SMHI HYDROLOGY
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APPLICATION OF THE HBV MODEL TO THE UPPER RIO CAUCA

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CVC CORPORACION AUTONOMA REGIONAL DEL CAUCA

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PREFACE

The work described in this report is part of a collaboration project between Corporación Autónoma Regional del Cauca (CVC), Colombia, and the Swedish Meteorological and Hydrological Institute (SMHI)

CVC is an entity, whose main objective is to promote the economic and social development of the upper Cauca basin in the provinces of Cauca and Valle as well as of part of the Colombian Pacific region. One specific objective is to regulate the river, Río Cauca, for flood control, hydropower generation and for pollution alleviation.

The collaboration project deals with the application of the conceptual HBV model to the upper Río Cauca. The work was started in February 1987 and completed in June 1988. The project was financially supported by the Swedish Agency for Technical and Economic Cooperation (BITS).

We would like to thank the staff of the Corporación Autónoma Regional del Cauca and the Swedish Meteorological and Hydrological Institute for their valuable contributions to the project. Special thanks are due to Mr. Arne Forsman and Mr. Magnus Persson at the SMHI.

Norrköping and Cali, June 1988,

Martin Häggström   Luz Amelia Sandoval
Göran Lindström   María Elvira Vega

1. INTRODUCTION

The Río Cauca flows from south to north between the mountain ranges Cordillera Occidental and Cordillera Central in western Colombia. It has a basin area of 58 500 km^2 and is the main tributary of the Río Magdalena.

A Swedish conceptual runoff model, the HBV model, has been applied for the upper part of the Río Cauca. The aim of the model application is to forecast the inflow to the Salvajina reservoir and also to forecast the discharge at a number of river sections downstream from Salvajina. The geographical situation of the project area can be seen in Figure 1.

Figure 1. Geographical situation of the project area.

2. CONCEPTUAL RUNOFF MODELS

2.1 General features

The basic need for river basin development, both at the planning and at the management stages, is the evaluation of temporal and spatial water availability in the region. Conceptual runoff models can be very useful for the purpose, as they compute runoff from precipitation as main input by quantifying the most dominant physical processes through a series of mathematical functions. The models continuously account for the water in storage in the basin and are capable of continuous simulation of flow for as long a period of time as there are input data available.

A common application of conceptual runoff models is for forecasting purposes. As input to the model a meteorological forecast is often used. The lead time for the hydrological forecast depends on the reliability of the meteorological forecast and the dynamics of the river system. A river with a slow response is thus easier to forecast than one with quick response to rainfall or snowmelt. For long range forecasts, historic climate records can be used as input to the model, and the forecast can be based on a statistical analysis of several sequences of computed hydrographs.

A common experience is that river runoff records at a particular site in a basin are too short for reliable statistical analysis for design purposes. Missing data of critical high-flow periods are also frequent problems. Often, however, there is a relatively long period of rainfall data available in the basin. In this situation mathematical models conceptually representing the runoff process can be useful for simulating missing runoff records, after calibration against existing data.

Several runoff simulation models have been developed since the late 1950's, e.g. the SSARR model (Rockwood, 1958), the

Stanford Watershed Model (Linsley and Crawford, 1960), the TANK model (Sugawara, 1961), the Dawdy and O'Donell model (Dawdy and O'Donell, 1965), the Boughton model (Boughton, 1966), the Hydrocomp Simulation Program (Hydrocomp Inc., 1969), the NWSRFS (NOAA, 1972), the UBC Model (Quick and Pipes, 1972), the NAM Model (Nielsen and Hansen, 1973), and the HBV model (Bergström, 1976).

The complexity of these models varies over a wide range, which also implies varying demands concerning computer facilities and input data. The HBV model developed by the Swedish Meteorological and Hydrological Institute (SMHI), (Bergström, 1976) is one of the simpler models in the range but has proved to yield satisfactory results for both simulation and forecasting.

