# Appendix-6 Hydrologic Study of Yauca 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 YAUCA RIVER

## Appendix-6

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# HYDROLOGY OF MAXIMUM FLOODS IN YAUCA RIVER

## CONTENTS

# HYDROLOGY OF MAXIMUM FLOODS IN YAUCA RIVER

## LIST OF TABLES

# HYDROLOGY OF MAXIMUM FLOODS IN YAUCA RIVER

## LIST OF FIGURES

# HYDROLOGY OF MAXIMUM FLOODS IN YAUCA RIVER

## I. INTRODUCTION

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

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

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

## II. GENERAL ASPECTS

### 2.1 Location

#### 2.1.1 Political Location

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

#### 2.1.2 Geographic Location

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

## 2.2 Background

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

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

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

## 2.3 Justification of the Project

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

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

## 2.4 Objectives of the Study

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

# III. PROJECT DESCRIPTION

## 3.1 Hydrographic System of Yauca River

### 3.1.1 General Description of the Basin

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

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

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

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

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

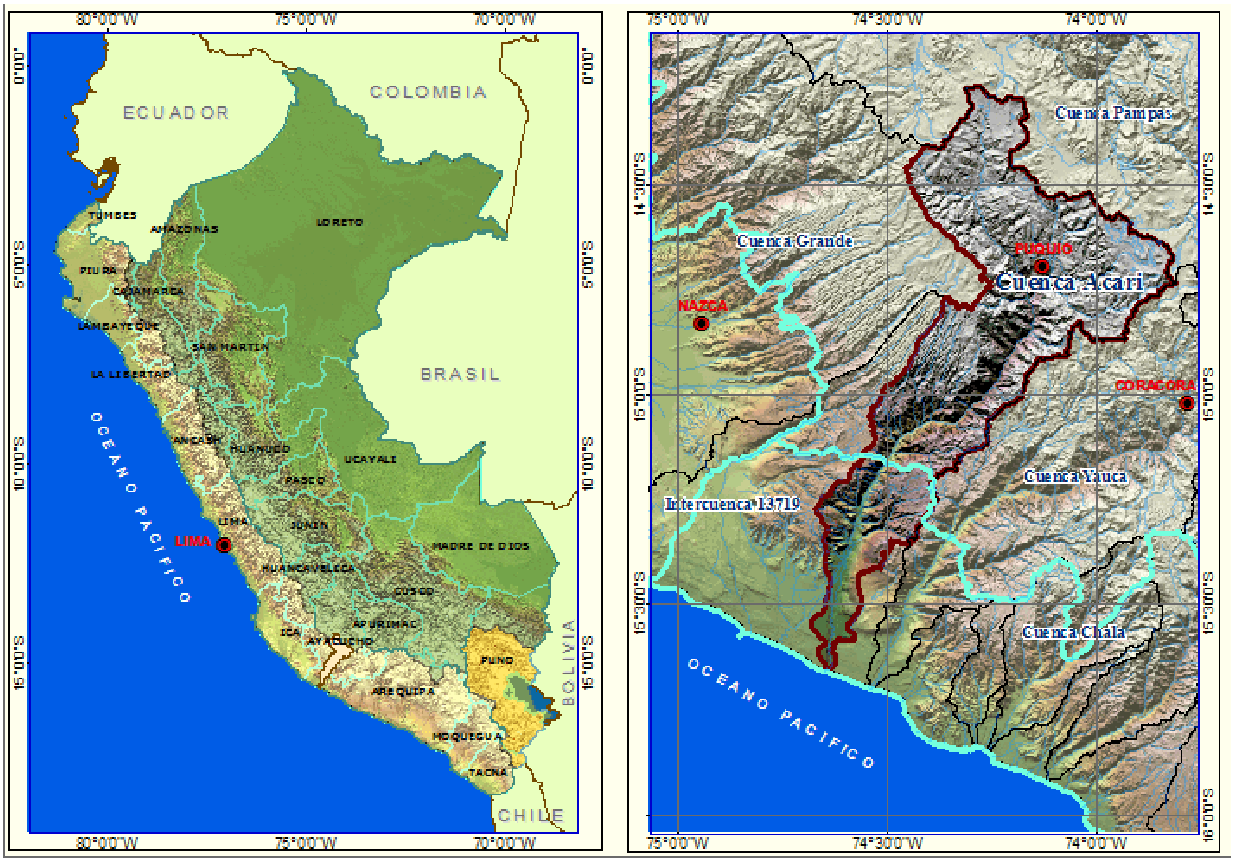



**Figure Nº 3.1. Location Map of the Yauca River Basin**

### 3.1.2 Hydrography of the Yauca River Basin

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

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

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

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

