Appendix-1 Hydrologic Study of Majes-Camana River Basin

International Cooperation
Agency Japan

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

HYDROLOGY OF MAXIMUM FLOODS IN CAMANA MAJES RIVER

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HYDROLOGY OF MAXIMUM FLOODS IN MAJES CAMANA RIVER

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I. INTRODUCTION

The Peruvian Coast is a very dry area where precipitation usually does not exceed 100 mm/yr. Therefore, it is necessary to irrigate the farm fields to grow the crops. The majority of the crops occupy the lower areas of the valleys due to its closeness to the rivers. Crops are usually located near the river banks and are subjected to flooding. Towns of varying size are also located along rivers of the Pacific Basin. Therefore, there is a need to protect population, their properties, crops and goods against flooding.

JICA is sponsoring an engineering study aimed to protect flood-prone areas in 7 valleys of the Peruvian Coast. One of these valleys is the Majes – Camana Valley, which is located in the Arequipa region. This study is part of the Project of Protection of Floodplains and Vulnerable Rural Population against Floods in The Republic of Peru.

The main outcomes of the hydrologic study are the discharges corresponding to the 2-yr, 5-yr, 10-yr, 20-yr, 50-yr, and 100-yr floods. This discharges will be used both in the hydraulic simulation for floodplain delineation and for the sediment transport estimations. In addition, the flow hydrographs and the 24-hr precipitations are also necessary as inputs for the other study teams.

II. GENERAL ASPECTS

In this section general information about the study area is provided.

The area is approximately located between parallels 14º 30´ S and 16º 30´ S and meridians 70º 30´ W and 73 º W. Figure 4 shows the location of the Majes – Camana Basin. A larger map of the basin can be seen in Appendix A.

The Majes – Camana Basin is located in the Arequipa Region, in Southern Peru. The surface area is approximately 17 031 km^2 of which 12 493 km^2 are located in the wet basin. It is considered that the production of surface runoff is negligible below 2 800 m.a.s.l. The lowlands are very dry average annual rainfall in coastal stations areas is below 10 mm/yr. In the continental divide, the precipitation can reach up to 700 mm/yr.

Annual rainfall and increase with altitude as can be seen in Notice that precipitations are lower near the Pacific Ocean and increases with altitude. The orographic effect is evident.

Figure 5. Rainfall intensity increases with altitude as well.

Annual temperatures are semi temperate in the lower reaches, between 0 and 800 m.a.s.l. with an average annual temperature of 19ºC. Temperature descends above 800 m. Between 2 200 m and 3 100, stations Pampacolca and Chuquibamba register average temperature ranges between 10.8 º C and 12.9 ºC. Between elevations 3100 m and 3900, the Sibayo station (3800 m.a.s.l.) has registered annual temperatures of 7.8 º C. However, higher temperatures reach 20 º C and the lower temperatures are around -6.8 ºC. Between 3 900 and 4 800 m.a.s.l., temperatures have been registered at Pañe, with an annual average temperature of 3.1ºC.

In addition, mean annual temperatures are obtained from a number of meteorological stations. These processed data (Table 1) are used to plot the variations in temperature with altitude. The results are shown in Figure 1. There are two mean annual temperature values, corresponding to Choco and Cotahuasi stations, with significant departures from the main cluster of points. These outliers may indicate errors in data climate readings. Additional temperature data can be found in Appendix B.2.

Table 1. Mean Annual Temperature versus Altitude

Weather Station	Altitude (m.a.s.l.)	Mean Annual Temperature (° C)
Andahua	3528	10.05
Aplao	645	19.67
Ayo	1956	18.64
Cabanaconde	3379	11.74
Camaná	15	19.67
Caravelí	1779	19.29
Chachas	3130	13.20
Chichas	2120	17.47
Chiguata	2943	12.27
Chivay	3661	10.09
Choco	3192	18.70
Chuquibamba	2832	11.71
Cotahuasi	5088	15.62
Crucero Alto	4470	3.91
El Frayle	4267	4.72
Huambo	3500	11.30
Imata	4445	2.83
La Angostura	4256	5.50
La Joya	1292	18.59
La Pampilla	2400	15.20
Lagunillas	4250	6.52
Las Salinas	4322	4.20
Machahuay	3150	11.76
Madrigal	3262	10.75
Orcopampa	3801	9.16
Pampa de Arrieros	3715	7.18
Pampa de Majes	1434	18.40
Pampacolca	2950	12.37
Pampahuta	4320	4.16
Pillones	4455	3.13
Porpera	4152	4.79
Pullhuay	3113	12.30
Salamanca	3303	12.68
Sibayo	3827	8.23
Sumbay	4294	5.42
Tisco	4175	6.39
Yanaquihua	2815	14.38

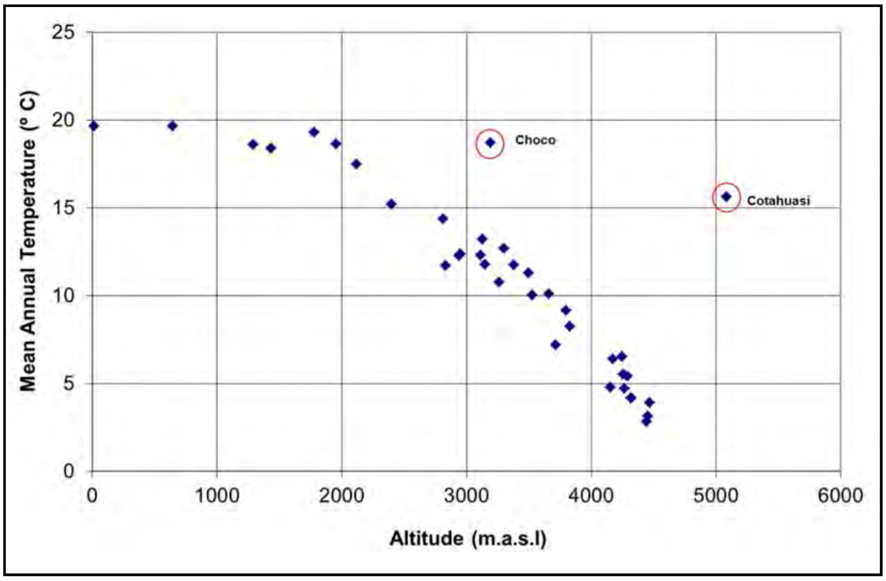


Figure 1. Mean Annual Temperature versus Altitude

Temperature analysis can be divided into two sections. In the first section, between sea level and the 2000 m.a.s.l. elevation, the mean annual temperature is almost constant. In this section, the mean annual temperature ranges between 18.4°C and 19.7°C. The second section is the linearly decreasing temperature. The temperature decreases in approximately 6°C / 1000 m. Figure 2 shows the second section with the corresponding R^2 value. The temperature decreases with altitude because there is convective heat loss from the ambient airflow.

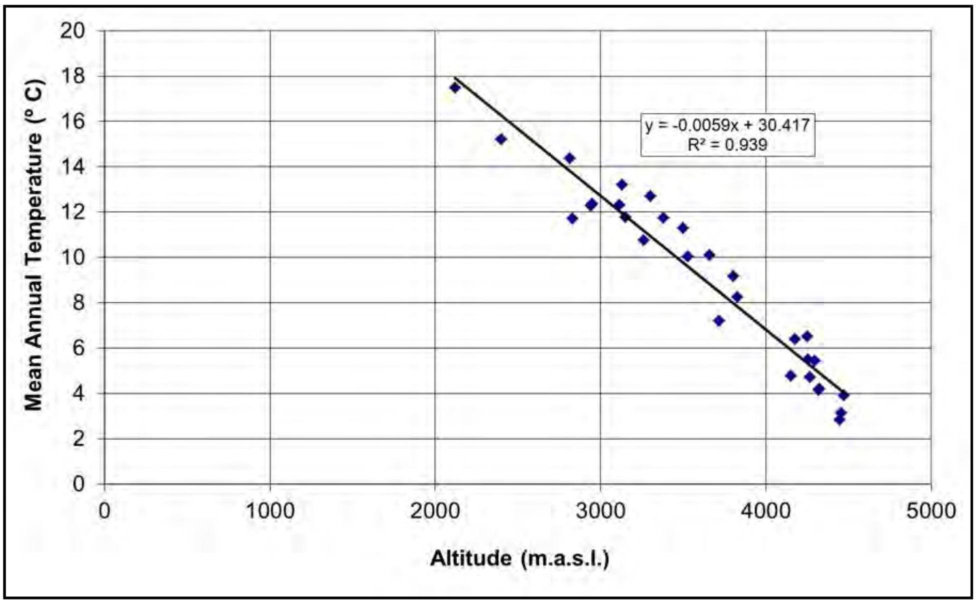


Figure 2. Mean Annual Temperature Versus Altitude above 2000 m.a.s.l. without outliers

In most of the stations, the available precipitation records show missing values. The concurrent measurements at two gaging stations were used to fill in missing values, based on the observed data. Gaps in one station were completed based on the data of a neighboring station, called base station (with complete or longer records). A linear interpolation was found between the station and the base station. For instance, Table 2 shows records from Tisco station with missing values and Figure 3 shows data sets from the base station (La Angostura station), X_i, and of the station having missing data (Tisco Station), Y_i, in which a regression of Y on X was performed for the periods when the data in both data sets exist. The high R^2 indicates good correlation and sufficient homogeneity for replacing missing data in the incomplete data series. Detailed information is presented in Appendix B.5. Moreover, Isohyets were calculated with these completed sequences (Notice that precipitations are lower near the Pacific Ocean and increases with altitude. The orographic effect is evident.

Figure 5).

Table 2. Monthly Precipitation Data in Tisco Station

TOTAL MONTHLY PRECIPITATION (mm)

BASIN	GAGE	DEPARTMENT	LONGITUDE	LATITUDE
Camaná - Majes	TISCO	AREQUIPA	71° 27'1	15° 21'1

Year	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1963											41.1	131.8	
1964	86.1	72.9	114.4	42.9	22.0	0.0	0.0	6.1	4.4	17.9	59.7	57.6	484.0
1965	75.0	161.1	85.9	42.5	0.3	0.0	9.2	0.0	24.0	22.0	10.4	151.7	582.1
1966	110.3	184.9	64.6	10.6	45.1	0.0	0.0	4.5	0.0	43.3	79.7	55.0	598.0
1967	103.8	161.0	220.2	64.5	13.1	0.6	8.2	9.4	41.8	23.6	12.7	90.5	749.4
1968	266.0	119.6	179.4	31.6	4.0	5.1	5.5	5.8	20.0	52.9	84.6	31.7	806.3
1969	150.1	113.0	52.5	0.0	0.0	0.0	0.0	0.0	0.0	4.0	60.8	97.7	478.0
1970	139.6	150.5	138.5	22.4	9.5	0.0	1.0	1.1	35.6	5.1	4.7	146.8	654.9
1971	140.0	183.5	101.2	30.1	2.6	0.9	0.0	0.0	0.0	5.0	2.2	132.7	598.2
1972	362.1	188.7	235.5	32.7	0.1	0.0	2.3	0.1	55.1	32.9	32.1	90.1	1031.7
1973	297.8	190.2	159.2	81.1	15.9	0.0	8.2	10.2	31.1	7.6	60.6	53.9	915.7
1974	290.2	172.9	44.7	80.7	1.5	14.5	0.0	111.1	9.3	4.3	7.5	50.2	786.8
1975	146.6	246.7	122.4	30.2	20.8	3.2	0.0	1.0	8.0	48.3	1.4	131.4	760.1
1976	153.0	107.7	166.8	41.6	9.3	7.5	4.6	2.3	58.9	0.5	0.6	71.9	624.7
1977	67.0	239.2	118.8	7.1	4.1	0.0	2.3	0.0	11.7	16.3	110.2	49.8	626.6
1978	317.6	24.1	78.7	68.9	0.0	4.0	0.0	1.0	2.3	26.9	78.6	60.0	662.2
1979	127.4	88.0	123.3	16.5	0.0	0.0	2.5	2.5	0.0	59.2	71.2	93.7	584.4
1980	72.5	43.1	183.6	2.2	0.0	0.0	13.5	25.9	28.1	94.1	2.1	30.2	495.3
1981	205.2		52.0	73.0	2.0	0.0	0.0	46.8	9.0	24.8	52.3	110.6	
1982	161.0	45.9	122.8	34.9	0.0	0.5	0.0	0.0	80.9	105.5	150.5	70.0	772.0
1983	46.7	93.7	81.0	47.9	12.0	0.5	0.5	0.0	35.2	18.0	2.5	32.4	370.5
1984	178.4	256.0	284.8	11.1	10.5	3.0	0.0	28.4	0.0	46.3	135.5	125.6	1079.6
1985	32.9	263.0	134.4	49.7	10.0	14.8	0.0	0.0	15.4	0.0	70.0	142.4	732.6
1986	105.9	162.7	178.9	98.4	12.5	0.0	2.8	52.2	18.1	11.0	11.0	149.6	803.1
1987	212.5	42.9	26.2	23.6	3.4	2.1	27.0	4.5	2.0	23.3	24.6	29.0	421.1
1988	216.9	72.5	97.0	63.5	8.5	0.0	0.0	4.0	6.8	0.0	4.0	30.2	503.4
1989	123.9	93.0	159.5	50.7	0.0	0.0	0.0	3.0	0.0	0.0	12.0	4.0	446.1
1990	118.4	27.6	58.5	25.6	12.5	39.5	0.0	13.0	5.0	52.5	0.0		
1991	150.6	72.7	162.3	10.7	3.5	30.7	3.0	1.6	3.5	29.2	48.6	0.0	516.4
1992	51.6	73.8	32.9	4.8	0.0	2.7	2.8	40.0	1.0	25.2	24.7	85.6	345.1
1993	230.9	82.4	133.9	49.9	6.2	1.3	0.3	25.1	15.5	34.2	63.7	106.1	749.5
1994	241.6	218.1	74.3	45.6	10.1	2.8	1.5	1.7	0.0	1.0	25.2	72.7	694.6
1995	121.5	135.0	215.7	27.8	3.7	0.1	0.0	2.8	8.6	13.1	22.3	122.0	672.7
1996	187.3	156.8	83.0	61.6	12.0	0.0	0.3	14.1	11.7	10.6	41.3	146.6	725.4
1997	175.0	201.8	86.5	31.7	18.1	0.0	0.0	33.1	64.8	14.0	60.1	102.2	787.3
1998	271.1	114.9	96.6	15.9	0.5	3.0	0.0	0.8	0.5	9.6	48.5	75.9	637.4
1999	199.2	273.9	198.2	30.5	6.0	0.1	1.2	0.6	23.5	75.3	10.7	90.3	909.5
2000	194.3	242.5	157.2	21.5	28.7	7.8	0.4	11.4	1.6	70.9	22.1	97.9	856.4
2001	240.3	239.0	144.2	108.9	31.3	5.4	16.5	12.0	8.4	18.7	8.6	35.9	869.0
2002	123.6	241.6	186.8	134.9	17.4	8.0	31.8	0.6	19.1	44.7	82.2	113.3	1004.1
2003	83.5		193.1	29.2	11.8	1.5	3.6	4.1	13.2	14.8		114.6	
2004	208.7	176.4	138.0	39.4	2.4	0.5	20.3	14.9	15.4	3.2	7.0	72.7	698.8
2005	124.4	207.0	127.5	56.9	0.5	0.0	0.1	0.7	23.2	11.6	18.8	103.4	674.1
2006	202.0	200.4	195.5	62.4	6.1	4.1	0.0	7.7	25.6	29.3	61.6	78.8	873.4
2007	187.0	179.7	180.4	38.4	9.1	0.1	9.7	0.8	16.1	13.7	22.9	96.2	753.8
2008	257.8	123.5	70.0	5.5	3.2	2.7	0.1	0.6	1.7	17.1	5.0	95.6	582.7
2009	104.6	203.6	133.3	65.6	2.8	0.0	11.1	2.4	23.9	9.9	47.9	64.6	669.7
2010	179.1	164.6	73.0	69.3	6.4	2.1	2.2	1.0	6.2	21.2	13.4	142.9	681.4
2011		233.8	96.9	104.8									
Pp Maxima	362.1	273.9	284.8	134.9	45.1	39.5	31.8	111.1	80.9	105.5	150.5	151.7	1079.6
Pp Media	166.8	153.2	128.4	43.7	8.5	3.6	4.1	10.8	16.7	25.8	38.7	85.9	687.9
Pp Minima	32.9	24.1	26.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	345.1

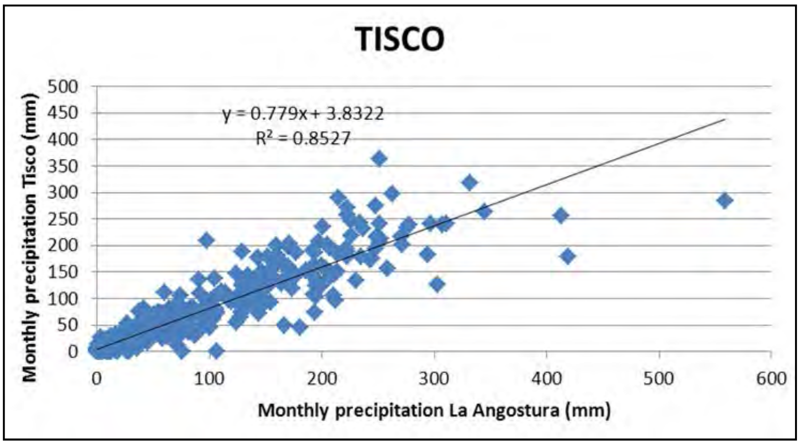


Figure 3. Regression between Two Sets of Monthly Precipitation Data

Peak floods mostly occur during the summer months: January, February and March, but occasionally peak floods have occurred in April. Sixty three percent of the annual volume runoff is produced in the summer months. Discharges are much lower the rest of the year flows and pose no threat for the crops or settlement located near the floodplains.

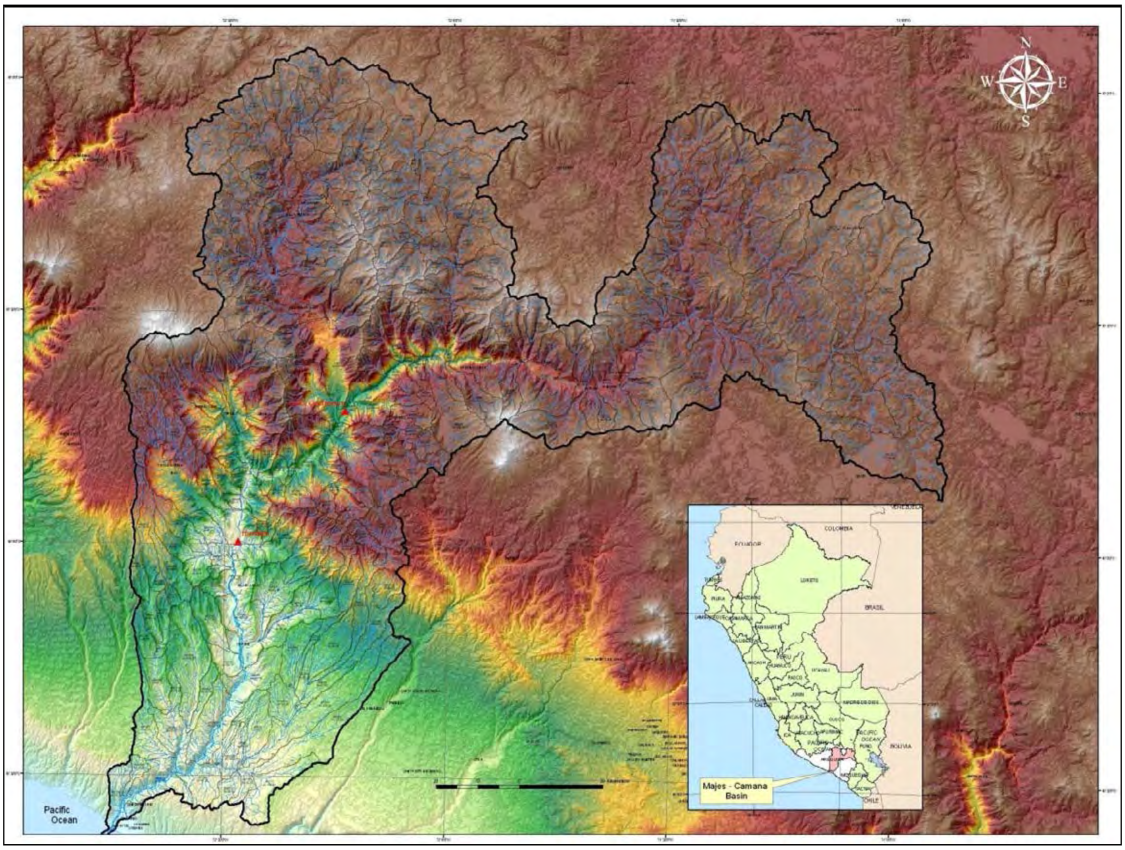
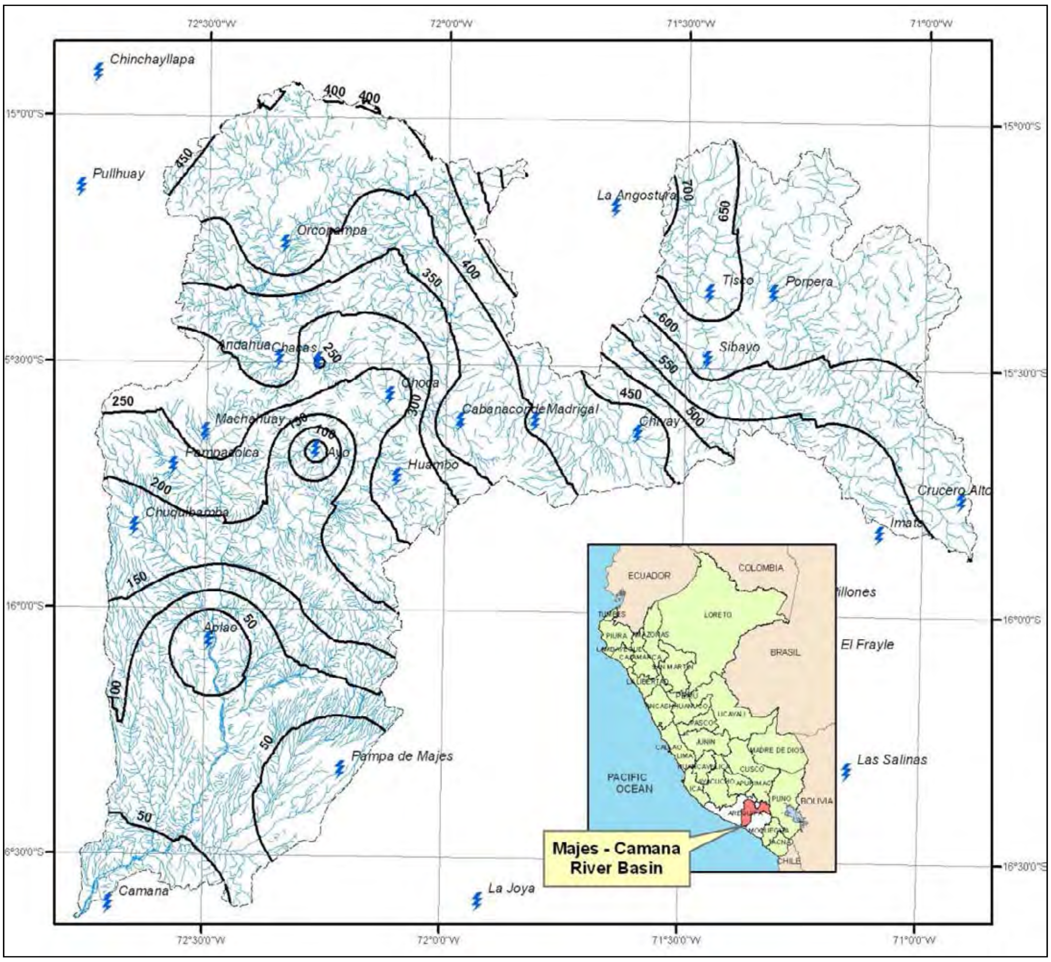


Figure 4. Map of the Majes-Camana Basin.



Notice that precipitations are lower near the Pacific Ocean and increases with altitude. The orographic effect is evident.

Figure 5. Isohyets of Annual Precipitation in the Majes - Camana Basin.

III. PROJECT DESCRIPTION

In this section, the tasks that led to the estimation of flood discharge for selected return periods are described. Available information, statistical analysis, theoretical and practical considerations are presented. At the end of this chapter, peak discharges and outflow hydrographs are given at two points along the Camana – Majes basin: Huatiapa station and at the confluence of the Andahua and Colca.

3.1. Available information

Weather information is available in the study area. Information from 48 weather stations in the study area has been identified. The majority of these stations have been installed in the Camana Majes Basin. Some of them are complete Climatologic Stations and other only provide rainfall records. The majority of the weather stations are not automatic and for a number of years only manual stations existed. Therefore, the longest records provide only manual readings. Only the Chivay rainfall station in upstream of the Camana Majes River basin is available hourly rainfall record by automatic rainfall gauge since 2001. However, the digitized hourly rainfall record at Chivay is available from year 2011. Other hourly rainfall observations by private mining company are not able to collect due to confidential record for mining purposes. The only widely available rainfall information is the 24-hour precipitation that has been recorded at all stations. Table 3 shows the list of weather stations that has been identified.

Table 3. List of Weather Stations in the Study Area.

Weather station	Coordinates			Entity
	Latitude	Longitude	Altitude (masl)	
Andahua	15° 29'37	72° 20'57	3528	SENAMHI
Aplao	16° 04'10	72° 29'26	645	SENAMHI
Ayo	15° 40'45	72° 16'13	1956	SENAMHI
Cabanaconde	15° 37'7	71° 58'7	3379	SENAMHI
Camaná	16° 36'24	72° 41'49	15	SENAMHI
Caravelí	15° 46'17	73° 21'42	1779	SENAMHI
Chachas	15° 29'56	72° 16'2	3130	SENAMHI
Chichas	15° 32'41	72° 54'59.7	2120	SENAMHI
Chiguata	16° 24'1	71° 24'1	2943	SENAMHI
Chinchayllapa	14° 55'1	72° 44'1	4497	SENAMHI
Chivay	15° 38'17	71° 35'49	3661	SENAMHI
Choco	15° 34'1	72° 07'1	3192	SENAMHI
Chuquibamba	15° 50'17	72° 38'55	2832	SENAMHI
Cotahuasi	15° 22'29	72° 53'28	5088	SENAMHI
Crucero Alto	15° 46'1	70° 55'1	4470	SENAMHI
El Frayle	16° 05'5	71° 11'14	4267	SENAMHI
Huambo	15° 44'1	72° 06'1	3500	SENAMHI
Imata	15° 50'12	71° 05'16	4445	SENAMHI
La Angostura	15° 10'47	71° 38'58	4256	SENAMHI
La Joya	16°35'33	71°55'9	1292	SENAMHI
La Pampilla	16° 24'12.2	71° 31'.6	2400	SENAMHI
Lagunillas	15° 46'46	70° 39'38	4250	SENAMHI
Las Salinas	16° 19'5	71° 08'54	4322	SENAMHI
Machahuay	15° 38'43	72° 30'8	3150	SENAMHI
Madrigal	15° 36'59.7	71° 48'42	3262	SENAMHI
Orcopampa	15° 15'39	72° 20'20	3801	SENAMHI
Pampa de Arrieros	16° 03'48	71° 35'21	3715	SENAMHI
Pampa de Majes	16° 19'40	72° 12'39	1434	SENAMHI
Pampacolca	15° 42'51	72° 34'3	2950	SENAMHI
Pampahuta	15° 29'1	70° 40'33.3	4320	SENAMHI
Pillones	15° 58'44	71° 12'49	4455	SENAMHI
Porpera	15° 21'1	71° 19'1	4152	SENAMHI
Pullhuay	15° 09'1	72° 46'1	3113	SENAMHI
Salamanca	15° 30'1	72° 50'1	3303	SENAMHI
Sibayo	15° 29'8	71° 27'11	3827	SENAMHI
Sumbay	15° 59'1	71° 22'1	4294	SENAMHI
Tisco	15° 21'1	71° 27'1	4175	SENAMHI
Yanaquihua	15° 46'59.8	72° 52'57	2815	SENAMHI

It was important to identify which information would be useful for the hydrologic study. Weather stations with few data (less than 20 years), or with data from the last 10 years missing would be discarded from this study. Some other stations were discarded because they were too far from the study area (in the middle reaches of the Atlantic Basin) and could distort the precipitation estimated in the basins that are of interest for this study. Therefore, Table 5 was constructed to identify the stations with adequate data and complete records.

Data from 10 weather stations was discarded. The reasons are given below in Table 4. The final number of stations that were used for this study is 38. The distribution of the stations that has been used for the hydrologic simulation is presented below in Figure 6 Detailed precipitation information is given in Appendix B.

Table 4. Weather Stations whose Data was Discarded for the Hydrologic Study.

Nº	Station	Reason for discarding station
1	Santo Tomás	Too far from the study zone and scarce data available
2	Yauri	Too far from the study zone and scarce data available
3	Condoroma	Scarce Data. Data from the last 15 years is missing
4	Cayllona	Few available data.
5	Huanca	Few available data.
6	Puica	Few available data.
7	Janacancha	Data from the last 10 years is missing
8	La Pulpera	Data from the last 15 years is missing
9	Yanque	Data from the last 15 years is missing
10	Socabaya	Data from the last 15 years is missing

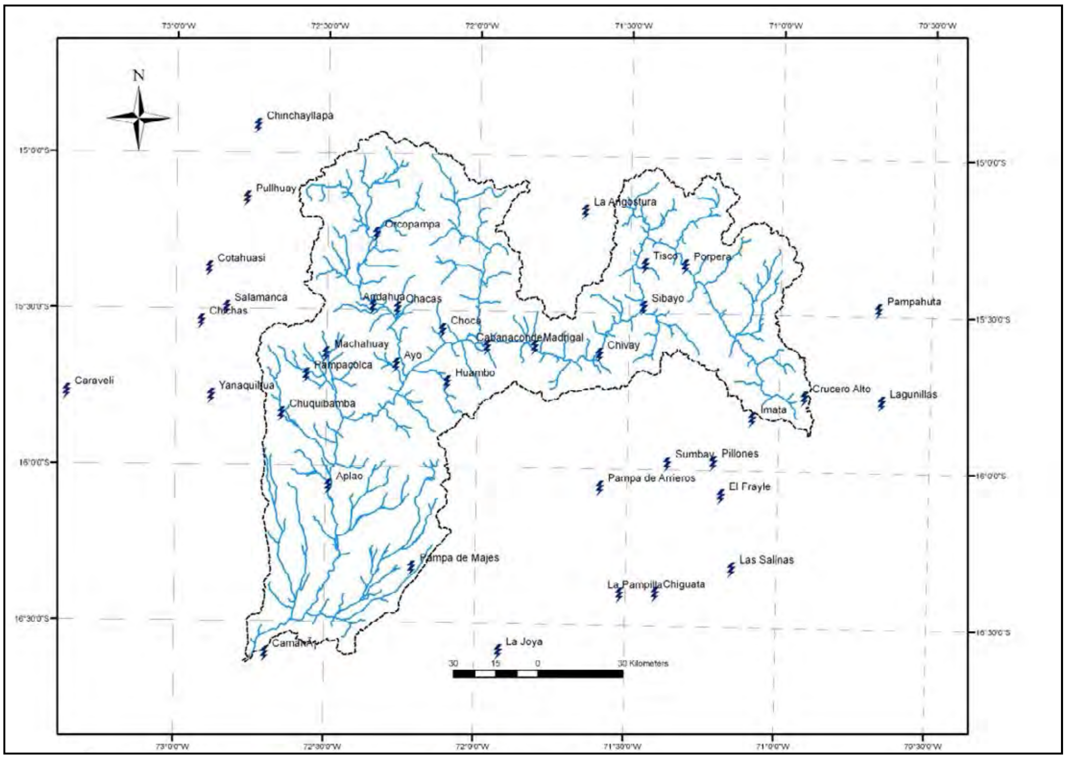
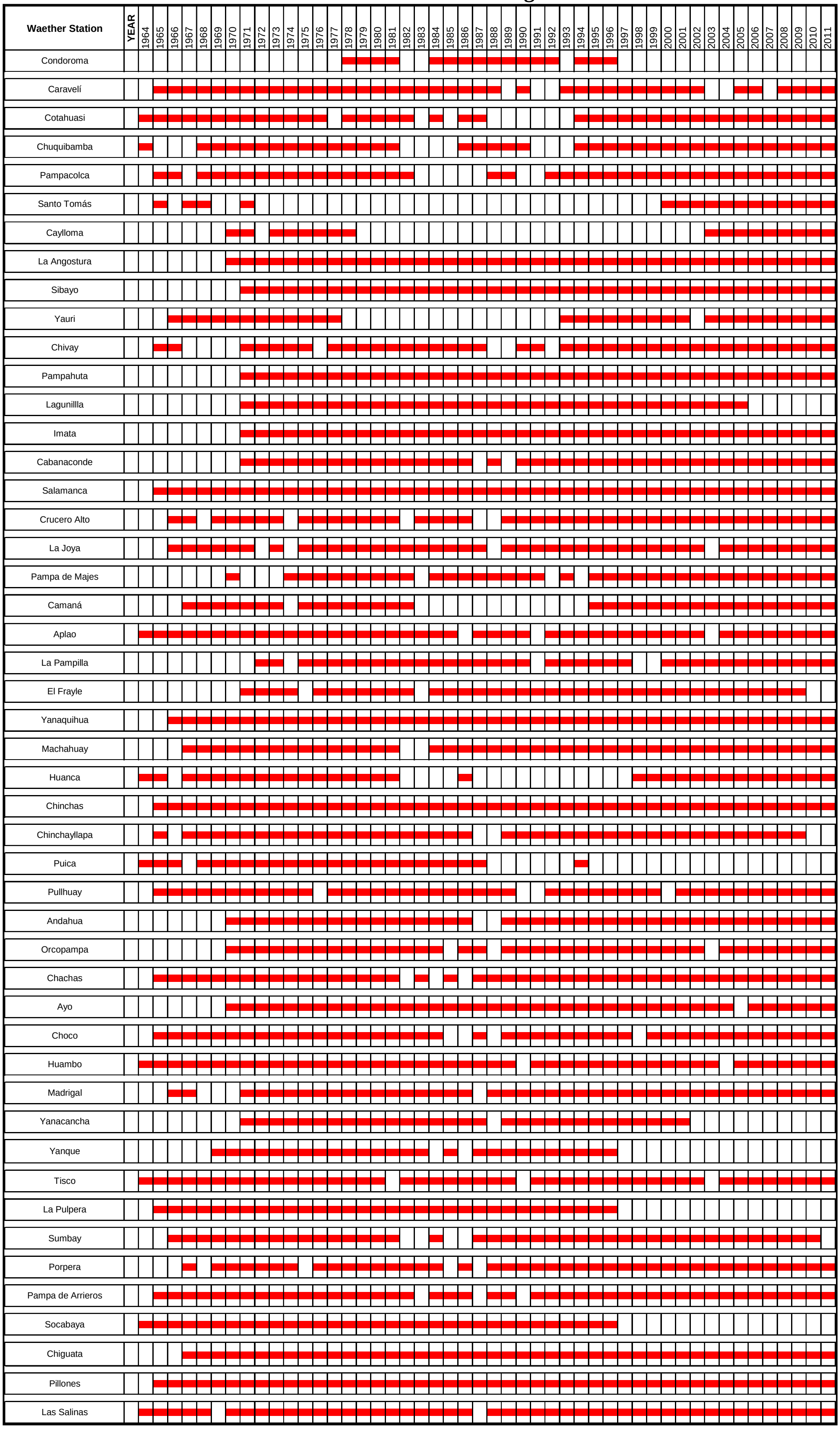


Figure 6. Distribution of 38 Weather Stations used in Hydrologic Simulations.

