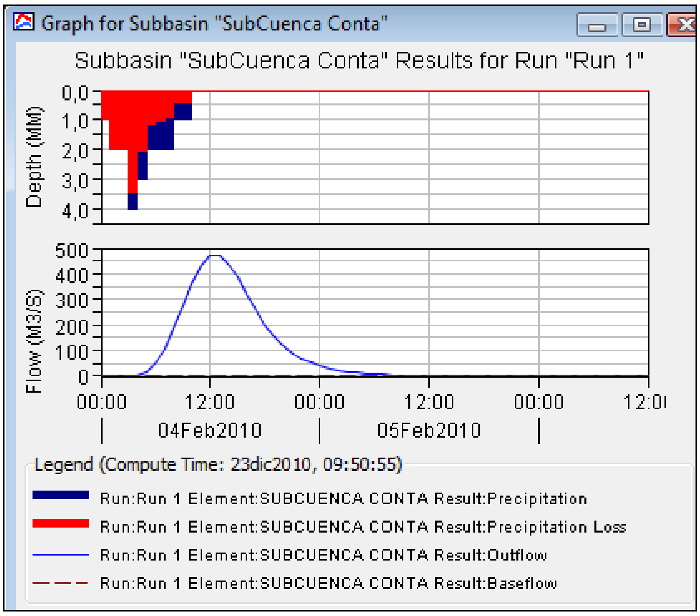


Figure Nº 4.12. Hydrograph Rainfall – Runoff models of the Chincha River basin, Return Period of 5 years

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

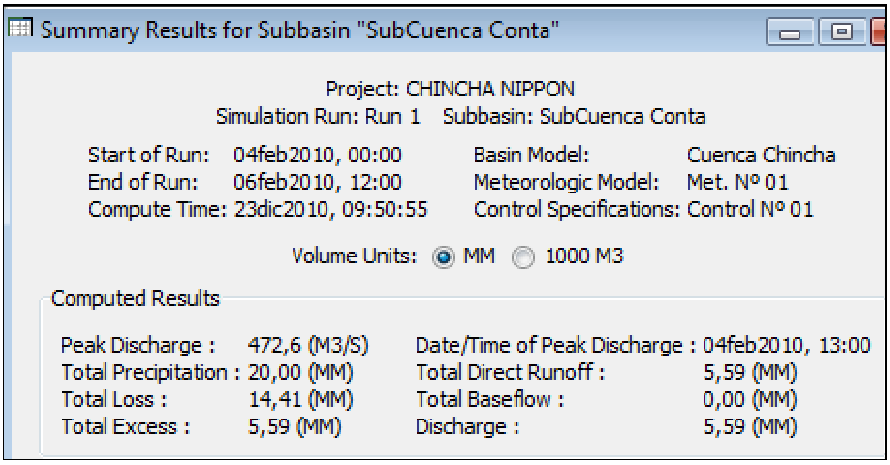


Figure Nº 4.13.Results Model Simulation of Rainfall – Runoff Chincha River, Return Period of 5 years