## 3.2 Climatology

### 3.2.1 Rainfall

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

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

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

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

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

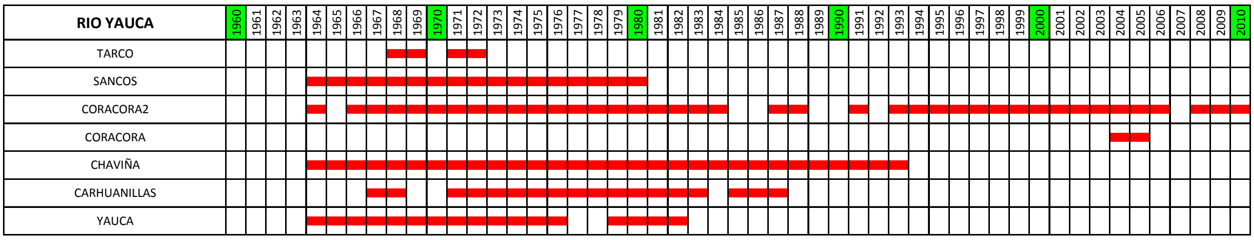



**Figure Nº 3.2. Period and longitude of the available information of the rainfall stations**

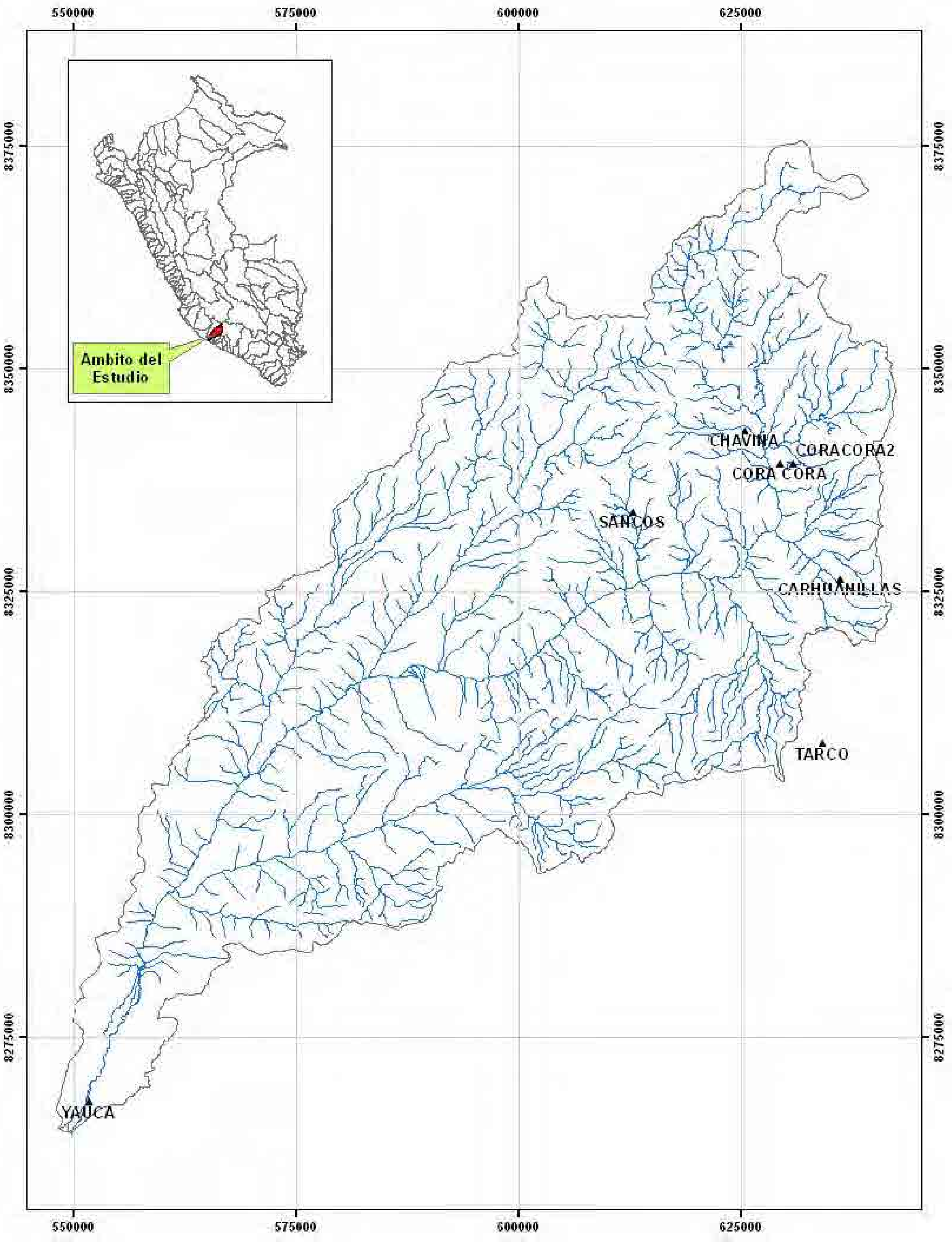


**Figure Nº 3.3. Location of the Rainfall Stations in Yauca River Basin and Adjacent Basins**

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

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

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

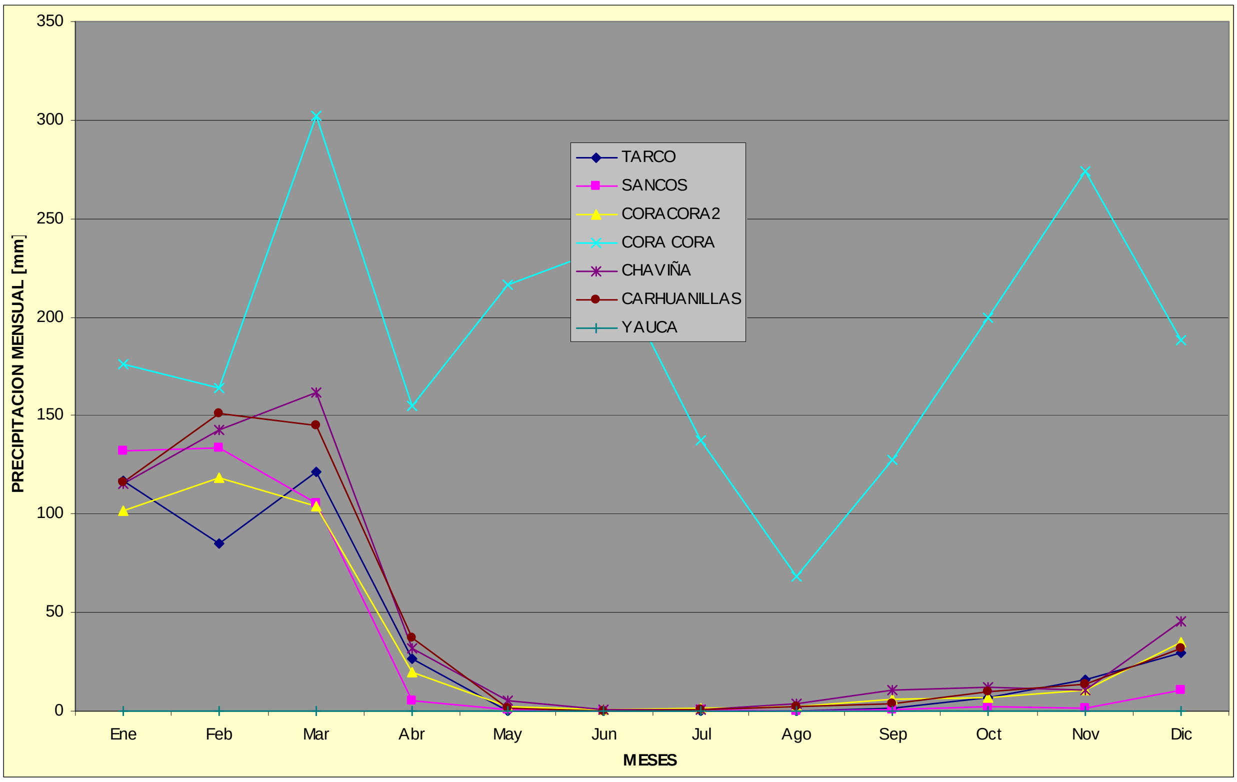



**Figure Nº 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope**

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

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

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

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

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

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

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

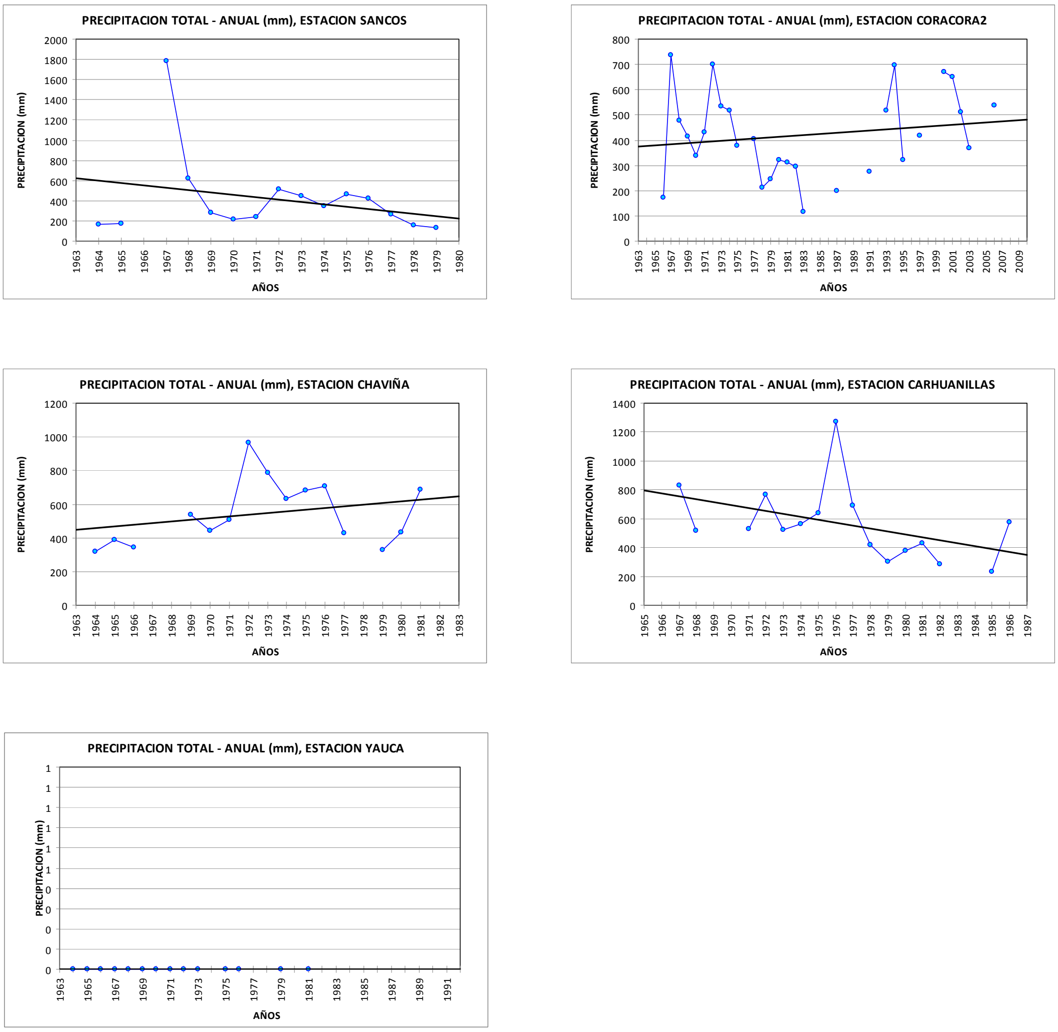



**Figure Nº 3.5. Annual Rainfall Trends at the Stations considered within the Study Scop**

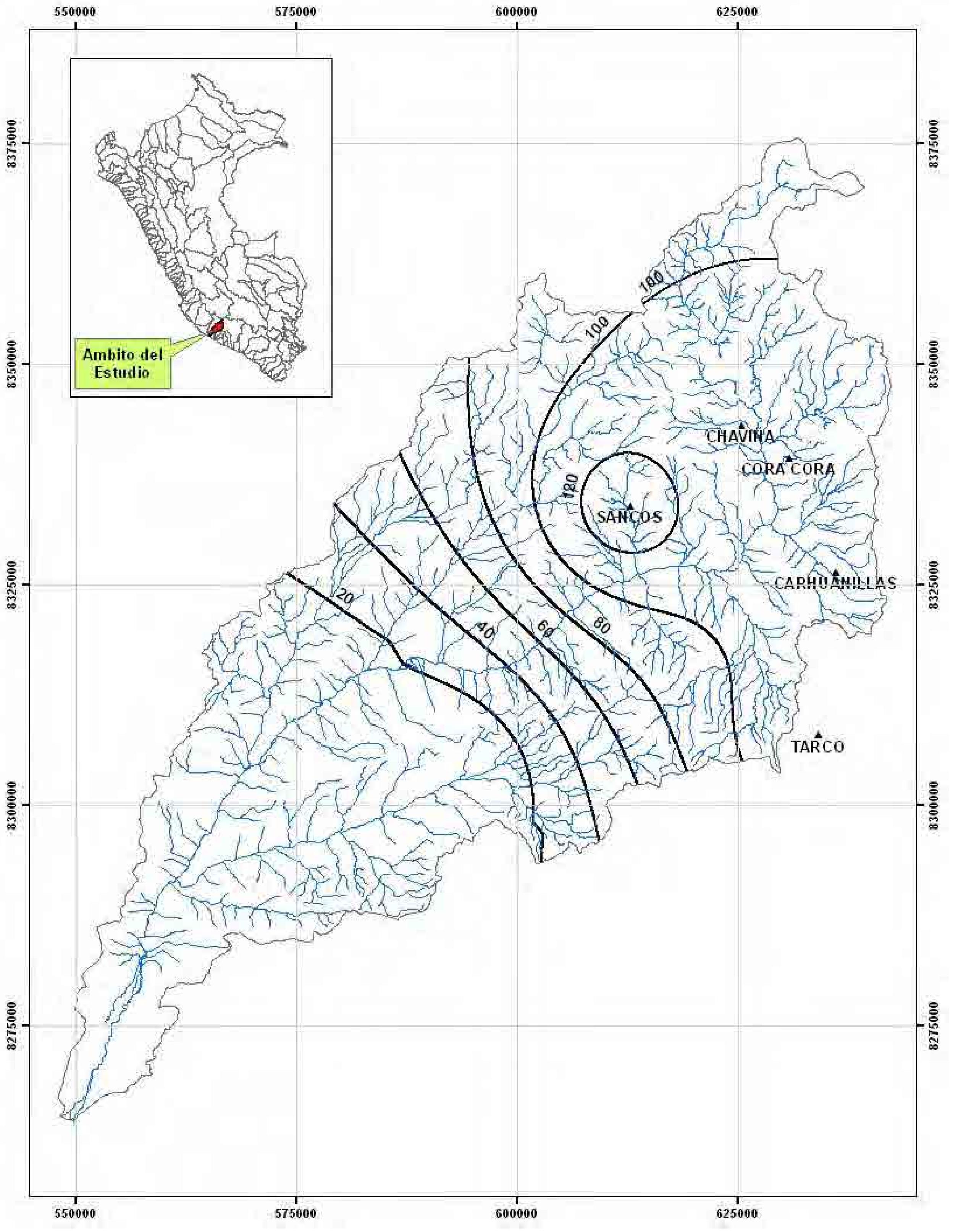



**Figure Nº 3.6. Isohyets for Mean Monthly Rainfall in the Yauca Basin, in January**

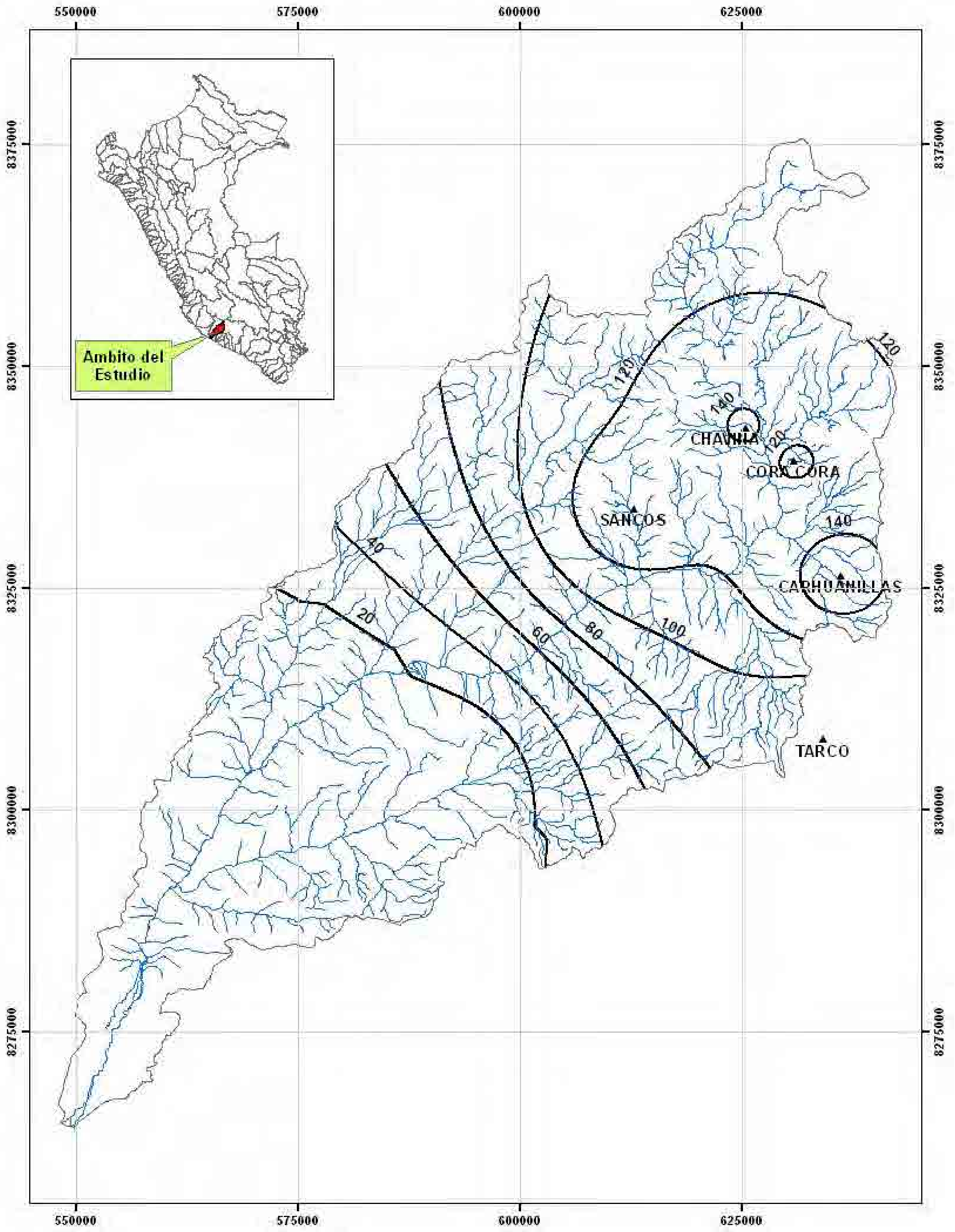



**Figure Nº 3.7. Isohyets for Mean Monthly Rainfall in the Yauca Basin, in February**

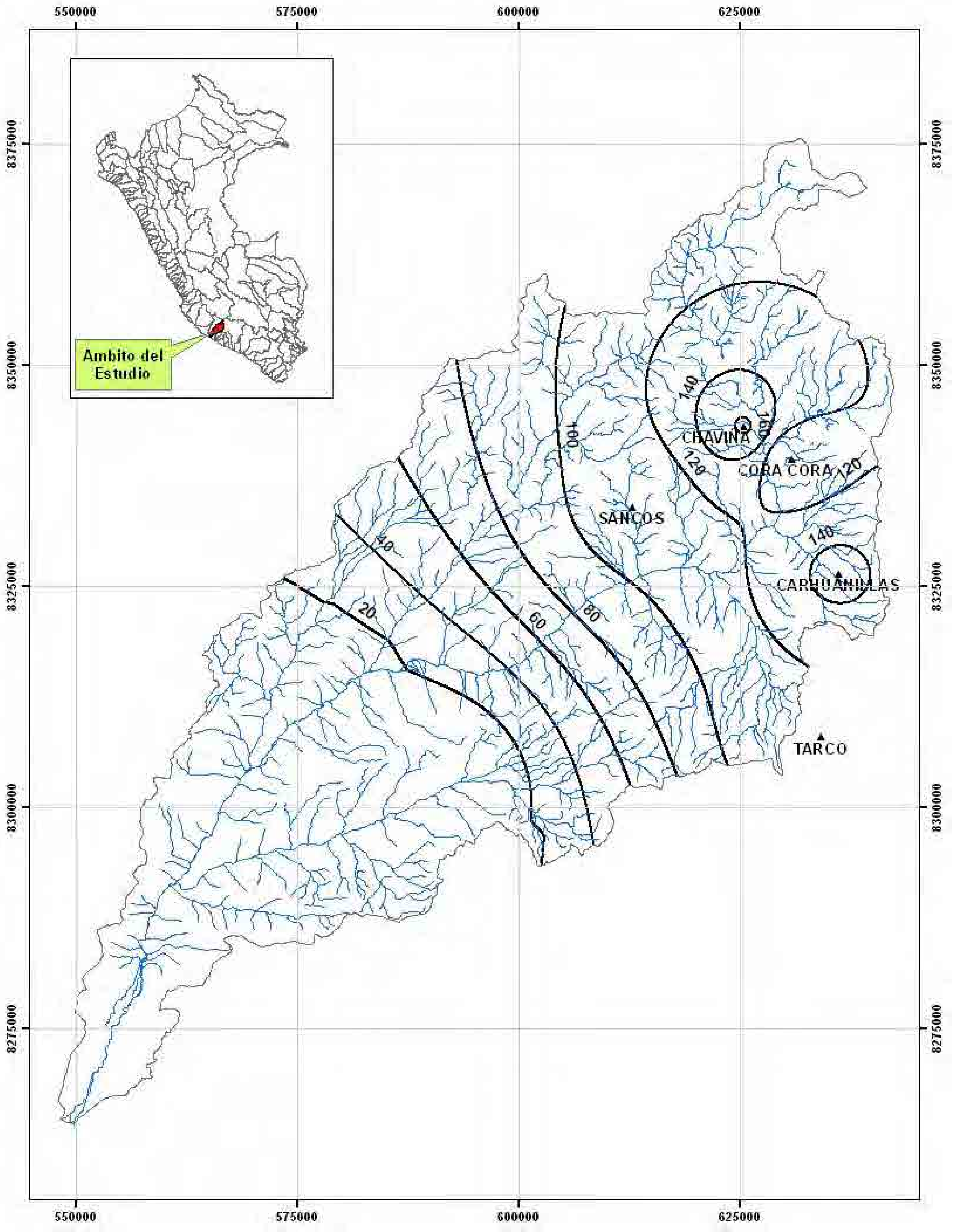



**Figure Nº 3.8. Isohyets Mean Monthly Rainfall in the  Yauca Basin, in March**

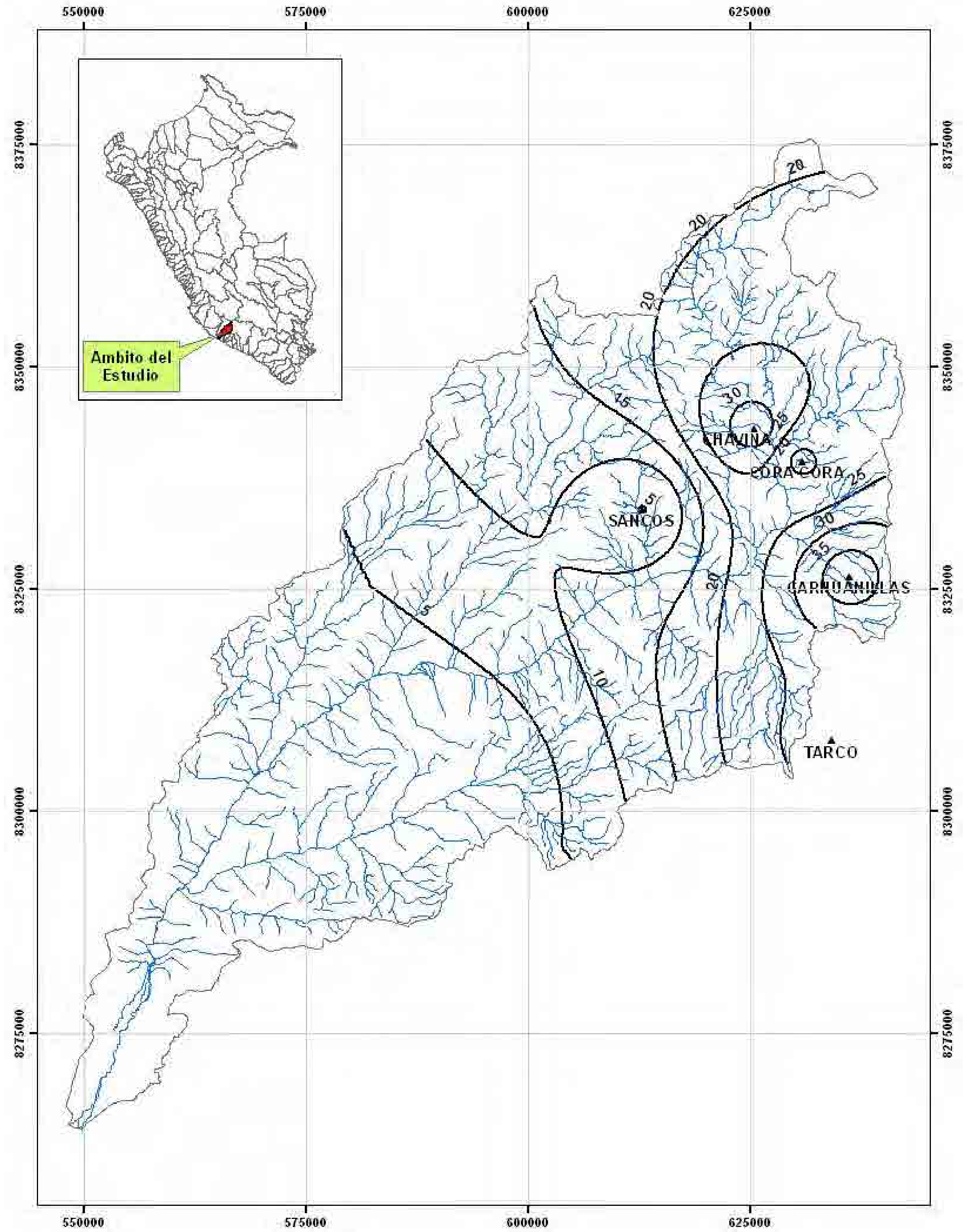



Figure Nº 3.9. Isohyets Mean Monthly Rainfall in the Yauca Basin, in April

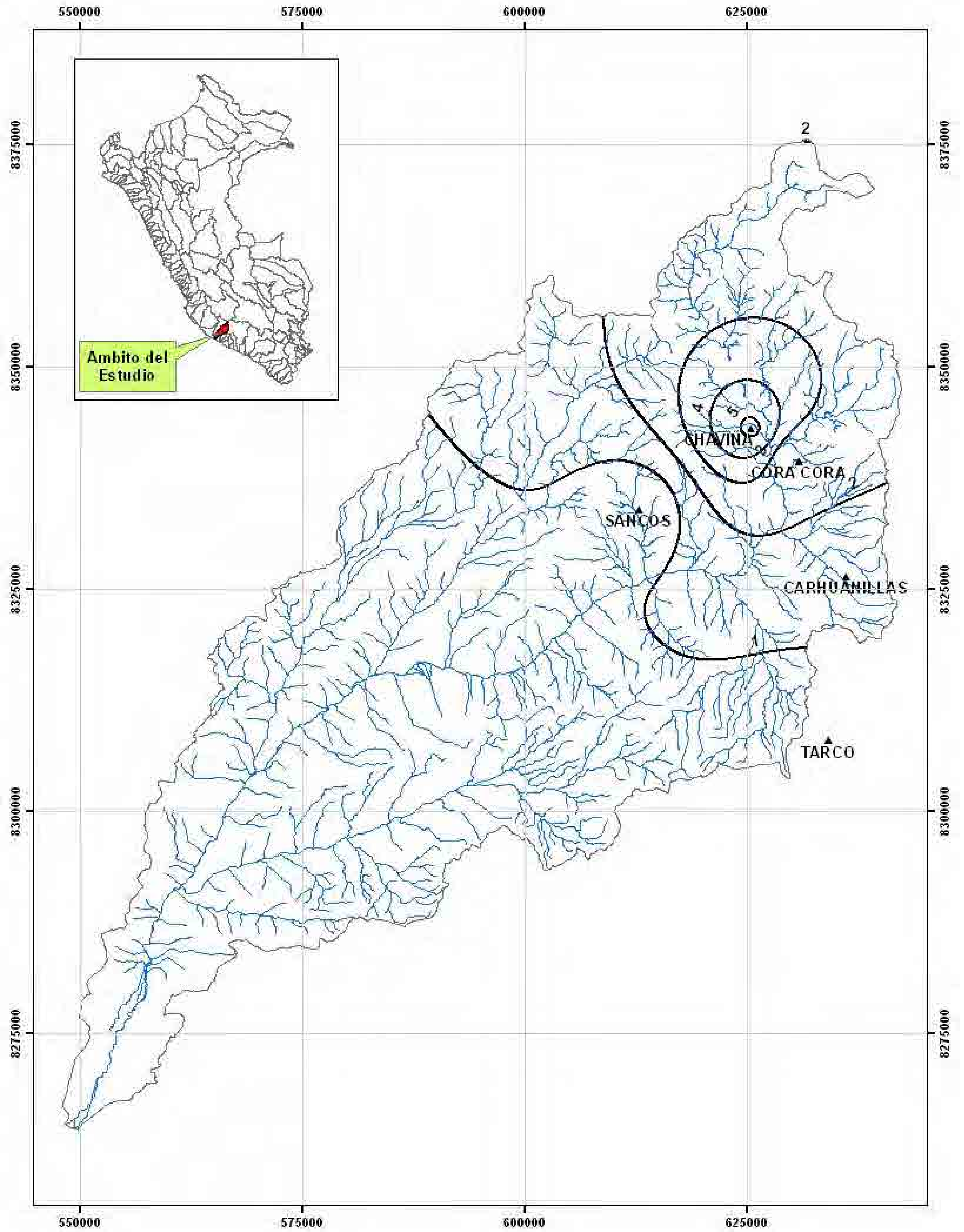



**Figure Nº 3.10. Isohyets Mean Monthly Rainfall in the Yauca Basin, in May**

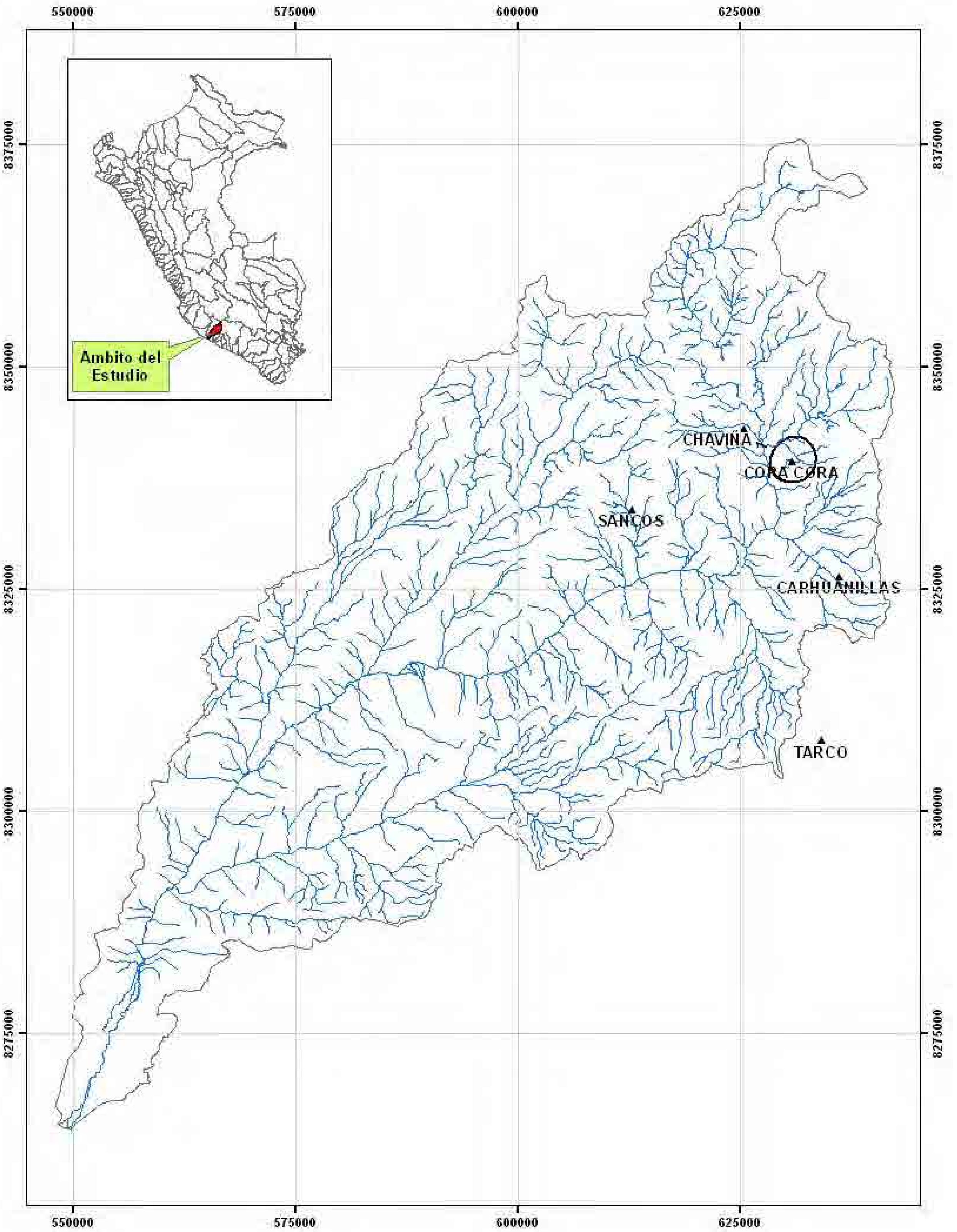