Table 5. Periods of Data in Weather Stations in the Study Area. A number of Weather Stations were Discarded due to Missing Data.



Hydrologic information is gathered at a few stream gages located along the Colca River, the Andahua River, and the Majes River. The first two are tributaries of the latter. The flow gauging stations in which streamflow information has been collected are Huatiapa Station and Puente Carretera Camana Station. Huatiapa Station started operating in 1964 and Puente Carretera Camana in 1942. The latter finished operating in 1986. The location of both stations is presented below in Table 6. All hydrological stations in the Majes-Canama River basin are shown in Table 7.

Table 6. Location of Main HydrologicStations at the Majes - Camana Basin.

Gauging Station	Latitude	Longitude	Elevation (M.a.s.l.)
Huatiapa	15°59'41.0" S	72°28'13.0" W	700
Puente Carretera Camaná	72°44'00.0" S	16°36'00.0" W	122

Table 7. Location of all hydrologic stations at the Majes - Camana Basin.

No.	Station Name	Category*	Catchment	Department	Province	District	Longitude	Latitude	Elevation	Condition	Working Period	
											Start	End
204601	MARIA PEREZ	HLG	CAMANA	AREQUIPA	CASTILLA	CHOCO	72° 01'1	15° 17'1	4540	Closed	1968-09	1979-03
204602	CALERA MOLLOCO	HLG	CAMANA	AREQUIPA	CASTILLA	CHOCO	72° 00'1	15° 17'1	4524	Closed		
204603	OSCOLLO	HLG	CAMANA	AREQUIPA	CAYLLOMA	SIBAYO	71° 29'41	15° 27'1	4439	Closed	1950-02	1974-08
204604	PUENTE COLGANTE-SIBAYO	HLG	CAMANA	AREQUIPA	CAYLLOMA	SIBAYO	71° 27'1	15° 28'1	4316	Operating	1950-06	1993-03
204605	PALLCA-HUARURO	HLG	CAMANA	AREQUIPA	CAYLLOMA	TAPAY	72° 00'1	15° 35'1	2393	Closed	1968-09	1978-01
204606	BAMPUTAÑE	HLG	CAMANA	AREQUIPA	CAYLLOMA	CALLALLI	71° 07'1	15° 34'1	4495	Paralyzed	1967-09	1974-08
204607	NEGROPAMPA	HLG	CAMANA	AREQUIPA	CAYLLOMA	CABANACONDE	72° 00'1	15° 36'1	2200	Closed	1968-09	1978-01
204608	BLANQUILLO	HLG	CAMANA	AREQUIPA	CAYLLOMA	SAN ANTONIO DE CHUCA	71° 04'1	15° 39'1	4444	Closed		
204609	LAGUNA MAMACOCHA	HLG	CAMANA	AREQUIPA	CASTILLA	AYO	72° 15'1	15° 41'1	1783	Closed		
204610	AYO	HLG	CAMANA	AREQUIPA	CASTILLA	CHOCO	72° 14'1	15° 42'1	1950	Closed		
204611	ANTASALLA	HLM	CAMANA	AREQUIPA	CAYLLOMA	SAN ANTONIO DE CHUCA	71° 04'1	15° 44'1	4439	Closed	1969-01	1973-12
204612	DIQUE LOS ESPANOLES	HLM	CAMANA	AREQUIPA	CAYLLOMA	SAN ANTONIO DE CHUCA	71° 02'1	15° 46'1	4410	Paralyzed	1968-09	1989-12
204614	CHARACTA	HLG	CAMANA	AREQUIPA	CAYLLOMA	MAJES	72° 31'1	16° 32'1	977	Closed		
204615	PUENTE CARRETERA CAMANA	HLG	CAMANA	AREQUIPA	CAMANA	JOSE MARIA QUIMPER	72° 44'1	16° 36'1	25	Paralyzed	1960-01	1986-10
204616	TINTO COLCA	HLG	CAMANA	AREQUIPA	CASTILLA	ANDAGUA	72° 17'1	15° 26'1	4527	Closed		
204617	CALLALLI	HLG	CAMANA	AREQUIPA	CAYLLOMA	CALLALLI	71° 28'1	15° 30'1	3807	Closed	1977-10	1988-12
204618	HUATIAPA	HLG	CAMANA	AREQUIPA	CASTILLA	APLAO	72° 28'14	15° 59'42	699	Operating	1944-09	2011-09
204619	CONDOROMA	HLG	CAMANA	AREQUIPA	CAYLLOMA	TISCO	71° 15'1	15° 15'1	4686	Closed	1977-09	2009-11
204620	PUENTE CARRETERA COLCA	HLG	CAMANA	AREQUIPA	CAYLLOMA	SIBAYO	71° 27'1	15° 29'1	3910	Closed	1950-02	1964-10
204621	REPRESA CONDOROMA	HLG	CAMANA	AREQUIPA	CAYLLOMA	CALLALLI	71° 16'1	15° 23'1	4239	Closed	1993-09	1995-02
204622	HACIENDA PAMPATA	HLG	CAMANA	AREQUIPA	CAMANA	NICOLAS DE PIEROLA	72° 41'58	16° 32'22	75	Operating	2002-11	2011-09
204807	ICHUPAMPA	HLG	CAMANA	AREQUIPA	CAYLLOMA	CABANACONDE	71° 55'1	15° 40'1	4513	Paralyzed	1983-11	1987-07
4729E39A	EMA PAMPA DE MAJES	MAP	CAMANA	AREQUIPA	CAYLLOMA	MAJES	72° 12'38	16° 19'39	1434	Operating	2011-11	2012-09
72D23BE	OCOÑA	EHA	OCOÑA	AREQUIPA	CAMANA	OCOÑA	73° 06'1	16° 26'1	270	Operating	2000-12	2012-09

*CATEGORY
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. Also it records continuously (hourly) water level data graphed in a recording paper.
EHA = Automatic Hydrometric Station (hourly data of water level using sensors).

Maximum annual discharges were obtained from a hydrologic study conducted by Cesar Reyes (2011). Forty one maximum annual discharges corresponding to the Huatiapa Station were available and 17 maximum annual discharges were available for the Puente Carretera Camana Station. At the Huatiapa hydrological gauging station, the float type automatic water level gauge was installed in 2006. However, these automatic hourly water level records have not been digitalized at present. Therefore, it is necessary to mention that maximum daily discharges by manual measurement are not instantaneous peak discharges, but the maximum of 4 times (7:00, 10:00, 14:00 and 18:00) flows manually measured at the Huatiapa stream gage during a day. Most likely, these records miss the instantaneous peak discharge of a day. The maximum annual discharge is the maximum daily discharge of a given year. The study by Reyes (2011) was provided to the consultant by ANA (Peru's National Water Authority) and is considered official information. Statistical analysis was conducted to verify the results given by Reyes (2011).

Statistical Analysis was performed using maximum yearly discharges of the Huatiapa Station. Log Normal, Log Pearson III, GEV, SQRTET and Extreme Value I (Gumbel) were used. The best fit was obtained using the GEV distribution. Selection of the best fit distribution function was based on the SLSC criterion and the error of estimation criterion, which is widely used in the Japan and other countries. Table 8 shows record of maximum annual floods. Table 9 shows the output of the different statistical distribution functions that were used in discharge estimation. Because the purpose of the hydrologic study is to find instantaneous peak discharge for the return periods of interest, a hydrologic simulation will be conducted.

Table 8. Maximum Annual Discharges at Huatiapa Station.

No.	Year	Annual Maximum Discharge (m^3/s)
1	1945	620.00
2	1946	619.00
3	1947	580.79
4	1948	506.50
5	1949	1,012.80
6	1950	458.33
7	1951	687.32
8	1952	592.50
9	1953	980.00
10	1954	980.00
11	1955	2,400.00
12	1956	445.30
13	1957	316.00
14	1958	985.50
15	1959	1,400.00
16	1960	600.00
	1961	
	1962	
	1963	
	1964	
17	1965	171.94
18	1966	237.00
19	1967	420.00
20	1968	442.55
21	1969	308.60
22	1970	362.00
23	1971	356.00
24	1972	633.00
25	1973	1,040.00
26	1974	902.00
27	1975	748.00
28	1976	514.00
29	1977	592.00
30	1978	1,600.00
31	1979	410.00
32	1980	415.00
33	1981	1,000.00
34	1982	345.00
35	1983	23.20
36	1984	1,025.00
	1985	
37	1986	750.00
	1987	
	1988	
	1989	
	1990	
	1991	
	1992	
	1993	
	1994	
	1995	
	1996	
	1997	
	1998	
	1999	
	2000	
	2001	
	2002	
	2003	
	2004	
	2005	
38	2006	590.87
39	2007	366.33
40	2008	418.50
41	2009	400.22

Table 9. Evaluation of Goodness of Fit of 5 Statistical Distributions. GEV Provided the Best Fit Based on the SLSC Criterion.

T (Years)	Log Normal	Log Pearson III	GEV	SQRTET	Gumbel
2	543.7	664.9	559.1	570.1	598.4
5	1,004.6	968.0	900.2	984.6	1,022.0
10	1,385.2	1,080.3	1,168.2	1,309.9	1,302.5
20	1,805.8	1,143.0	1,462.5	1,658.9	1,571.5
25	1,950.8	1,156.4	1,564.3	1,777.1	1,656.9
50	2,433.7	1,184.2	1,905.9	2,163.8	1,919.8
100	2,969.1	1,197.8	2,291.5	2,580.9	2,180.7
200	3,561.8	1,203.5	2,728.0	3,029.1	2,440.7
500	4,400.6	1,205.1	3,396.1	3,669.9	2,783.8
SLSC	0.0877	0.0714	**0.0342**	0.0440	0.0493
Error of Estimation	887.5	759.6	**424.5**	444.3	369.3
Maximum flood on record: 2,400 m^3/s					

3.2. Assumed risk level

The risk level assumed for a structure with a lifespan of n years, designed to resist stresses for a return period T, is:

$$\boxed{R = 1 - \left[1 - \frac{1}{T}\right]^n}$$

The river training works are usually designed to withstand floods ranging between the 20-yr flood and the 100-yr flood. If the river training works lifespan is 20 years, and that return period T, for which the river training works are designed, is 100 years, risk level would be 18.2 %. Table 10 shows risk levels for lifespan ranging between 2 and 500 years and for design return periods between 25 and 500 years.

Table 10. Failure Risk Level for Structures with a Lifespan of n years, Designed for a Return Period T.

Lifespan	**Failure risk for works designed for a return period T, and a lifespan of n years** **Return period, T**				
n (years)	25	50	**100**	200	**500**
2	0.078	0.040	0.020	0.010	0.004
5	0.185	0.096	0.049	0.025	0.010
10	0.335	0.183	0.096	0.049	0.020
20	0.558	0.332	0.182	0.095	0.039
50	0.870	0.636	0.395	0.222	0.095
100	0.983	0.867	0.634	0.394	0.181
200	1.000	0.982	0.866	0.633	0.330
500	1.000	1.000	0.993	0.918	0.632

3.3. Basin Delineation

The main source of information was the National Geographic Institute (IGN) maps. These maps are presented in a 1: 100 000 scale and contour lines are spaced every 50 m and are part of the National Chart ("Carta Nacional"). The list of IGN maps used for this study is given below in Table 11.

Table 11. List of IGN Maps used for Basin Delineation.

Zone 18 S		Zone 19 S		
	30-r			
31-q	31-r	31-s	31-t	31-u
32-q	32-r	32-s	32-t	32-u
33-q	33-r			
34-q	34-r			

The Majes – Camaná Basin was divided in 4 sub basins for the purpose of estimating the discharges and for sediment transport simulations. Arc Map®, a Geographic Information System (GIS) package was used to divide the basins. Arc Hydro® is a module that allows one to divide the terrain in sub basins. In addition, delineation was improved by manual adjustments recommended in GIS textbooks. Figure 7 shows the Majes-Camana basin and its sub divisions.

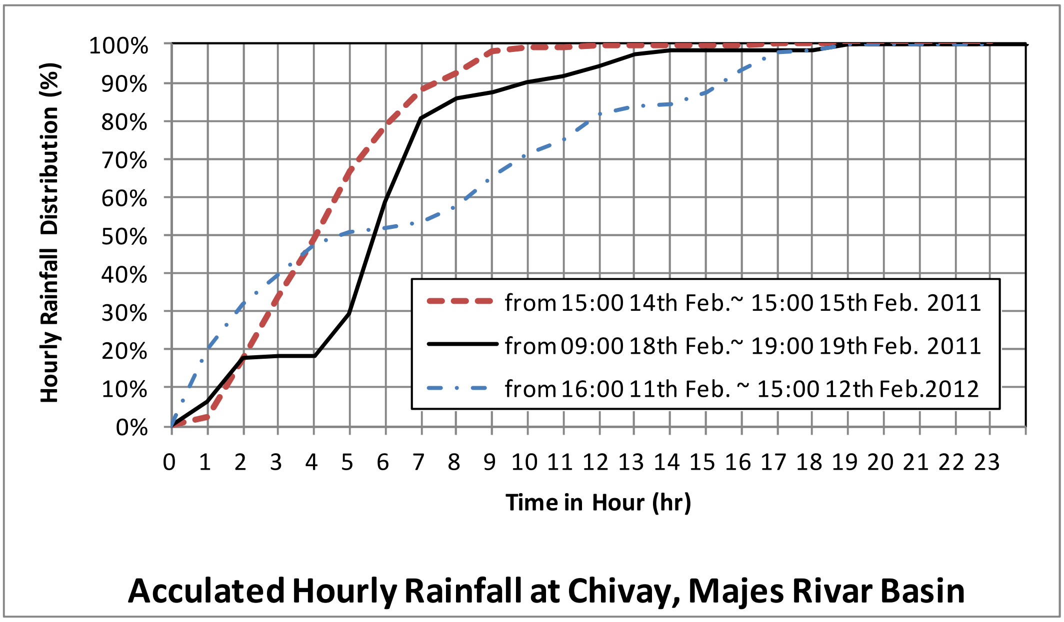
Figure 7. Majes - Camaná Basin and its 4 Sub Basins.

3.4. Design Precipitation

Data from a number of weather stations are available for this study. The majority belong to the Peruvian National Meteorological and Hydrological Service (SENAMHI, in Spanish). However, many stations were permanently or temporarily deactivated. Therefore, much data is missing. Maximum annual 24 hr precipitation data is available. Statistical analysis was conducted.

Only the Chivay rainfall station in upstream of the Camana Majes River basin is available hourly rainfall record by automatic rainfall gauge since 2001. However, the digitized hourly rainfall record at Chivay is available from year 2011. The JICA Study Team collected the hourly rainfall records of rainy season (January to March) of year 2011 and 2012. Figure 8 shows the depth-duration analysis (D-D Analysis) of hourly rainfall data at Chivay rainfall station for major floods in February 2011 and February 2012. The peak discharge at Huatiapa water level gauging station in February 11, 2012 is at 1,400 m^3/s. According to the Figure 8, the rainfall duration of major floods is around 7 to 17 hours.

Twenty four hour precipitation was estimated for the 2, 5, 10, 20, 25, 50 and 100 year design period using the Normal, Log Normal, Log Pearson III and Extreme Value Type I (Gumbel) statistical distributions due to D-D analysis of Chivay hourly rainfall data. The best fit was determined using the Kolmogorov Smirnov method. This is a non-parametric method and can be applied to all distributions. The estimated precipitations for each weather station are given below in Table 12.



Source: Prepared by JICA Study Team based on the hourly rainfall record at Chivay by SENAMHI

Figure 8. Accumulated Hourly Rainfall of Major Floods at Chivay Rainfall Station.

Table 12. Precipitation for Different Return Periods at each Selected Weather Station.

	Coordinates			Precipitation for T (years)						
Station	**Latitude**	**Longitude**	**Altitude (masl)**	**2**	**5**	**10**	**25**	**50**	**100**	**200**
Andahua	15° 29'37	72° 20'57	3538	24.30	31.33	34.83	38.29	40.33	42.02	43.43
Aplao	16° 04'10	72° 29'26	625	1.71	5.03	7.26	9.51	10.71	11.56	12.14
Ayo	15° 40'45	72° 16'13	1950	10.28	16.43	20.51	25.66	29.48	33.27	37.05
Cabanaconde	15° 37'7	71° 58'7	3369	26.58	37.88	45.89	56.58	64.95	73.67	82.79
Camaná	16° 36'24	72° 41'49	29	3.18	7.16	9.79	13.11	15.58	18.03	20.46
Caravelí	15° 46'17	73° 21'42	1757	7.67	16.07	22.60	31.46	38.30	45.21	52.15
Chachas	15° 29'56	72° 16'2	3130	22.21	28.60	32.08	35.83	38.24	40.37	42.30
Chichas	15° 32'41	72° 54'59.7	2120	16.28	23.47	27.01	30.37	32.23	33.67	34.80
Chiguata	16° 24'1	71° 24'1	2945	18.88	29.98	37.33	46.40	52.94	59.27	65.42
Chinchayllapa	14° 55'1	72° 44'1	4514	23.12	31.21	36.57	43.34	48.37	53.35	58.32
Chivay	15° 38'17	71° 35'49	3663	24.50	32.74	38.20	45.09	50.21	55.29	60.35
Choco	15° 34'1	72° 07'1	3160	16.10	22.92	27.45	33.16	37.39	41.60	45.79
Chuquibamba	15° 50'17	72° 38'55	2839	21.65	36.96	47.09	59.89	69.39	78.82	88.21
Cotahuasi	15° 22'29	72° 53'28	5086	21.20	29.97	35.78	43.12	48.56	53.96	59.35
Crucero Alto	15° 46'1	70° 55'1	4486	25.33	31.66	35.20	39.10	41.67	44.02	46.17
El Frayle	16° 05'5	71° 11'14	4110	22.33	29.95	35.43	42.89	48.83	55.12	61.82
Huambo	15° 44'1	72° 06'1	3500	22.87	30.14	34.96	41.05	45.57	50.05	54.52
Imata	15° 50'12	71° 05'16	4451	28.35	37.09	42.87	50.18	55.60	60.98	66.34
La Angostura	15° 10'47	71° 38'58	4260	35.90	45.89	53.22	63.31	71.46	80.18	89.57
La Joya	16°35'33	71°55'9	1279	1.22	4.74	7.89	11.93	14.65	16.98	18.92
La Pampilla	16° 24'12.2	71° 31'.6	2388	12.65	21.64	27.66	35.01	40.23	45.20	49.94
Lagunillas	15° 46'46	70° 39'38	4385	28.55	34.30	37.75	41.81	44.67	47.40	50.05
Las Salinas	16° 19'5	71° 08'54	3369	18.05	25.72	30.80	37.22	41.98	46.70	51.41
Machahuay	15° 38'43	72° 30'8	3000	21.06	29.80	34.71	40.03	43.45	46.46	49.14
Madrigal	15° 36'59.7	71° 48'42	3238	23.63	30.07	33.66	37.59	40.17	42.50	44.63
Orcopampa	15° 15'39	72° 20'20	3805	21.51	29.58	36.83	48.66	59.81	73.37	89.92
Pampa de Arrieros	16° 03'48	71° 35'21	3720	18.86	32.08	40.82	51.88	60.07	68.21	76.32
Pampa de Majes	16° 19'40	72° 12'39	1442	2.07	6.68	10.56	15.55	18.98	22.04	24.69
Pampacolca	15° 42'51	72° 34'3	2895	21.13	29.11	34.40	41.08	46.04	50.95	55.86
Pampahuta	15° 29'1	70° 40'33.3	4317	34.18	39.66	42.87	46.58	49.14	51.57	53.89
Pillones	15° 58'44	71° 12'49	4428	24.00	32.95	38.88	46.36	51.92	57.43	62.92
Porpera	15° 21'1	71° 19'1	4142	27.40	40.61	49.37	60.42	68.63	76.77	84.88
Pullhuay	15° 09'1	72° 46'1	3098	24.47	32.43	37.63	44.15	48.97	53.77	58.60
Salamanca	15° 30'1	72° 50'1	3153	19.86	26.64	31.13	36.81	41.02	45.20	49.36
Sibayo	15° 29'8	71° 27'11	3839	31.25	38.61	42.98	48.06	51.59	54.93	58.13
Sumbay	15° 59'1	71° 22'1	4300	25.43	35.57	43.10	53.56	62.08	71.26	81.17
Tisco	15° 21'1	71° 27'1	4198	33.41	42.74	51.24	65.12	78.15	93.95	113.15
Yanaquihua	15° 46'59.8	72° 52'57	2834	20.70	35.78	45.76	58.38	67.74	77.03	86.29

The precipitation in each basin was calculated using the inverse weight method based upon the precipitation in the selected stations. Isohyets for each return period that was studied were obtained. Figures 9, 10, 11, 12, 13 and 14 show the 24-hr precipitation isohyets estimated for the 2, 5, 10, 25, 50 and 100-yr return periods.

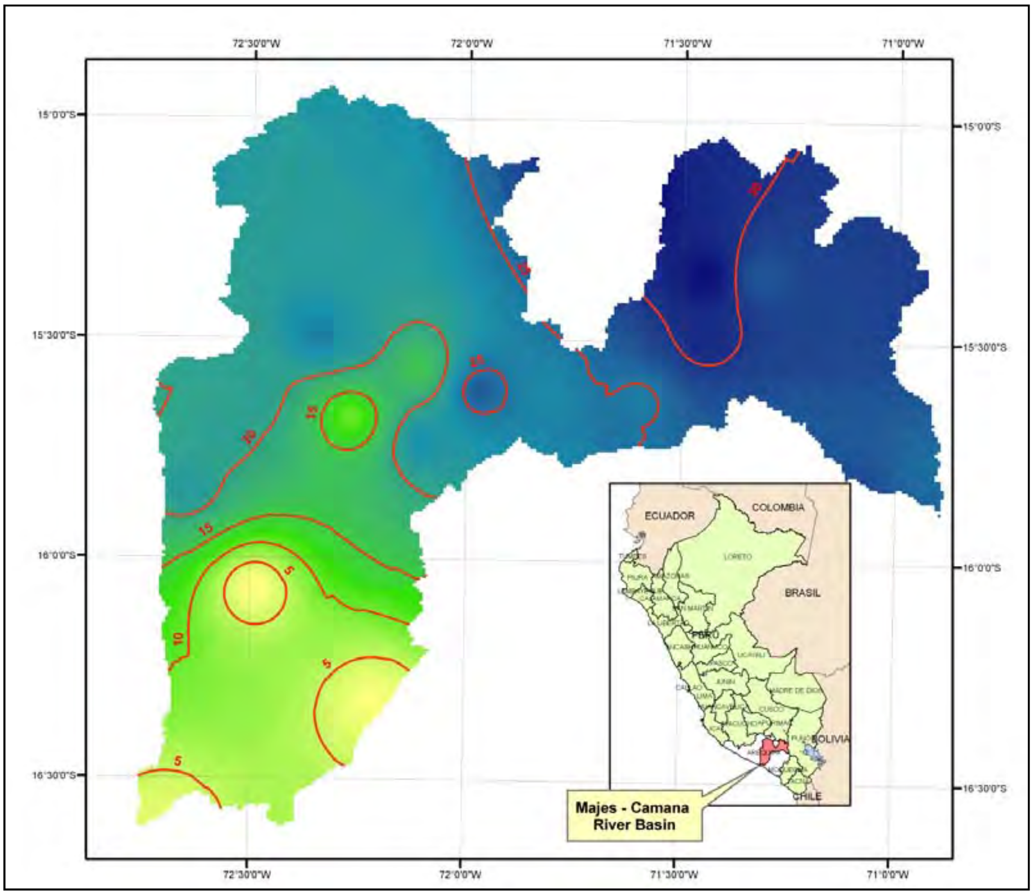


Figure 9. Isohyets Delineated for 2-yr 24 hr Precipitation.

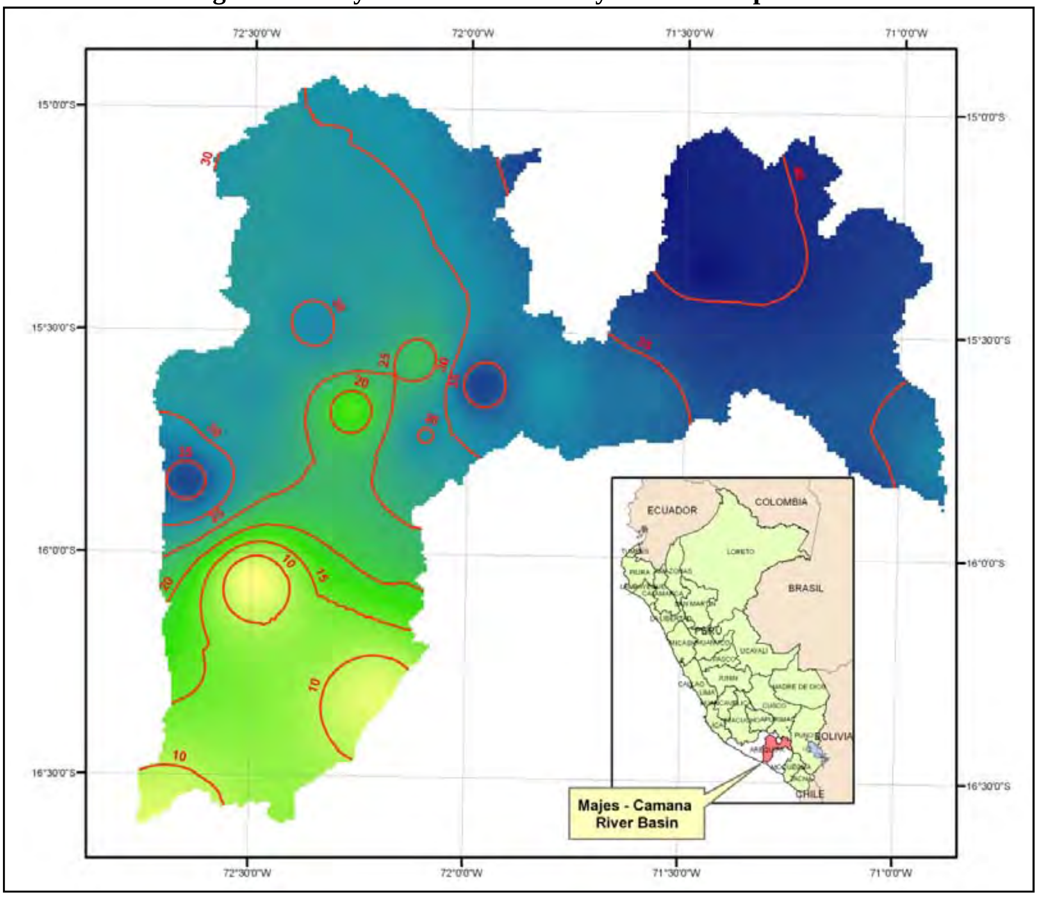


Figure 10. Isohyets Delineated for 5-yr 24 hr Precipitation.

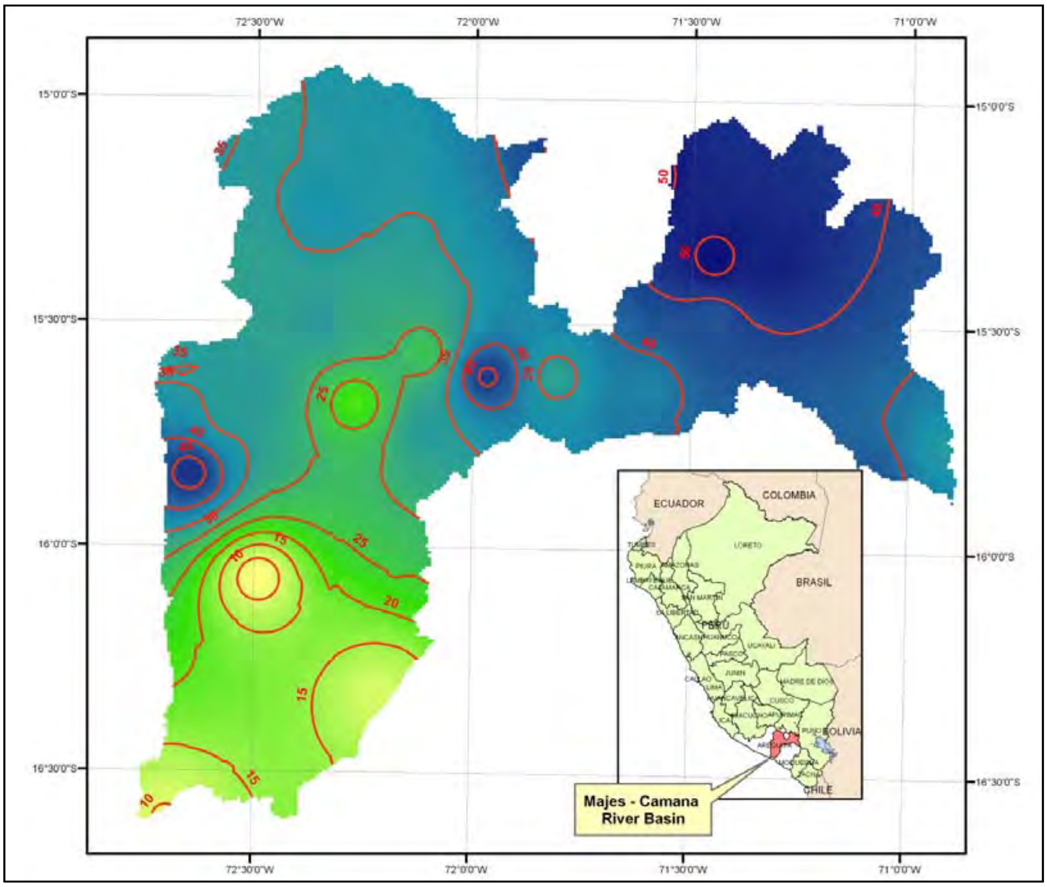


Figure 11. Isohyets Delineated for 10-yr 24 hr Precipitation.