In Figure Nº 4.13 is the maximum flow is calculated for a return period of 5 years of 472 m^3/s. The maximum discharge spends approximately 13 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 Nº 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)
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	2,00	2,00	0,00	0,0
04-Feb-10	03:00	2,00	2,00	0,00	0,0
04-Feb-10	04:00	4,00	3,46	0,54	3,9
04-Feb-10	05:00	3,00	2,03	0,97	18,5
04-Feb-10	06:00	2,00	1,15	0,85	50,3
04-Feb-10	07:00	2,00	1,03	0,97	106,2
04-Feb-10	08:00	2,00	0,92	1,08	185,2
04-Feb-10	09:00	1,00	0,42	0,58	273,7
04-Feb-10	10:00	1,00	0,40	0,60	360,5
04-Feb-10	11:00	0,00	0,00	0,00	430,6
04-Feb-10	12:00	0,00	0,00	0,00	469,9
04-Feb-10	13:00	0,00	0,00	0,00	472,6
04-Feb-10	14:00	0,00	0,00	0,00	440,3
04-Feb-10	15:00	0,00	0,00	0,00	385,0
04-Feb-10	16:00	0,00	0,00	0,00	321,1
04-Feb-10	17:00	0,00	0,00	0,00	256,3
04-Feb-10	18:00	0,00	0,00	0,00	199,5
04-Feb-10	19:00	0,00	0,00	0,00	152,5
04-Feb-10	20:00	0,00	0,00	0,00	117,1
04-Feb-10	21:00	0,00	0,00	0,00	90,4
04-Feb-10	22:00	0,00	0,00	0,00	69,8
04-Feb-10	23:00	0,00	0,00	0,00	53,8
05-Feb-10	00:00	0,00	0,00	0,00	41,3
05-Feb-10	01:00	0,00	0,00	0,00	31,9
05-Feb-10	02:00	0,00	0,00	0,00	24,6
05-Feb-10	03:00	0,00	0,00	0,00	18,9
05-Feb-10	04:00	0,00	0,00	0,00	14,6
05-Feb-10	05:00	0,00	0,00	0,00	11,3
05-Feb-10	06:00	0,00	0,00	0,00	8,8
05-Feb-10	07:00	0,00	0,00	0,00	6,8
05-Feb-10	08:00	0,00	0,00	0,00	5,3
05-Feb-10	09:00	0,00	0,00	0,00	4,0
05-Feb-10	10:00	0,00	0,00	0,00	3,0
05-Feb-10	11:00	0,00	0,00	0,00	2,1
05-Feb-10	12:00	0,00	0,00	0,00	1,3
05-Feb-10	13:00	0,00	0,00	0,00	0,8
05-Feb-10	14:00	0,00	0,00	0,00	0,4
05-Feb-10	15:00	0,00	0,00	0,00	0,1
05-Feb-10	16:00	0,00	0,00	0,00	0,0

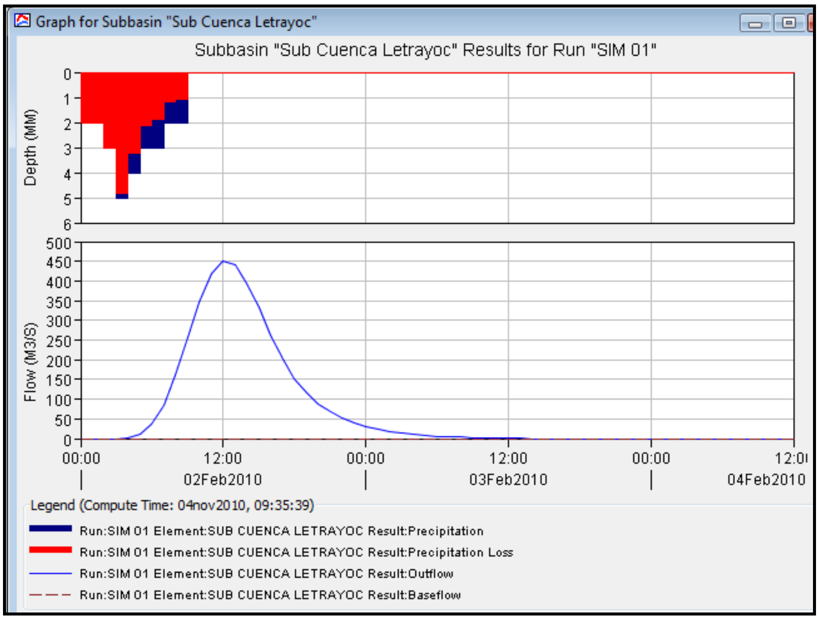


Figure Nº 4.14. Hydrograph Rainfall – Runoff models of the Chincha River basin, Return Period of 10 years