2.2 The HBV model

The HBV model is a conceptual runoff model for continuous calculation of runoff. Its formulation is easily understood, and computer and input data demands are moderate. The model is in most cases run on daily values of rainfall and estimates of potential evapotranspiration. If the snow routine of the model is to be used, it requires temperature data as well. The model is usually run with a time step of 24 hours. A complete forecasting system based on the HBV model has been developed at the SMHI for interactive use on an IBM personal computer.

The HBV model consists of routines for snow accumulation and melt, soil moisture accounting, runoff response and finally a routing procedure. The model can be used in a distributed fashion by dividing the area into subbasins. Each subbasin can be divided into zones according to altitude and vegetation. The model structure within a subbasin is shown in Figure 2.

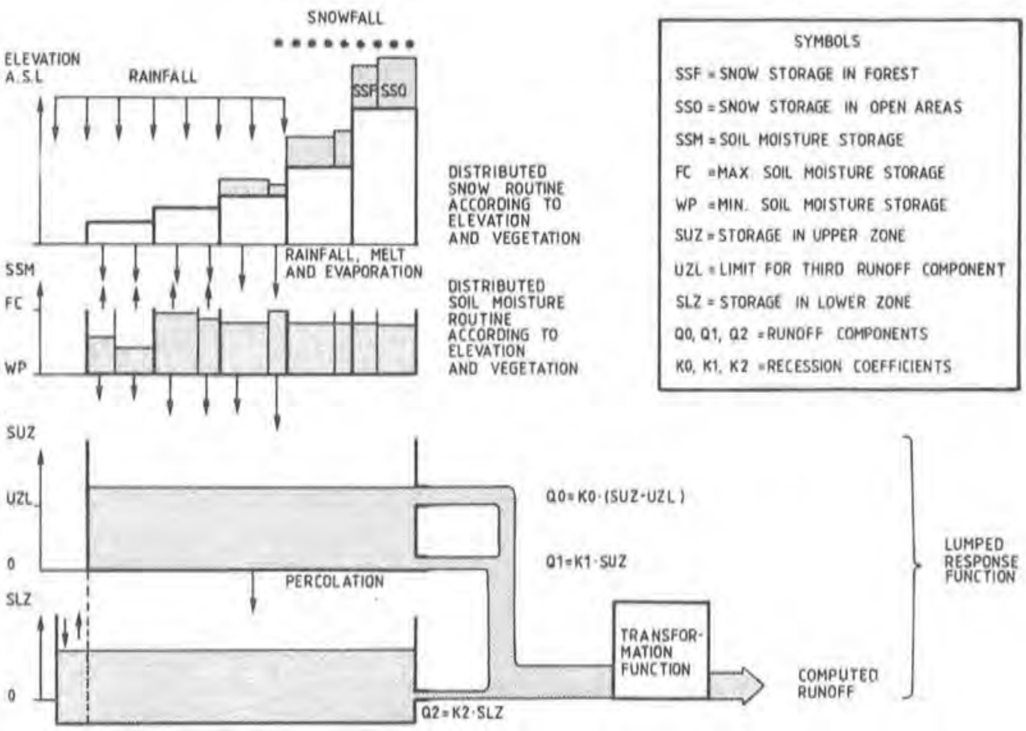


Figure 2. Basic structure of the HBV model.

The snow routine is based on a degree-day approach and runs separately for each elevation and vegetation zone. The variation of temperature with altitude is accounted for by a temperature lapse rate. Thus the temperature is corrected from a weighted average altitude of the temperature stations in the subbasin to the mean altitude of each elevation zone. Different snow melt rates in forested and non-forested land can be accounted for by a division into vegetation zones with separate degree-day parameters.

The variation of precipitation with altitude can be accounted for by applying a precipitation lapse rate in the same manner as for the temperature. In addition, there is a general precipitation correction parameter, which can be used for adjusting the precipitation, when the stations are not representative for the basin.