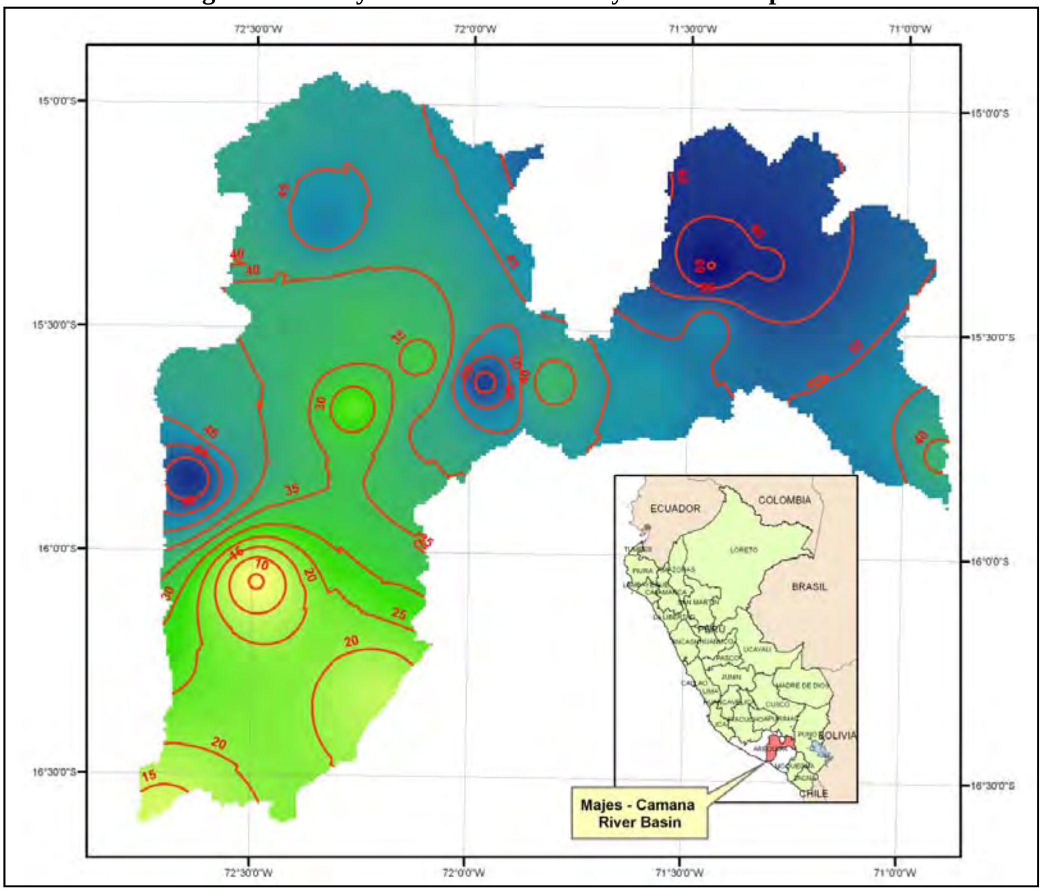


Figure 12. Isohyets Delineated for 25-yr 24 hr Precipitation.

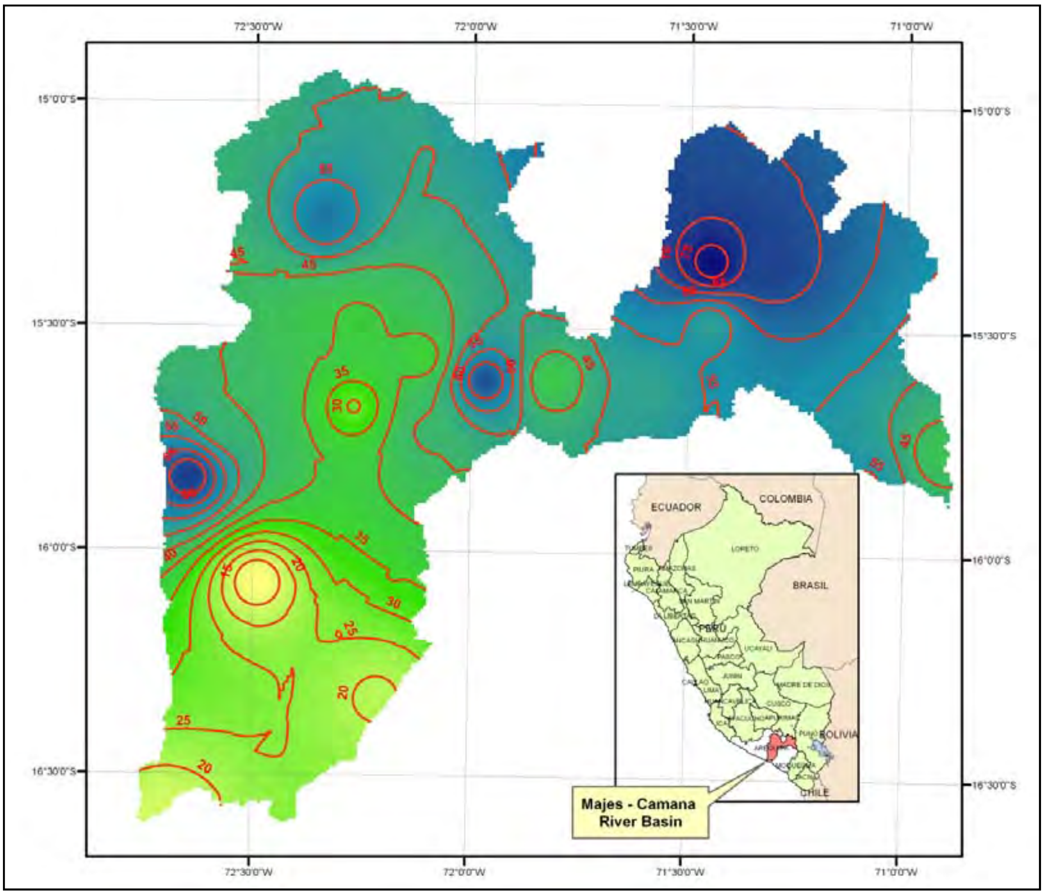


Figure 13. Isohyets Delineated for 50-yr 24 hr Precipitation.

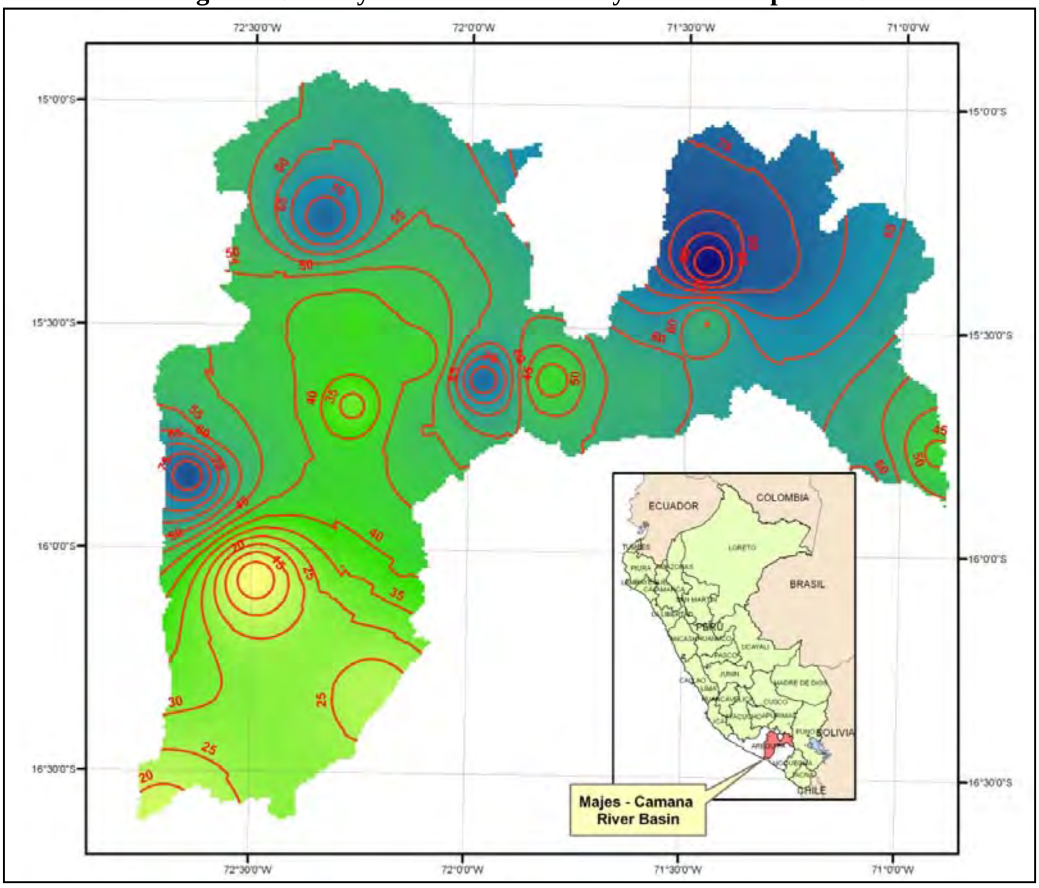


Figure 14. Isohyets Delineated for 100-yr 24 hr Precipitation.

Twenty four-hour precipitations were calculated for each sub basin. The database corresponding to the precipitation of each weather station was used to determine the values of precipitations corresponding to the 2, 5, 10, 25, 50 and 100 year return periods for each sub basin. Thiessen polygons were used to estimate the area of influence of each rain gage. Areas of influences are presented in Appendix B.6. Schematic of the area of influence is shown below in Figure 15. Mean areal rainfall for each sub basin was found thereafter. Table 13 summarizes the precipitations for each sub basin.

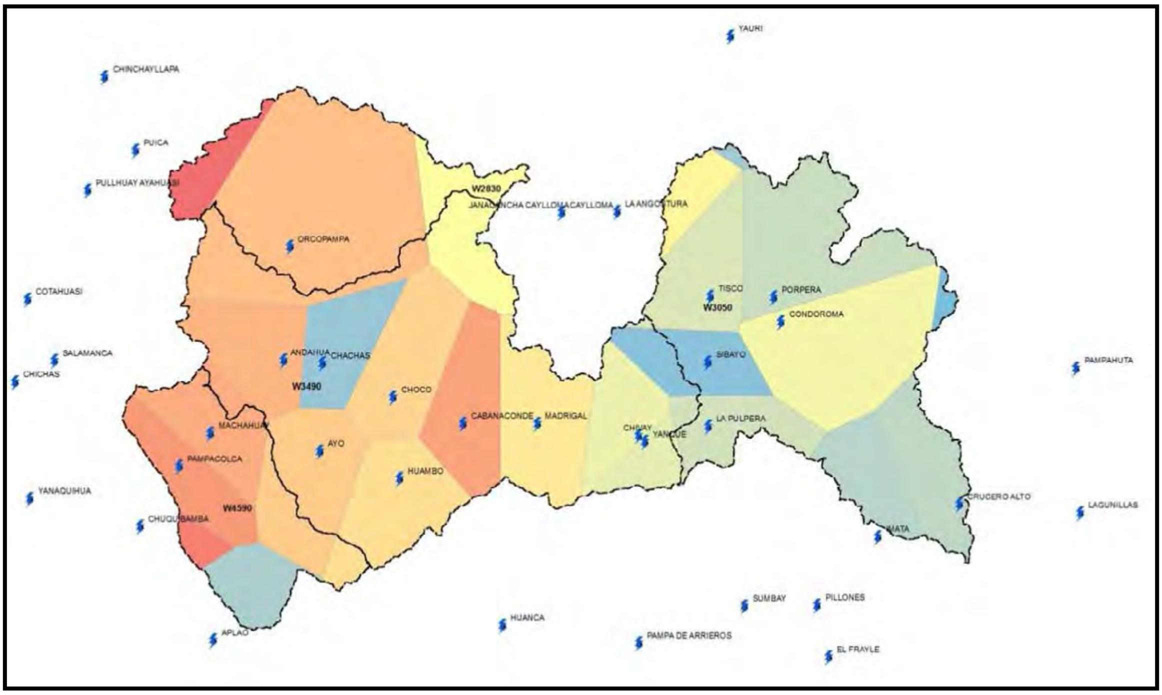


Figure 15. Schematics of the Areas of Influence of Rainfall Stations for Estimating Precipitation in each Sub Basin.

Table 13. Precipitation for each Sub Basin of the Majes-Camana Basin.

Sub basin	Mean areal rainfall (mm.)				
	T5	T10	T25	T50	T100
W2830	29.60	36.80	48.68	59.96	73.45
W3050	38.20	46.10	55.14	62.47	70.23
W3490	29.25	34.14	40.63	45.15	50.03
W4590	23.05	27.70	33.23	36.98	40.77

Because 24 hour precipitations are available, and there is much uncertainty on the rainfall distribution, an SCS distribution was used. This distribution can be essentially used with any rainfall duration. SCS rainfall distributions are shown in Table 14. In this case, a modified SCS Type I distribution was used due to the hourly rainfall patterns of major flood in February 2011 and 2012 at Chivay rainfall station as shown in Figure 8 above.

Table 14. SCS Rainfall Distributions Type I, IA, II and III.

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

3.5. Infiltration Model

The infiltration model used for this study was the Curve Number (CN) method. This method was first proposed by the former Soil Conservation Service (Natural Resources Conservation Service – NCRS, nowadays) of the United States of America. This method allows one to estimate a single parameter based on the type of soil and the land use.

The CN method assumes that a basin has a storage capacity S (inches). There is an Initial abstraction, I_a, that is the height of rain that completely infiltrates before runoff begins. After runoff begins, the infiltration is F_a and runoff is P_e (effective precipitation), therefore, total precipitation, P is:

$$P = P_e + I_a + F_a$$

The CN method assumes that there is a relation between effective precipitation, storage capacity and initial abstraction, as follows:

$$\frac{P_e}{S} = \frac{P_e}{P - I_a}$$

Using the two previous equations and after algebraic manipulations, results in:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

In addition, it is assumed that P_e = 0.2 S.

$$P_e = \frac{(P_e - 0.2S)^2}{P + 0.8S}$$

The CN is related to S by:

$$S = \frac{1000}{CN} - 10$$

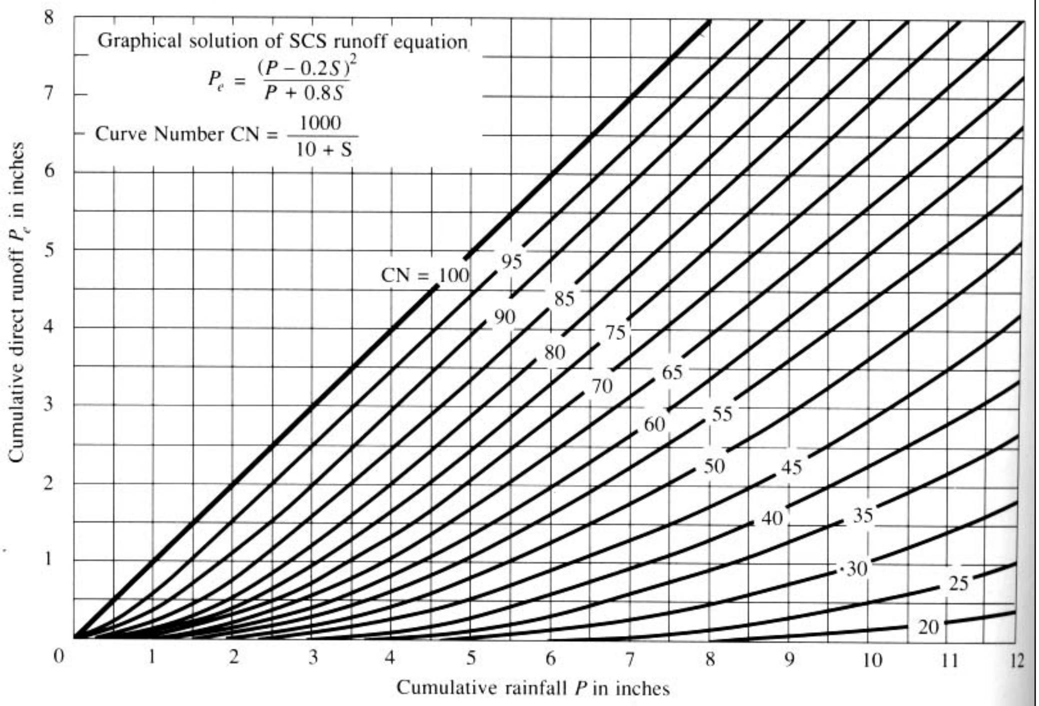


FIGURE 5.5.2
Solution of the SCS runoff equations. (*Source:* Soil Conservation Service, 1972, Fig. 10.1, p. 10.21)

Figure 16. Relation between Total Precipitation, P, and Effective Precipitation, P_e.

The CN values are given for "normal conditions", this is when the precipitation registered the 5-day period preceding the event ranges between 35.5 mm and 53.3 mm. CN values for normal conditions are given in Tables 15, 16 and 17. CN values are estimated based on the type of soil and land use.

If the precipitation falls below 35.5 mm a correction factor that lowers the value of CN is applied. This is called Antecedent Moisture Condition I (AMC I). If the precipitation exceeds 53.3 mm during the preceding 5-day period, the precipitation is adjusted and the CN value increases. This is called Antecedent Moisture Condition III, AMC III.

Equation for estimating CN for AMC I as follows:

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)}$$

Equation for estimating CN for AMC III follows:

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)}$$

Table 15. Values of CN Based Upon Soil Type (Hydrologic Soil Group) and Land Use.

TABLE 5.5.2
Runoff curve numbers for selected agricultural, suburban, and urban land uses (antecedent moisture condition II, $I_a = 0.2S$)

Land Use Description	Hydrologic Soil Group A	B	C	D
Cultivated land[1]: without conservation treatment	72	81	88	91
with conservation treatment	62	71	78	81
Pasture or range land: poor condition	68	79	86	89
good condition	39	61	74	80
Meadow: good condition	30	58	71	78
Wood or forest land: thin stand, poor cover, no mulch	45	66	77	83
good cover[2]	25	55	70	77
Open Spaces, lawns, parks, golf courses, cemeteries, etc.				
good condition: grass cover on 75% or more of the area	39	61	74	80
fair condition: grass cover on 50% to 75% of the area	49	69	79	84
Commercial and business areas (85% impervious)	89	92	94	95
Industrial districts (72% impervious)	81	88	91	93
Residential[3]:				
Average lot size — Average % impervious[4]				
1/8 acre or less — 65	77	85	90	92
1/4 acre — 38	61	75	83	87
1/3 acre — 30	57	72	81	86
1/2 acre — 25	54	70	80	85
1 acre — 20	51	68	79	84
Paved parking lots, roofs, driveways, etc.[5]	98	98	98	98
Streets and roads:				
paved with curbs and storm sewers[5]	98	98	98	98
gravel	76	85	89	91
dirt	72	82	87	89

[1]For a more detailed description of agricultural land use curve numbers, refer to Soil Conservation Service, 1972, Chap. 9

[2]Good cover is protected from grazing and litter and brush cover soil.

[3]Curve numbers are computed assuming the runoff from the house and driveway is directed towards the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[4]The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

[5]In some warmer climates of the country a curve number of 95 may be used.

Table 16. Values of CN Numbers for Rural Areas and Arid and Semiarid Areas. Source: Maidment (1993).

TABLE 5.5.1 SCS Runoff Curve Numbers *(Continued)*

c. Other agricultural areas

Cover description: Cover type	Hydrologic condition	Curve numbers for hydrologic soil group: A	B	C	D
Pasture, grassland, or range—continuous forage for grazing*	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element†	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods-grass combination (orchard or tree farm)‡	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods§	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots	—	59	74	82	86

* *Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.
† *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
‡ CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.
§ *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.
Source: Ref. 105.

d. Arid and semiarid range areas

Cover description: Cover type	Hydrologic condition*	Curve numbers for hydrologic soil group: A†	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Piñon-juniper—piñon, juniper, or both: grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55

Table 17. Values of CN Numbers for Arid and Semiarid areas. Source: Maidment (1993).

TABLE 5.5.1 SCS Runoff Curve Numbers *(Continued)*

d. Arid and semiarid range areas

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition*	A†	B	C	D
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

* *Poor:* <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.
† Curve numbers for group A have been developed only for desert shrub.
Source: Ref. 105.

For establishing the initial CN values, the basin's territory was divided in different areas. The highlands of the upper basin, a barren land, barely covered by soils left by glacier retreat, mostly moraines, and with scarce vegetation, composed by pastures, were assigned a CN value of 65. This was corrected using the equation for the AMC III condition, and a value of 81 was obtained. The middle reaches are covered with pastures, small bushes and threes, and a CN value of 55 was assigned. In this area, it was also necessary to correct the value using the AMC III correction, and a value of 75 was obtained. Finally, the lower reaches are located in a hyper arid area, with annual precipitations of less than 50 mm. A value of 79 was assigned, but the correction factor for AMC I condition was applied, rendering a value of 61 for the lower reaches. Figure 17 shows the distribution of the initial and final CN values that were adjusted during the calibration process.

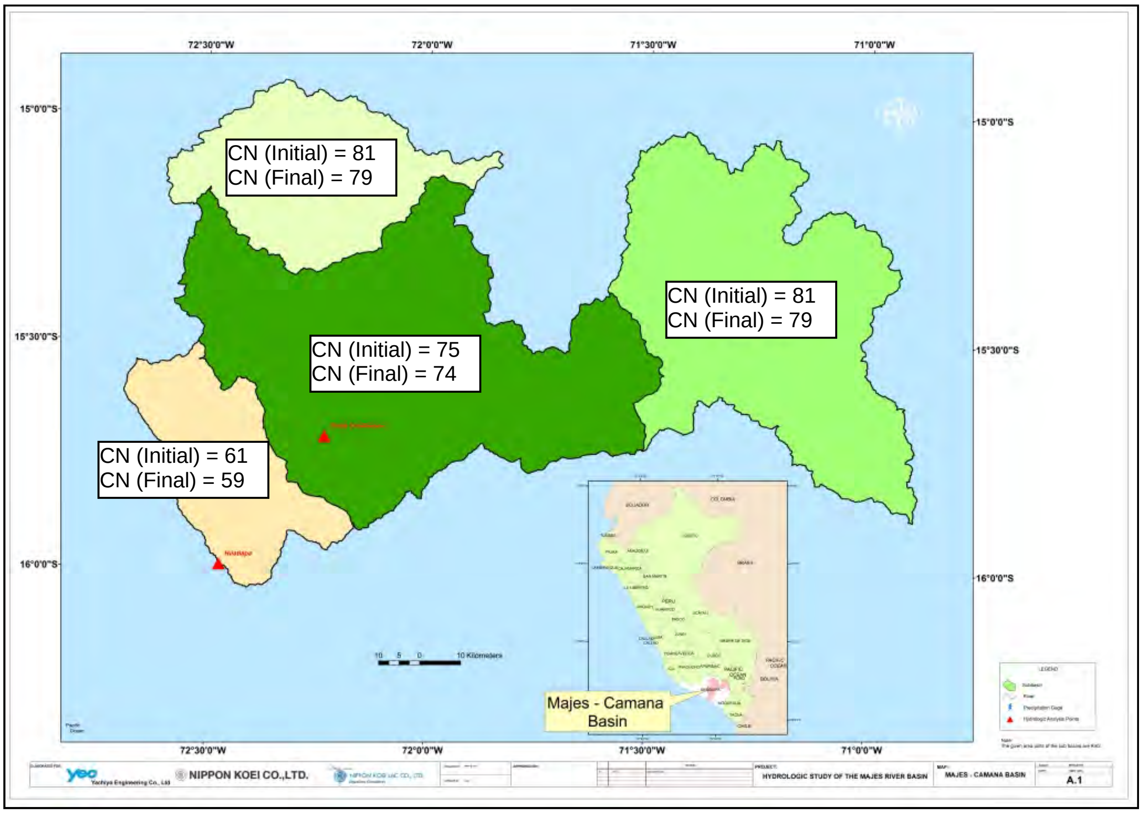


Figure 17. Initial and Final Distribution of Curve Number for the Hydrologic Simulation and Calibration.

3.6. Unit Hydrograph (Transform) Model

The Unit Hydrograph model used is the former SCS method. This method estimates a time of concentration based on the length of the basin, L, the slope of the basin, S, in percentage, and CN. The formula is presented below.

$$\boxed{t_c(hr) = \frac{4.3611 L^{0.8}\left[\dfrac{1000}{CN} - 9\right]^{0.7}}{1900 S^{0.5}}}$$

The lag time is 0.6 t_c. The lag time is entered in the HEC-HMS program as the only variable that will be used to estimate the hydrograph in each basin. Lag times for each basin are presented in Appendix C.1.

3.7. Flood Routing Model

The flood routing model used in this study is the kinematic wave method. This method is based on the

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$

$$S_o = S_f$$

It is also assumed that the area, A, is proportional to the discharge, Q, as follows:

$$A = \alpha Q^{\beta}$$

Rewriting Manning's equation results in:

$$A = \left(\frac{nP^{2/3}}{S_o^{1/2}} \right)^{3/5} Q^{3/5}$$

Therefore:

$$\alpha = \left(\frac{nP^{2/3}}{S_o^{1/2}} \right)^{3/5}$$

$$\beta = 0.6$$

This is solved using a numerical method using:

$$Q_{i+1}^{j+1} = \frac{\left[\frac{\Delta t}{\Delta x}\right] Q_i^{j+1} + \alpha\beta Q_{i+1}^{j} \left(\frac{Q_{i+1}^{j} + Q_i^{j+1}}{2} \right)^{\beta-1} + \Delta t \left(\frac{q_{i+1}^{j+1} + q_{i+1}^{j}}{2} \right)}{\left[\frac{\Delta t}{\Delta x} + \alpha\beta \left(\frac{Q_{i+1}^{j} + Q_i^{j+1}}{2} \right)^{\beta-1} \right]}$$

3.8. Baseflow calculations

Baseflow was estimated using discharges from the Huatiapa Station. The minimum flow for each month was identified and the average of the minimum flow was found. This value is assumed constant for each month of the year and has been based upon field data from the Huatiapa Station. Finally, the average of the minimum flows for February was used as the total baseflow discharge for the rainfall-runoff simulations. Because the Majes – Camana basin has been divided in 4 sub-basins and data is entered for each sub basin in the HEC-HMS model, baseflows were assumed to be proportional to the sub basins areas, so that the sum of the baseflows would equal the flow in Huatiapa. Results are presented in Table 18.

Table 18. Estimated Baseflow Discharge (m^3/s) at Huatiapa Station.

Sub basin	January	February	March
W2830	8.37	14.69	14.24
W3050	17.46	30.65	29.72
W3490	22.32	39.18	37.99
W4590	6.25	10.98	10.64
Total	54.4	95.5	92.6

Based on these new baseflow values and the new discharge data provided (maximum daily discharge), calibration is performed in order to find the new curve numbers.

3.9. Logical Support (Software)

The program used to carry out the hydrologic simulation is the HEC – HMS version 3.4 program that was developed by the United States Army Corps of Engineers, in order estimate the flow at the interest points. This program allows for simulating surface runoff produced in the basins, flood flows through channels or conduits, and dam flood flows. The basin model has modules to calculate infiltration, the unit hydrograph, and the base flow by different methods. In this case, the SCS method has been chosen to calculate infiltration, the SCS method has been chosen to estimate the surface runoff hydrograph, and later, the base flow has been included. The kinematic wave model was used for modeling flood routing.

Sub – basins join at points called junctions. The program allows for including reservoirs of any size in the model. The design precipitation and the rainfall type are introduced into the meteorological model.) In this case, discharges will be estimated for the 2, 5, 10, 25, 50 and 100 yr floods. Figurer 18 shows the schematic of the HEC-HMS 3.4 program implemented with the Majes – Camaná basin data.

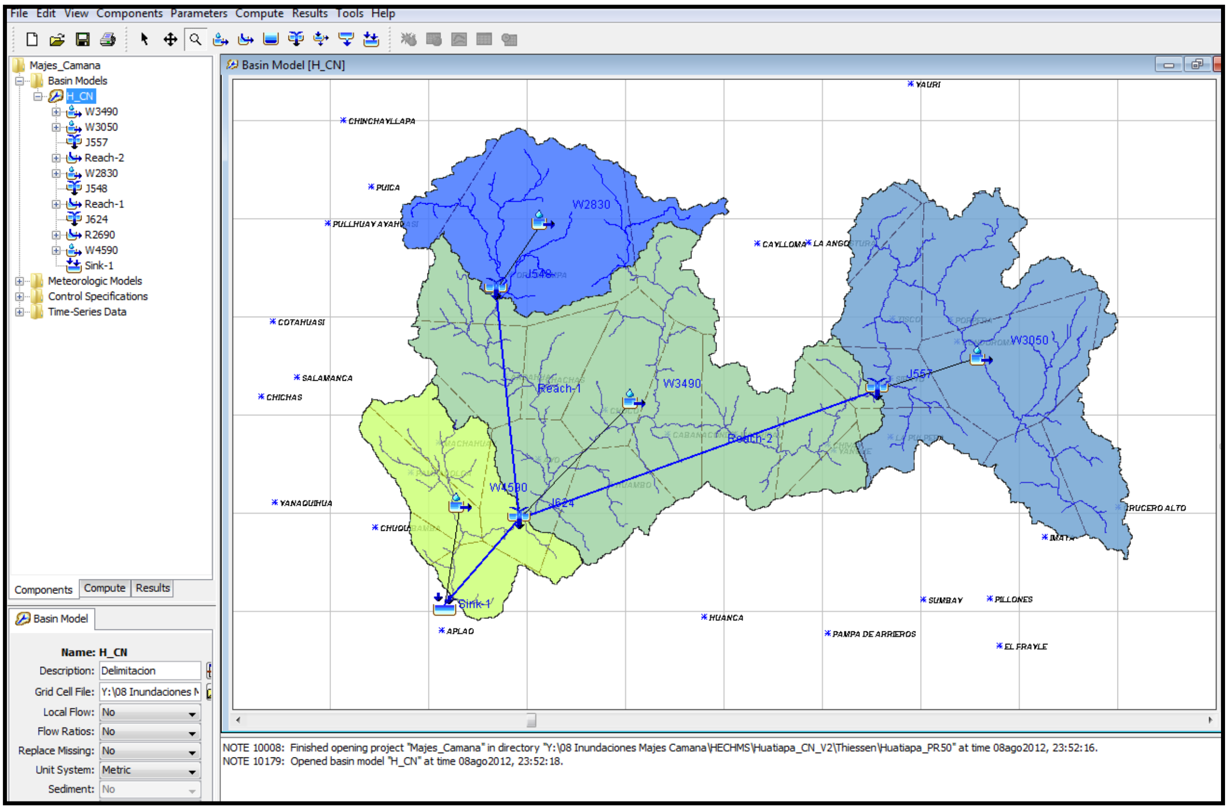


Figure 18. HEC-HMS Schematic of the Majes - Camaná Basin showing its 4 sub Basins.

3.10. Calibration of the Curve Number

The Curve Number (CN, hereafter) is the only variable that can be calibrated. The rest of the variables can be measured directly or estimated from maps or other sources. Therefore, initial values were assumed taking into account the type of soil and the land use. Values were extracted from tables published by the former Soil Conservation Service (Currently, the Natural Resources Conservation Service, NCRS). The precipitation of the N year return period must correspond to the peak discharge of the N year return period.

The peak discharge using the precipitations corresponding to the return periods of interest were estimated at Huatiapa station. If the values exceeded the maximum daily discharges for the same return periods, then the duration of the time exceeding the maximum daily discharge was analyzed.

In this case, initial CN values produced floods much larger than the calculated using flood records. Therefore, CN values decreased in each sub zone until an appropriate hydrograph was found. Initial and final CN values are given in Table 19. A map showing the initial CN values in the Majes – Camana basin can also be found in Appendix C.2.

The final values produced hydrographs that will be used for the other teams involved in the study. The peak discharges will be used for floodplain delineation in the lower reaches.

Table 19. Initial and Final Values of CN.

Area	Description	Estimated Initial CN	Final CN
Upper Basin - Colca	Barren area with scarce vegetation.	81	79
Upper Basin - Andahua	Barren area with scarce vegetation.	81	79
Middle Basin – Colca and Andahua	Pastures, shrub, small trees.	75	74
Lower Basin - Majes	Desert, hyper arid area	61	59

The times of concentration, t_c, were found for every condition tested and lag times were recalculated. Final values of discharges at Station Huatiapa were found for the 2, 5, 10, 20, 25, 50 and 100 year return periods and are presented in Table 20. Figures 19 through 32 show the summary of results and hydrographs for the same return periods. Detailed information of flood hydrographs at Huatiapa can be found in Appendix C.3.

Table 5. Peak Discharges for Different Return Periods at Huatiapa.

T (years)	Q (m^3/s)
2	305,8
5	637,7
10	1007
20	1415,9
25	1565,6
50	2083,6
100	2702,6

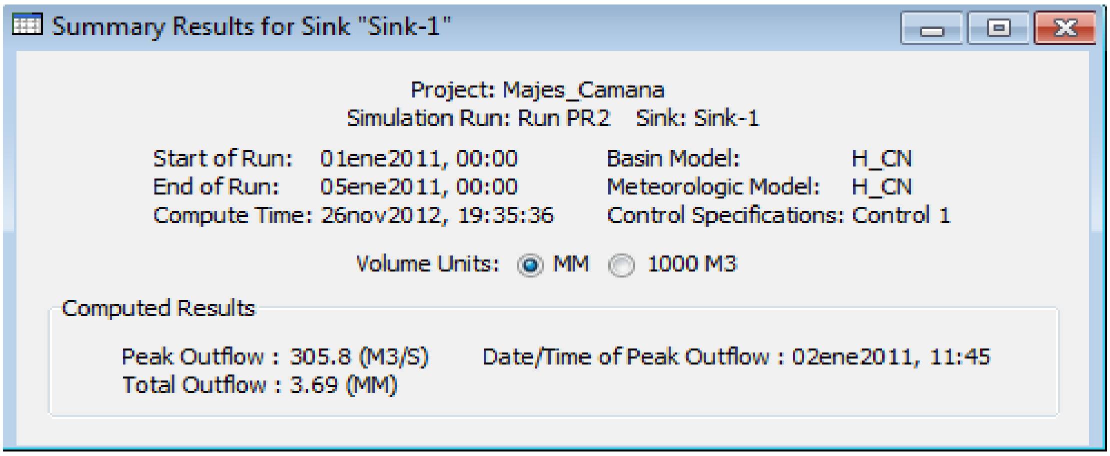


Figure 19. Summary of Results of HEC-HMS Program for 2-year Flood at Station Huatiapa.