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

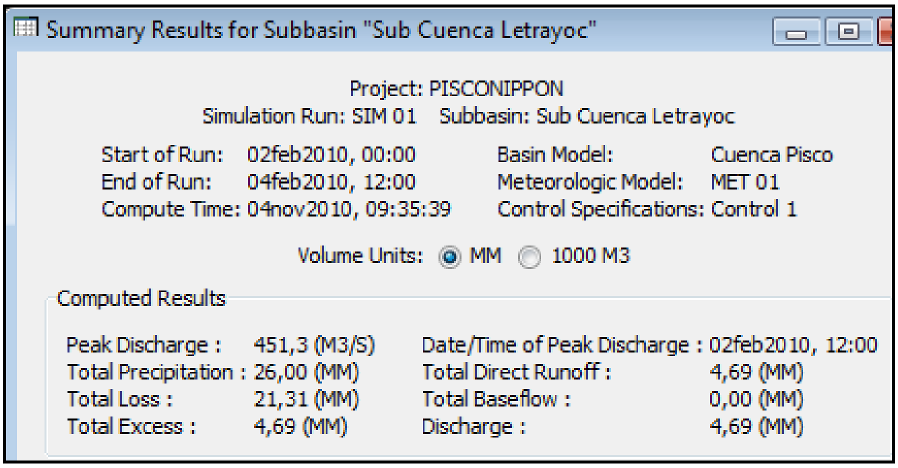


Figure Nº 4.15. Results Model Simulation of Rainfall – Runoff Chincha River, Return Period of 10 years

In Figure Nº 4.15 is the maximum flow is calculated for a return period of 10 years of 579 m^3/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 Nº 4.16. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 10 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	2,00	2,00	0,00	0,0
04-Feb-10	03:00	3,00	2,96	0,04	0,3
04-Feb-10	04:00	4,00	3,21	0,79	6,4
04-Feb-10	05:00	3,00	1,90	1,10	26,1
04-Feb-10	06:00	3,00	1,58	1,42	70,2
04-Feb-10	07:00	2,00	0,92	1,08	145,4
04-Feb-10	08:00	2,00	0,83	1,17	248,0
04-Feb-10	09:00	1,00	0,38	0,62	360,7
04-Feb-10	10:00	1,00	0,36	0,64	465,1
04-Feb-10	11:00	0,00	0,00	0,00	541,8
04-Feb-10	12:00	0,00	0,00	0,00	579,6
04-Feb-10	13:00	0,00	0,00	0,00	572,2
04-Feb-10	14:00	0,00	0,00	0,00	526,1
04-Feb-10	15:00	0,00	0,00	0,00	454,0
04-Feb-10	16:00	0,00	0,00	0,00	375,3
04-Feb-10	17:00	0,00	0,00	0,00	298,5
04-Feb-10	18:00	0,00	0,00	0,00	232,3
04-Feb-10	19:00	0,00	0,00	0,00	177,8
04-Feb-10	20:00	0,00	0,00	0,00	136,5
04-Feb-10	21:00	0,00	0,00	0,00	105,4
04-Feb-10	22:00	0,00	0,00	0,00	81,3
04-Feb-10	23:00	0,00	0,00	0,00	62,7
05-Feb-10	00:00	0,00	0,00	0,00	48,2
05-Feb-10	01:00	0,00	0,00	0,00	37,2
05-Feb-10	02:00	0,00	0,00	0,00	28,7
05-Feb-10	03:00	0,00	0,00	0,00	22,1
05-Feb-10	04:00	0,00	0,00	0,00	17,0
05-Feb-10	05:00	0,00	0,00	0,00	13,2
05-Feb-10	06:00	0,00	0,00	0,00	10,3
05-Feb-10	07:00	0,00	0,00	0,00	8,0
05-Feb-10	08:00	0,00	0,00	0,00	6,2
05-Feb-10	09:00	0,00	0,00	0,00	4,7
05-Feb-10	10:00	0,00	0,00	0,00	3,4
05-Feb-10	11:00	0,00	0,00	0,00	2,3
05-Feb-10	12:00	0,00	0,00	0,00	1,5
05-Feb-10	13:00	0,00	0,00	0,00	0,8
05-Feb-10	14:00	0,00	0,00	0,00	0,4
05-Feb-10	15:00	0,00	0,00	0,00	0,2
05-Feb-10	16:00	0,00	0,00	0,00	0,0