**Figure Nº 3.11. Isohyets Mean Monthly Rainfall in the Yauca Basin, in June**

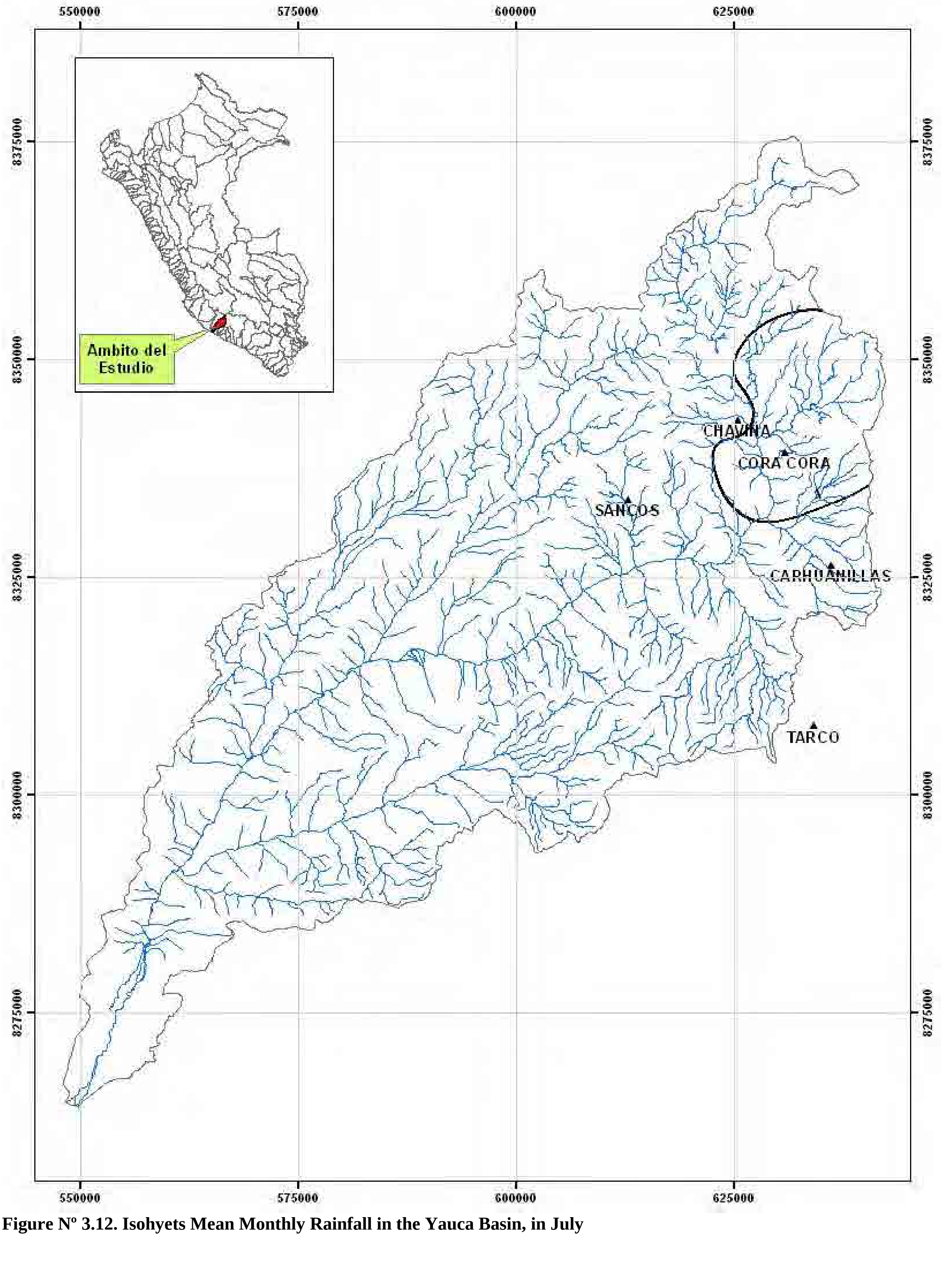



**Figure Nº 3.12. Isohyets Mean Monthly Rainfall in the Yauca Basin, in July**

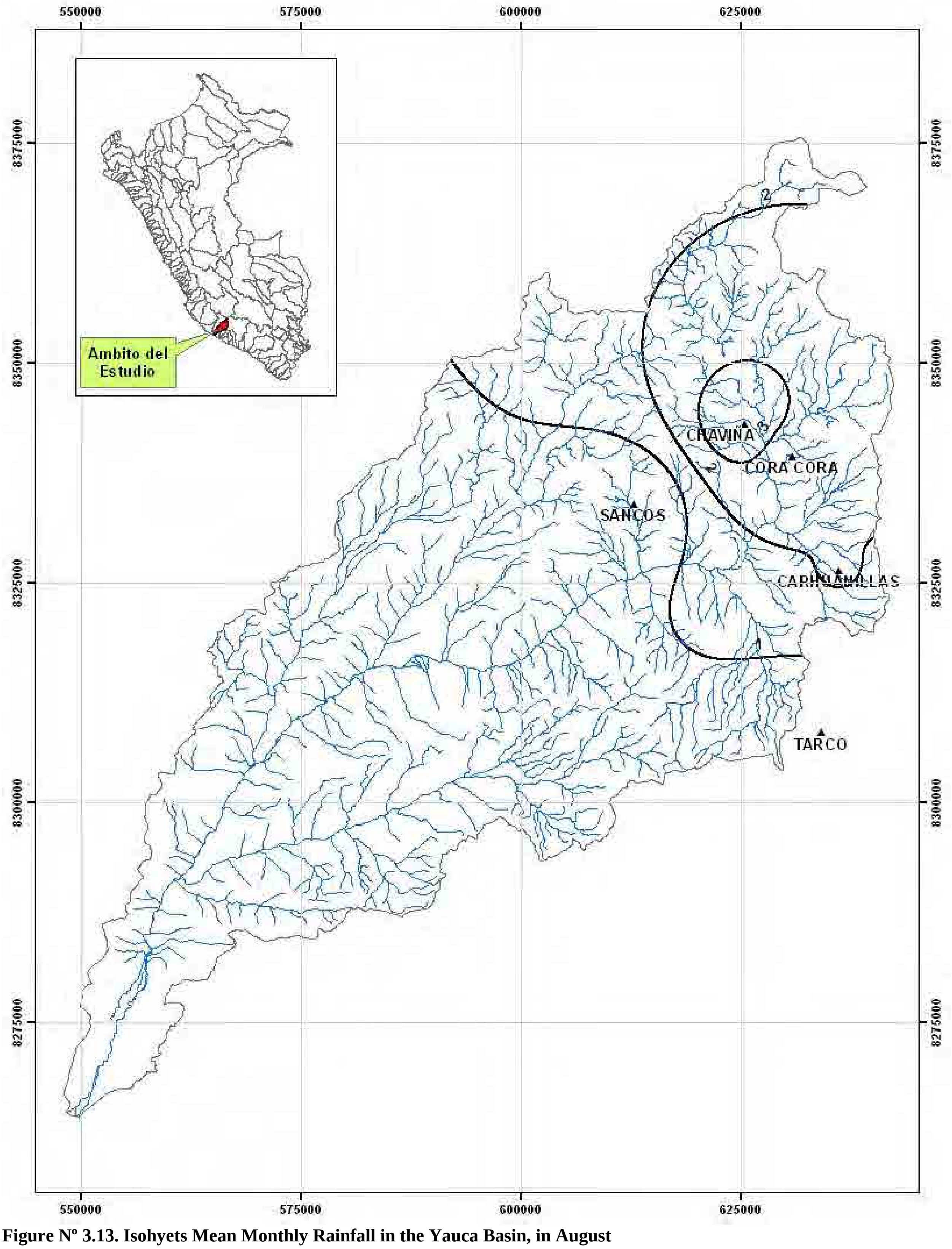



**Figure Nº 3.13. Isohyets Mean Monthly Rainfall in the Yauca Basin, in August**

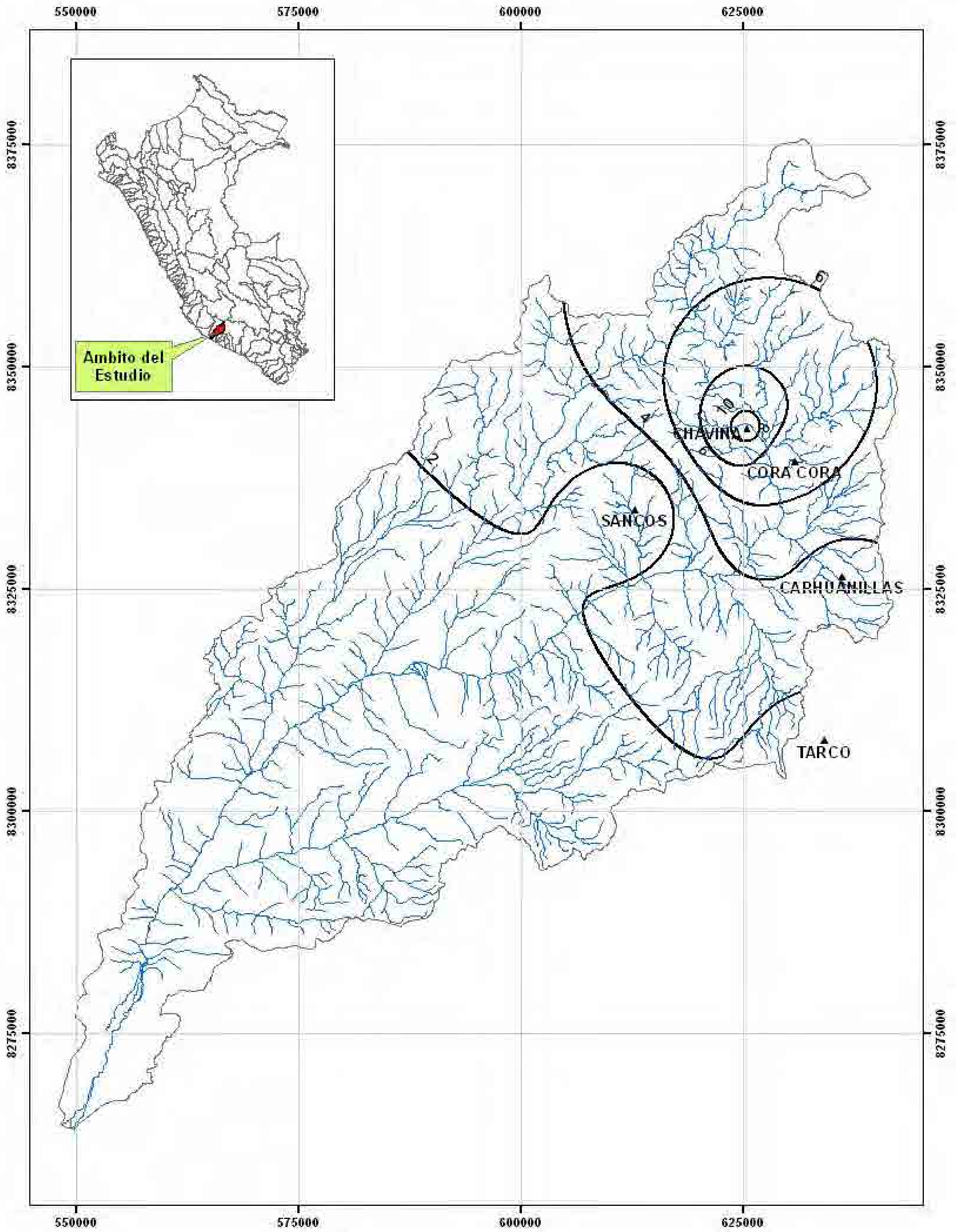



**Figure Nº 3.14. Isohyets Mean Monthly Rainfall in the Yauca Basin, in September**

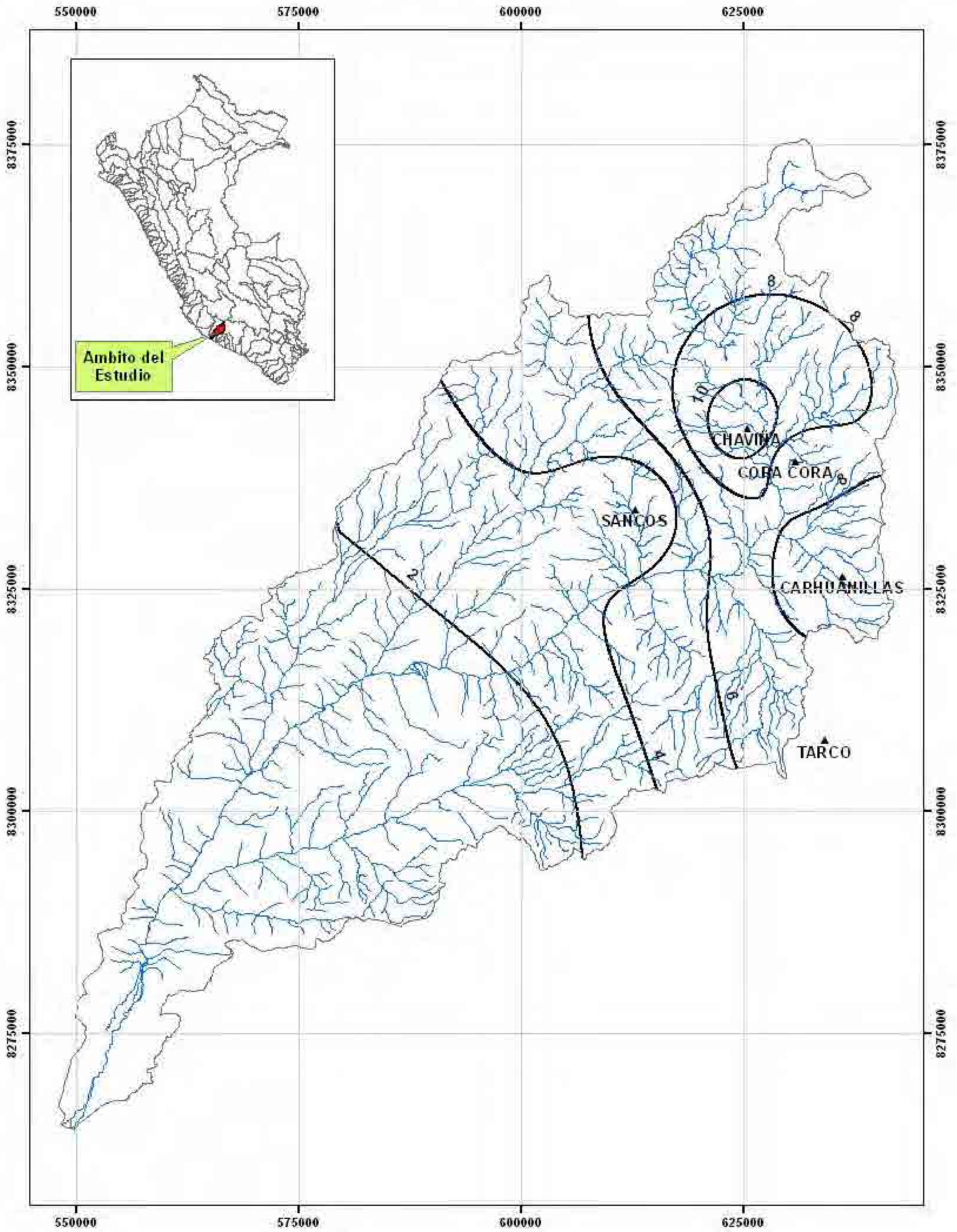



**Figure Nº 3.15. Isohyets Mean Monthly Rainfall in the Yauca Basin, in October**

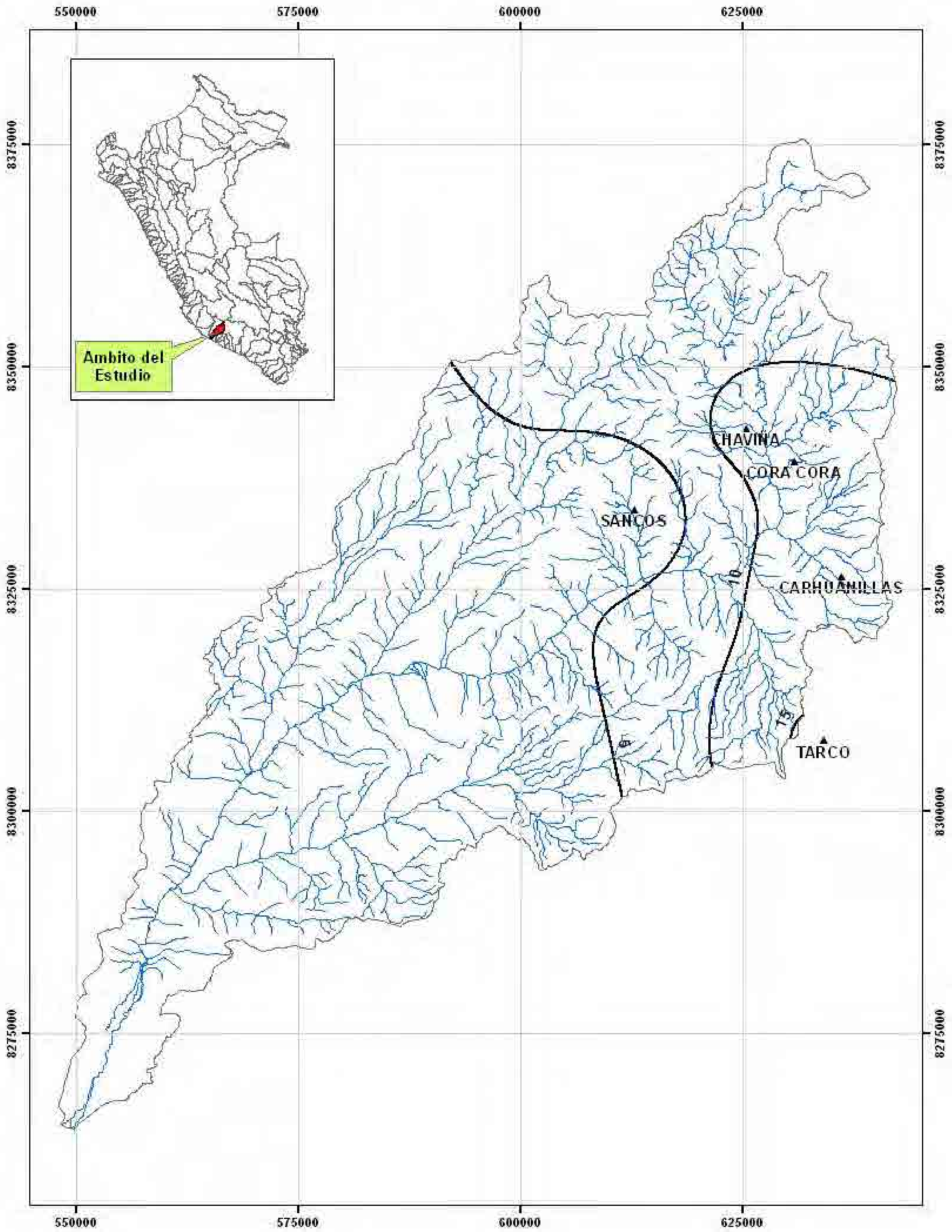



**Figure Nº 3.16. Isohyets Mean Monthly Rainfall in the Yauca Basin, in November**

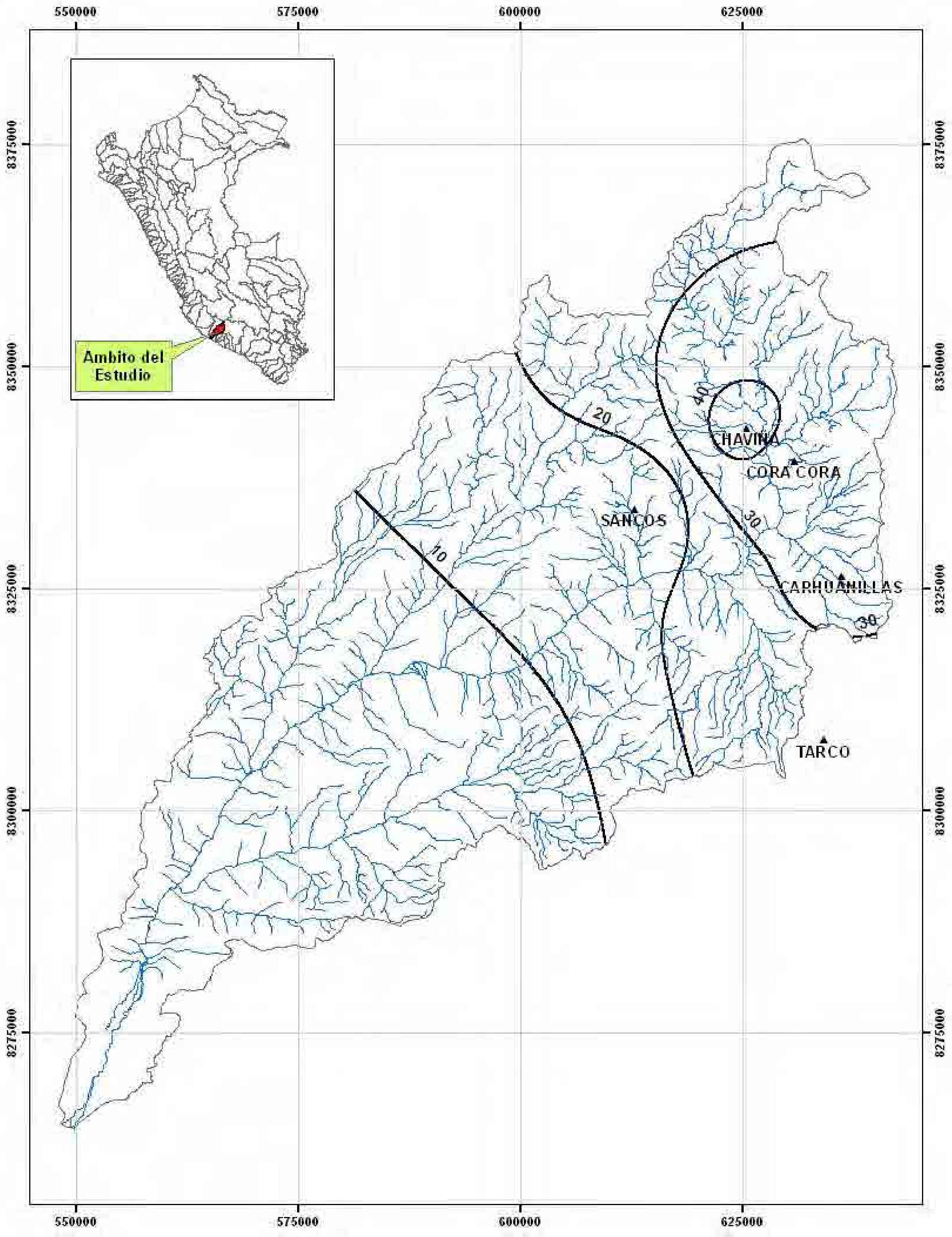



**Figure Nº 3.17. Isohyets Mean Monthly Rainfall in the Yauca Basin, in December**

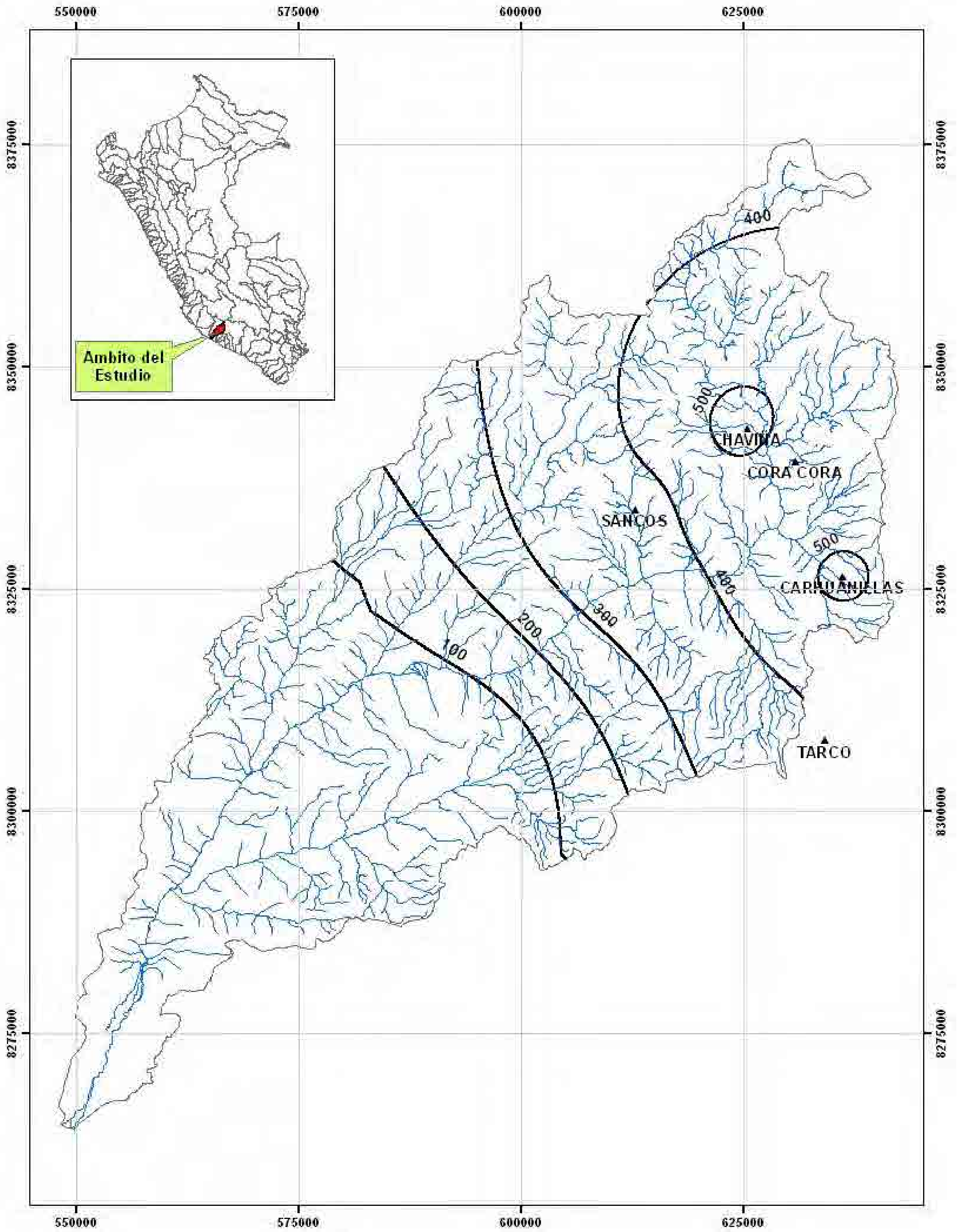



**Figure Nº 3.18. Isohyets Annual Mean Monthly Rainfall in the Yauca Basin**

### 3.2.2 Temperature

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

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

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

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

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

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

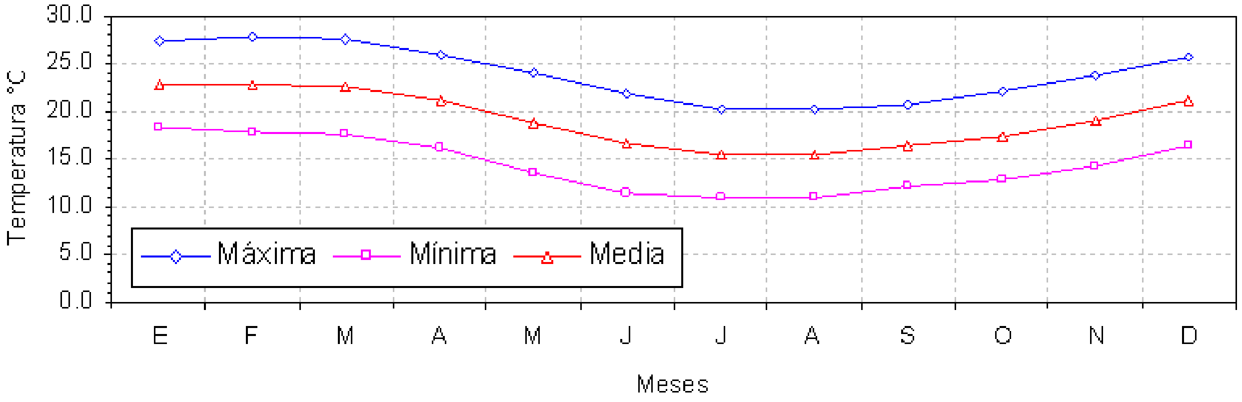



**Figure Nº 3.19. Distribution of the monthly minimum and maximun temperature of Yauca Station**
*Fuente: Asignación de Agua en Bloque en el Valle Yauca, ATDR Acari-Yauca-Puquio, 2006*

## 3.3 Hydrometry

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

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

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

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

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

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

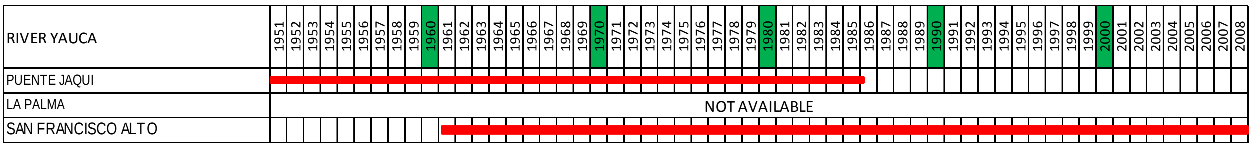



**Figure Nº 3.20. Period and longitude of the available information of the Hydrometric Stations**

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