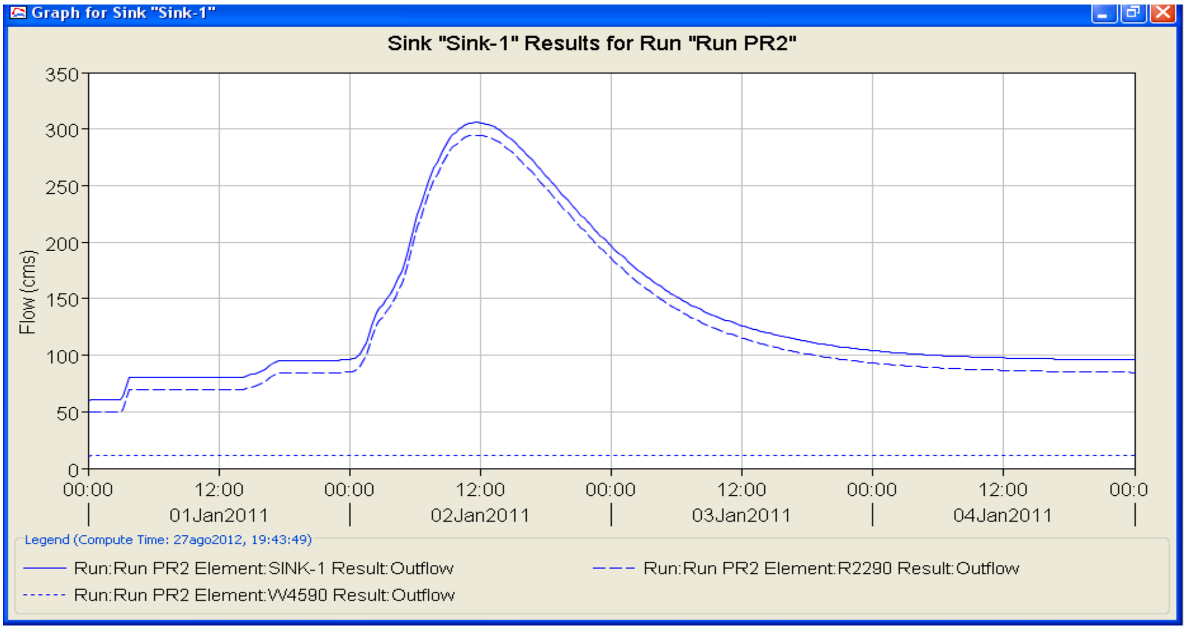


Figure20. Hydrograph for 2-year Return Period.

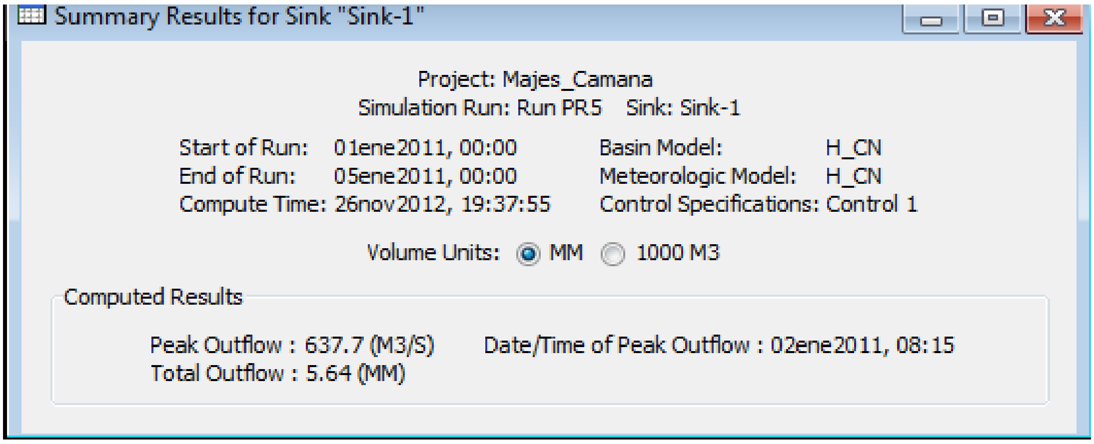


Figure 21. Summary of Results of HEC-HMS Program for 5-year Flood at Station Huatiapa.

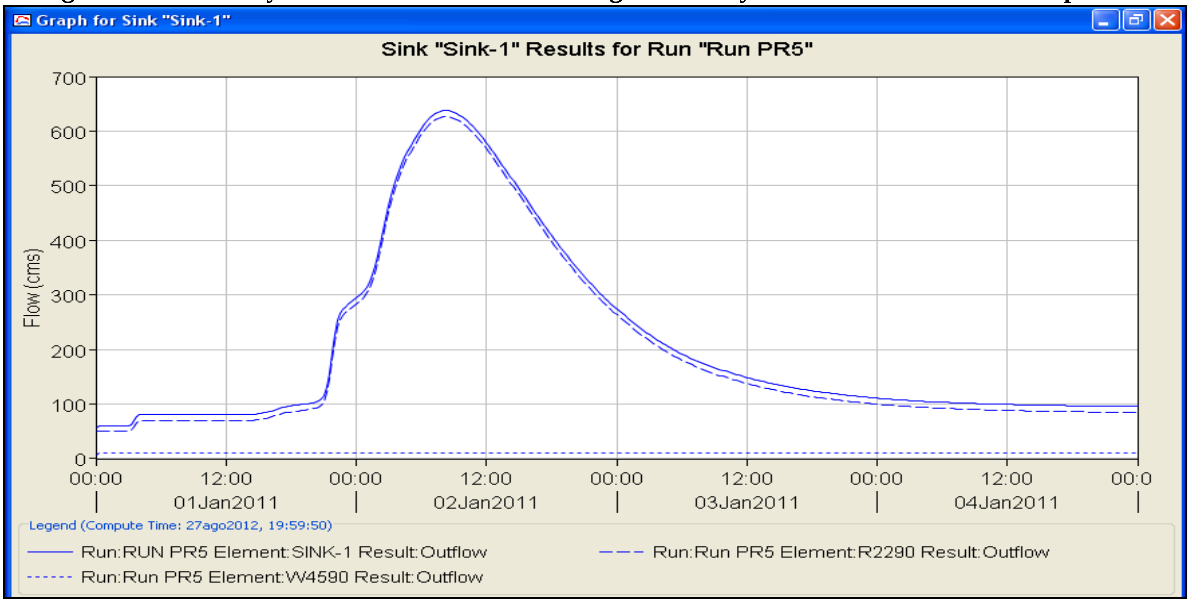


Figure 22. Hydrograph for 5-year Return Period.

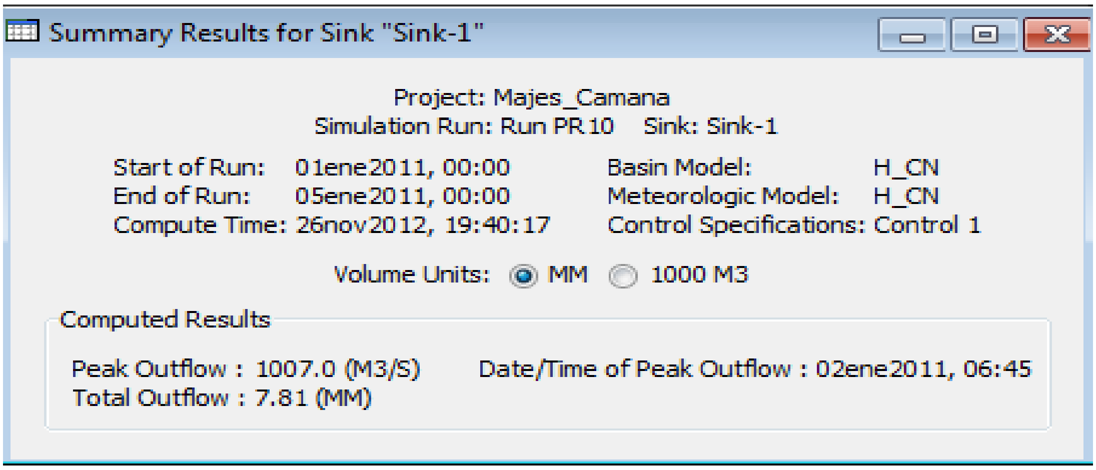


Figure 23. Summary of Results of HEC-HMS Program for 10-year Flood at Station Huatiapa.

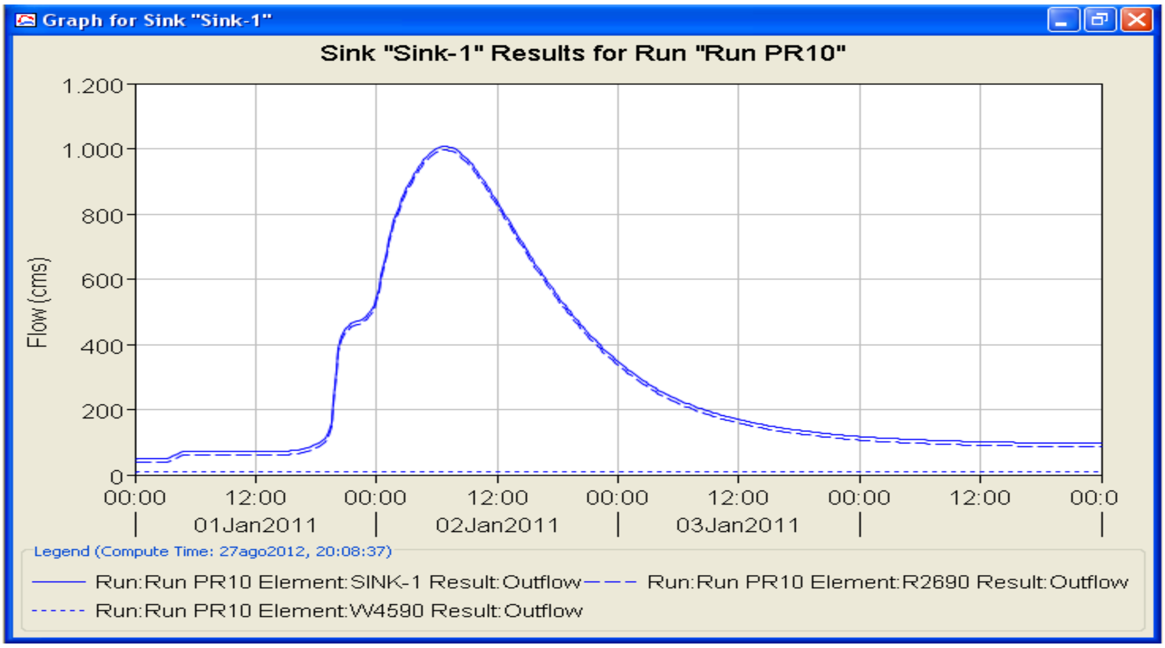


Figure 24. Hydrograph for 10-year Return Period.

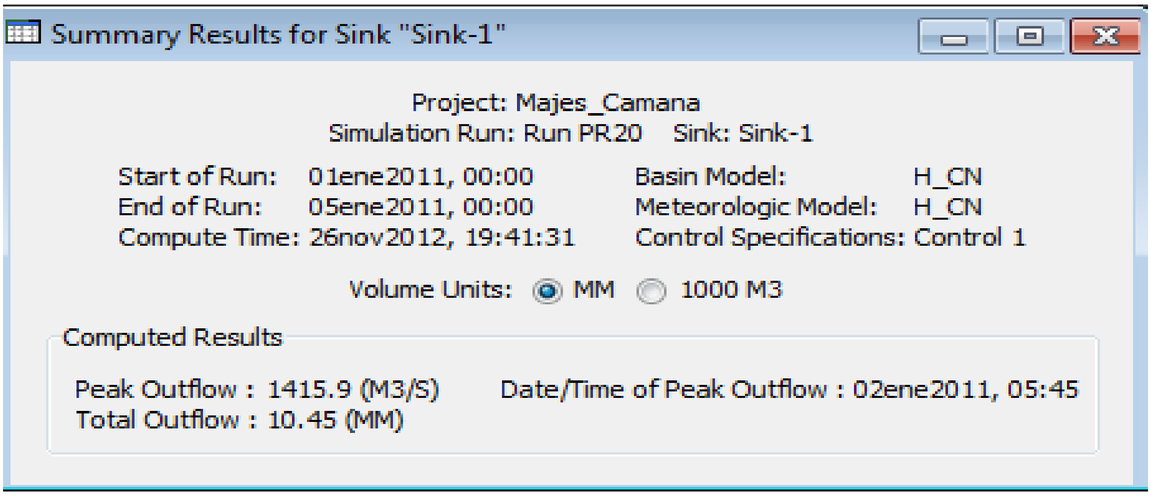


Figure 25. Summary of Results of HEC-HMS Program for 20-year Flood at Station Huatiapa.

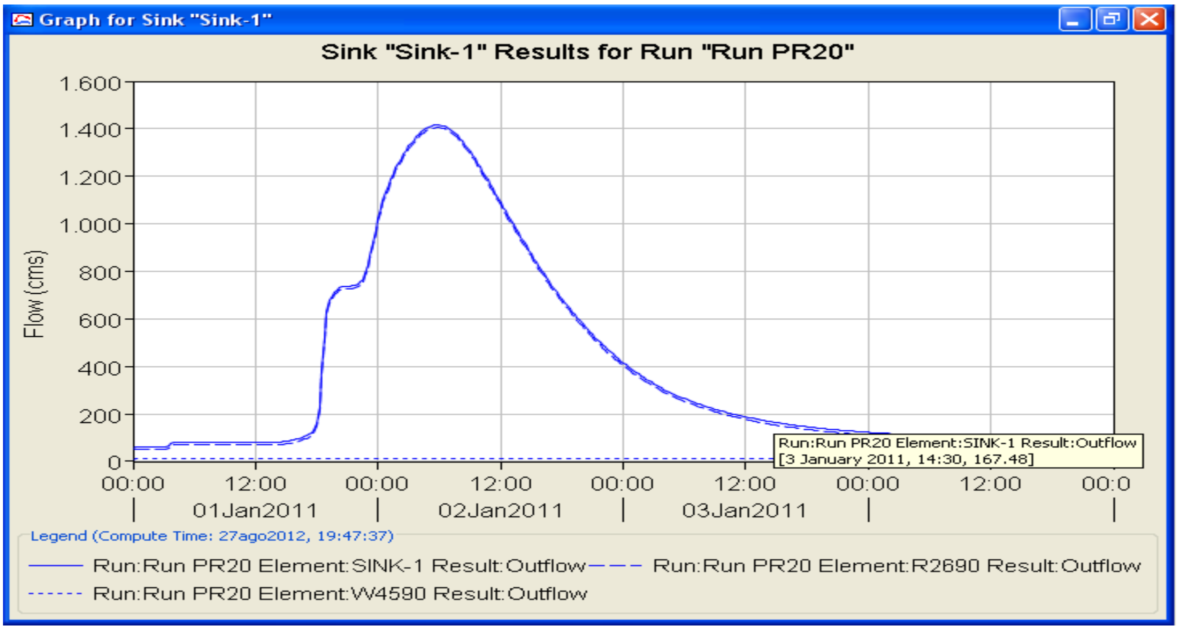


Figure 26. Hydrograph for 20-year Return Period.

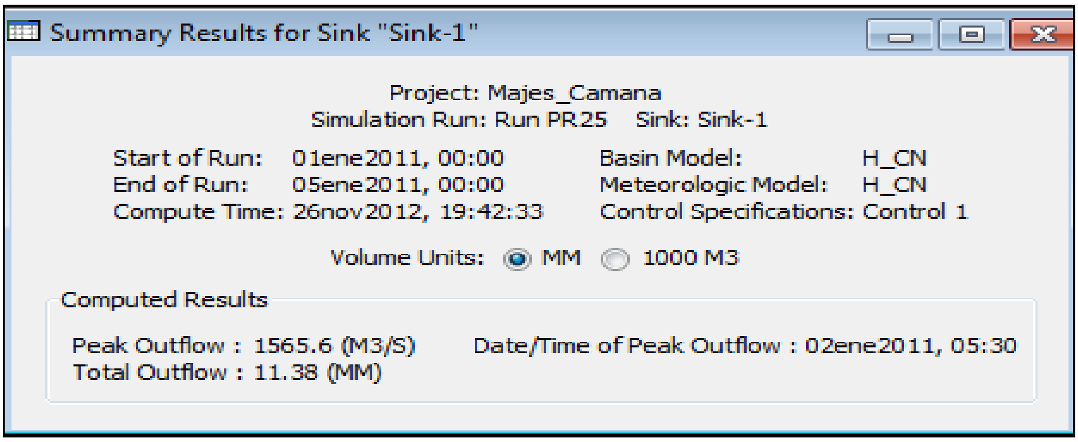


Figure 27. Summary of Results of HEC-HMS Program for 25-year Flood at Station Huatiapa.

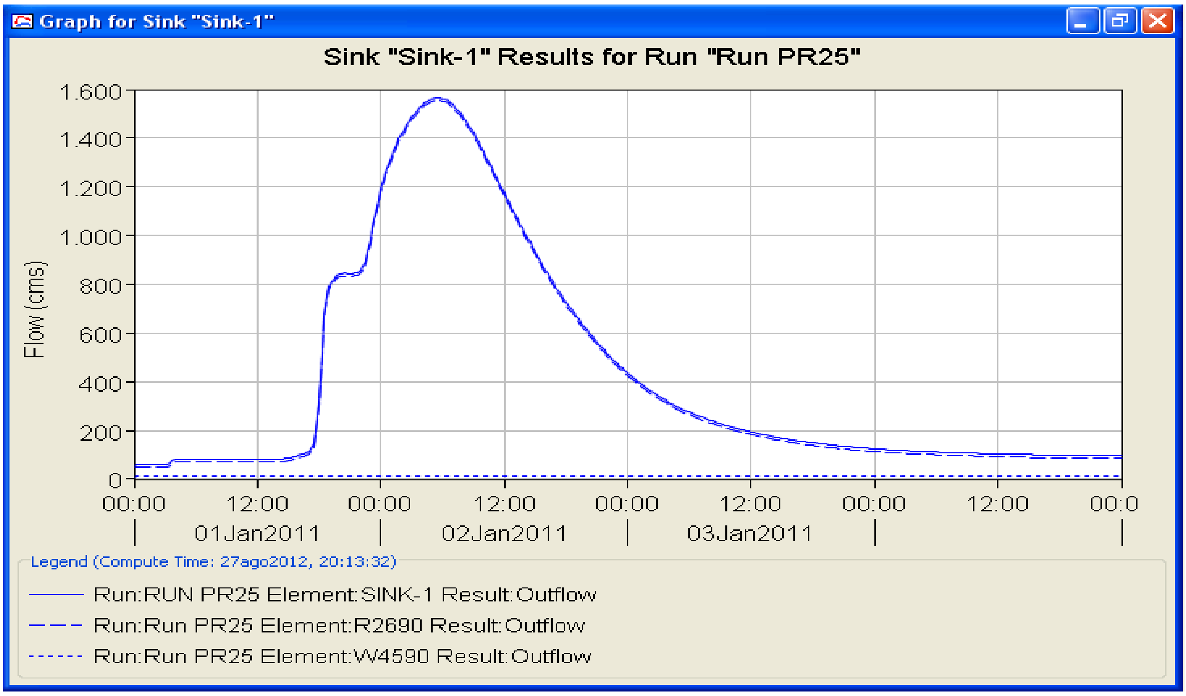


Figure 28. Hydrograph for 25-year Return Period.

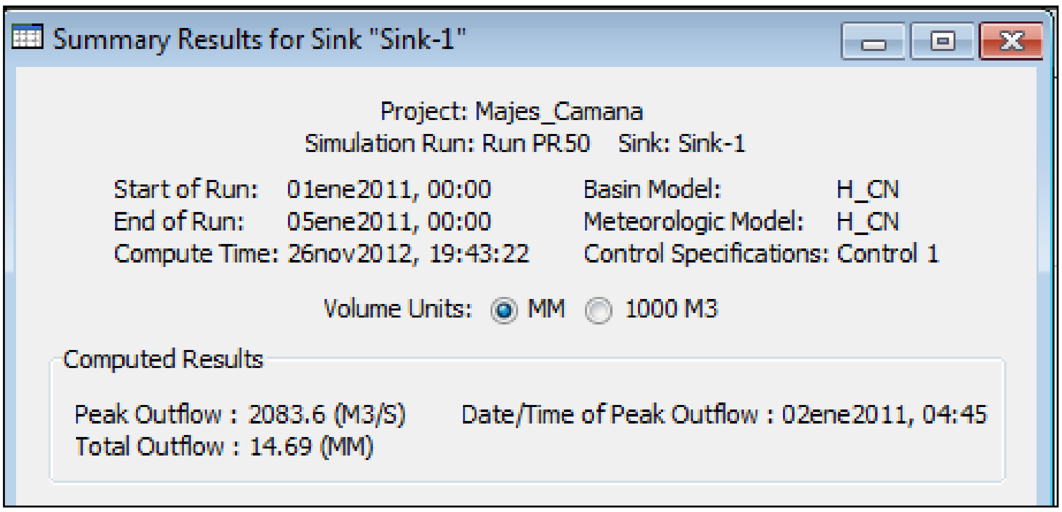


Figure 29. Summary of Results of HEC-HMS Program for 50-year Flood at Station Huatiapa.

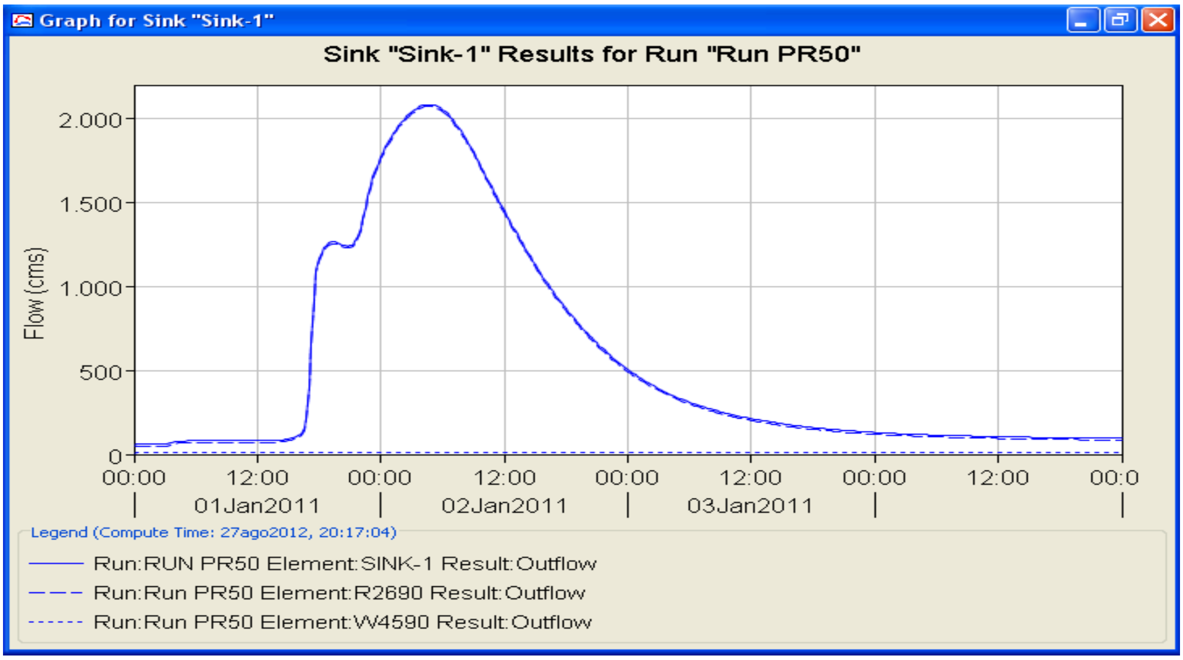


Figure 30. Hydrograph for 50-year Return Period.

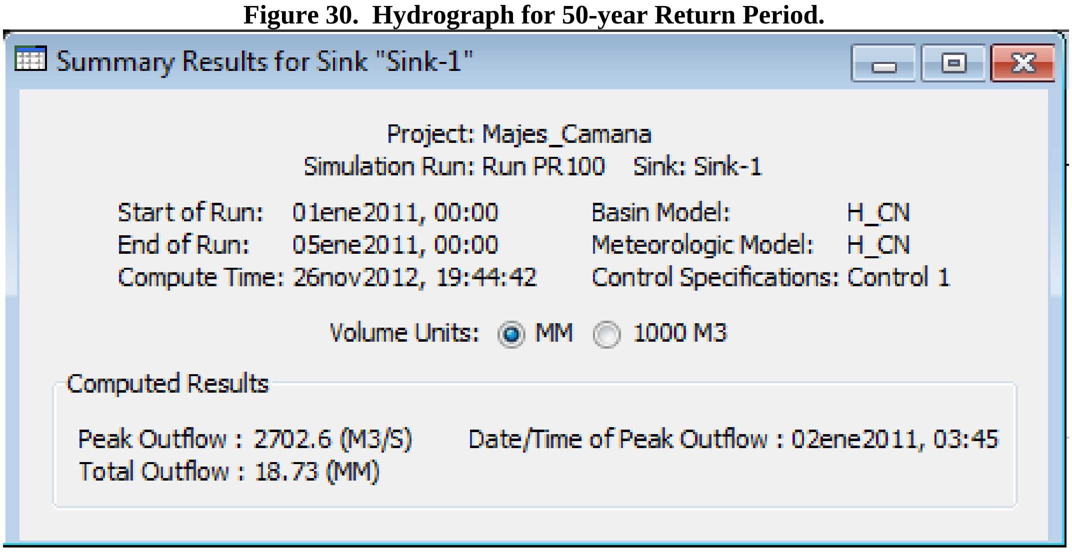


Figure 31. Summary of Results of HEC-HMS Program for 50-year Flood at Station Huatiapa.

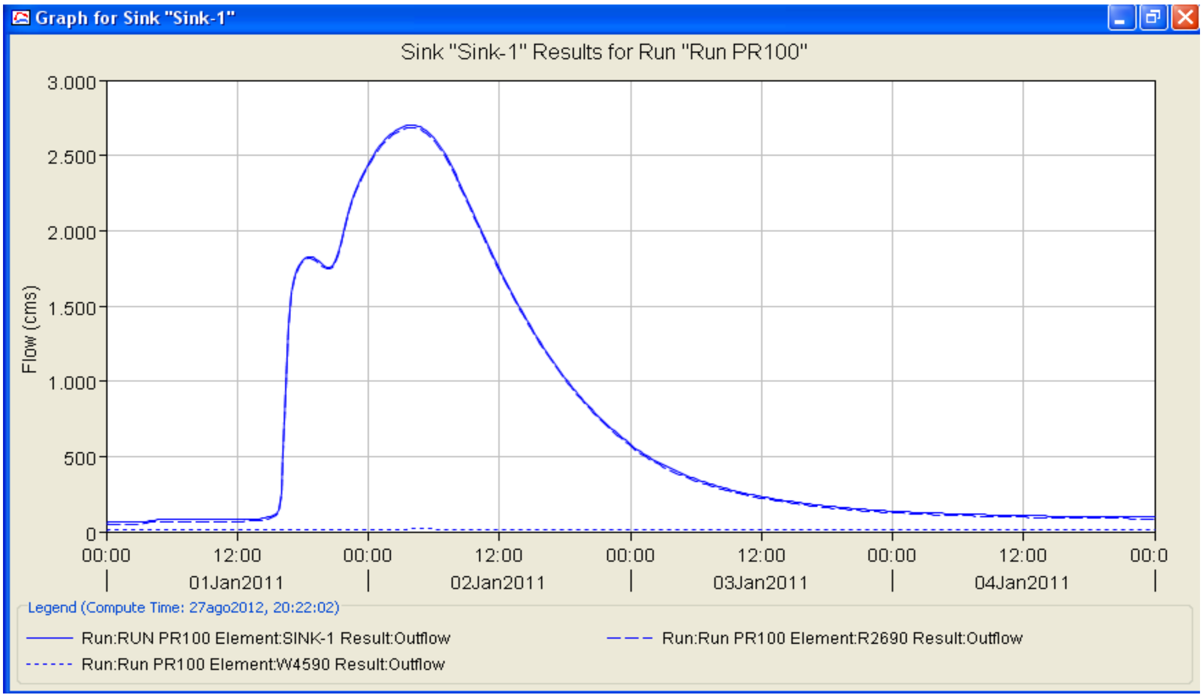


Figure 32. Hydrograph for 100-Year Return Period.

Figure 33 to 36 shows specific discharge of statistical flood peak in the coastal area of Perú and the estimated peak discharge of the Majes-Camana at Huatiapa station by the HEC-HMS Model. According to these specific discharge and the Creager's curves, the estimated peak discharge of the Majes-Camana at Huatiapa station by the HEC-HMS Model for each return periods are determined to be within a reasonable range of nearby area.

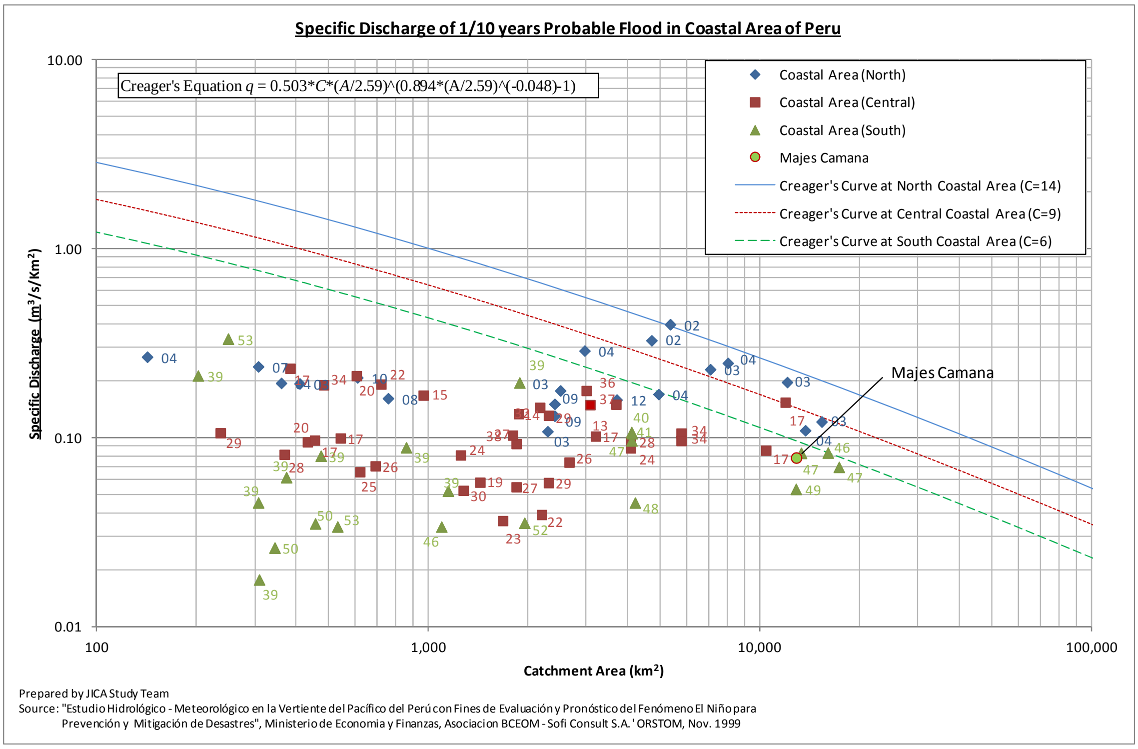


Figure 33. Specific Discharge of Flood Peak in the Coastal Area of Peru and Estimated Peak Discharge of Majes-Camana at Huatiapa Station by HEC-HMS Model (1/10 year return period).

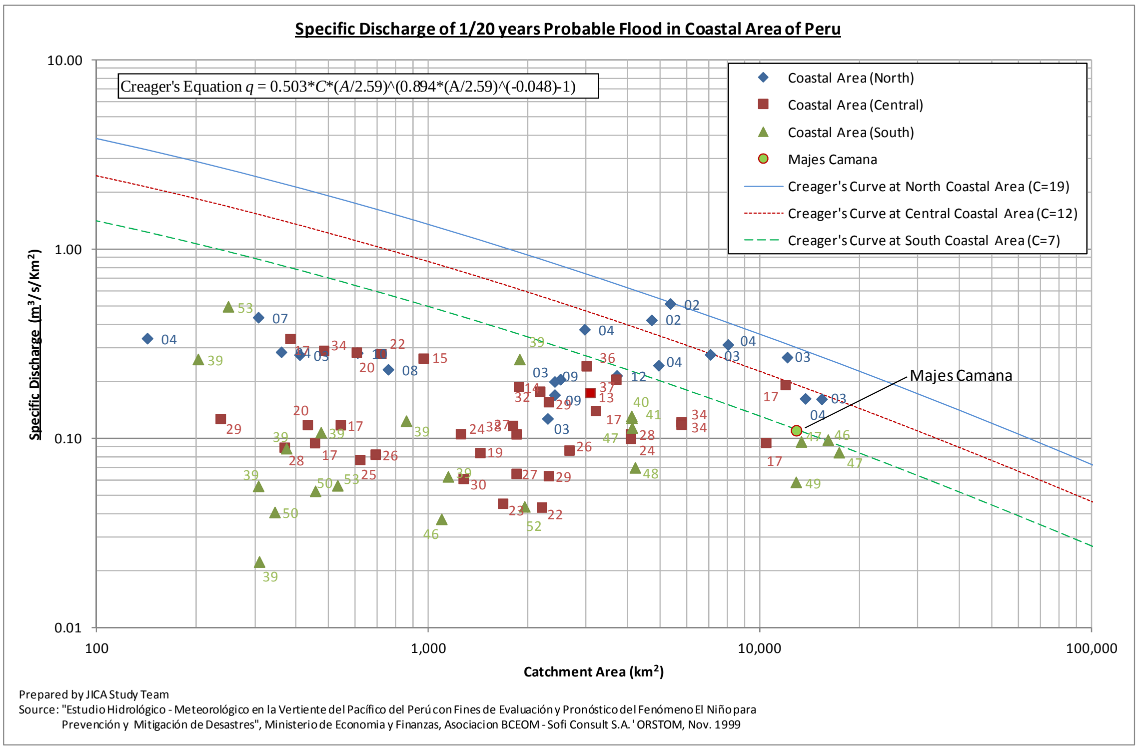


Figure 34. Specific Discharge of Flood Peak in the Coastal Area of Peru and Estimated Peak Discharge of Majes-Camana at Huatiapa Station by HEC-HMS Model (1/20 year return period).