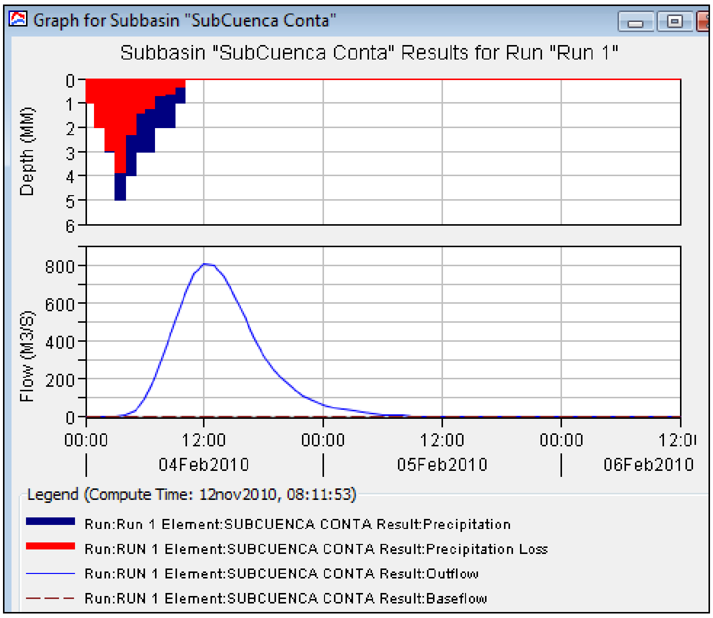


Figure Nº 4.16. Hydrograph Rainfall – Runoff models of the Chincha River basin, Return Period 25 years

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

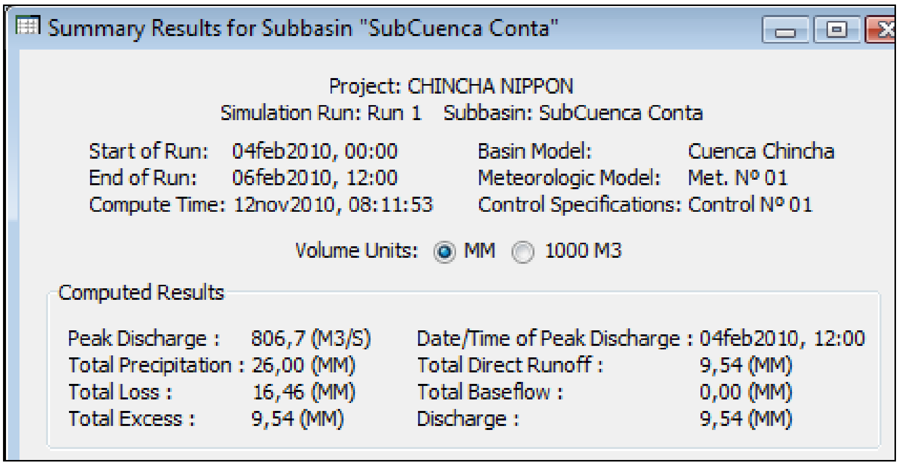


Figure Nº 4.17. Results Model Simulation of Rainfall – Runoff Chincha River, Return Period of 25 years