The soil moisture routine is the main part controlling runoff generation. It runs separately in each elevation and vegetation zone. The routine is based on three empirical parameters, BETA, FC and LP, as shown in Figure 3. BETA controls the contribution to the runoff response routine (ΔQ) and the increase in soil moisture storage ($1 - \Delta Q$). In order to avoid problems with non-linearity, the soil moisture routine is fed by snowmelt and rainfall, millimetre by millimetre. The routine results in a small contribution to runoff, when the soil is dry (low SSM values), and a great contribution when conditions are wet. FC is the maximum soil moisture storage in the model, and LP is the value of soil moisture storage, above which evapotranspiration reaches its potential value. The actual evapotranspiration decreases with increasing soil moisture deficit.

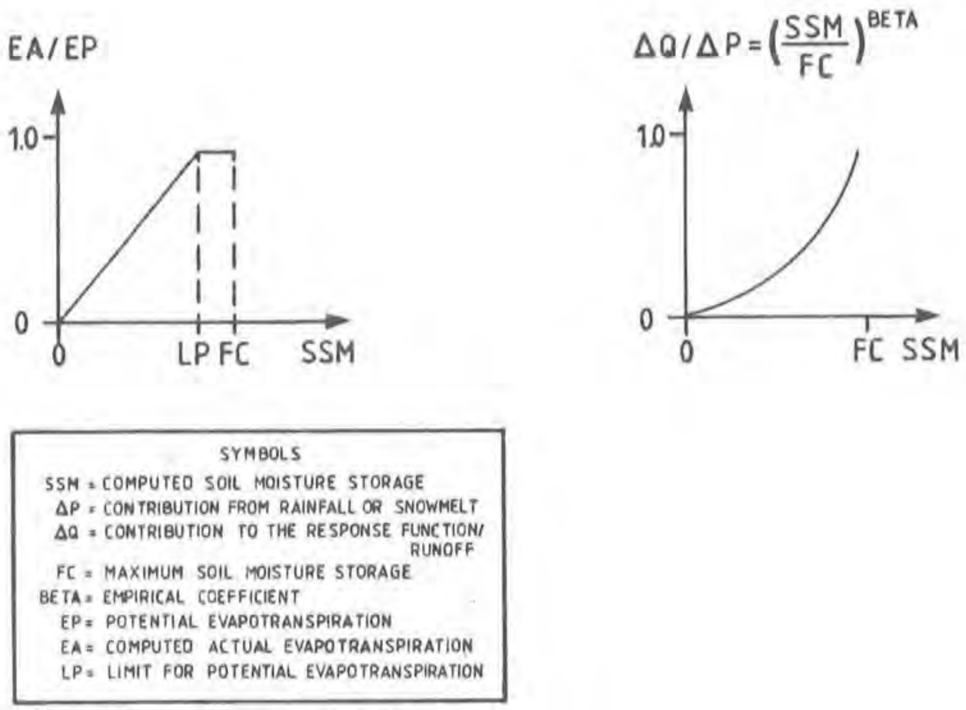


Figure 3. Schematic presentation of the soil moisture accounting in the HBV model.

The runoff response routine transforms excess water from the soil moisture routine to runoff for each subbasin, see Figure 4. It also includes the effects of direct precipitation and evaporation for open water bodies (LAKE) in the subbasin. The routine consists of two reservoirs, which distribute the generated runoff in time and can be used to obtain the quick and slow parts of the recession normally encountered in hydrograph analysis.