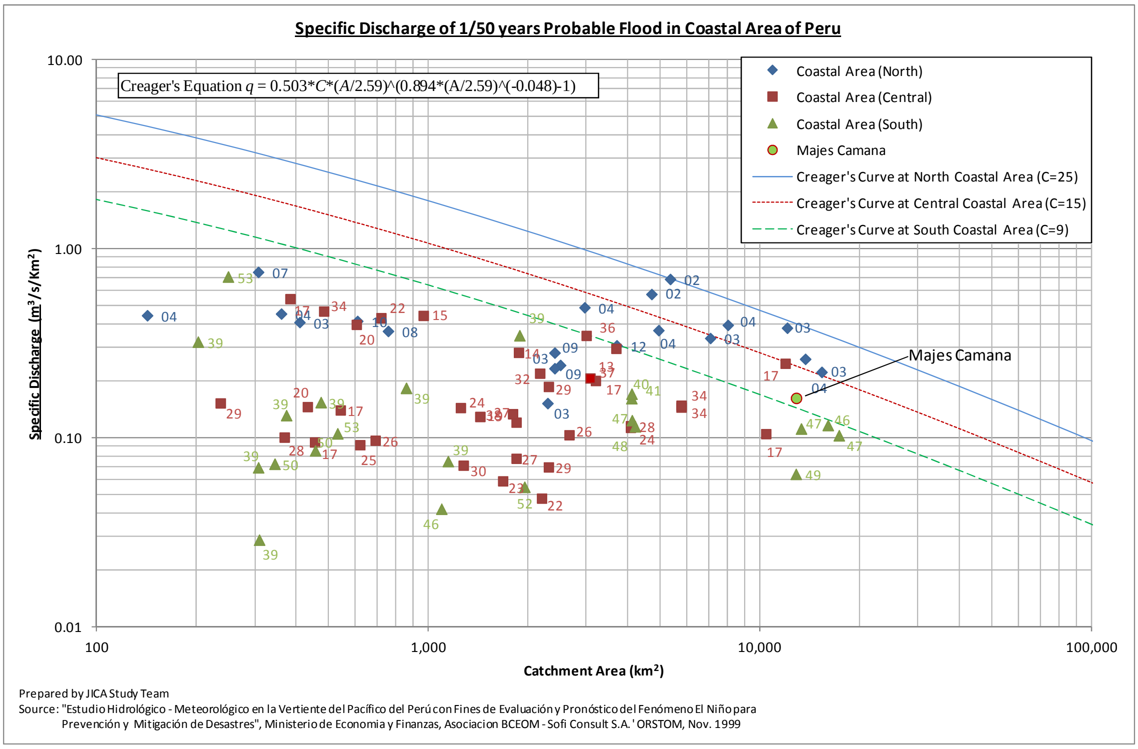


Figure 35. Specific Discharge of Flood Peak in the Coastal Area of Peru and Estimated Peak Discharge of Majes-Camana at Huatiapa Station by HEC-HMS Model (1/50 year return period).

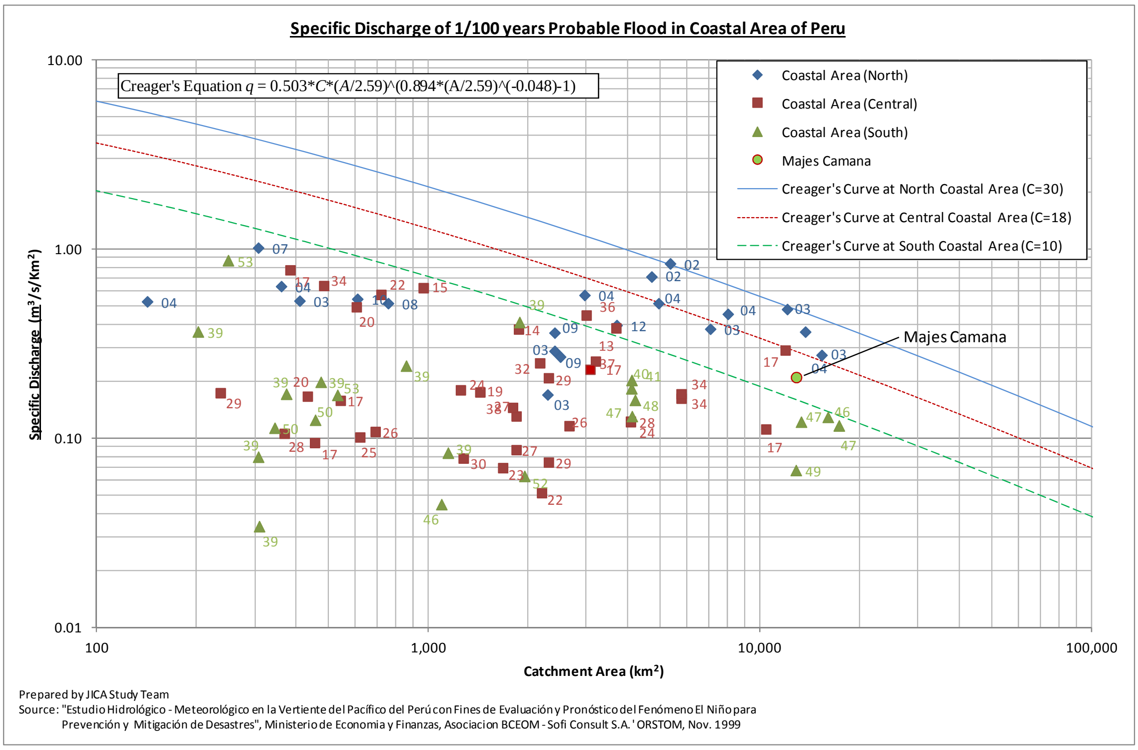


Figure 36. Specific Discharge of Flood Peak in the Coastal Area of Peru and Estimated Peak Discharge of Majes-Camana at Huatiapa Station by HEC-HMS Model (1/100 year return period).

IV. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this study is to estimate the discharges and hydrographs that will occur for the following return periods: 2, 5, 10, 25, 50 and 100 years.

The majority of the precipitation records available for the study zone have been obtained manually. Only in recent years automatic weather stations have been installed in the study zone. Precipitation used for the hydrologic simulation is the 24 hour precipitation.

The orographic effect is very pronounced in the Majes – Camana Basin. Precipitation is close zero in the lower reaches and increases with altitude. Precipitation is 700 mm/yr near the Continental Divide.

Stream gages in the Majes-Camana Basin are scarce. Only Huatiapa Station has been operating without major interruptions since it started functioning. Data has been obtained manually is available as flows are measured three or four times a day. The float type automatic water level gauge was installed in 2006 at Huatiapa gauging station. However the digitalized hourly water level data is not available for Huatiapa gauging station. Maximum daily discharges are obtained by selecting the largest flow measured in a day. Therefore, it was considered necessary to conduct hydrologic simulations.

In the absence of instantaneous peak discharge, it was decide to conduct hydrologic simulation for obtaining peak flows and peak hydrographs. Initial CN values were obtained from tables and they were adjusted take into account the Antecedent Moisture Condition (AMC) in each land subdivision.

Peak discharges at Huatiapa Station were estimated using hydrologic simulations. The results are given below.

T (years)	Q (m^3/s)
2	305,8
5	637,7
10	1007
20	1415,9
25	1565,6
50	2083,6
100	2702,6

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

December 2012

Yachiyo Engineering Co., Ltd.

NIPPON KOEI CO.,LTD.

LATIN AMERICA - CARIBBEAN

NIPPON KOEI LAC CO., LTD.

Ingenieros Consultores

D

HYDROLOGY OF MAXIMUM FLOODS IN CAÑETE RIVER

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HYDROLOGY OF MAXIMUM FLOODS IN CAÑETE 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 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.

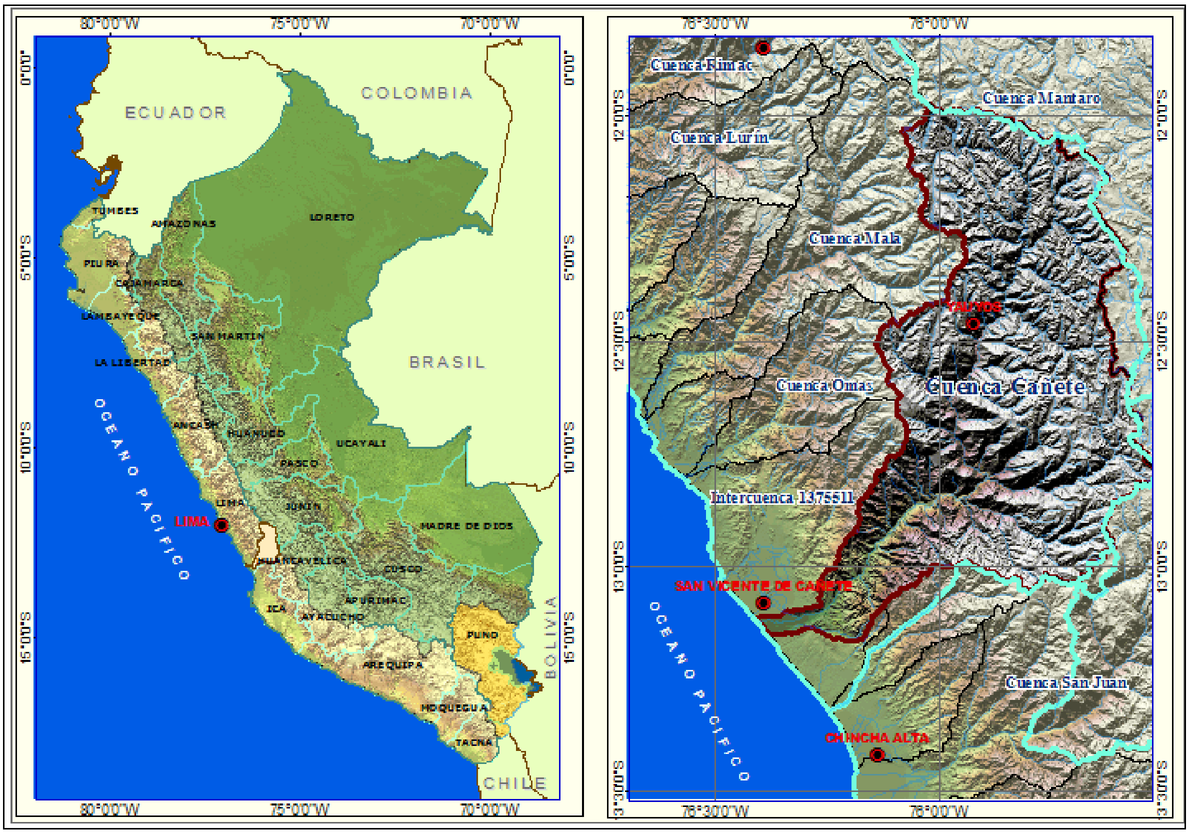


Figure Nº 3.1. Location Map of the Cañete River Basin

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

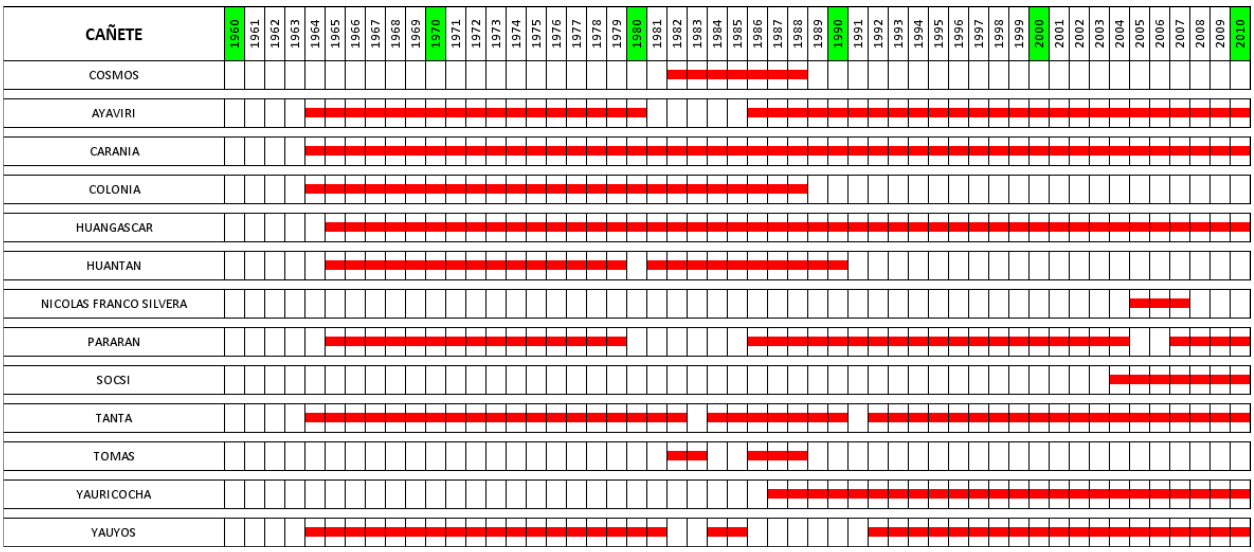


Figure Nº 3.2. Period and longitude of the available information of the rainfall stations

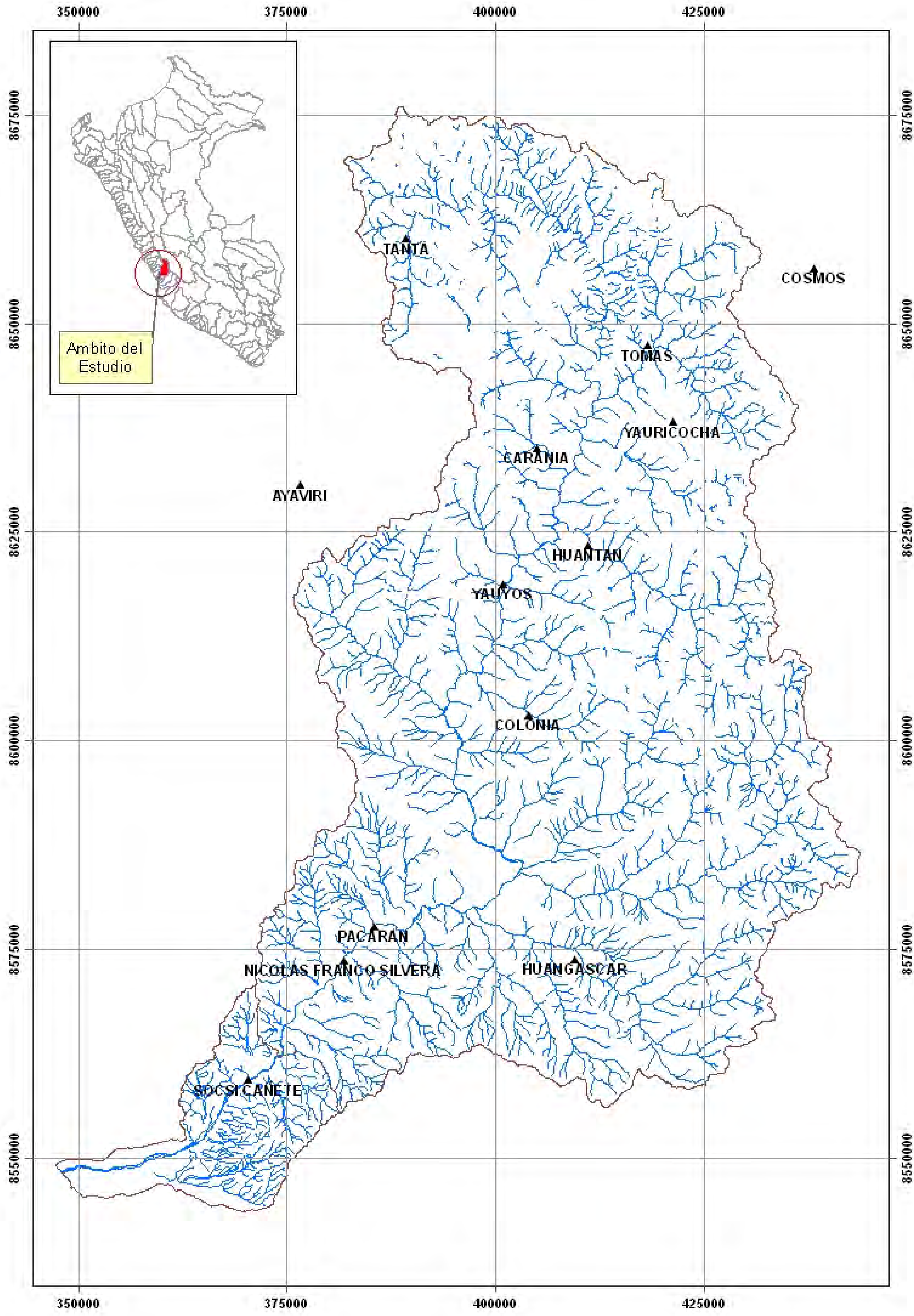


Figure Nº 3.3. Location of the Rainfall Stations in Cañete River Basin and Adjacent Basins

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

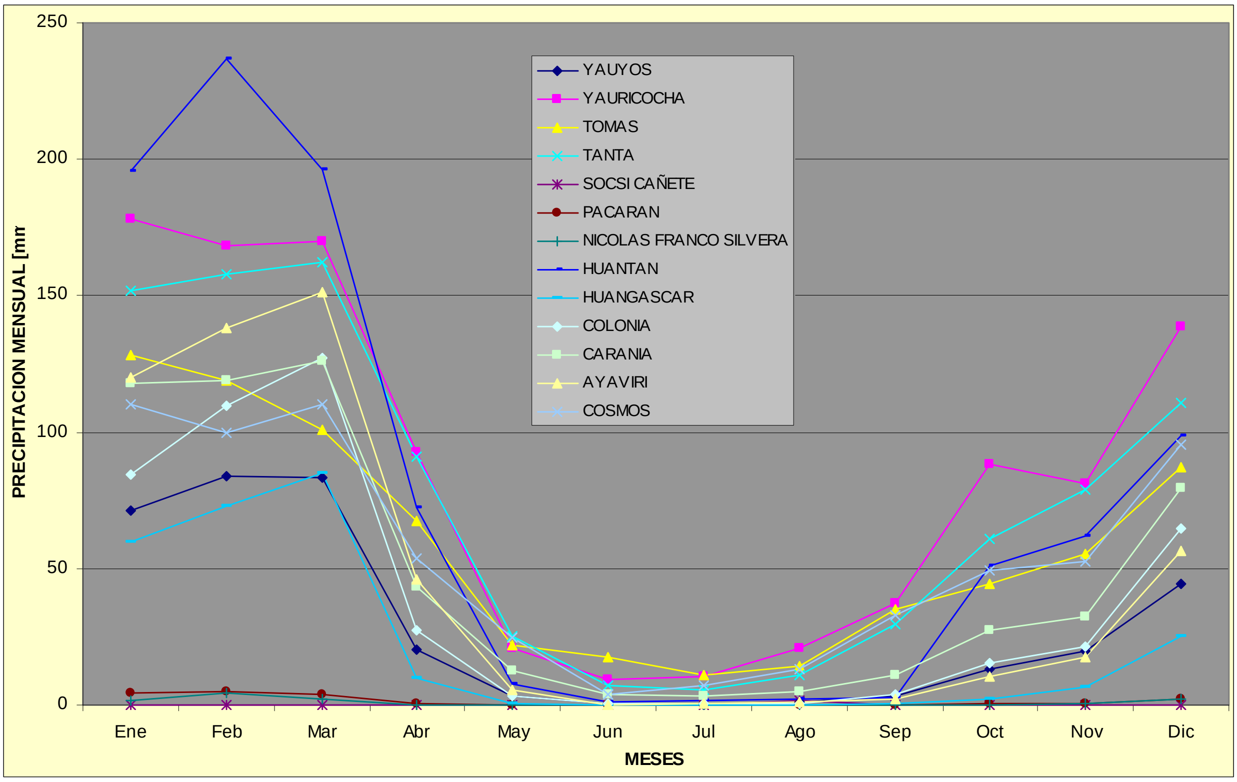


Figure Nº 3.4. Monthly Histogram of Rainfall Stations considered within the Study Scope

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.

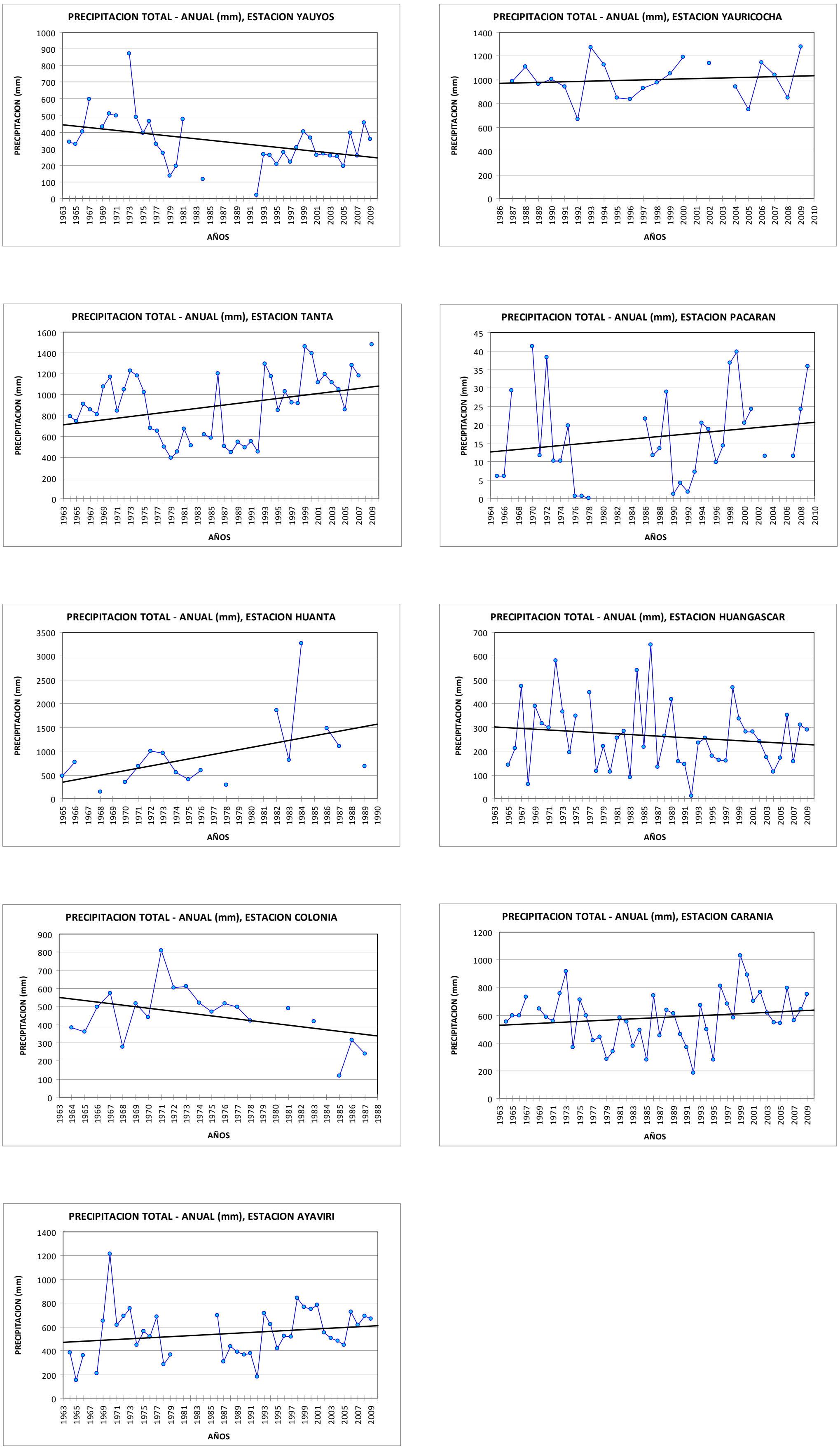


Figure Nº 3.5. Annual Rainfall Trends at the Stations considered within the Study Scope

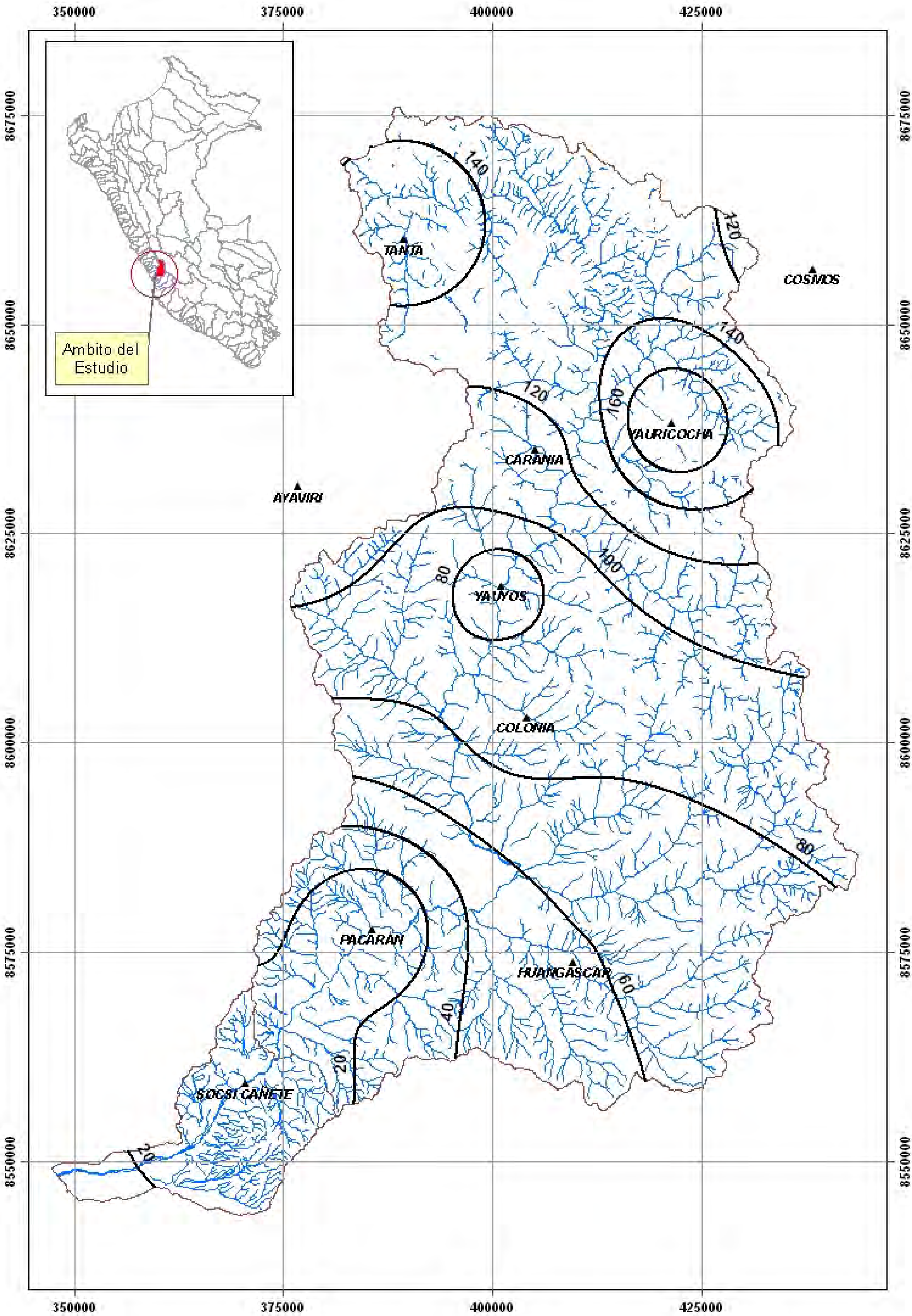


Figure Nº 3.6. Isohyets for Mean Monthly Rainfall in the Cañete Basin, in January

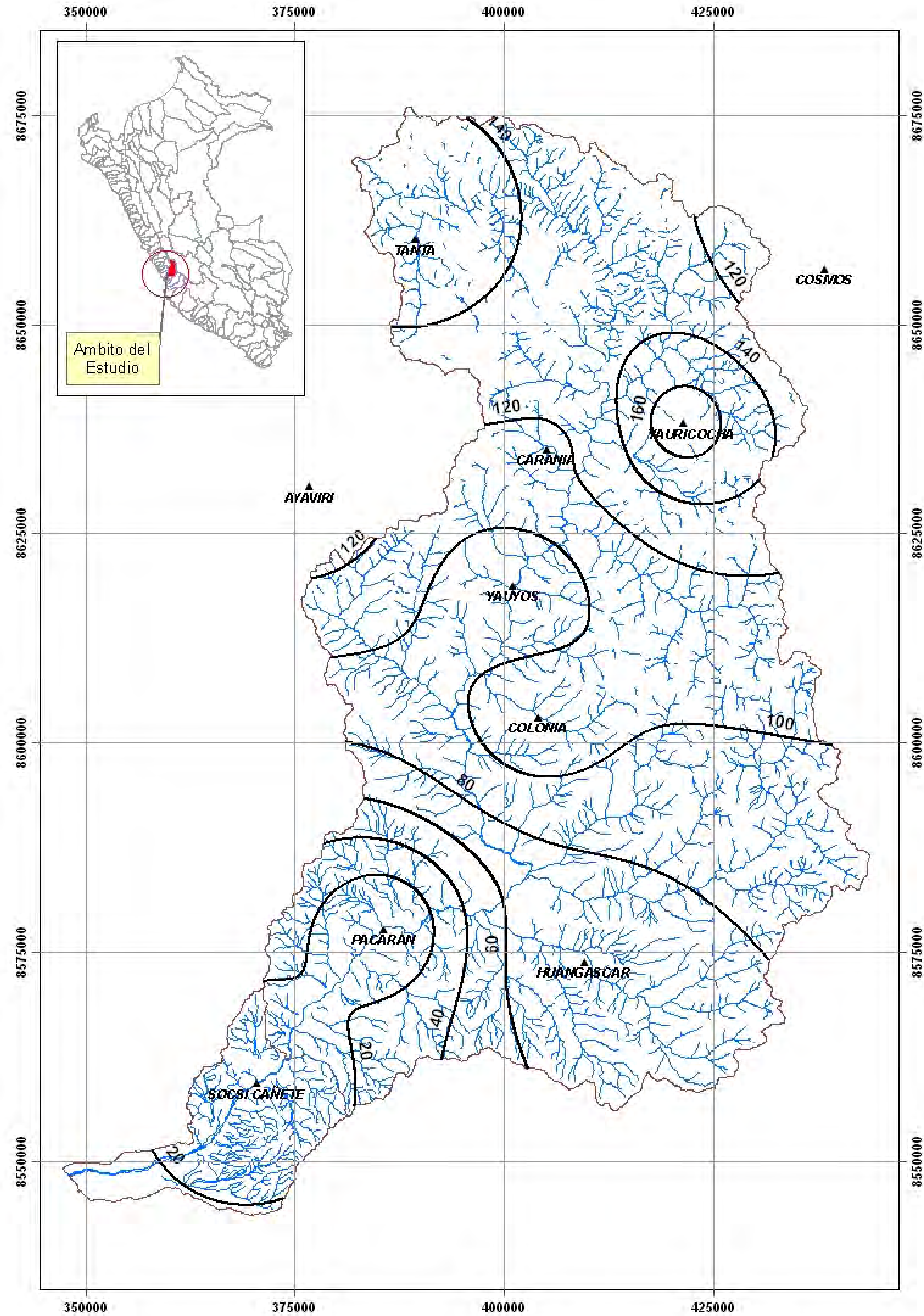


Figure Nº 3.7. Isohyets for Mean Monthly Rainfall in the Cañete Basin, in February