In Figure Nº 4.17 is the maximum flow is calculated for a return period of 25 years of 806 m^3/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 Nº 4.17. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 25 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	2,00	2,00	0,00	0,0
04-Feb-10	03:00	3,00	2,96	0,04	0,3
04-Feb-10	04:00	5,00	3,89	1,11	8,7
04-Feb-10	05:00	4,00	2,31	1,69	37,2
04-Feb-10	06:00	3,00	1,42	1,58	98,1
04-Feb-10	07:00	3,00	1,21	1,79	203,0
04-Feb-10	08:00	2,00	0,71	1,29	343,4
04-Feb-10	09:00	2,00	0,65	1,35	497,7
04-Feb-10	10:00	1,00	0,30	0,70	642,2
04-Feb-10	11:00	0,00	0,00	0,00	750,5
04-Feb-10	12:00	0,00	0,00	0,00	806,7
04-Feb-10	13:00	0,00	0,00	0,00	800,1
04-Feb-10	14:00	0,00	0,00	0,00	735,2
04-Feb-10	15:00	0,00	0,00	0,00	637,2
04-Feb-10	16:00	0,00	0,00	0,00	526,3
04-Feb-10	17:00	0,00	0,00	0,00	419,7
04-Feb-10	18:00	0,00	0,00	0,00	325,1
04-Feb-10	19:00	0,00	0,00	0,00	248,4
04-Feb-10	20:00	0,00	0,00	0,00	190,9
04-Feb-10	21:00	0,00	0,00	0,00	147,4
04-Feb-10	22:00	0,00	0,00	0,00	114,0
04-Feb-10	23:00	0,00	0,00	0,00	87,6
05-Feb-10	00:00	0,00	0,00	0,00	67,4
05-Feb-10	01:00	0,00	0,00	0,00	52,1
05-Feb-10	02:00	0,00	0,00	0,00	40,1
05-Feb-10	03:00	0,00	0,00	0,00	30,9
05-Feb-10	04:00	0,00	0,00	0,00	23,8
05-Feb-10	05:00	0,00	0,00	0,00	18,4
05-Feb-10	06:00	0,00	0,00	0,00	14,4
05-Feb-10	07:00	0,00	0,00	0,00	11,1
05-Feb-10	08:00	0,00	0,00	0,00	8,6
05-Feb-10	09:00	0,00	0,00	0,00	6,5
05-Feb-10	10:00	0,00	0,00	0,00	4,8
05-Feb-10	11:00	0,00	0,00	0,00	3,3
05-Feb-10	12:00	0,00	0,00	0,00	2,1
05-Feb-10	13:00	0,00	0,00	0,00	1,2
05-Feb-10	14:00	0,00	0,00	0,00	0,6
05-Feb-10	15:00	0,00	0,00	0,00	0,2
05-Feb-10	16:00	0,00	0,00	0,00	0,0

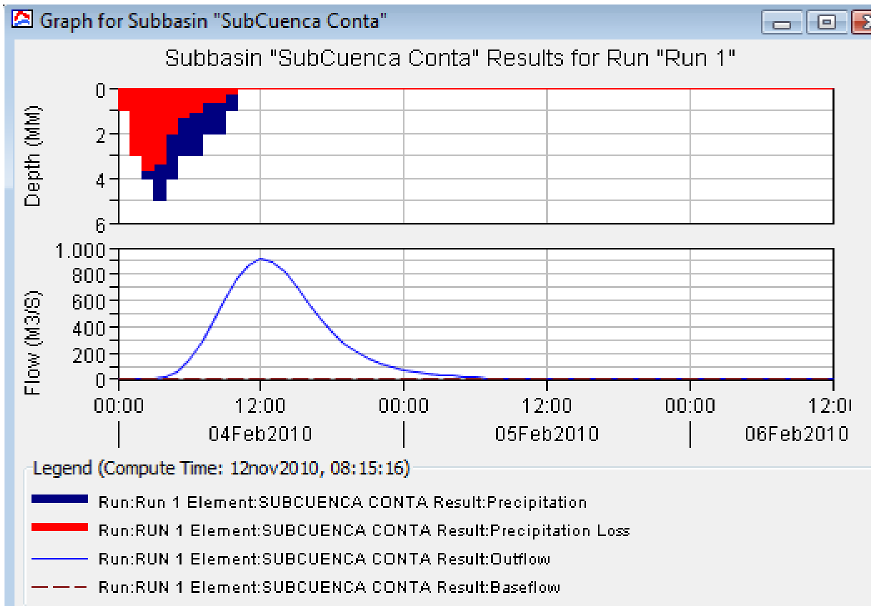


Figure Nº 4.18. Hydrograph Rainfall – Runoff models of the Chincha River basin, Return Period 50 years