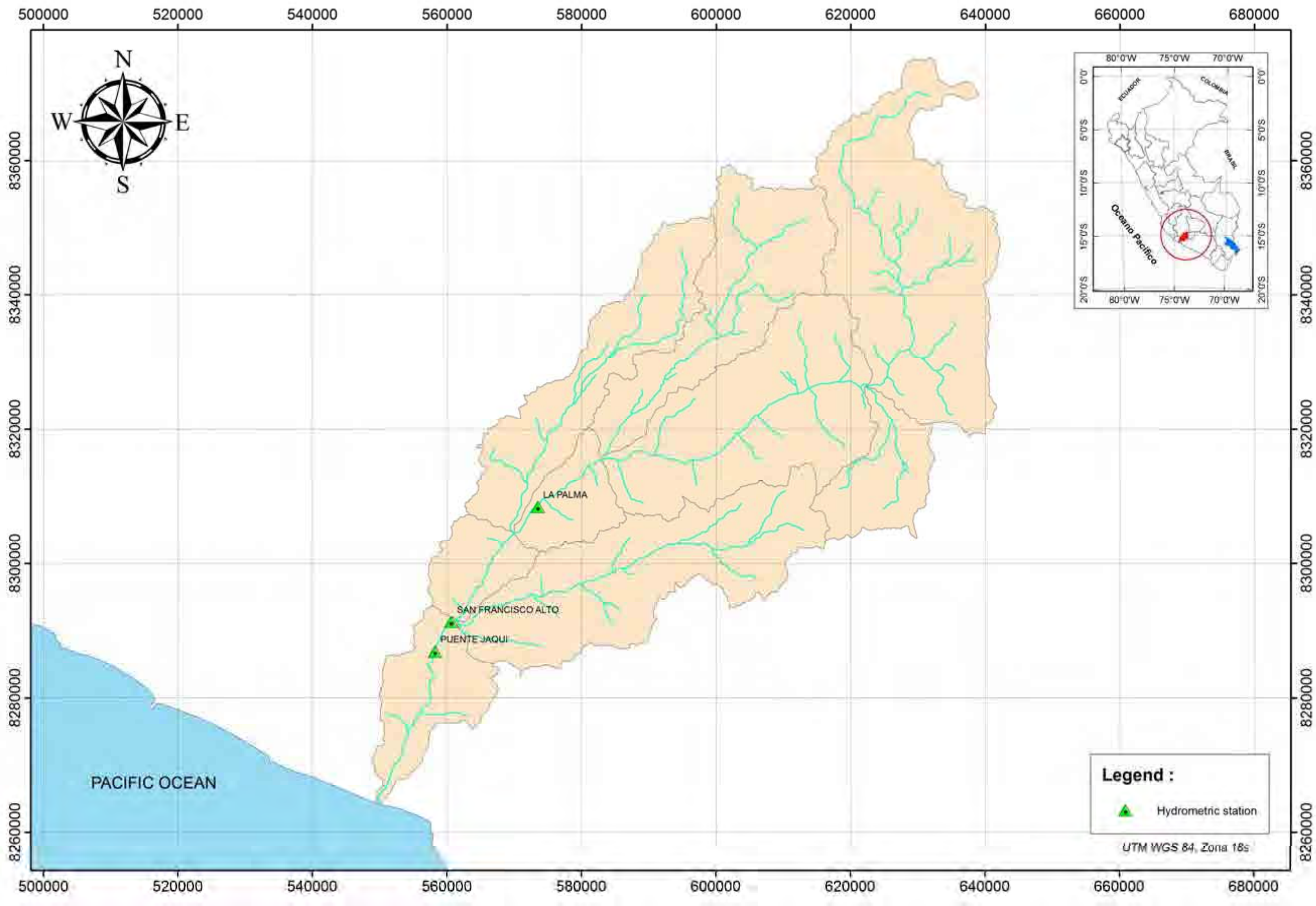



**Figure Nº 3.21. Location of the Hydrometric Stations Yauca River basin**

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

### 3.4.1 On Pluviometric Stations.

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

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

### 3.4.2 On Hydrometric Stations.

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

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

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

$$Q = aH^b$$

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

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

### 3.4.3 Recommendations

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

**On the Equipment**

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

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

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

.

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

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

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

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

On the Operation and Maintenance of the Equipments

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

On the Quality of the Measured Data

- Data taken manually by SENAMHI operators should be verified independently.
- In order to guarantee the quality of the information collected in previous years a verification study program of the data should be done by the government.
- Redundant equipment should be available in the main weather stations. This means that duplicate equipment should be installed in selected stations to compare readings with pattern equipment.
- When automatic stations are available they should operate simultaneously with manual stations at least for one year to verify the consistency of the data registered automatically.

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