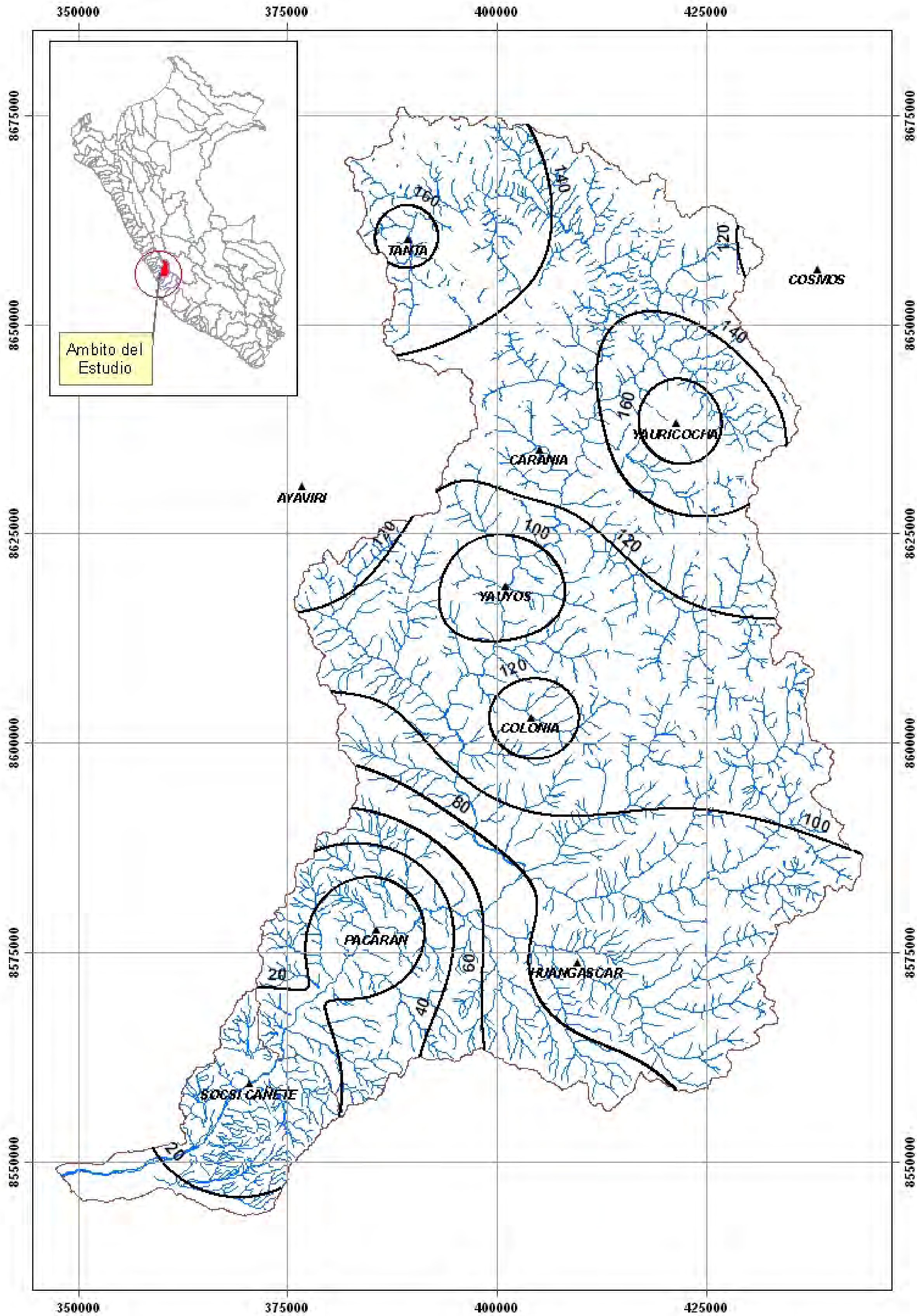


Figure Nº 3.8. Isohyets Mean Monthly Rainfall in the Cañete Basin, in March

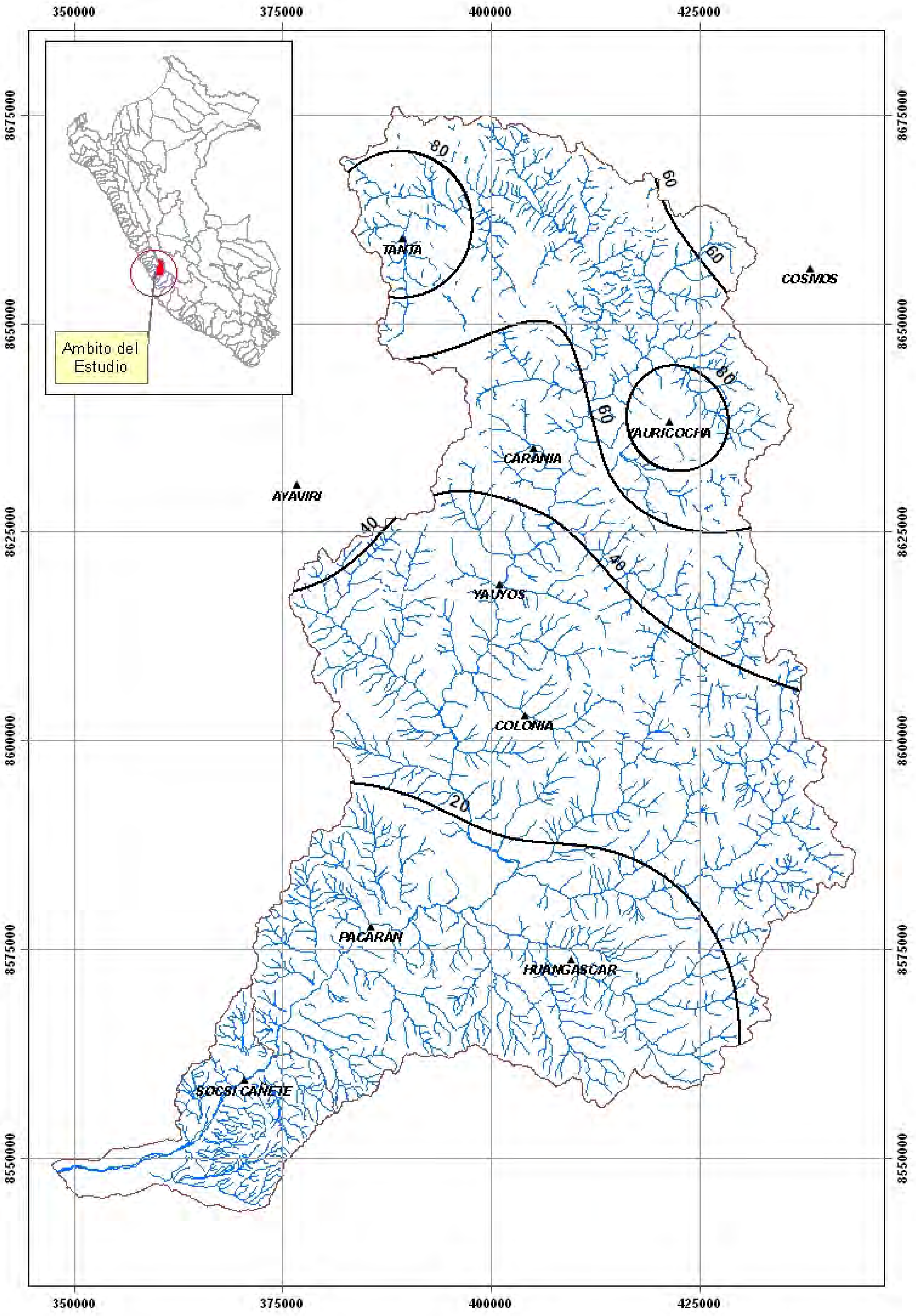


Figure Nº 3.9. Isohyets Mean Monthly Rainfall in the Cañete Basin, in April

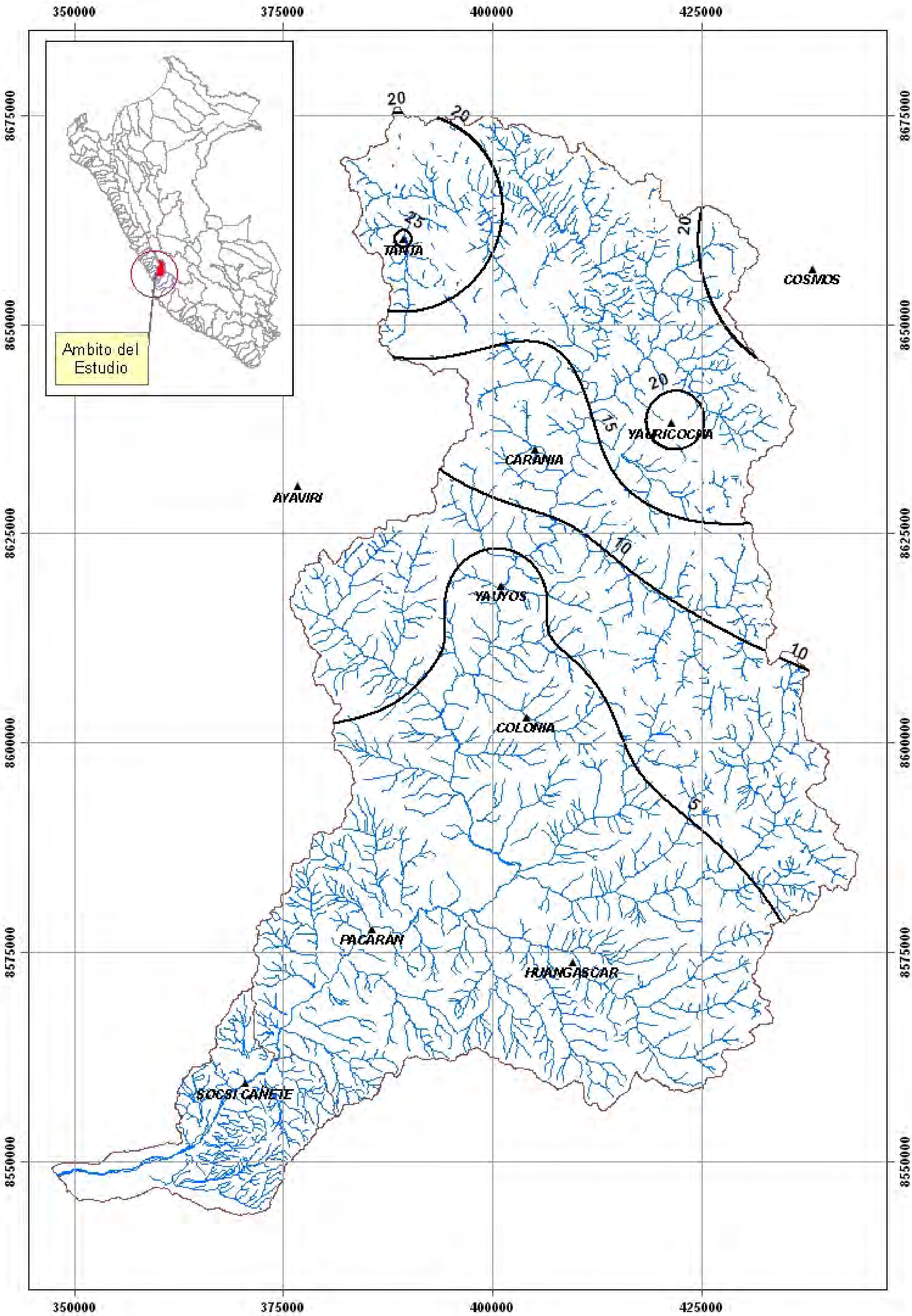


Figure Nº 3.10. Isohyets Mean Monthly Rainfall in the Cañete Basin, in May

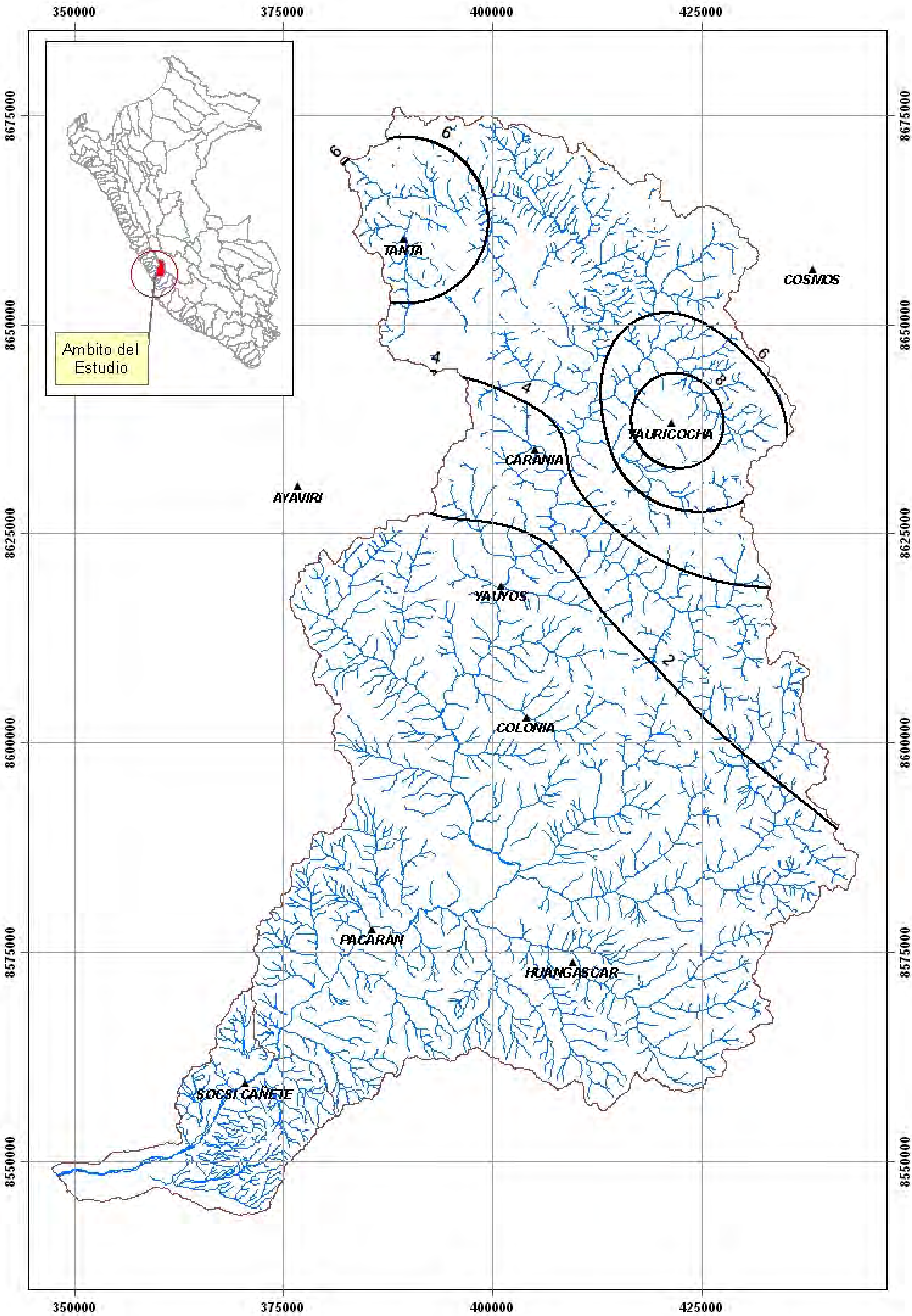


Figure Nº 3.11. Isohyets Mean Monthly Rainfall in the Cañete Basin, in June

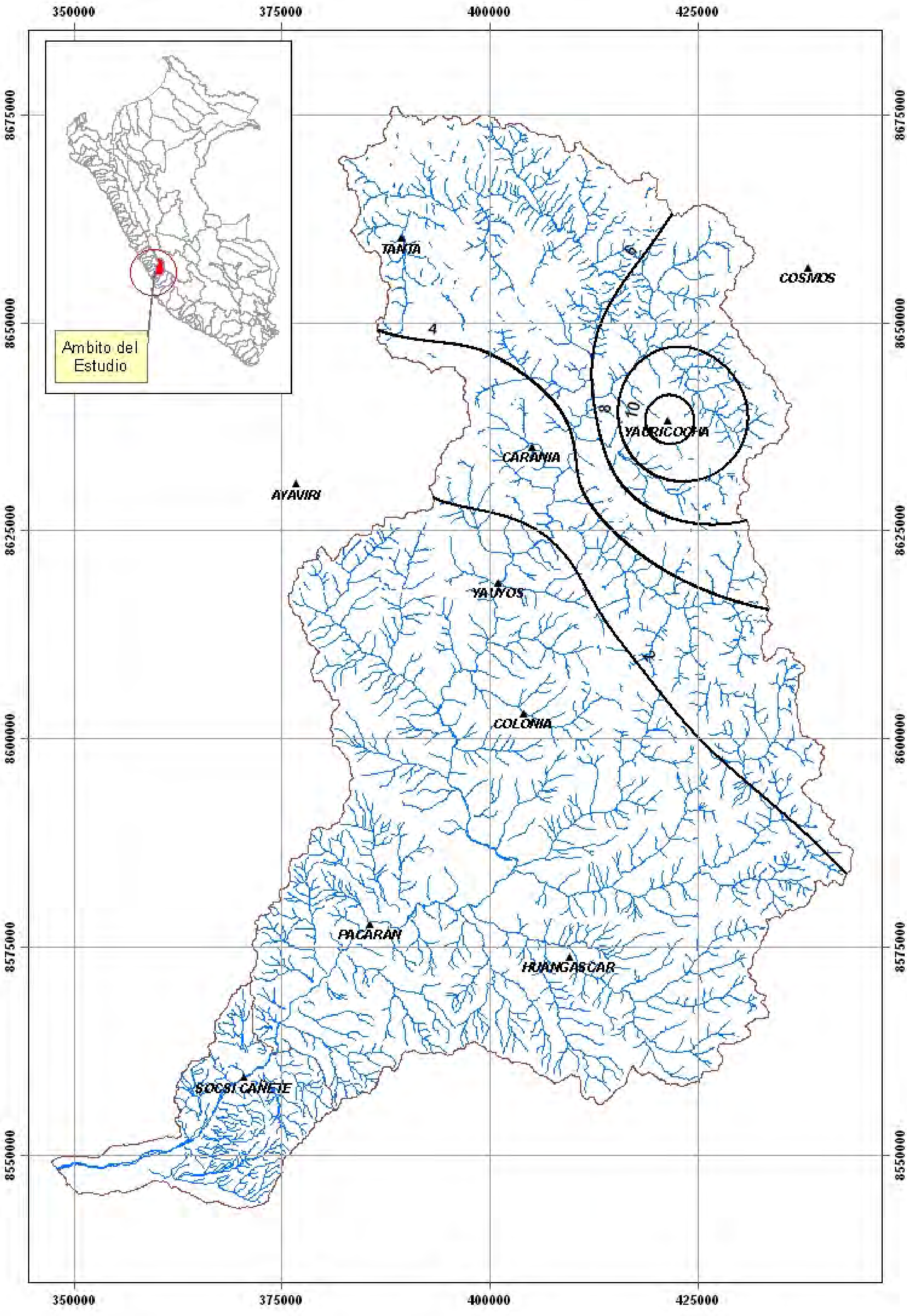


Figure Nº 3.12. Isohyets Mean Monthly Rainfall in the Cañete Basin, in July

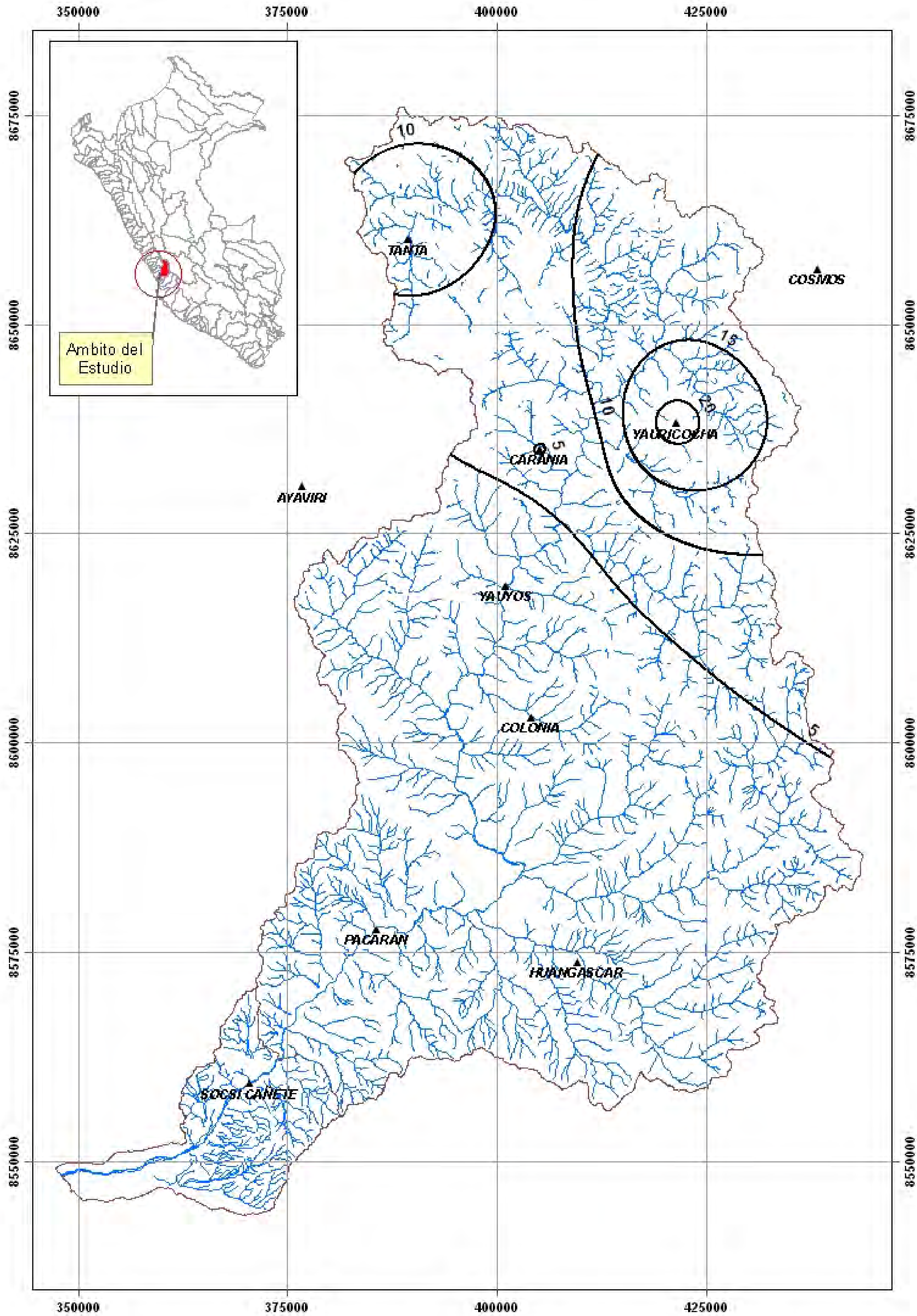


Figure Nº 3.13. Isohyets Mean Monthly Rainfall in the Cañete Basin, in August

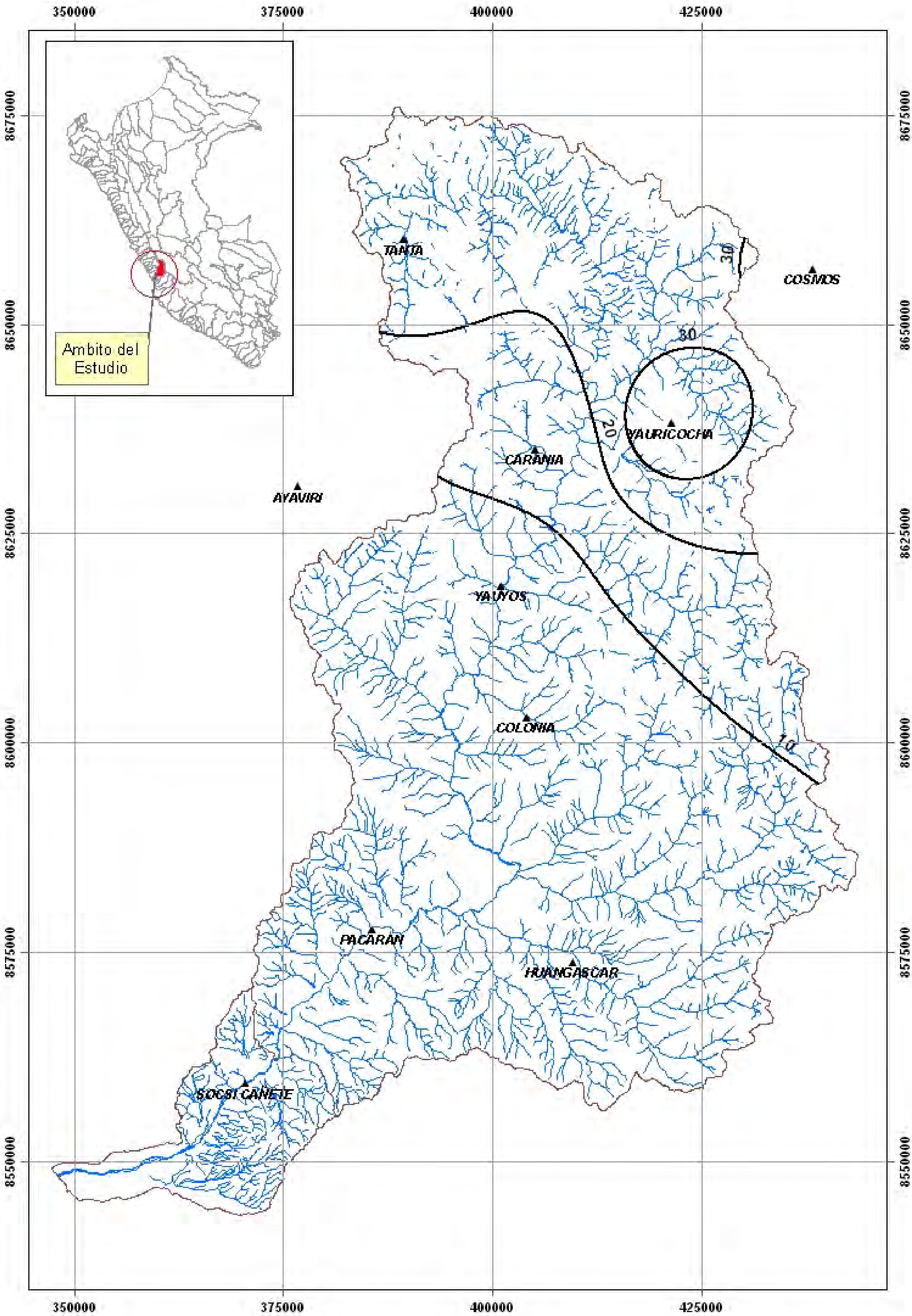


Figure Nº 3.14. Isohyets Mean Monthly Rainfall in the Cañete Basin, in September

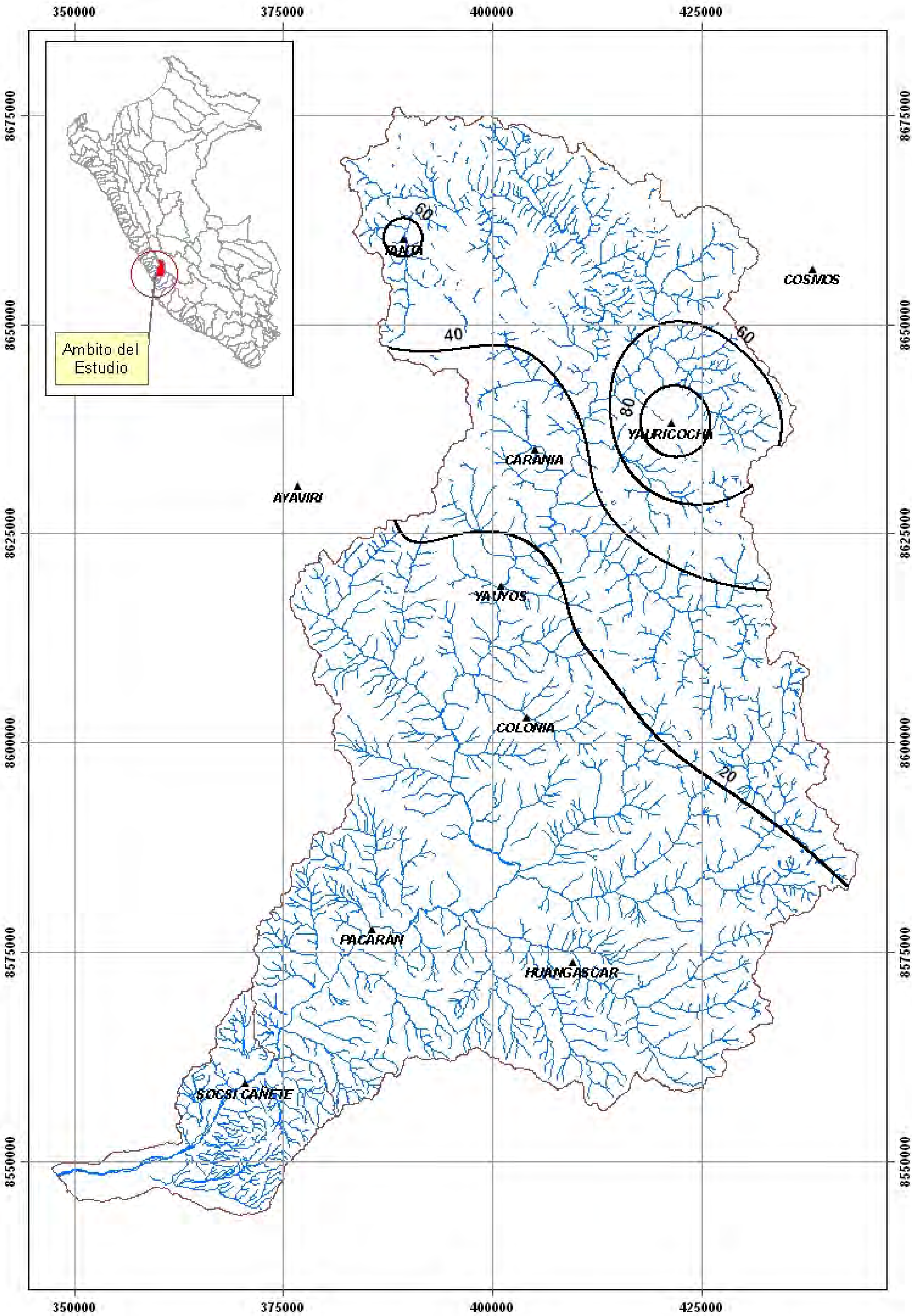


Figure Nº 3.15. Isohyets Mean Monthly Rainfall in the Cañete Basin, in October

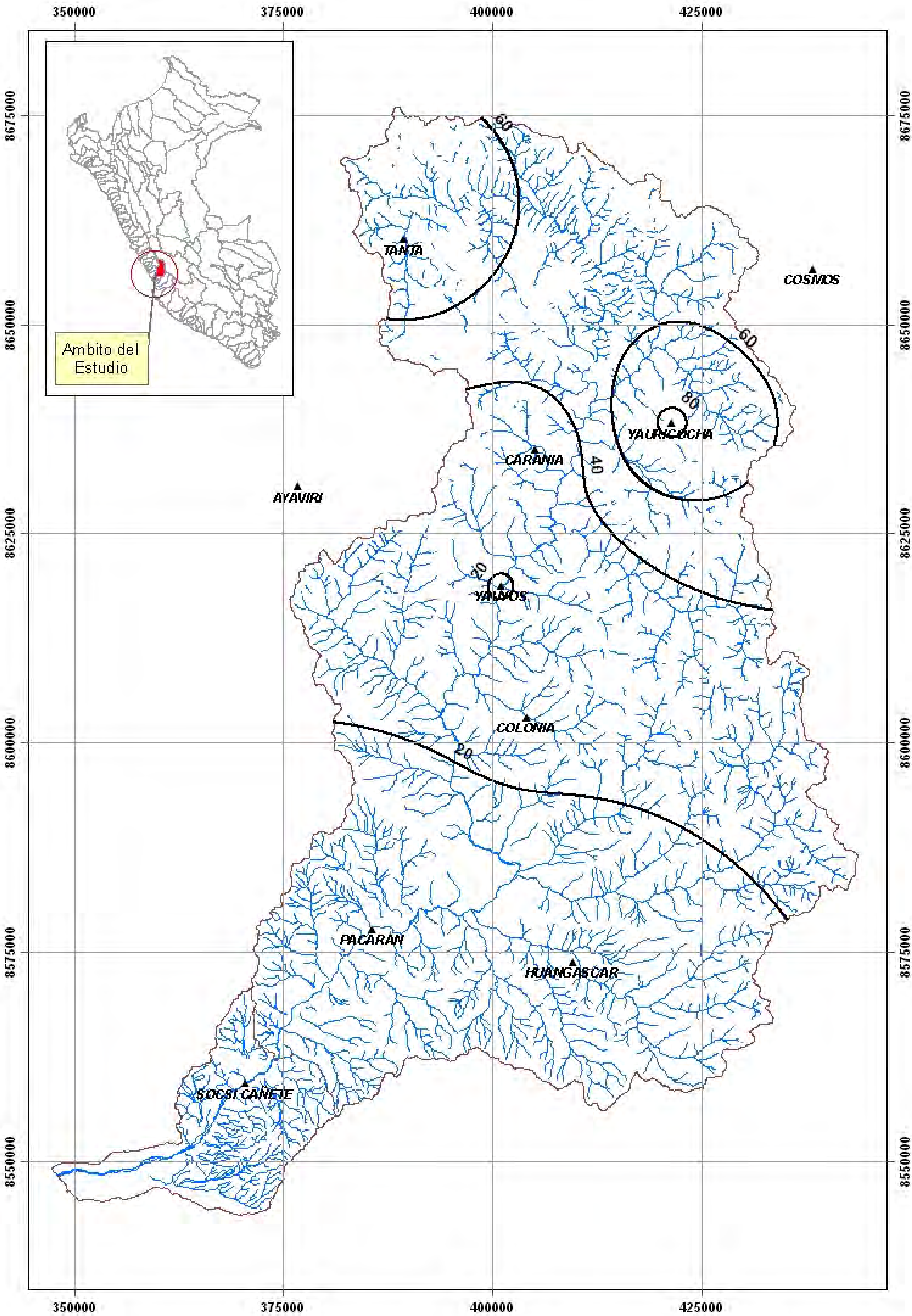


Figure Nº 3.16. Isohyets Mean Monthly Rainfall in the Cañete Basin, in November

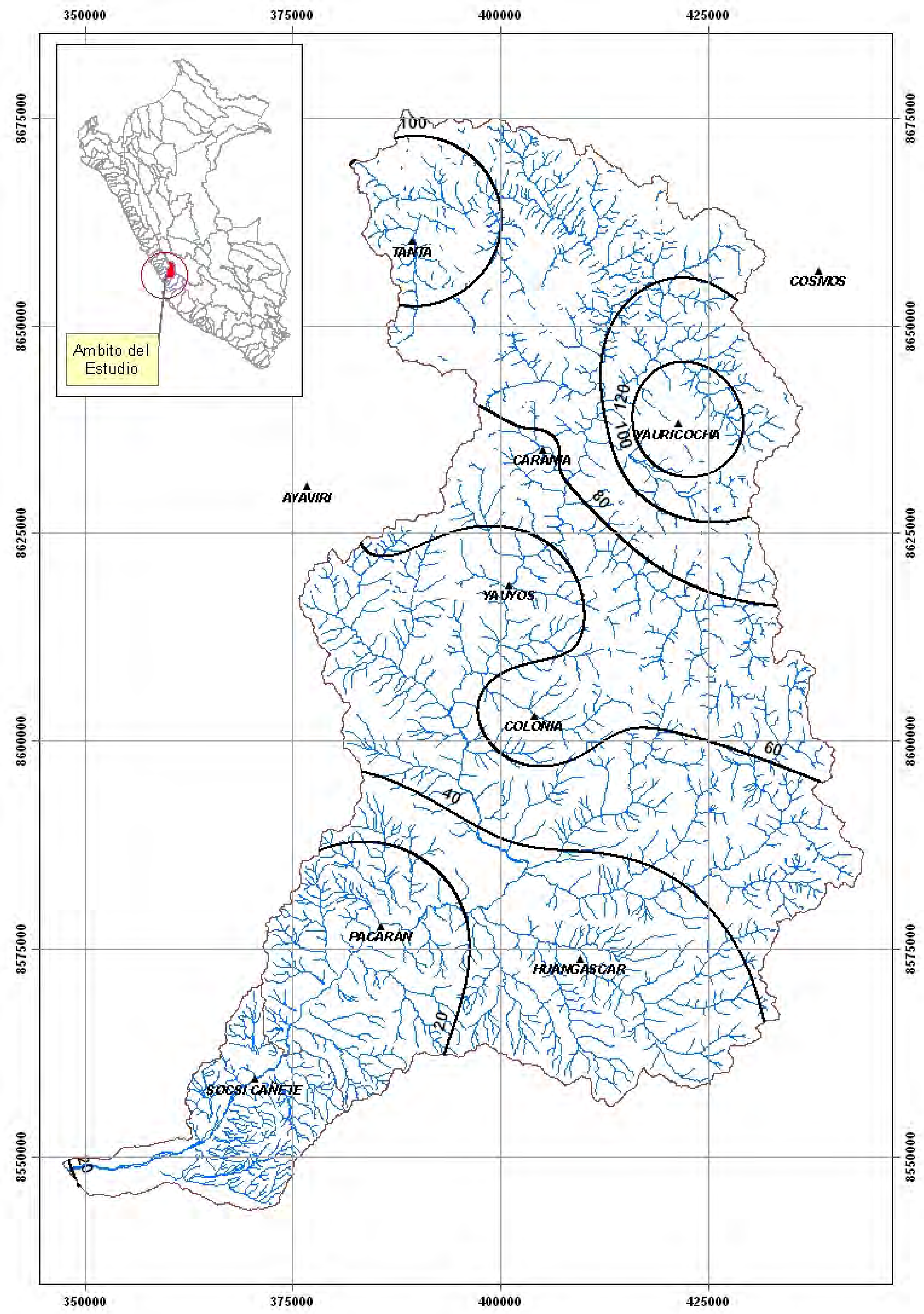


Figure Nº 3.17. Isohyets Mean Monthly Rainfall in the Cañete Basin, in December

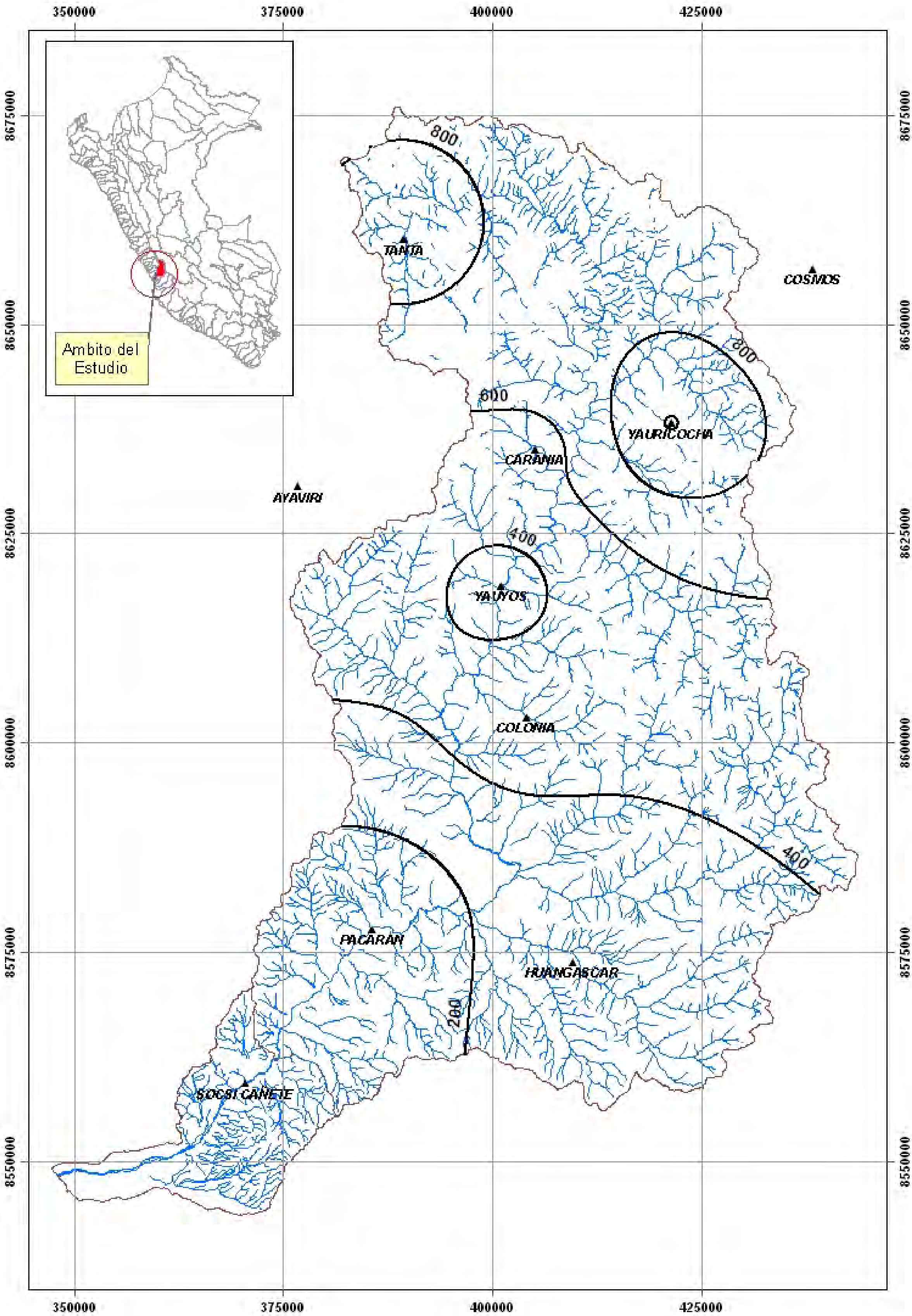


Figure Nº 3.18. Isohyets Annual Mean Monthly Rainfall in the Cañete Basin

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

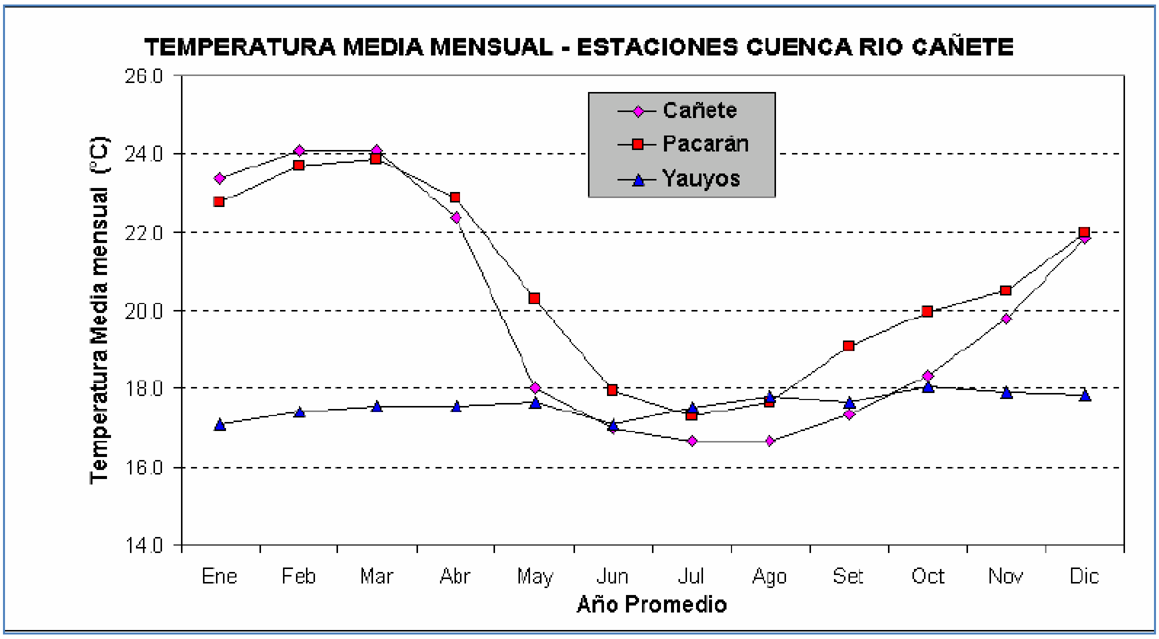