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

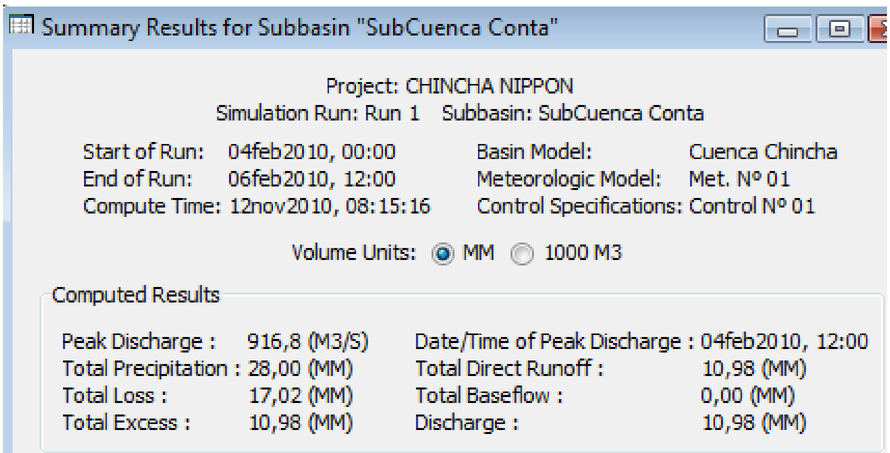


Figure Nº 4.19. Results Model Simulation of Rainfall – Runoff Chincha River, Return Period of 50 years

In Figure Nº 4.19 is the maximum flow is calculated for a return period of 50 years of 916 m^3/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 Nº 4.18. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 50 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	1,00	1,00	0,00	0,0
04-Feb-10	02:00	3,00	3,00	0,00	0,0
04-Feb-10	03:00	4,00	3,68	0,32	2,3
04-Feb-10	04:00	5,00	3,39	1,61	18,2
04-Feb-10	05:00	4,00	2,06	1,94	61,7
04-Feb-10	06:00	3,00	1,27	1,73	146,1
04-Feb-10	07:00	3,00	1,10	1,90	279,3
04-Feb-10	08:00	2,00	0,65	1,35	444,2
04-Feb-10	09:00	2,00	0,59	1,41	614,3
04-Feb-10	10:00	1,00	0,28	0,72	765,2
04-Feb-10	11:00	0,00	0,00	0,00	870,9
04-Feb-10	12:00	0,00	0,00	0,00	916,8
04-Feb-10	13:00	0,00	0,00	0,00	894,6
04-Feb-10	14:00	0,00	0,00	0,00	813,1
04-Feb-10	15:00	0,00	0,00	0,00	700,1
04-Feb-10	16:00	0,00	0,00	0,00	576,3
04-Feb-10	17:00	0,00	0,00	0,00	458,7
04-Feb-10	18:00	0,00	0,00	0,00	355,2
04-Feb-10	19:00	0,00	0,00	0,00	271,5
04-Feb-10	20:00	0,00	0,00	0,00	208,7
04-Feb-10	21:00	0,00	0,00	0,00	161,2
04-Feb-10	22:00	0,00	0,00	0,00	124,5
04-Feb-10	23:00	0,00	0,00	0,00	95,8
05-Feb-10	00:00	0,00	0,00	0,00	73,7
05-Feb-10	01:00	0,00	0,00	0,00	56,9
05-Feb-10	02:00	0,00	0,00	0,00	43,8
05-Feb-10	03:00	0,00	0,00	0,00	33,7
05-Feb-10	04:00	0,00	0,00	0,00	26,0
05-Feb-10	05:00	0,00	0,00	0,00	20,2
05-Feb-10	06:00	0,00	0,00	0,00	15,7
05-Feb-10	07:00	0,00	0,00	0,00	12,2
05-Feb-10	08:00	0,00	0,00	0,00	9,4
05-Feb-10	09:00	0,00	0,00	0,00	7,0
05-Feb-10	10:00	0,00	0,00	0,00	5,1
05-Feb-10	11:00	0,00	0,00	0,00	3,5
05-Feb-10	12:00	0,00	0,00	0,00	2,2
05-Feb-10	13:00	0,00	0,00	0,00	1,2
05-Feb-10	14:00	0,00	0,00	0,00	0,6
05-Feb-10	15:00	0,00	0,00	0,00	0,2
05-Feb-10	16:00	0,00	0,00	0,00	0,0