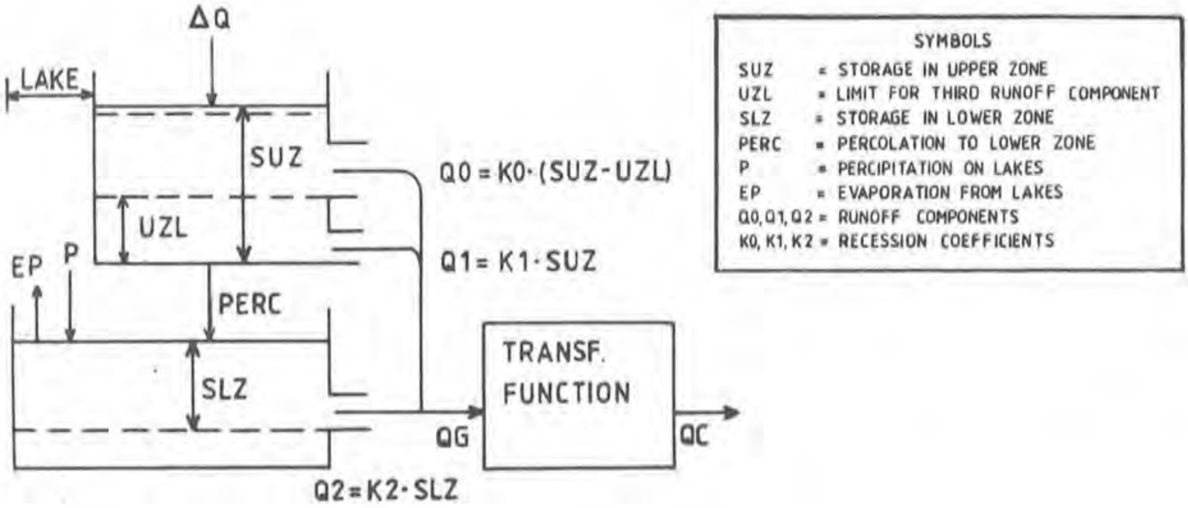


Figure 4. The runoff response function of the HBV model.

The lower reservoir can be interpreted to represent groundwater and lake storage contributing to base flow. The drainage is controlled by the recession coefficient K2. If the yield (ΔQ) from the soil moisture routine exceeds the percolation capacity (PERC), the upper reservoir will start to fill and be drained by the coefficient K1. This represents water drained through more superficial channels. When the storage exceeds UZL, an even faster drainage will start according to K0.

The runoff is computed independently for each subbasin and then routed through a transformation routine to get the proper shape of the hydrograph at the basin outlet. There are three alternatives of transformation routines. The main routine is based on the Muskingum routing method. If there is a lake at the outlet of a subbasin, the outflow from this lake can be calculated according to the rating curve. There is also a simple filter (unit hydrograph) with a triangular distribution of weights.

The HBV model is calibrated by a manual trial and error procedure. Usually 5 - 10 years of observed daily discharge data are sufficient. To fit the model three main criteria are used:

1) Visual inspection of the computed and observed hydrographs.
2) A continuous plot of the accumulated difference between the computed and observed hydrographs.
3) The explained variance expressed as:

$$R^2 = 1 - \frac{\sum_{t=1}^{n} [Q_{comp}(t) - Q_{obs}(t)]^2}{\sum_{t=1}^{n} [Q_{obs}(t) - \overline{Q_{obs}}]^2}$$

where: Q_{comp} = computed discharge (m^3/s),
Q_{obs} = observed discharge (m^3/s),
t = time variable (usually days),
n = number of timesteps,
$\overline{Q_{obs}} = \frac{1}{n} \sum_{t=1}^{n} Q_{obs}(t)$.

In addition to these criteria, the calibration can be supported by plots of the observed and computed flow duration curves.

It is desirable to save a few years data for an independent test period.

The HBV model is usually used for forecasting purposes. Before a forecast the model is run on observed data until the timestep (day) before the timestep of forecasting. If there is a discrepancy between the computed and observed hydrographs during the last days of the run, updating of the model should be considered. The HBV-model is updated by adjustment of either a few days of input data or the model state with the intention of reducing the discrepancy. The updating procedure is a manual iterative procedure, and usually the computed hydrograph is accepted after a few runs. For snowmelt conditions there is also a semi-automatic procedure for updating the temperature. However, one should be cautious to update, and one has to be aware of the fact that the updating procedure can introduce additional uncertainty.

The model can be used for either short range or long range forecasts.

The short range forecast is mainly used in flood situations. The runoff development is forecasted until the culmination has passed. A meteorological forecast is used as input, and there is a possibility to use alternative precipitation and temperature sequences in the same run. This is often desirable due to the low reliability of meteorological forecasts, especially for precipitation. For snowmelt conditions it is often more useful to run the model with a number of temperature alternatives as input.