# IV. HYDROLOGY OF MAXIMUM FLOOD

## 4.1 Preliminary Considerations

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

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

**Field Reconnaissance:**

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

**Methodology and Procedures:**

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

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

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

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

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

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

## 4.2 Hydrology characterization, analysis of rainfall and river information

### 4.2.1 Hydrology Characterization

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

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

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

### 4.2.2 Maximum 24-Hours Rainfall Analysis

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

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

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

| Year | Pluviometric Stations |
|---|---|

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

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

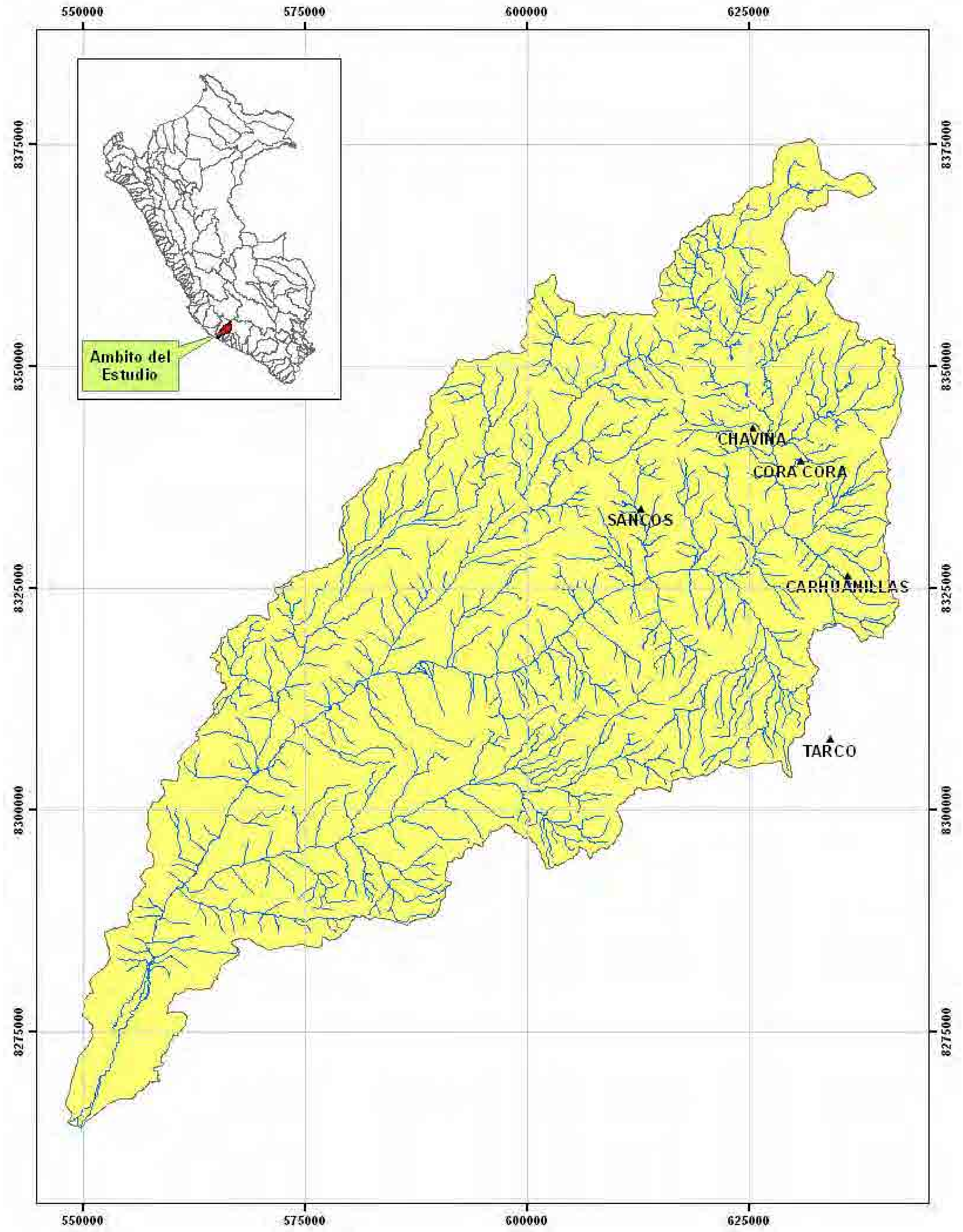



**Figure Nº 4.1. Rainfall Stations considered for HEC - HMS Software application**

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

#### *4.2.2.1 Distribution Functions*

The following describes the distribution functions:

1. Distribution Normal or Gaussiana

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

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

   To -∞ < x < ∞

   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<∞, must be x~logN($\mu_y$, $\sigma_y$ 2)

   Where:

   $\mu_y$, $\sigma_y$ = 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:

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

To $x_o \le x < \infty$

Where:

xo = Positional parameter in the domain x

$\mu_y$, = Scale parameter in the domain x.