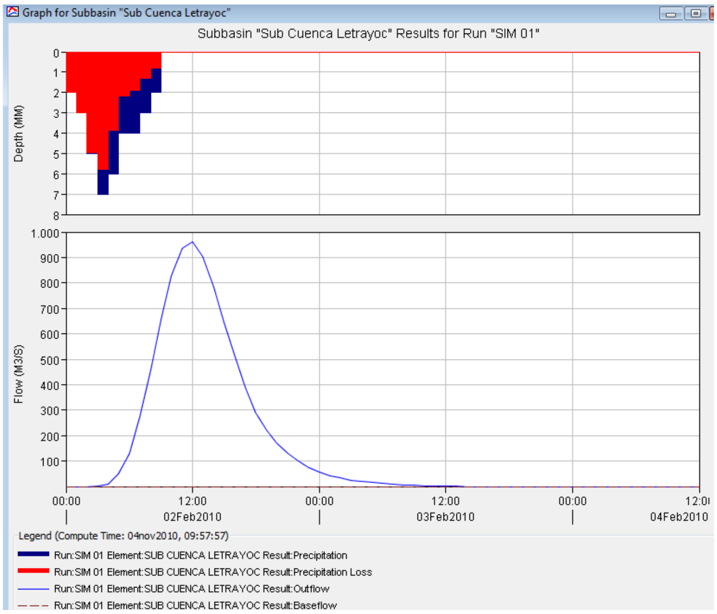


Figure Nº 4.20. Hydrograph Rainfall – Runoff models of the Chincha River basin, Return Period 100 years

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

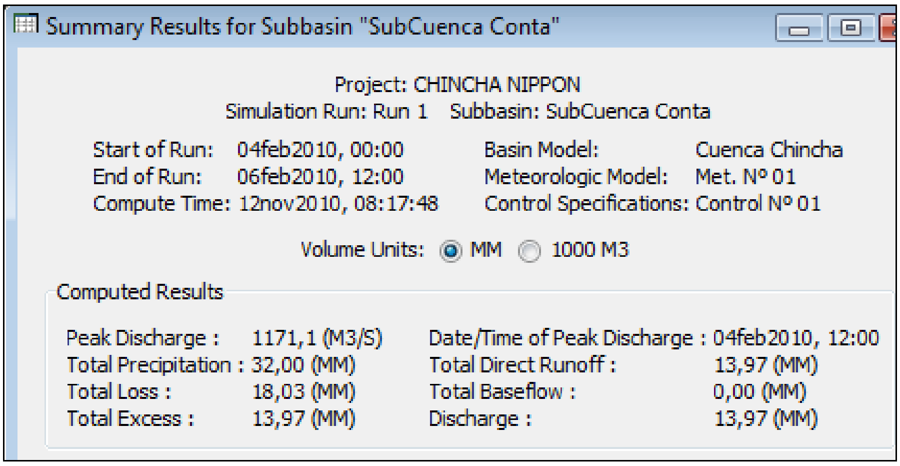


Figure Nº 4.21. Results Model Simulation of Rainfall – Runoff Chincha River, Return Period of 100 years