Long range forecasts are mainly used for two purposes: prediction of peak flow and of runoff volume. For regulation of hydropower reservoirs the remaining inflow to a given date is the most interesting figure, while in other basins the interest is concentrated towards the distribution of peak flows. The later aspect is, of course, the most important, if flood damages is the main problem. On the other hand, for some rivers, low flow forecasts can be the most interesting ones. The forecast uses precipitation and temperature data from the corresponding dates during preceding years as input. Usually data from at least 10 years are used, and often from 20 years or more. The distribution of the different simulations gives an indication of the probability that a given value will be exceeded. Based on that, the volume forecast is supplemented with a statistical interpretation of the result.

3. DESCRIPTION OF BASIN AND CLIMATE

3.1 Basin characteristics

The Río Cauca is one of the main Colombian rivers. A large number of people live in its drainage basin, which is one of the richest regions in the country. The river runs towards the north 1 200 km along an Andian valley, through the provinces of Cauca, Valle, Risaralda, Caldas, Antióquia, Sucre and Bolívar. Its drainage basin covers 58 500 km^2, equivalent to 5 % of the total extension of the country. The HBV model has been applied to the upper part of the river, from its origin in the province of Cauca down to La Victoria in the province of Valle, where the basin area is 16 284 km^2.

The Río Cauca initiates its course in the region of the volcanoes Sotará and Puracé, southeast of the city of Popayán. The first 70 km of the course runs in a northwest direction through narrow canyons. It then turns to the north, over 60 km of rolling country and narrow valleys, and in that reach the reservoir of Salvajina is situated. At Timba the river enters an alluvial plain and continues northward, forming meanders over a length of almost 400 km. The downstream end of the project area almost coincides with the northern end of the plain.

The western basin divide follows the Cordillera Occidental, which has peaks to an altitude of about 4 000 m. In general the altitude of the divide is between 2 000 - 3 000 m. The eastern basin divide follows the Cordillera Central, which is higher, and the general altitude of the divide is 3 000 - 4 000 m. The southern basin divide against the Río Patía has an altitude of 1 500 - 2 000 m. The distance between the western and eastern divides is about 75 km, and the north-south length of the project area is almost 300 km.

The most conspicuous part of the Cauca depression is the upper Cauca plain "El Valle" between Santander and Cartago. The average width of the southern part of this plain is about 30 km, but the northern part is only about 10 km wide. The Río Cauca flows along the western side of the plain. Due to an asymetrical form of the valley, the crest of the Cordillera Occidental is nearer the plain than is the crest of the Cordillera Central.

The geological history of the valley shows several periods, in which the floor was covered by a lake. Volcanic upheaval impeded the drainage of the valley and converted it to a lake, which was later drained. Sediments deposited during the lake stages have, however, mostly been eroded away. The area has instead been filled up with younger alluvial deposits. The tributaries entering the valley plain from the Cordilleras have gradually built up alluvial fans, which on the eastern side coalesce into a long alluvial plain. The actual flood-plain of the Río Cauca is rather narrow, because the alluvial fans at both sides have advanced far towards the river. The Río Cauca is a meandering river in the whole flat part of the valley and shows the normal pattern of abandoned channels and natural levees (Reese and Goosen, 1957).

Forests cover only a minor portion of the mountains due to a combination of steep slopes and deforestation carried out by the population. Within recent centuries, and particularly the present, the forest-covered area has decreased under the impact of population expansion. Most of the remaining forests are situated in the Cordillera Occidental near the basin divide. In some small areas reforestation projects are carried out.

The treeline is at about 3 000 m altitude and from 3 000 - 5 000 m there is a natural forestless stratum with shrub and grass vegetation called "páramos". Above the snowline at about 5 000 m altitude there are only insignificant areas.

Most of the tributaries of the Río Cauca can be considered as torrents due to physiographic, morphological and climatic characteristics of their drainage basins. That implies a rapid response to the short and intense rainfalls occurring in the area, producing very high peaks of short duration, though relatively low flows prevail for most of the year. Contrary to its tributaries, the Río Cauca presents relatively moderate variations.