$\sigma_y^2$ = 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:

$0 \le x < \infty$

$0 < y < \infty$

$0 < \beta < \infty$

As:

γ = Shape parameter (+)

β = Scale Parameter (+)

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

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

5. Three- Parameter Gamma Distribution or Pearson Type III

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

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

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

To

$x_o \leq x < \infty$

$-\infty < x_o < \infty$

$0 < \beta < \infty$

$0 < \gamma < \infty$

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

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

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

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

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

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

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

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

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

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

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

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

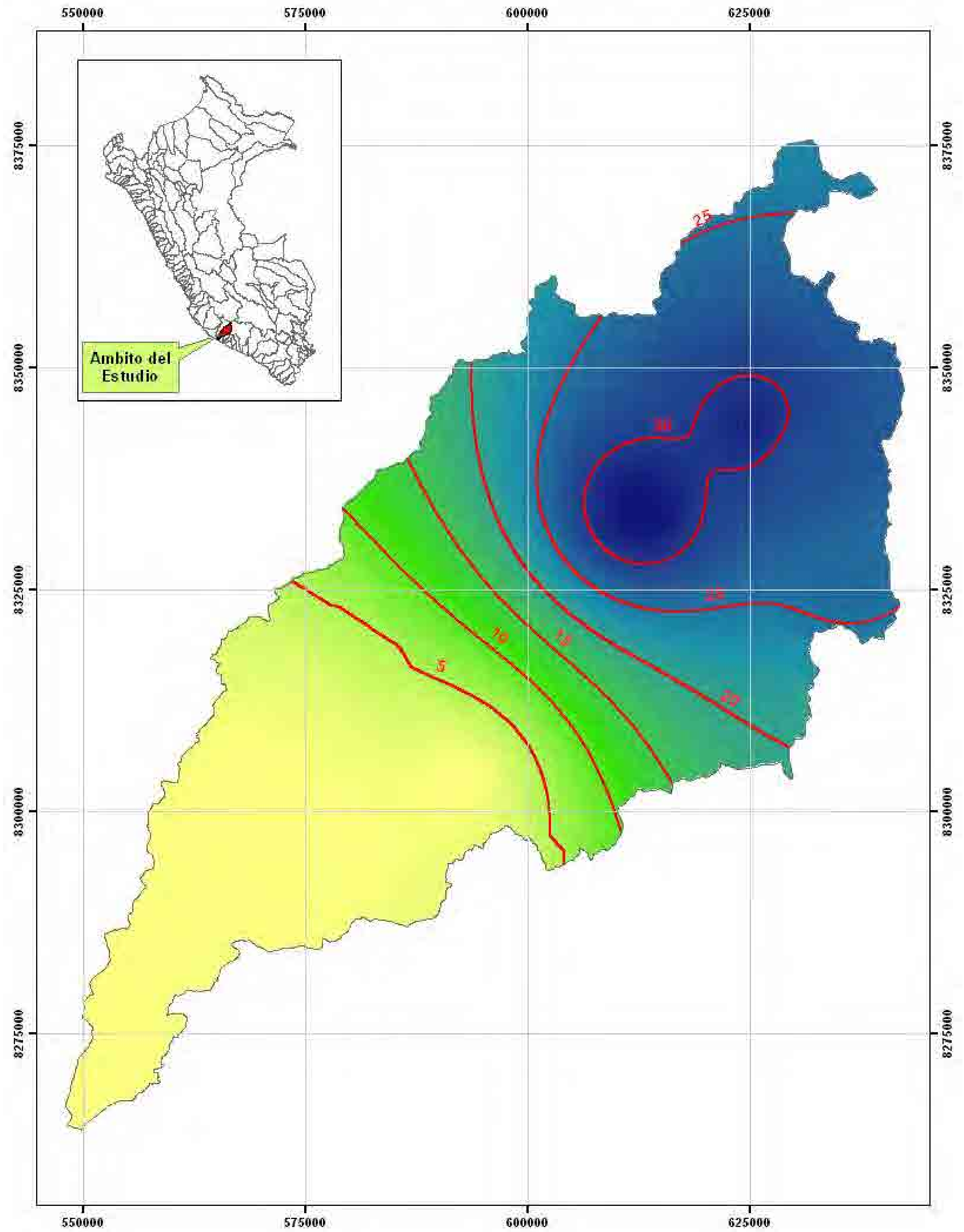



**Figure Nº 4.2. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin**

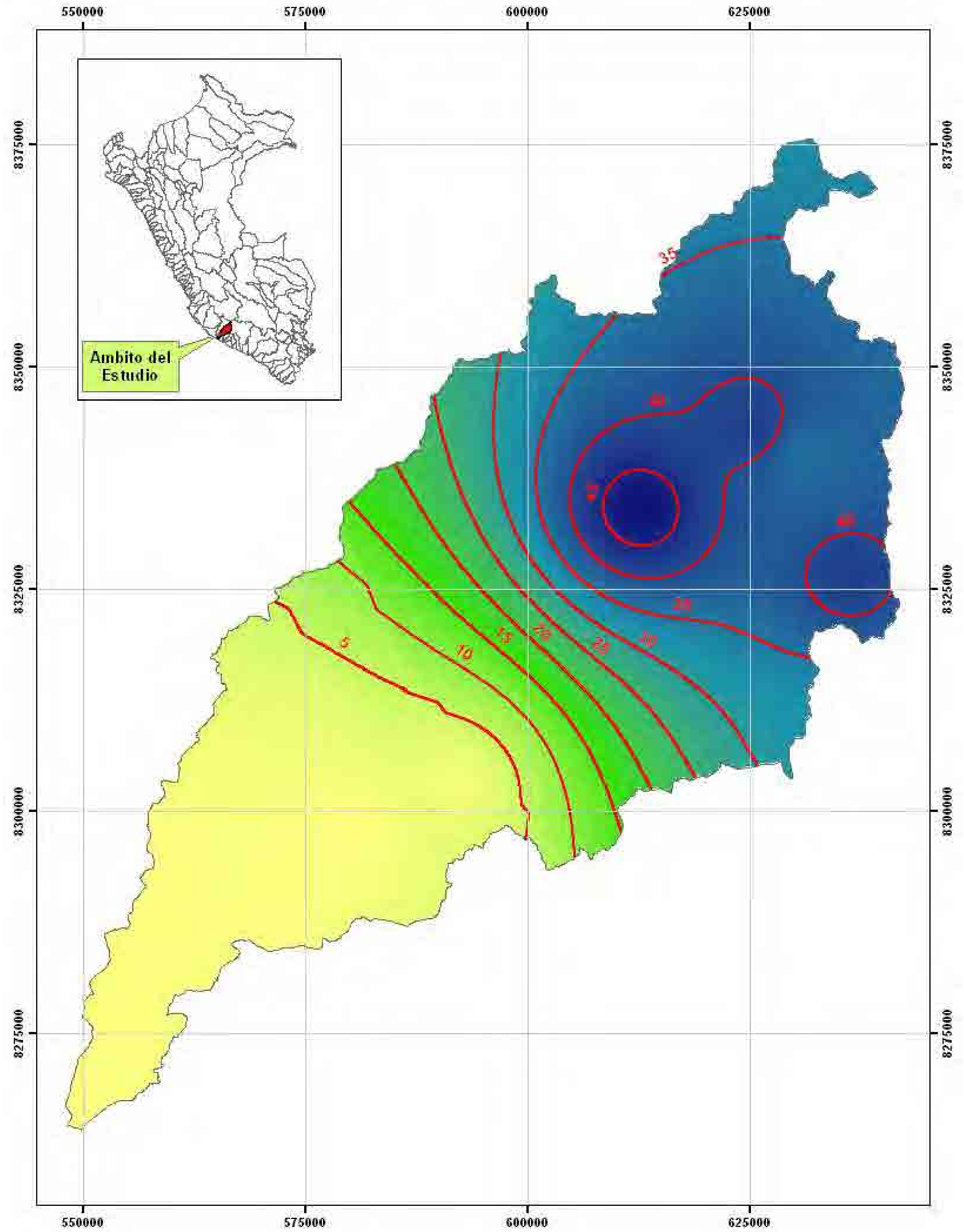



**Figure Nº 4.3. Isohyets for the 5 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin**

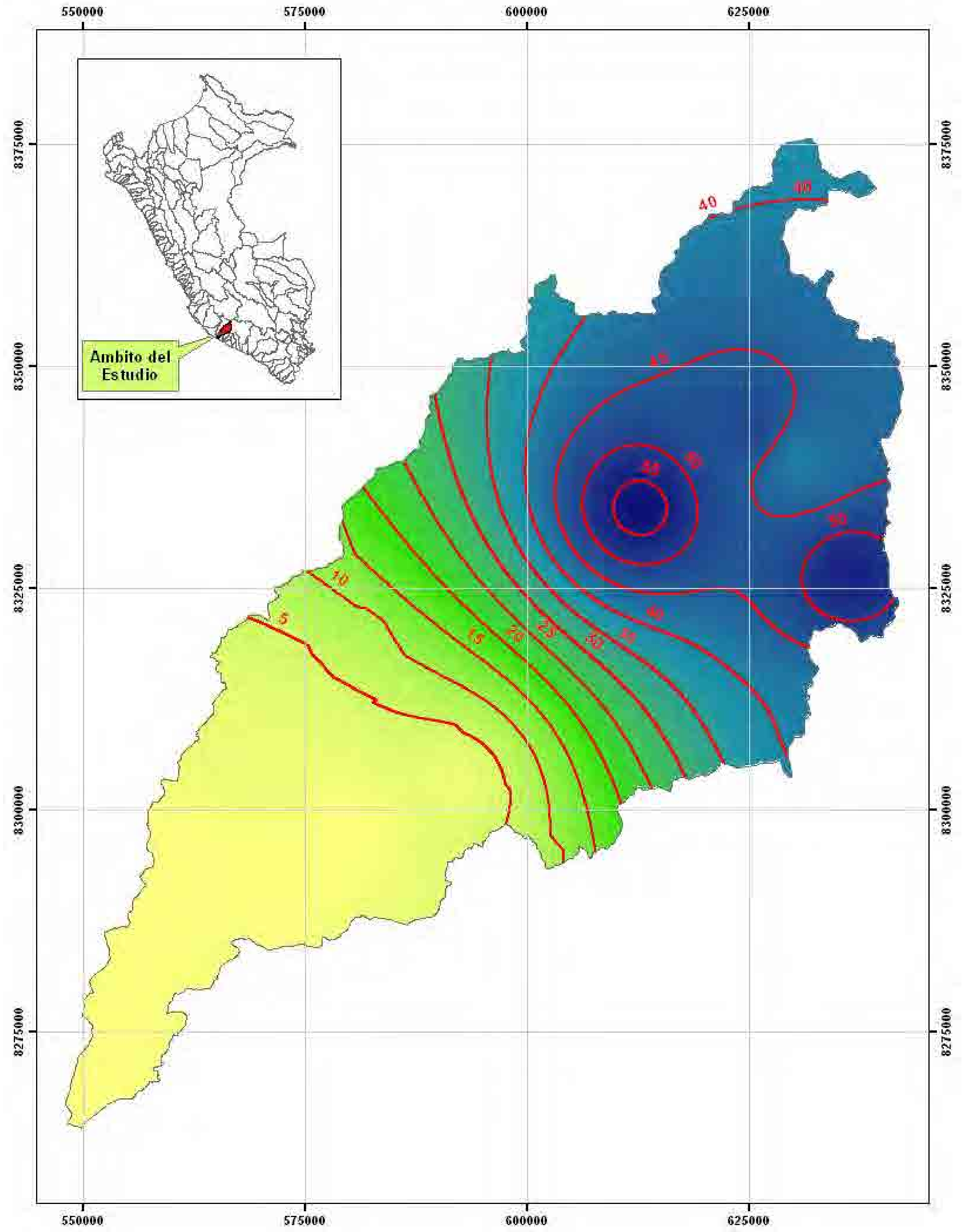



**Figure Nº 4.4. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin**

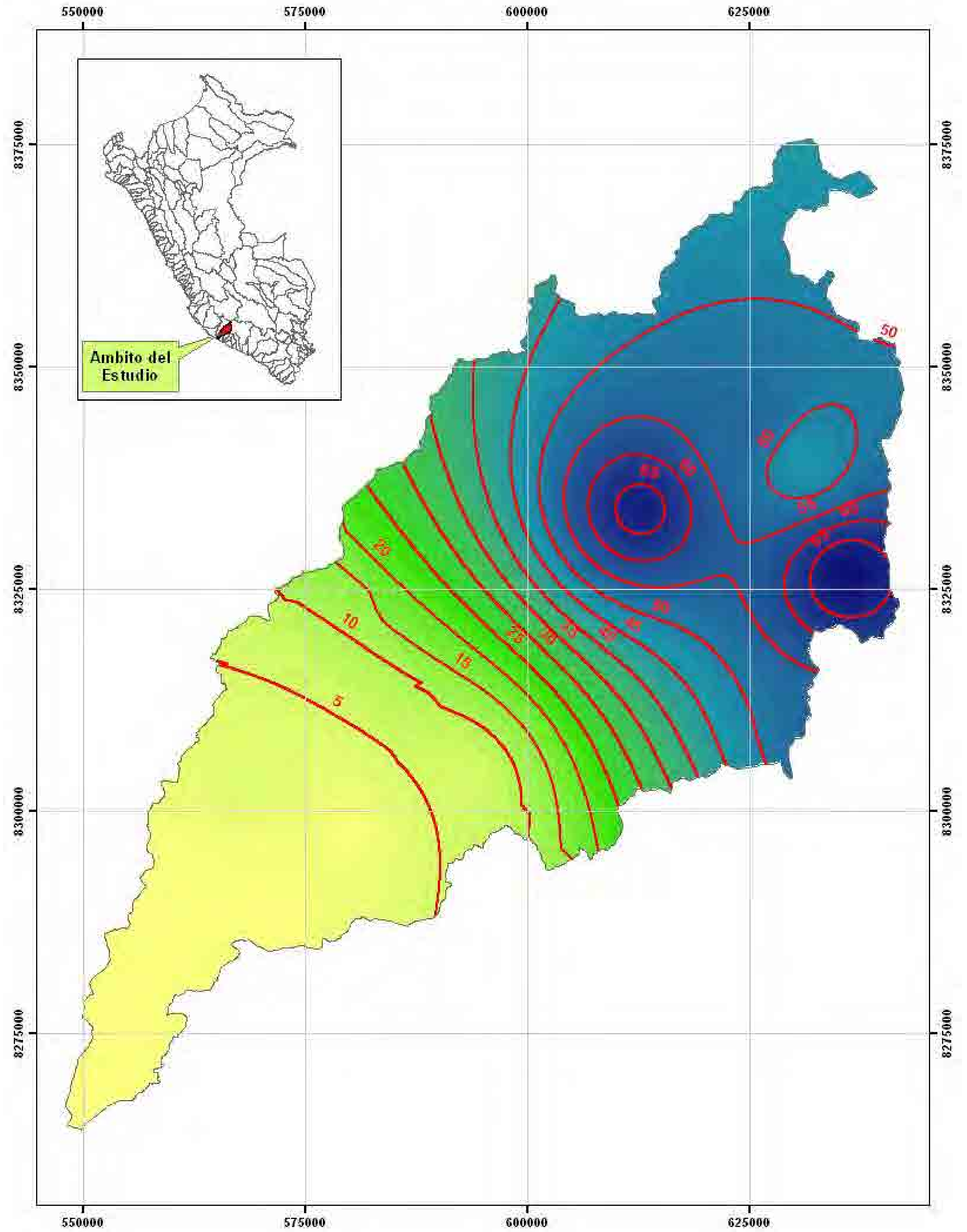



**Figure Nº 4.5. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin**

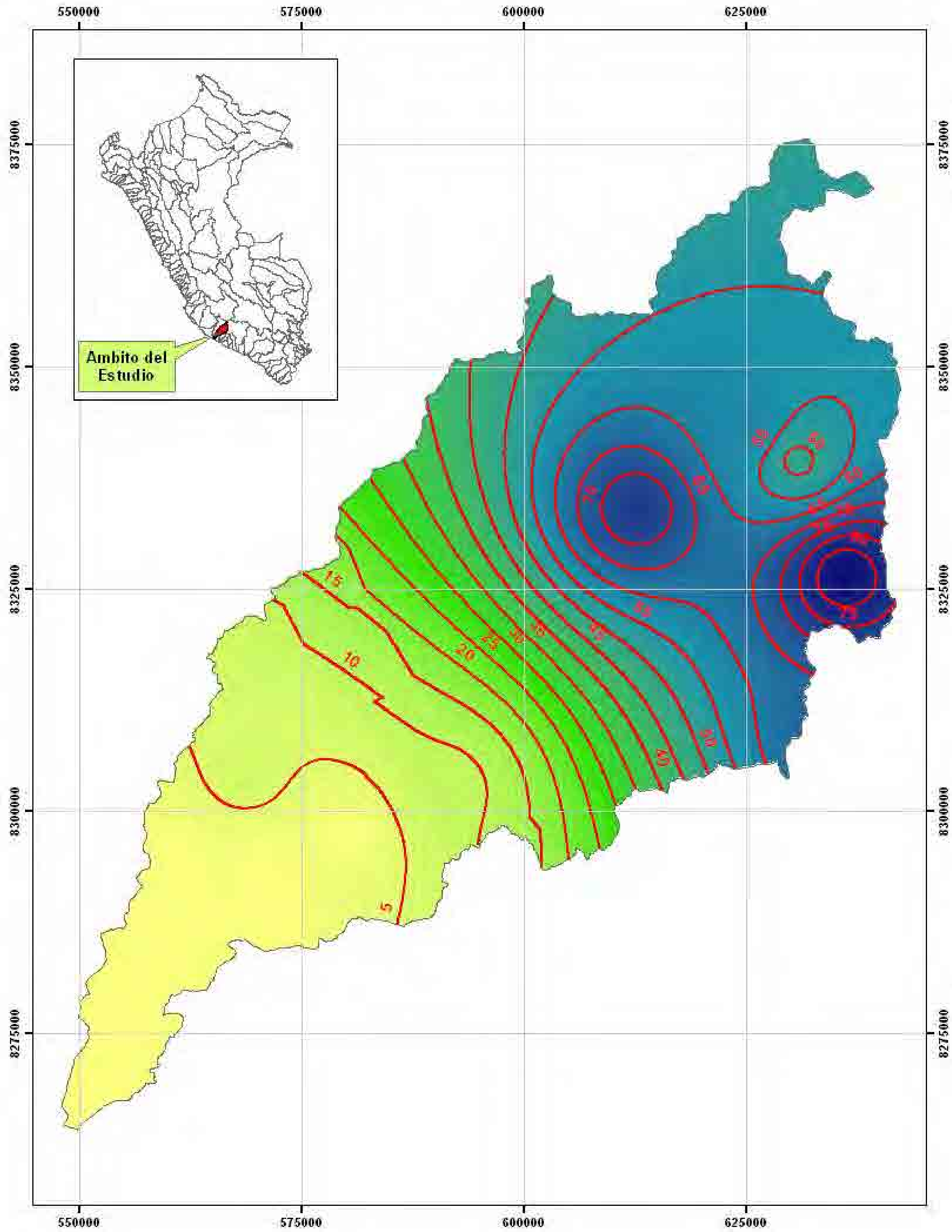



**Figure Nº 4.6. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin**

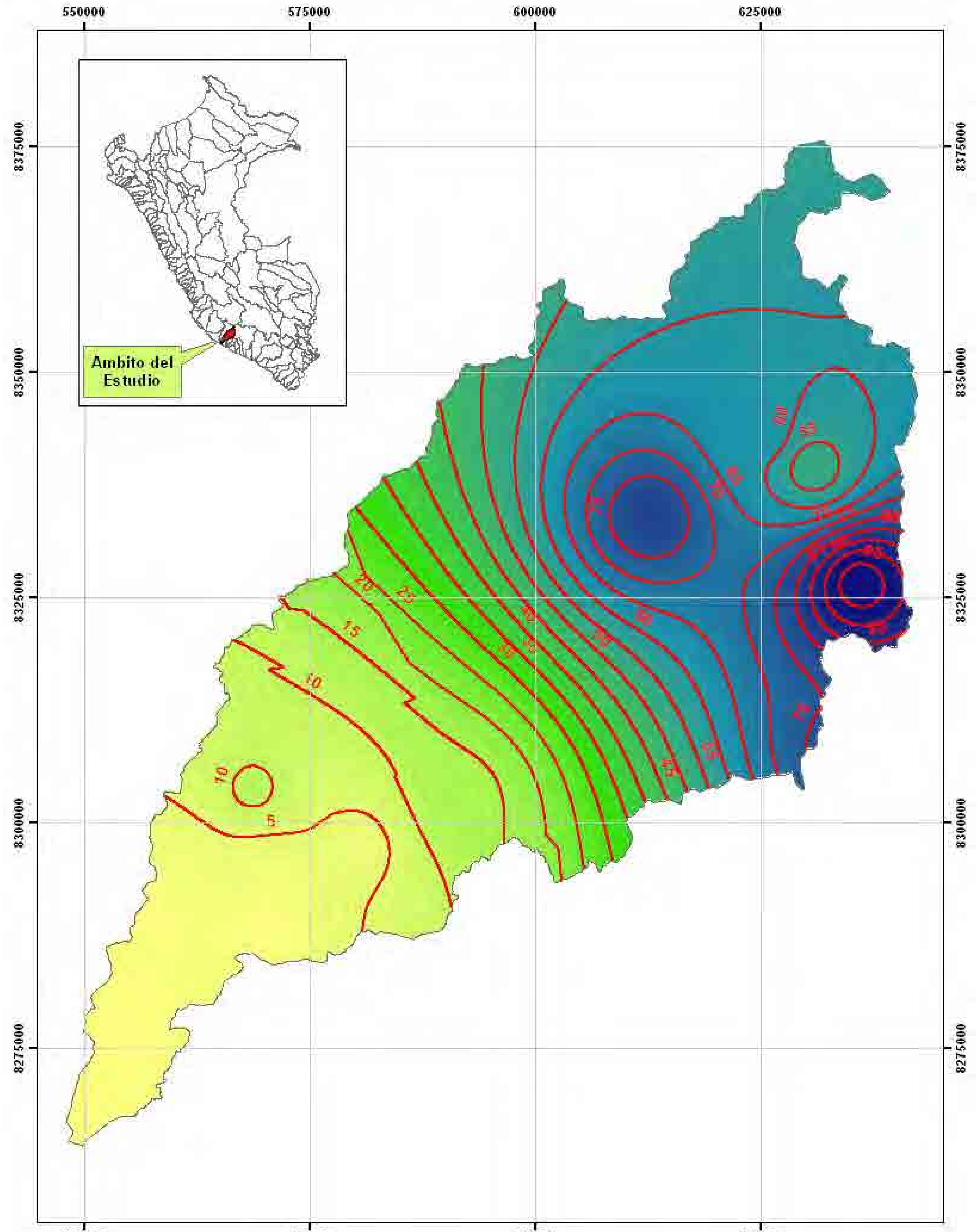