In Figure Nº 4.21 is the maximum flow is calculated for a return period of 100 years of 1,171 m^3/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 Nº 4.19. Generated Flood Hydrograph with HEC-HMS Model for a Return Period of 100 Years

Date	Time	Rainfall (mm)	Loss (mm)	Excess (mm)	Runoff (m^3/s)
04-Feb-10	00:00				0,0
04-Feb-10	01:00	2,00	2,00	0,00	0,0
04-Feb-10	02:00	3,00	3,00	0,00	0,0
04-Feb-10	03:00	4,00	3,46	0,54	3,9
04-Feb-10	04:00	6,00	3,71	2,29	27,9
04-Feb-10	05:00	4,00	1,84	2,16	87,7
04-Feb-10	06:00	4,00	1,50	2,50	202,4
04-Feb-10	07:00	3,00	0,95	2,05	376,4
04-Feb-10	08:00	3,00	0,84	2,16	588,0
04-Feb-10	09:00	2,00	0,50	1,50	803,8
04-Feb-10	10:00	1,00	0,24	0,76	992,1
04-Feb-10	11:00	0,00	0,00	0,00	1121,0
04-Feb-10	12:00	0,00	0,00	0,00	1171,1
04-Feb-10	13:00	0,00	0,00	0,00	1130,8
04-Feb-10	14:00	0,00	0,00	0,00	1021,8
04-Feb-10	15:00	0,00	0,00	0,00	873,4
04-Feb-10	16:00	0,00	0,00	0,00	716,3
04-Feb-10	17:00	0,00	0,00	0,00	566,6
04-Feb-10	18:00	0,00	0,00	0,00	437,6
04-Feb-10	19:00	0,00	0,00	0,00	334,9
04-Feb-10	20:00	0,00	0,00	0,00	257,7
04-Feb-10	21:00	0,00	0,00	0,00	199,1
04-Feb-10	22:00	0,00	0,00	0,00	153,5
04-Feb-10	23:00	0,00	0,00	0,00	118,2
05-Feb-10	00:00	0,00	0,00	0,00	91,0
05-Feb-10	01:00	0,00	0,00	0,00	70,2
05-Feb-10	02:00	0,00	0,00	0,00	54,1
05-Feb-10	03:00	0,00	0,00	0,00	41,6
05-Feb-10	04:00	0,00	0,00	0,00	32,1
05-Feb-10	05:00	0,00	0,00	0,00	25,0
05-Feb-10	06:00	0,00	0,00	0,00	19,4
05-Feb-10	07:00	0,00	0,00	0,00	15,1
05-Feb-10	08:00	0,00	0,00	0,00	11,5
05-Feb-10	09:00	0,00	0,00	0,00	8,7
05-Feb-10	10:00	0,00	0,00	0,00	6,2
05-Feb-10	11:00	0,00	0,00	0,00	4,2
05-Feb-10	12:00	0,00	0,00	0,00	2,6
05-Feb-10	13:00	0,00	0,00	0,00	1,4
05-Feb-10	14:00	0,00	0,00	0,00	0,7
05-Feb-10	15:00	0,00	0,00	0,00	0,2
05-Feb-10	16:00	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 Chincha river basin for the location of hydrometric station Conta.

Table Nº 4.20. Summary of Peak Flows at the Base Point for each Return Period

T [Años]	Q [m³/s]
2	203.0
5	472.6
10	579.6
25	806.7
50	916.8
100	1,171.1

Peak flows at the base point obtained with HEC-HMS model for the return periods of 2, 5, 10, 25, 50 and 100 years have been estimated from the maximum rainfall generated for these return periods, a number curve and geomorphological parameters of the basin. These peak flows have been obtained with the same number of curve (equal to 91).

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 Hydrologyl, 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.