Figure Nº 3.19. Distribution of the Monthly Half Temperature of the Weather Stations Located in the Cañete River Basin

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.

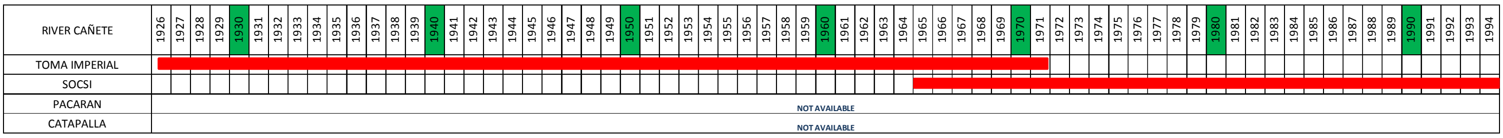


Figure Nº 3.20. Period and longitude of the available information of the Hydrometric Stations

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.

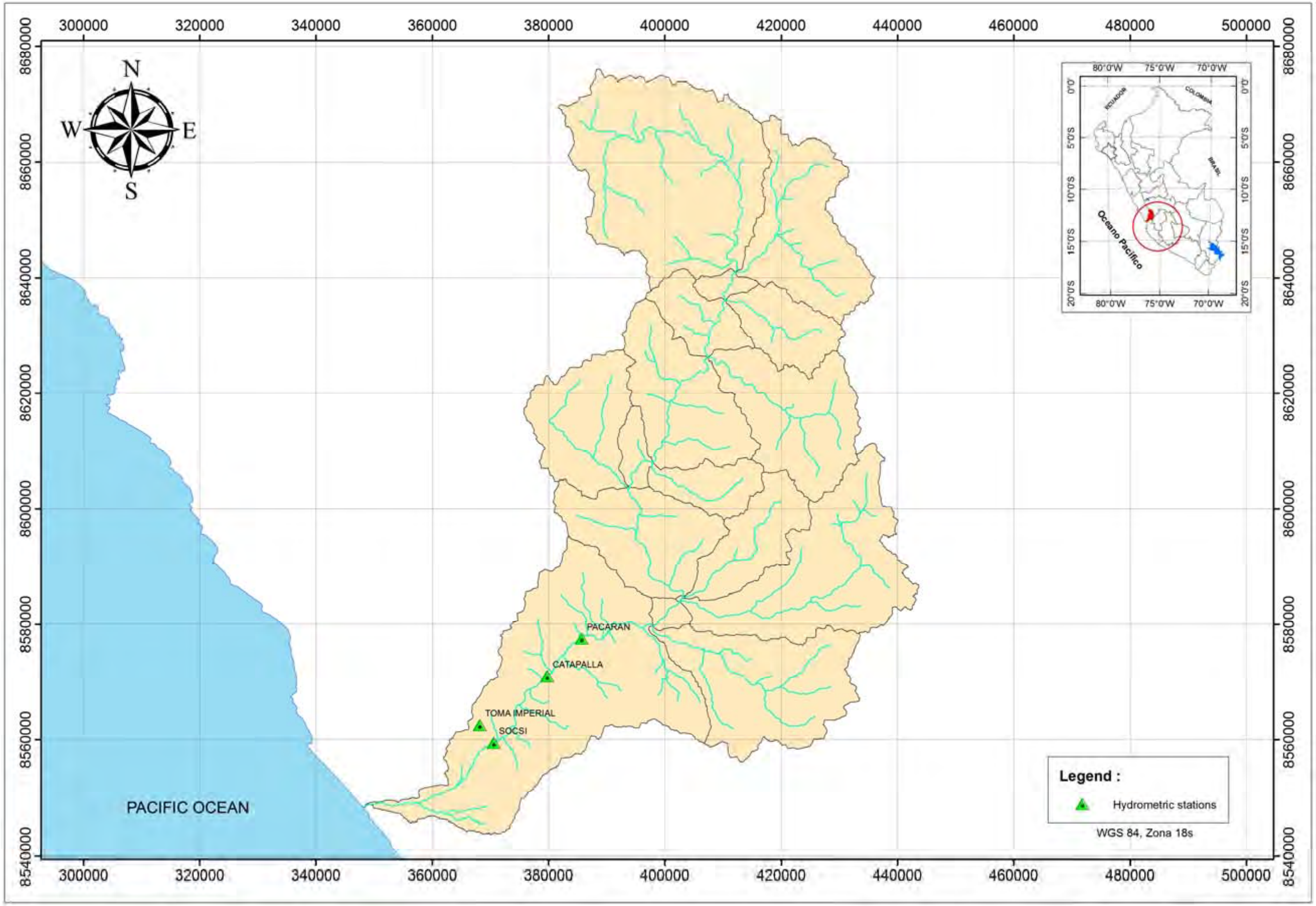


Figure Nº 3.21. Location of the hydrometric station Socsi in Cañete River basin

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.

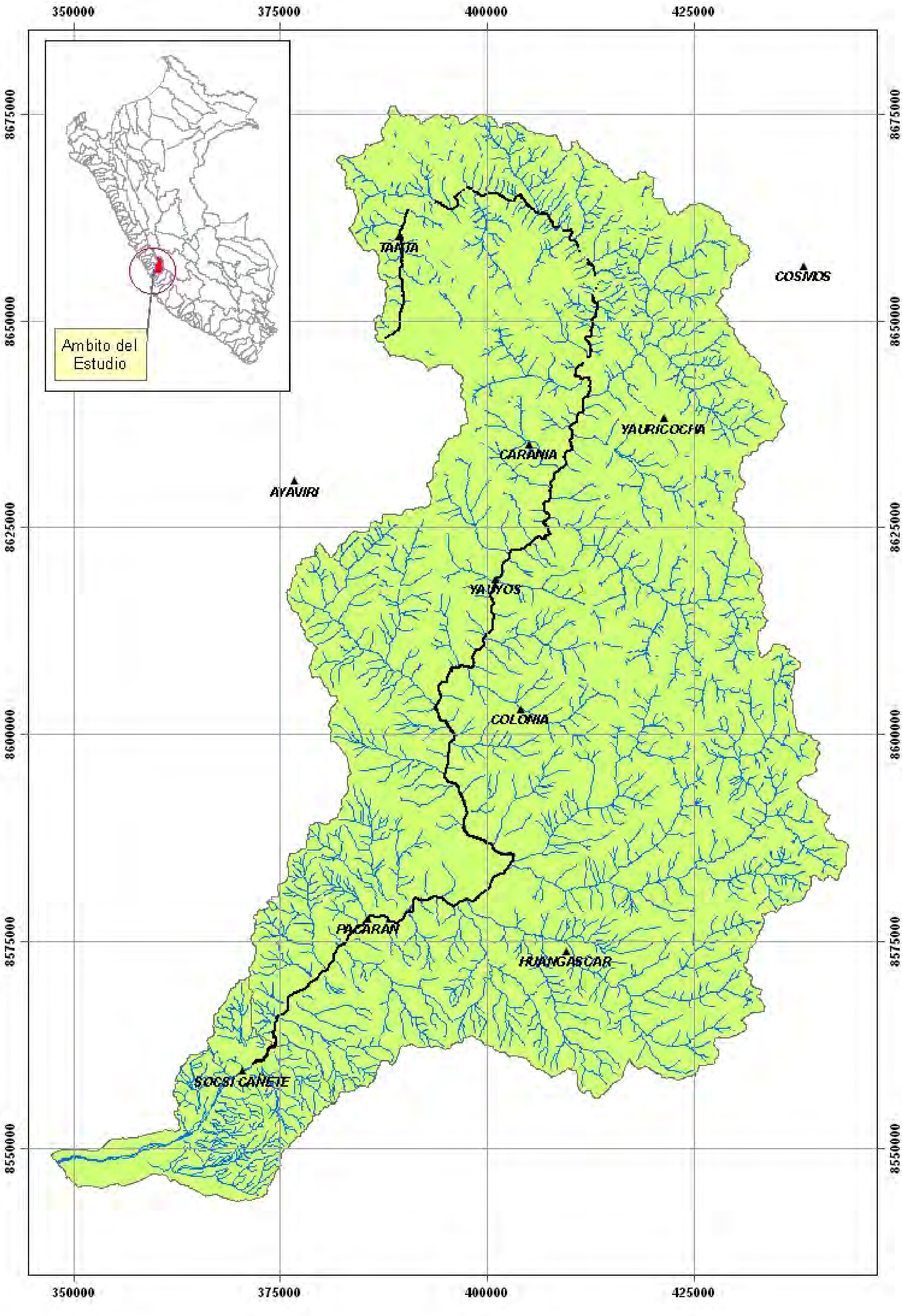


Figure Nº 4.1. Rainfall Stations considered for HEC - HMS Software application

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 -∞ < 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 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<∞, must be x~logN(μ_y, σ_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.

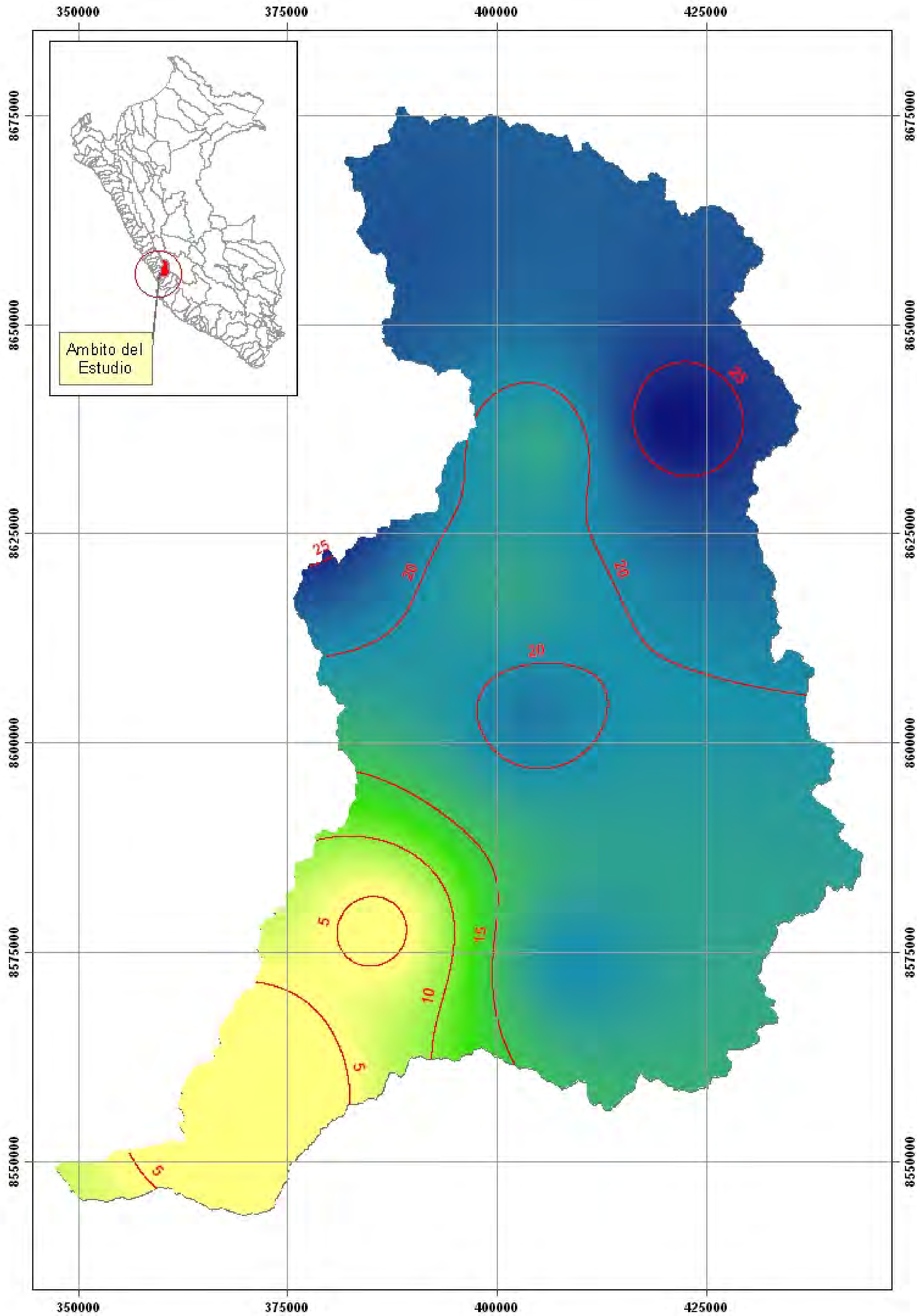


Figure Nº 4.2. Isohyets for the 2 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

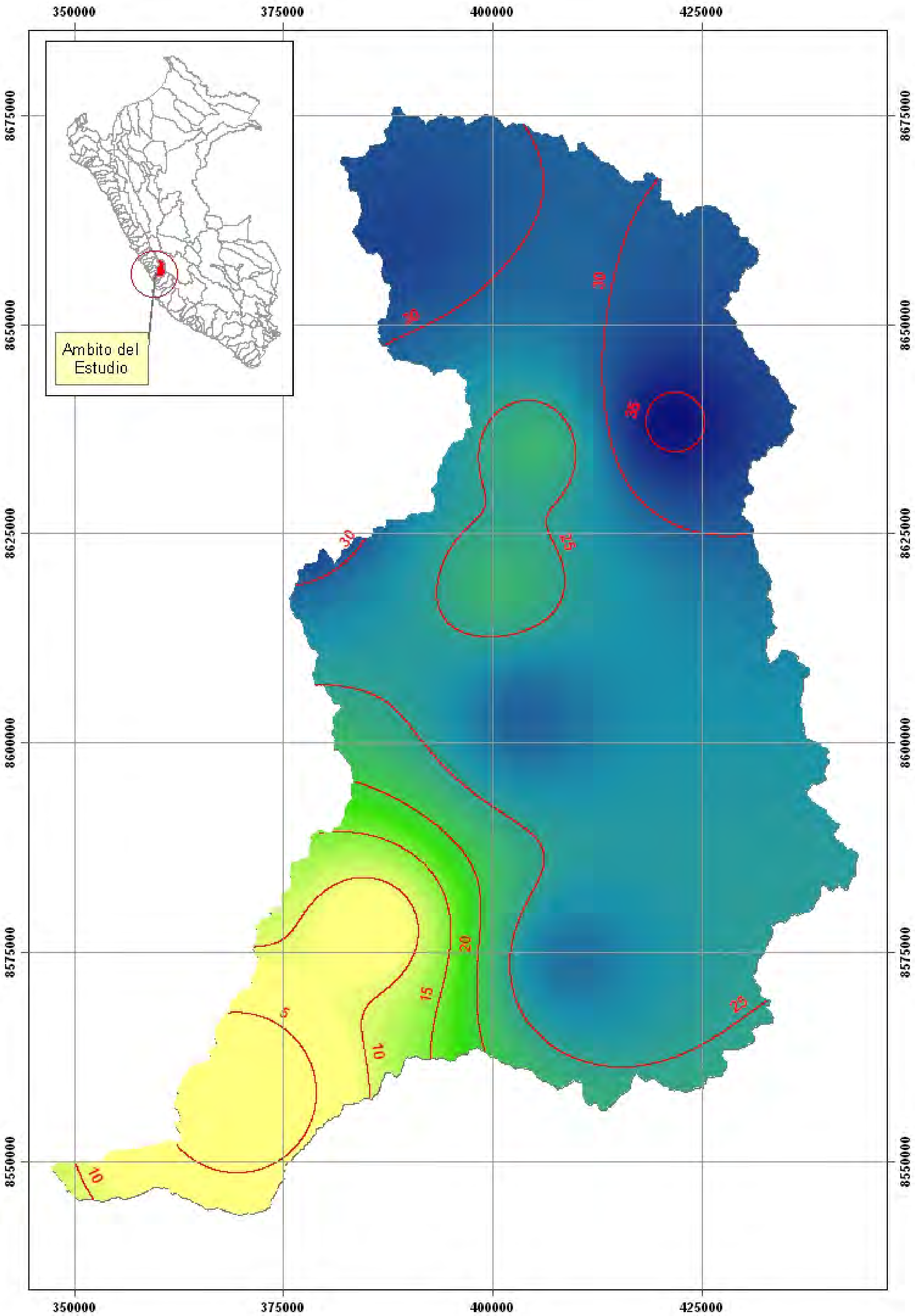


Figure Nº 4.3. Isohyets for the 5 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

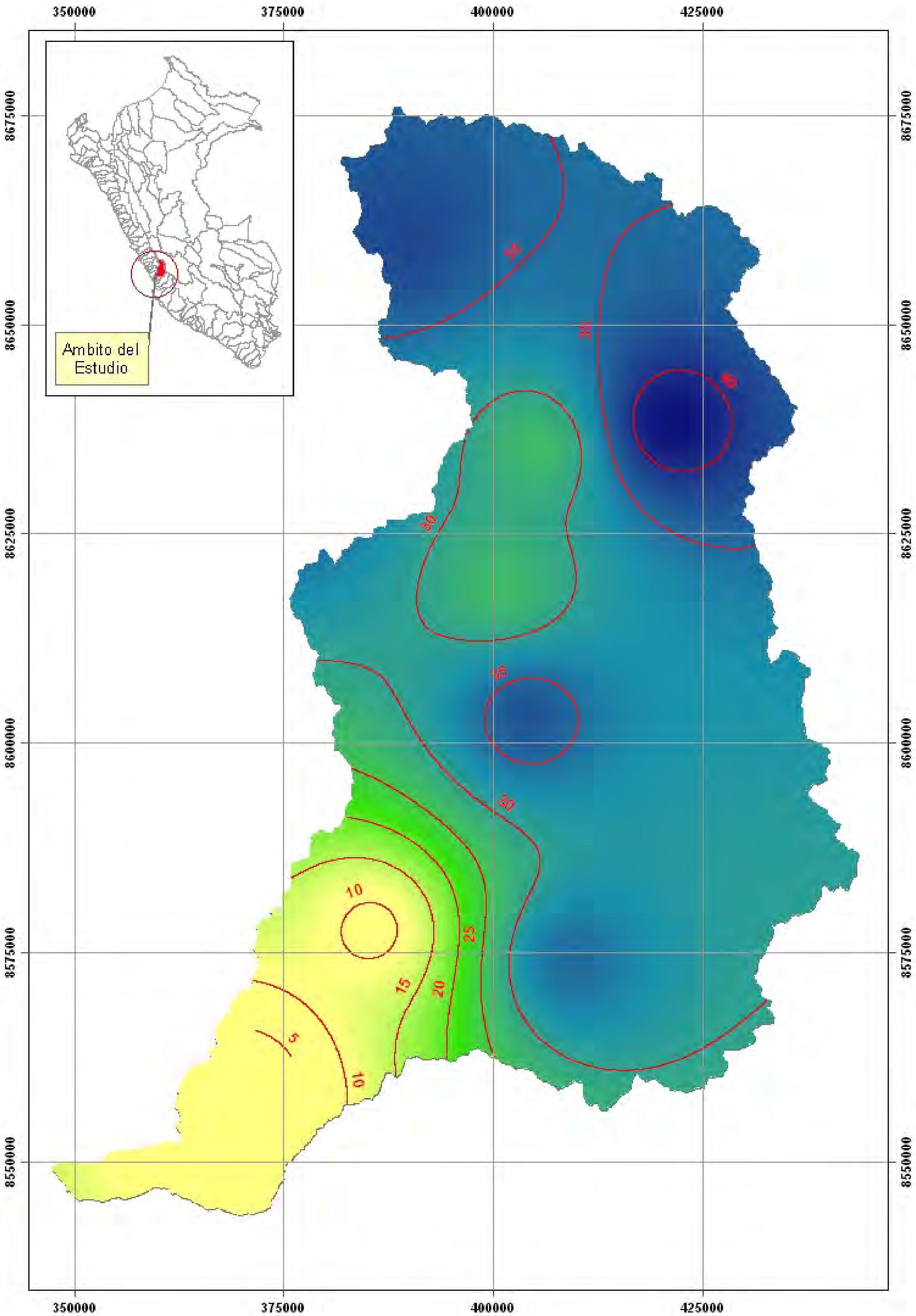


Figure Nº 4.4. Isohyets for the 10 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

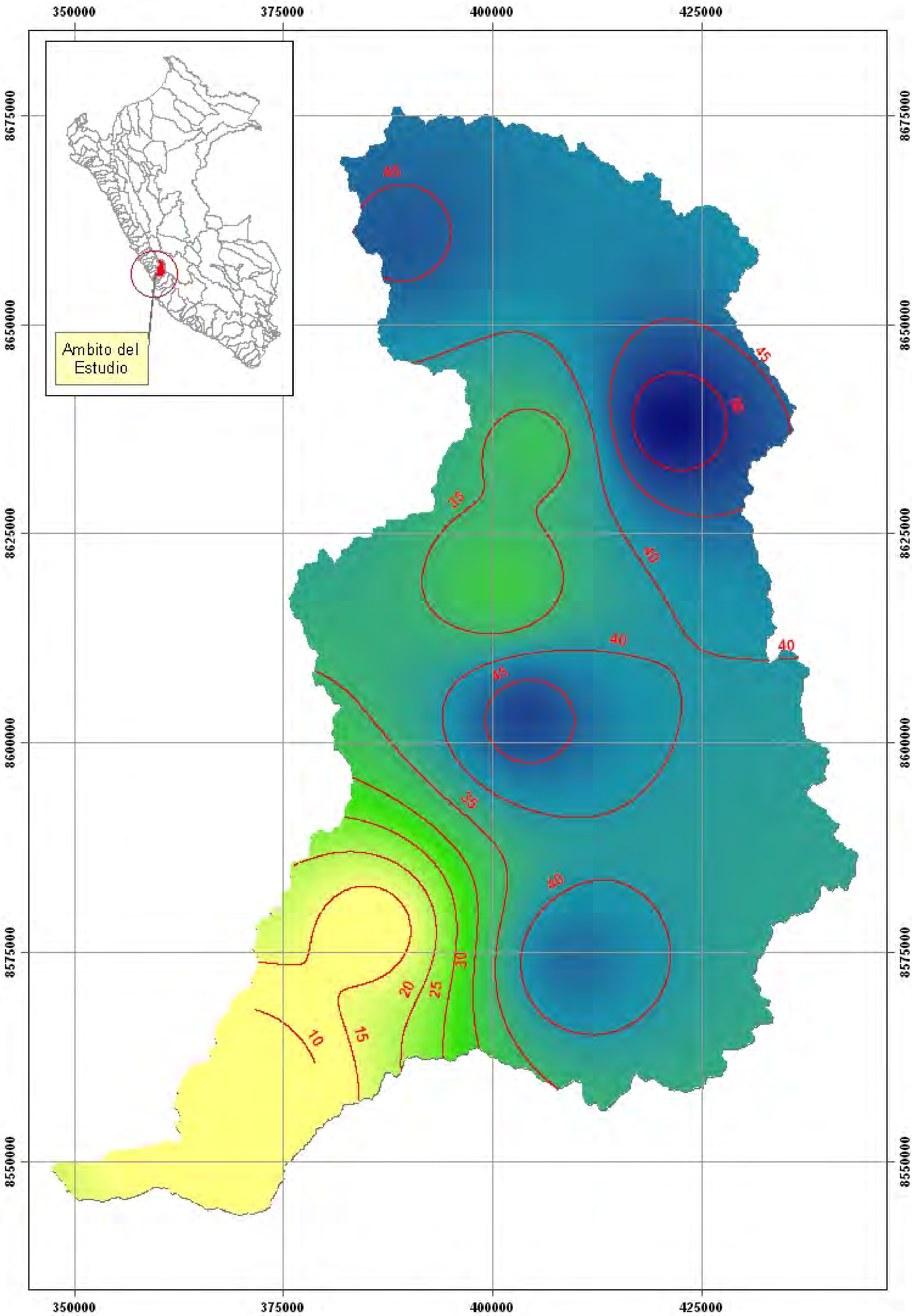


Figure Nº 4.5. Isohyets for the 25 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