**Figure Nº 4.8. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Yauca Basin**

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

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

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

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

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

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

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

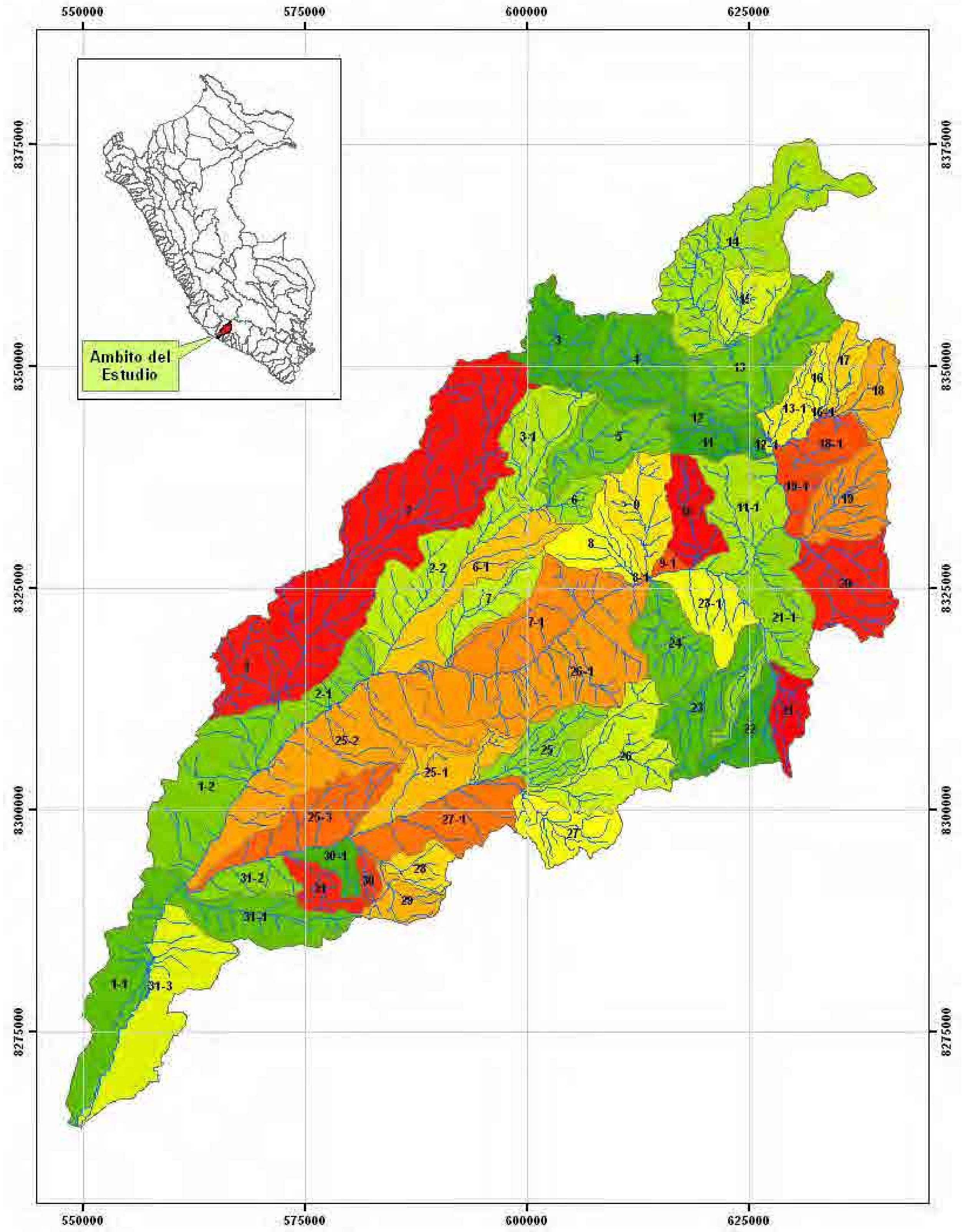



**Figure Nº 4.8. Yauca River Subbasin**

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

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

### 4.2.3 Maximum Daily Discharge Analysis

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

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

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

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

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

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

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

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

## 4.2.4 Simulation Model, Application of HEC-HMS Software

### *4.2.4.1 Hydrological Model*

**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 and Travel Times for the Base Point (station San Francisco Alto)**

| | | |
|---|---|---|
| L = | 136.00 | Km |

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

## Maximum Rain Storm Duration

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

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

## Storm Depth

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

Dick and Peschke equation :

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

Where:

Pd = Maximum rainfall for a duration d

$Pd_{24}$= 24 – hour maximum rainfall

Tc= Concentration time (minutes)