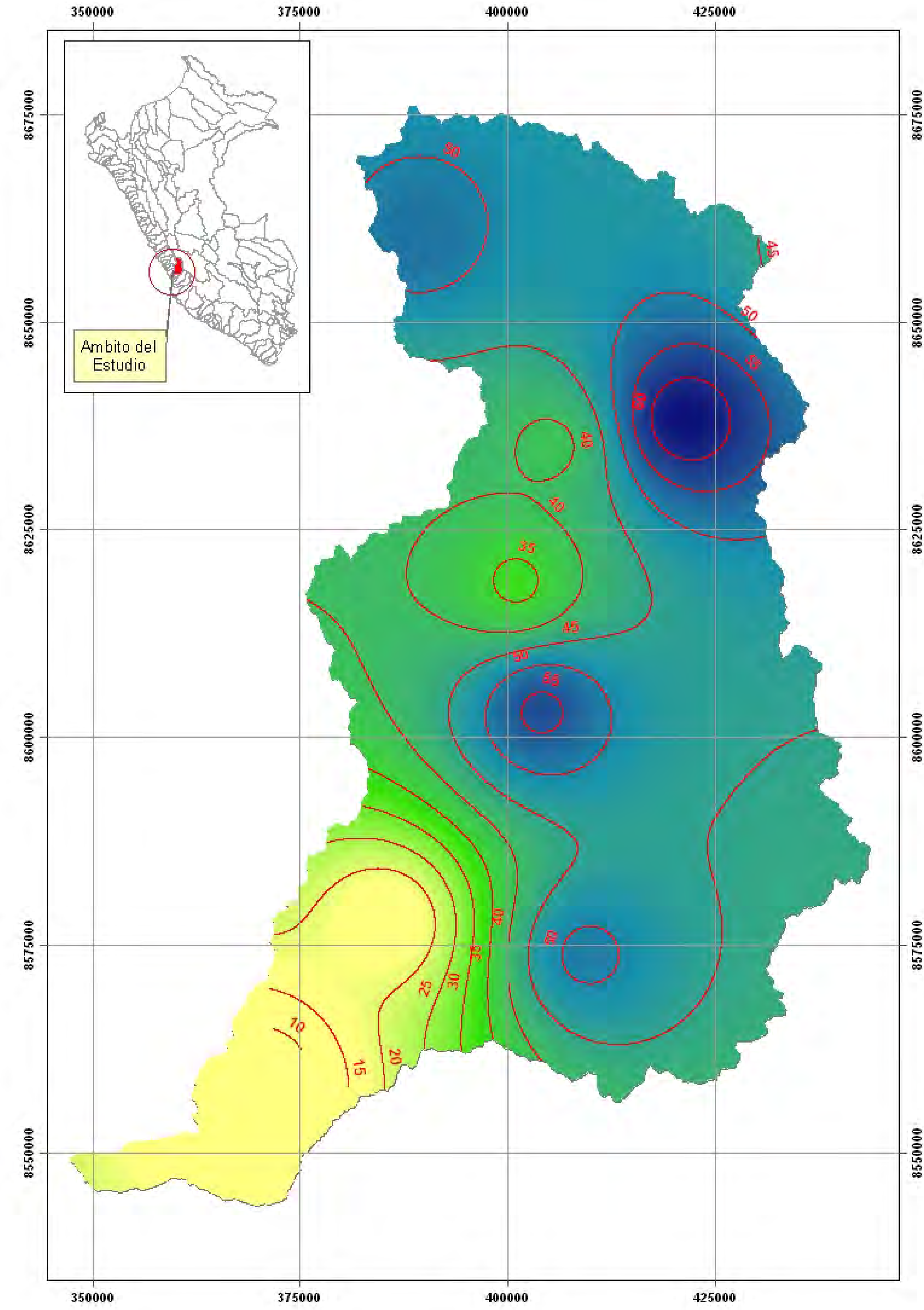


Figure Nº 4.6. Isohyets for the 50 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

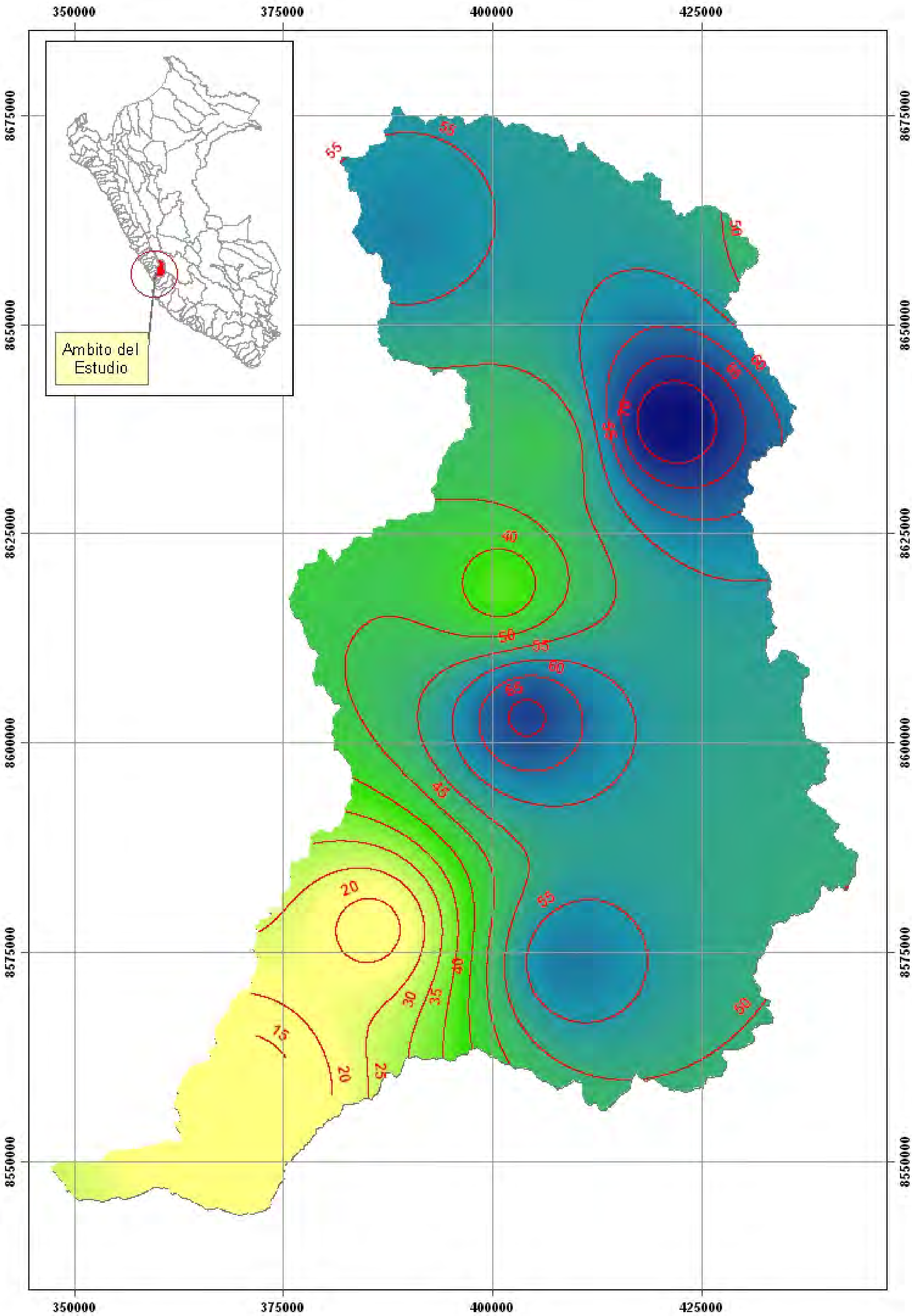


Figure Nº 4.7. Isohyets for the 100 - Years Return Period Maximum 24-Hours Rainfall in the Cañete Basin

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.

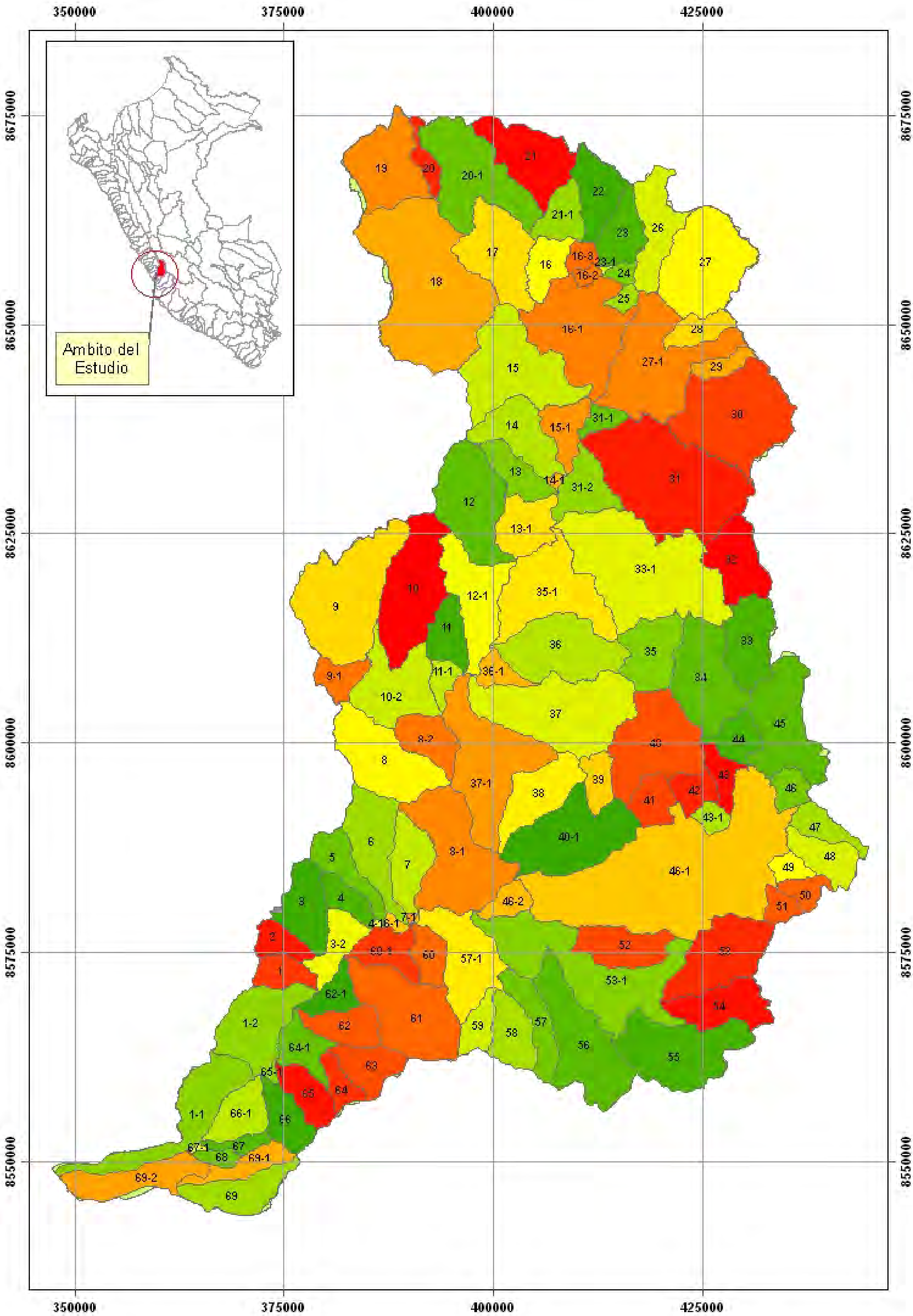


Figure Nº 4.8. The Cañete River Subbasin

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.

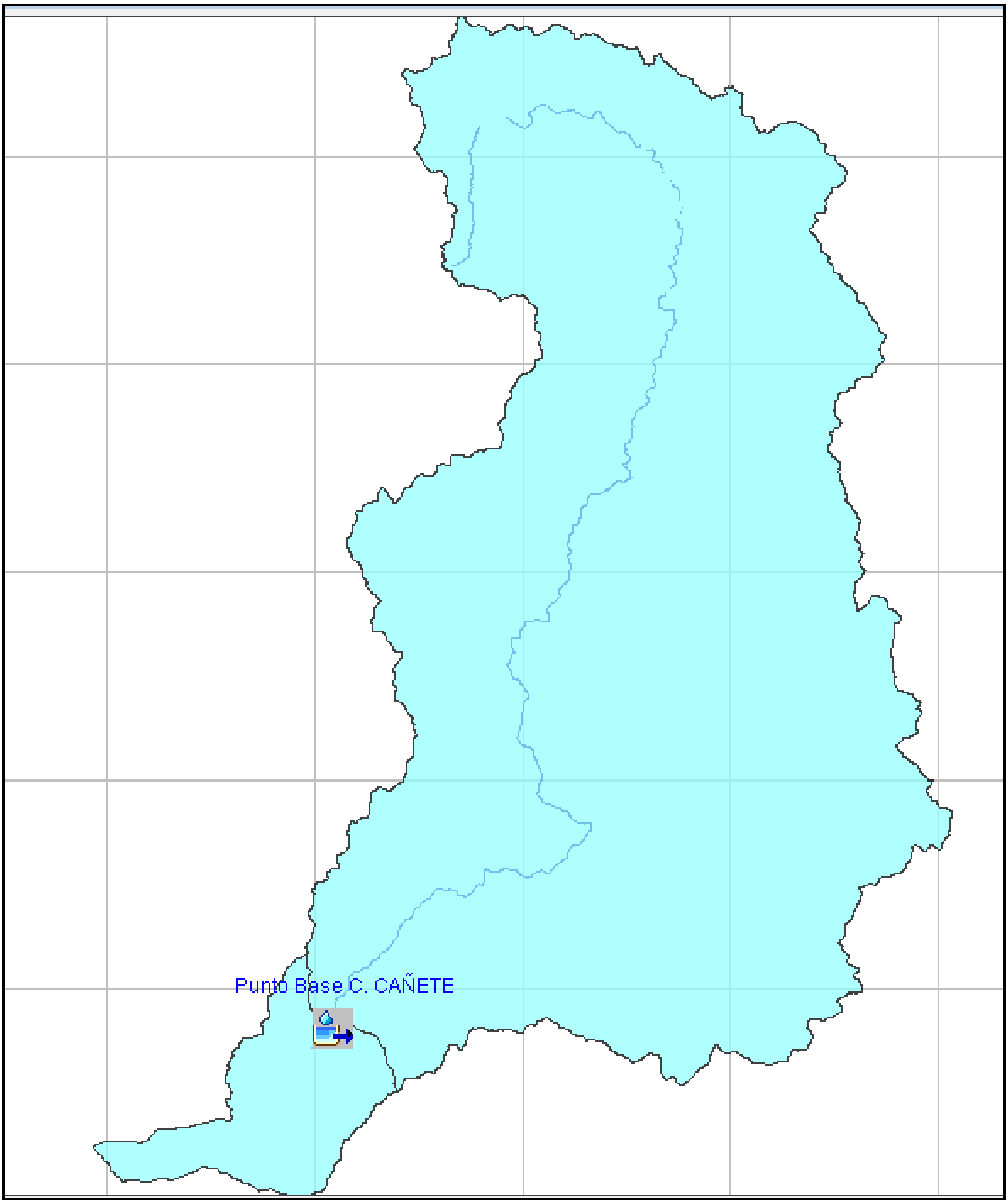


Figure Nº 4.9. Cañete River Basin Model in HEC-HMS Software

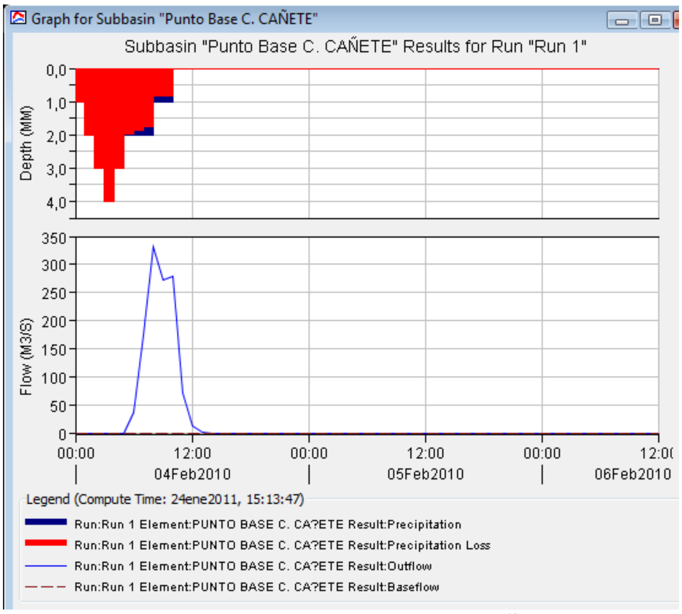


Figure Nº 4.10. Hydrograph Rainfall – Runoff models for the Cañete River basin, 2 -year Return Period

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.

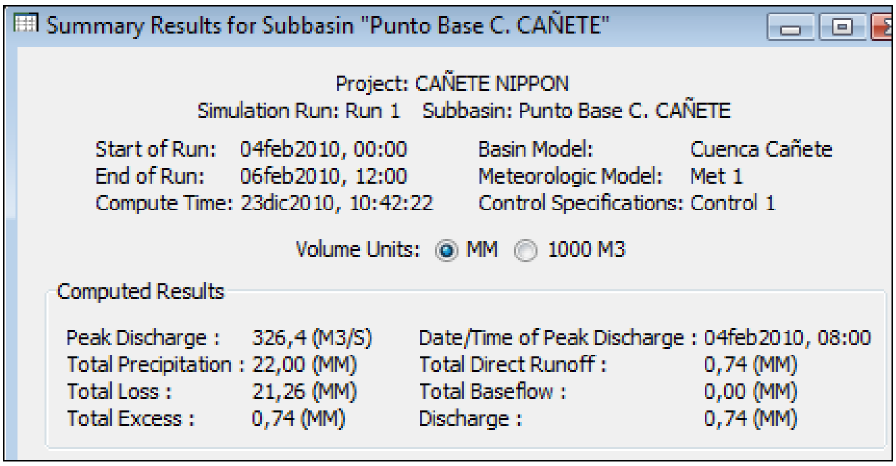


Figure Nº 4.11. Results of Rainfall – Runoff Model Simulation Cañete River, 5 – year Return Period

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

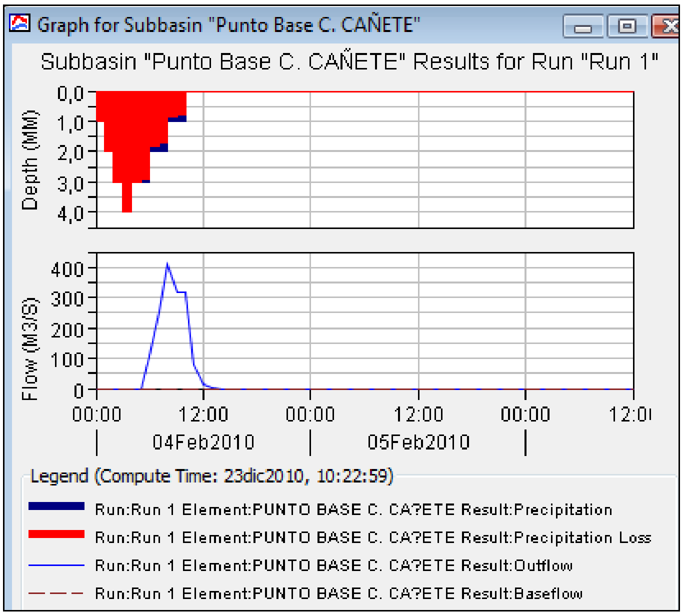


Figure Nº 4.12. Hydrograph Rainfall – Runoff models for the Cañete River basin, 5 -year Return Period

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

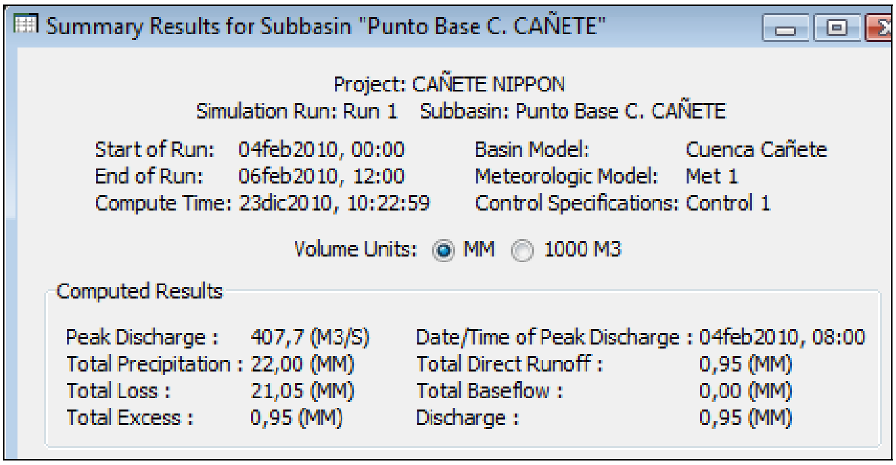


Figure Nº 4.13. Results of Rainfall – Runoff Model Simulation Cañete River, 5 – year Return Period

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

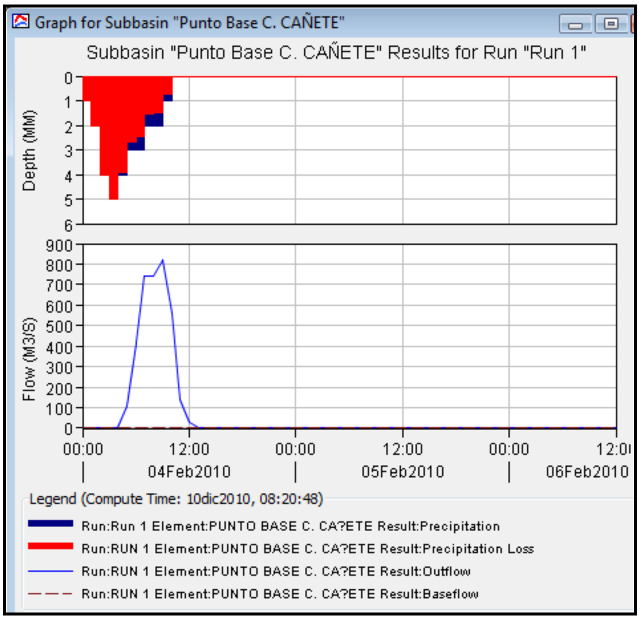


Figure N° 4.14. Hydrograph Rainfall – Runoff models for the Cañete River basin, 10 - year Return Period

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

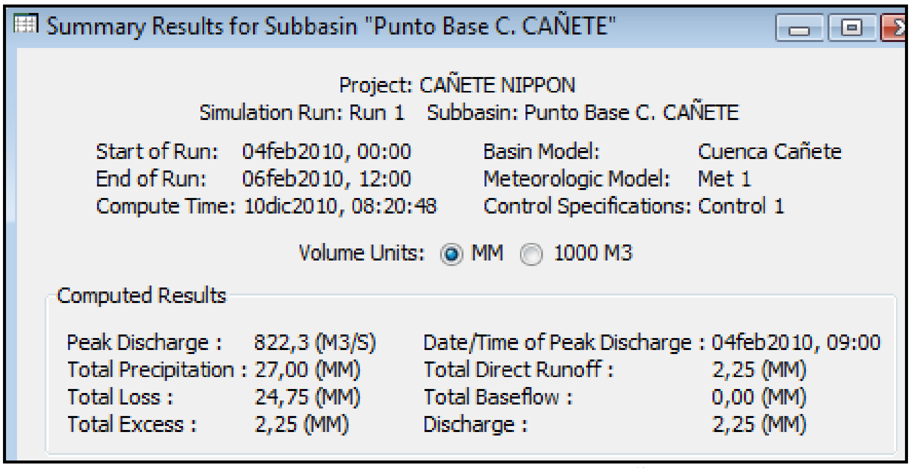


Figure N° 4.15. Results Rainfall – Runoff Model Simulation Cañete River, 10 – year Return Period

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

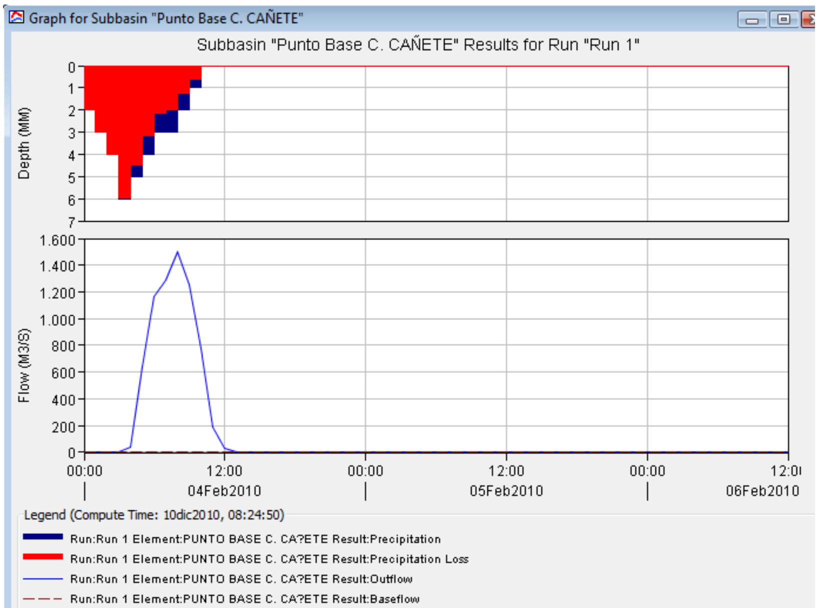


Figure Nº 4.16. Hydrograph Rainfall – Runoff model for the Cañete River basin, 25 – year Return Period

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

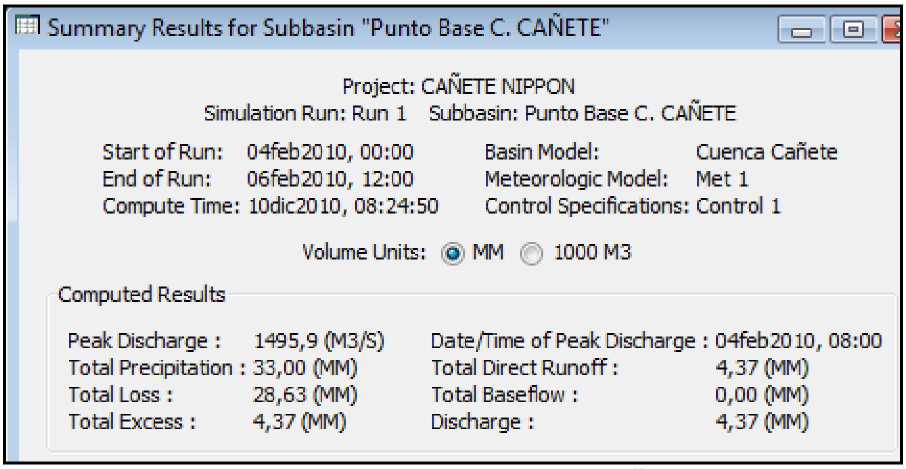


Figure Nº 4.17. Results Rainfall – Runoff Model Simulation Cañete River, 25 – year Return Period

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

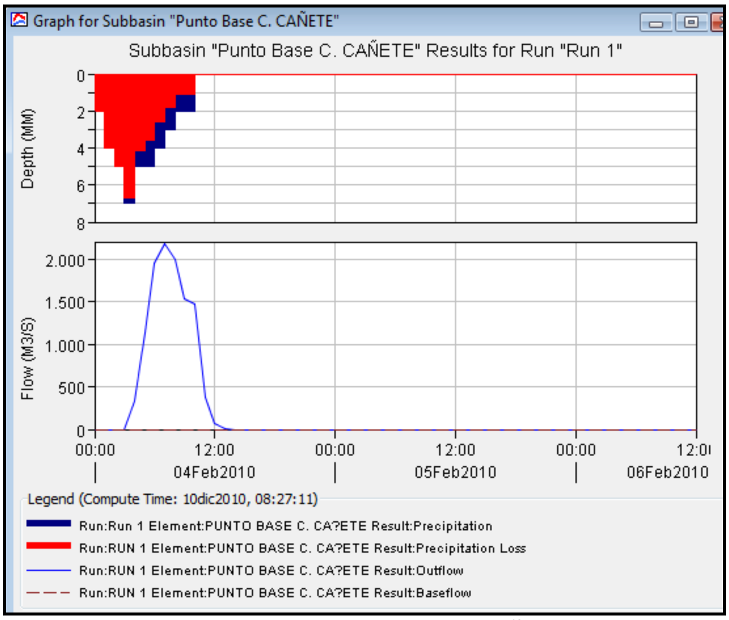
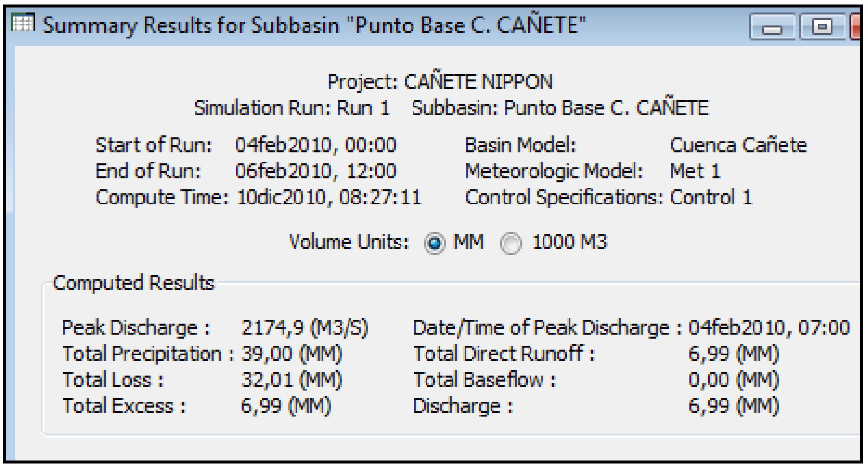


Figure Nº 4.18. Hydrograph Rainfall – Runoff model for the Cañete River basin, 50 – year Return Period

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

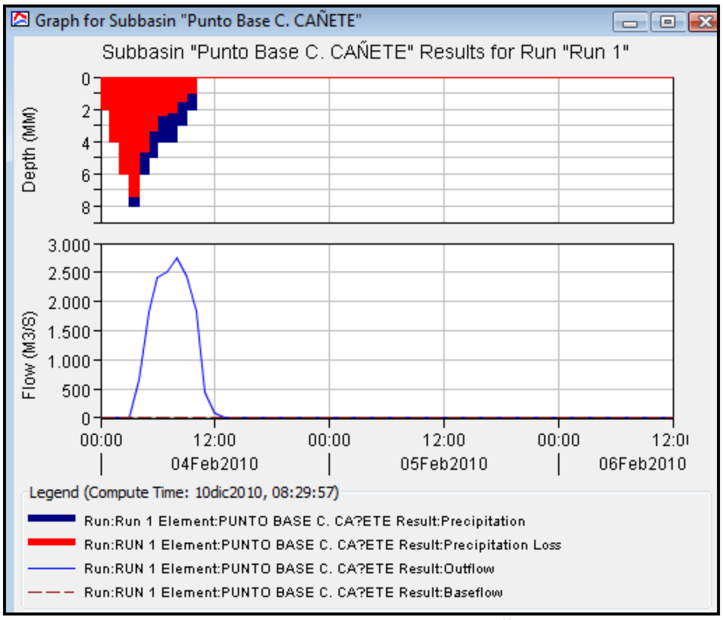


Figure Nº 4.20. Hydrograph Rainfall – Runoff model for the Cañete River basin, 100 – year Return Period

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

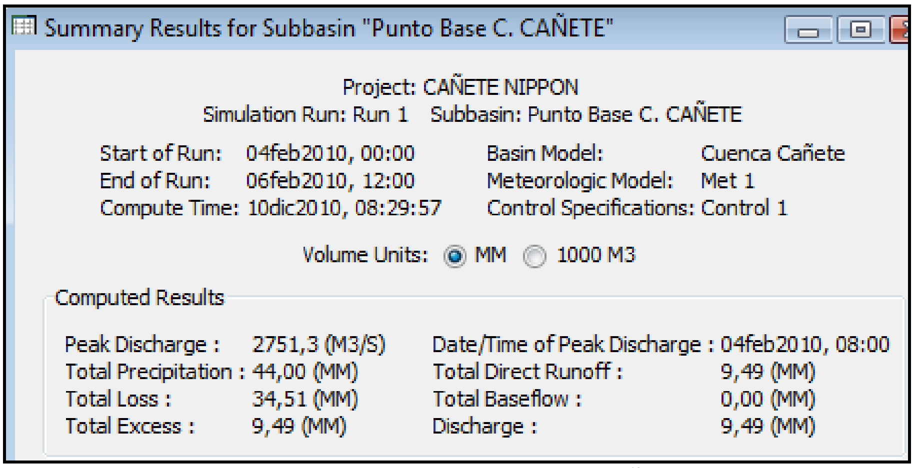


Figure Nº 4.21. Results Rainfall – Runoff Model Simulation Cañete River, 100 – year Return Period

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.