**Table Nº 4.10. Maximum Rainfall according to Dick - Peschke**

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

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

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

**Table Nº 4.11. Hyetograph for different Return Period**

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

## Selection of Curve Number

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

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

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

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

**Group D:** Expansive soils, highly plastic clays.

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

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

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

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

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

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

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

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

*4.2.4.2 HEC – HMS Modeling*

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

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

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

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

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

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

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

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

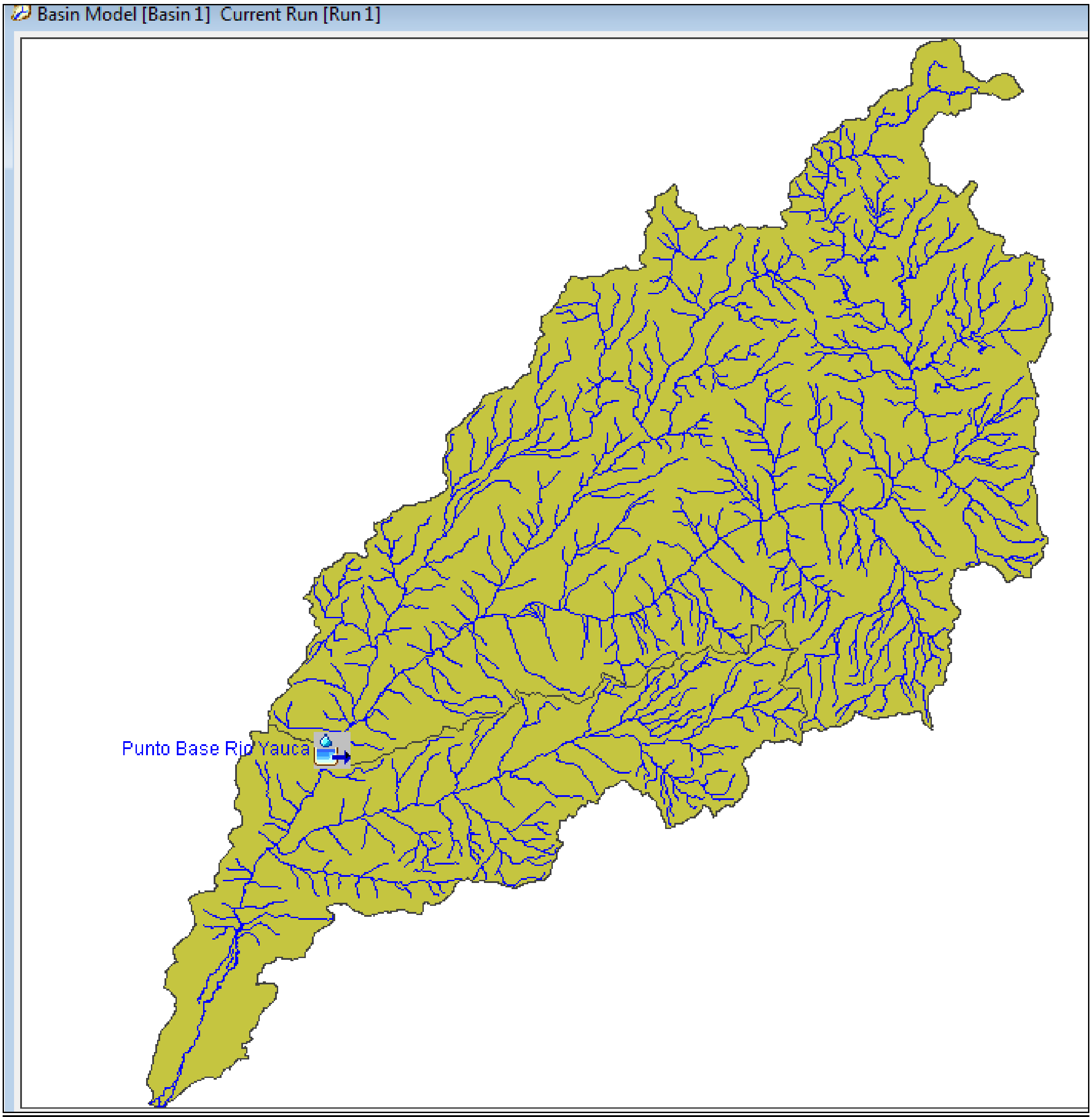



**Figure Nº 4.9. Model Yauca River Basin in the HEC-HMS Software**

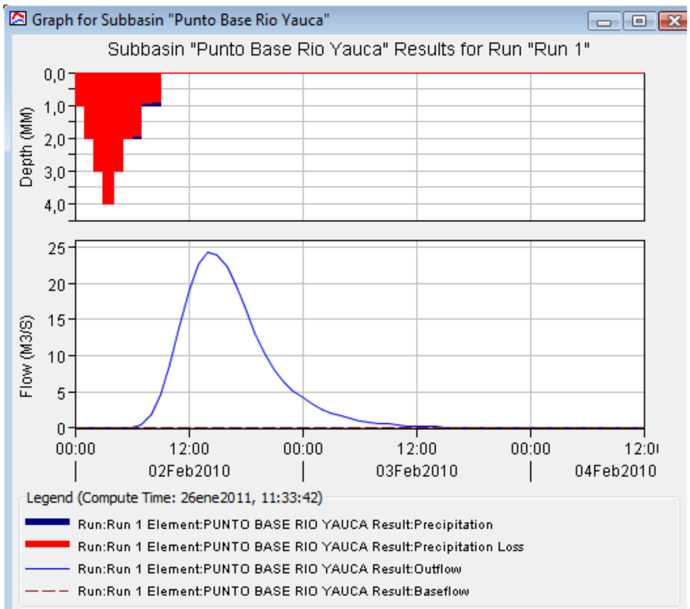



**Figure Nº 4.10. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period of 2 years**

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

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

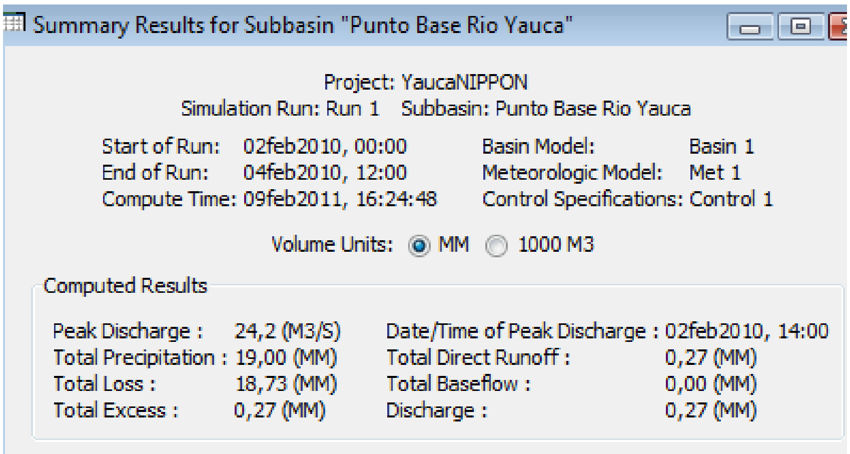



**Figure Nº 4.11.Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 2 years**

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

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

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

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

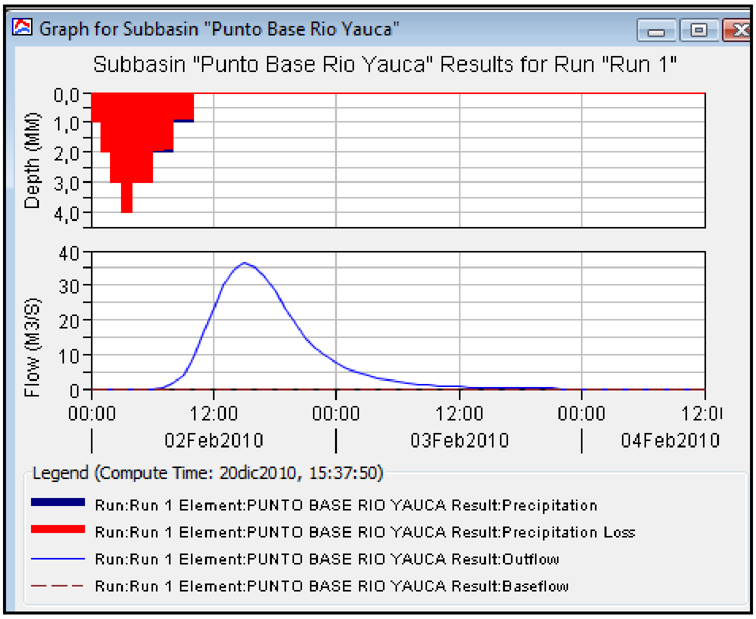



**Figure Nº 4.12. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period of 5 years**

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

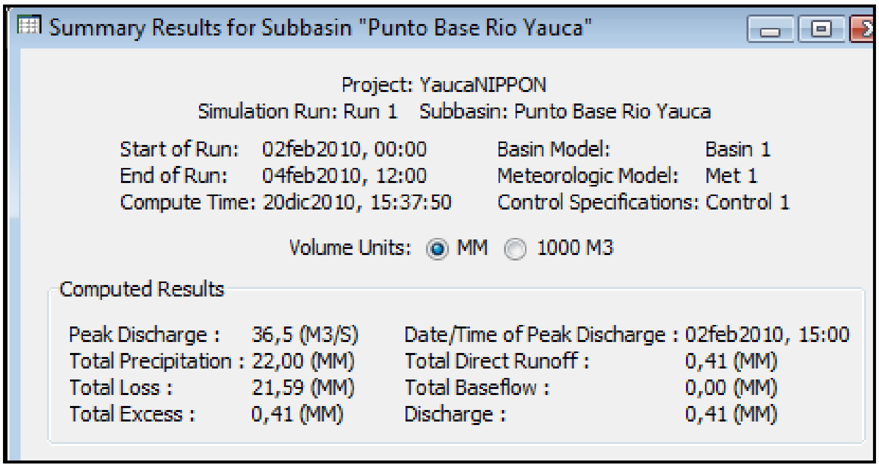



**Figure Nº 4.13.Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 5 years**

In Figure Nº 4.13 is the maximum flow is calculated for a return period of 5 years of 36.5 $m^3/s$. The maximum discharge spends approximately 15 hours after the storm started in the tax (for extreme conditions as defined above).

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

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

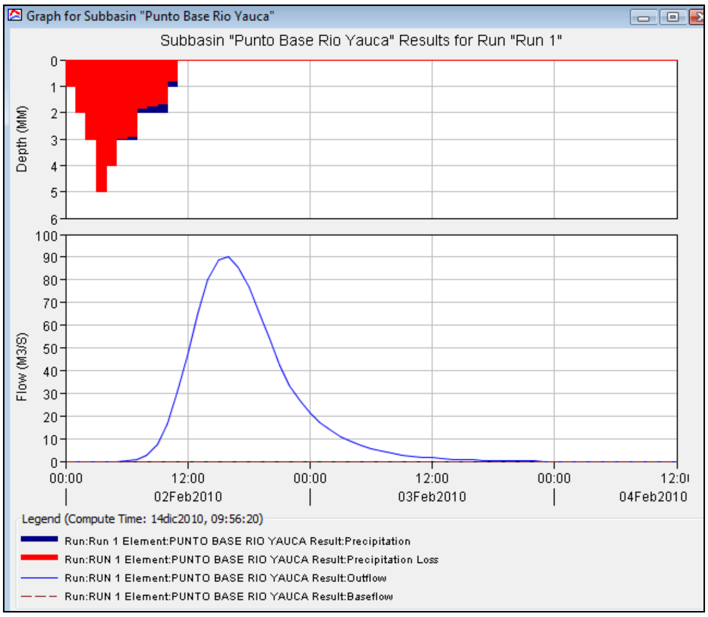
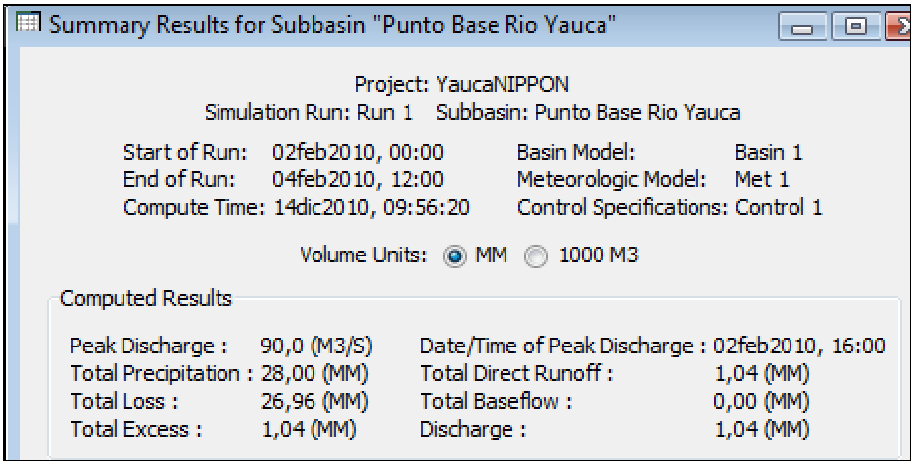



**Figure Nº 4.14. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period of 10 years**

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


Summary Results for Subbasin "Punto Base Rio Yauca"

Project: YaucaNIPPON
Simulation Run: Run 1 Subbasin: Punto Base Rio Yauca

| | | | |
|---|---|---|---|
| Start of Run: | 02feb2010, 00:00 | Basin Model: | Basin 1 |
| End of Run: | 04feb2010, 12:00 | Meteorologic Model: | Met 1 |
| Compute Time: | 14dic2010, 09:56:20 | Control Specifications: | Control 1 |

Volume Units: MM 1000 M3

Computed Results

| | | | |
|---|---|---|---|
| Peak Discharge : | 90,0 (M3/S) | Date/Time of Peak Discharge : | 02feb2010, 16:00 |
| Total Precipitation : | 28,00 (MM) | Total Direct Runoff : | 1,04 (MM) |
| Total Loss : | 26,96 (MM) | Total Baseflow : | 0,00 (MM) |
| Total Excess : | 1,04 (MM) | Discharge : | 1,04 (MM) |

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

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

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

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

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

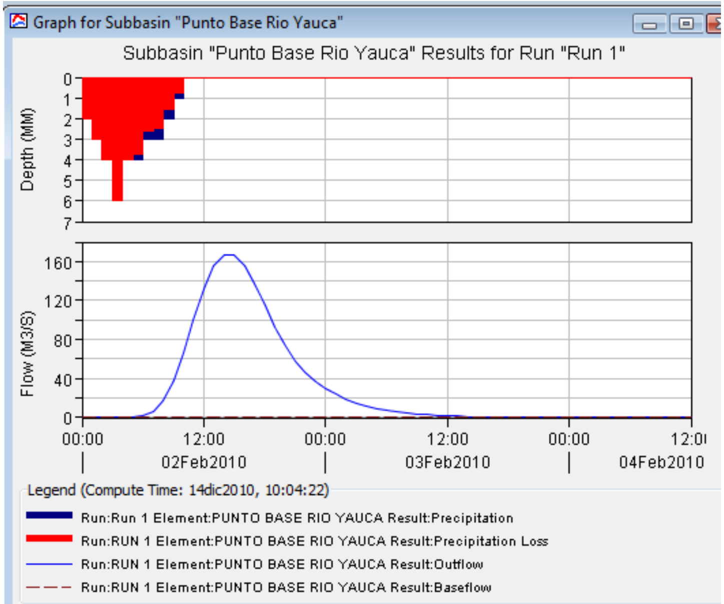



**Figure Nº 4.16. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period 25 years**

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

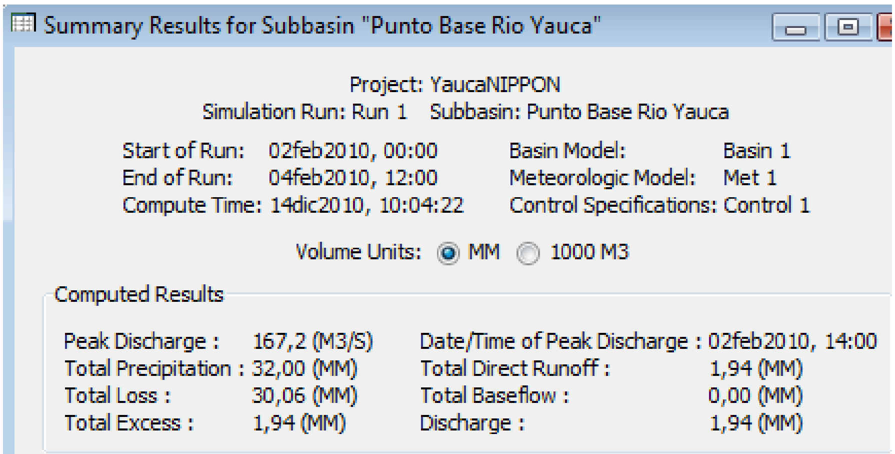



**Figure Nº 4.17. Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 25 years**

In Figure Nº 4.17 is the maximum flow is calculated for a return period of 25 years of 167.2 $m^3/s$. The maximum discharge spends approximately 14 hours after the storm started in the tax (for extreme conditions as defined above).

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

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

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

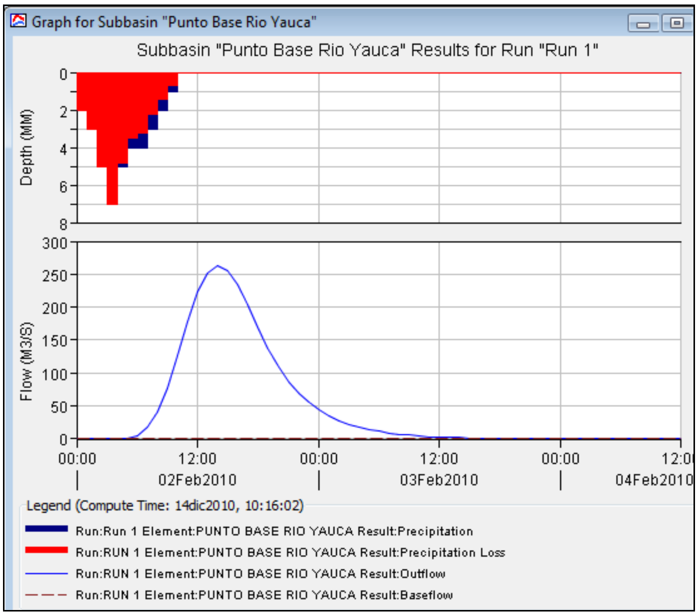



**Figure Nº 4.18. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period 50 years**

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

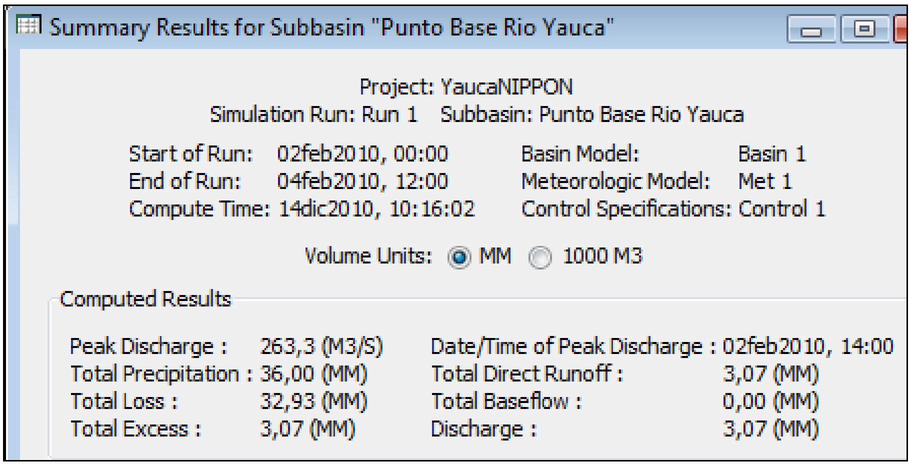



**Figure Nº 4.19. Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 50 years**

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

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

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

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

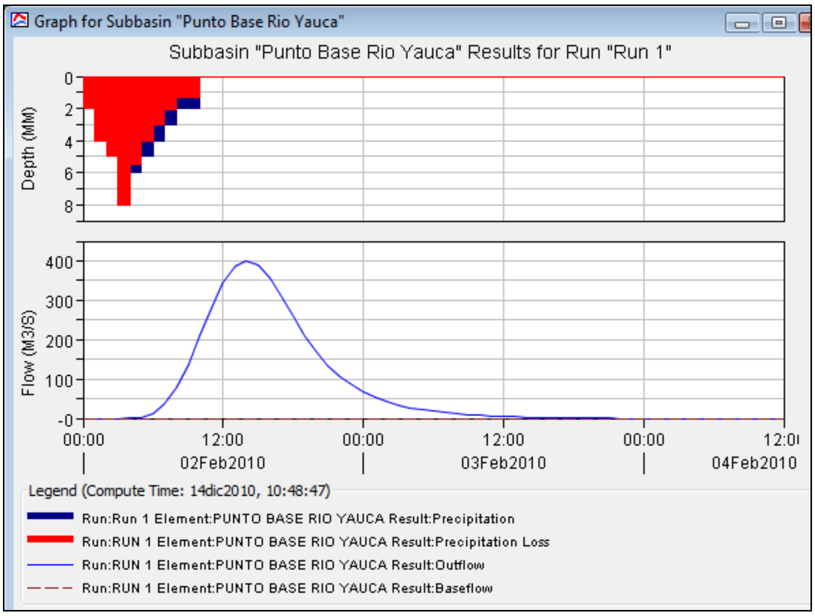



**Figure Nº 4.20. Hydrograph Rainfall – Runoff models of the Yauca River basin, Return Period 100 years**

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

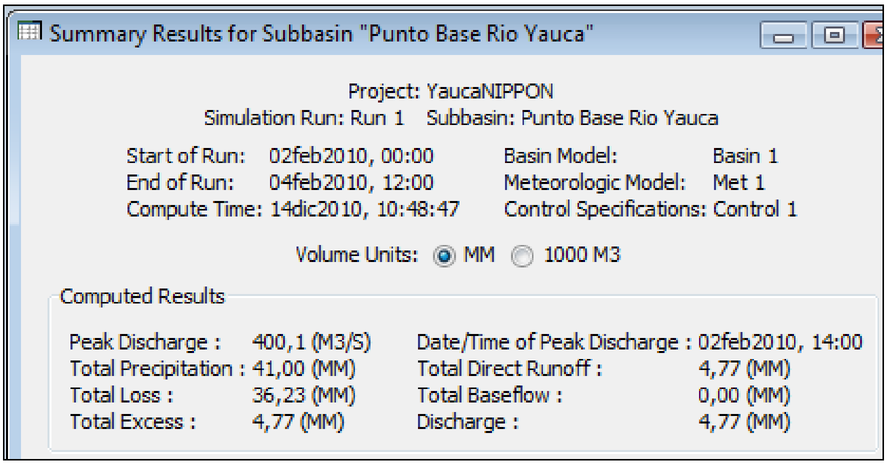



**Figure Nº 4.21. Results Model Simulation of Rainfall – Runoff Yauca River, Return Period of 100 years**

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

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

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

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

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

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

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

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

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

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

# V. REFERENCES

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

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.