Large parts of the Cauca plain are flood-afflicted, and some areas were earlier flooded every year. The floods are caused by long periods of rain and not by occasional rainstorms. It has been estimated that for floods of the probability once in thirty years, the area inundated by the Río Cauca at unregulated conditions is about 1 000 km^2. Large areas are also flooded by the tributaries. Other areas are flooded by inadequate drainage of rainwater, and land neighbouring flooded areas suffers from high groundwater levels. The drainage of flooded areas is slow, due to river banks, which are often higher than the adjacent land (CVC, 1975). The last severe inundation was in October/November 1984, when an area of more than 250 km^2 of the valley floor was inundated. Other severe indundations during the last decades occurred in 1950, 1966, 1971, 1974 and 1975.

In order to alleviate the costly damages caused by overflows, CVC studied and designed the so called Cauca river regulation project with three main objectives, namely: (i) flood control, (ii) pollution alleviation, and (iii) hydropower generation.

The project works consist of two main groups: (i) the dam and associated works at Salvajina for flood regulation; and (ii) the works in the flood plain consisting of levees, drainage canals and pumping station.

The Salvajina reservoir started regulation in January, 1985. Its overall volume is 908 million cubic meters, of which 731 million are useful reservoir. The maximum reservoir area is

22 km^2. The power generation installed capacity is 270 MW with three units of 90 MW each. Average annual energy production is 1 050 GWh.

During recent years, artificial levees have been constructed along the river banks. This has significantly reduced the overflows.

The upper Cauca Valley is an economically important region with a population of about 3 millions. The biggest urban community is the city of Cali, which has 1.4 million inhabitants. In the Cauca plain agriculture is very important. Historically, sugar-cane has been the main crop. It is still the most important crop, but cultivation has decreased during recent years. Large areas of the plain, mostly on poorer soils, are used as pastures.

3.2 Climate

The Cauca Valley is located within the zone that is influenced by the intertropical convergence. As a result, it has two dry seasons and two wet seasons. The dry seasons occur from mid-December through mid-March and from June through September with July and August being the driest months. The wet seasons occur from mid-March through May and from October through mid-December with October and November being the rainiest months.

In the Cordillera Central near the eastern basin divide, there is a different precipitation pattern, which is similar to the pattern in the Llanos area in eastern Colombia. It has only one dry season with lowest precipitation in January and February and one wet season with highest precipitation in July. The extent of the area with the Llanos precipitation pattern is not very well known. However, it is situated at a high altitude, and partly coincides with the páramo, the forestless stratum above 3 000 m.

The average annual precipitation has maximum values on the mountain slopes at an altitude of about 2 000 m and minimum values on the valley floor and in the páramo region. The highest precipitation, more than 3 000 mm annually, falls on the slopes of the Cordillera Occidental southwest of Cali. On the valley plain north of Cali and in the páramo region, the annual precipitation can be 1 000 mm or less. The distribution of the average annual precipitation can be seen in Figure 5.

Most of the rain occurring in the area is of convective or orographic origin, and the intense precipitation events can often be identified as generated by a combination of these two rainfall types. Another interesting aspect is the fact that between 80 % and 90 % of the rain normally falls during the first three hours of a heavy rainstorm.

The average annual temperature on the valley floor is about 24 °C. The seasonal fluctuations of temperature are insignificant and follow the general weather trend. The diurnal range is about 10 °C on the plain and somewhat higher on the mountain slopes. The average temperature decrease is 5 - 6 °C per 1 000 m of altitude. In the páramo region the temperature normally ranges between 0 and 12 °C.

The average relative humidity is 70 - 75 % on the valley plain and increases with altitude. The seasonal variation in relative humidity is small in spite of large variations in rainfall.

Winds are primarily of local origin and can be described as light and predominantly diurnal in nature. During the day the wind blows from the valley towards the mountains and at night in the opposite direction. In the atmospheric layers immediately above the mountains there is evidence that the winds are from the east or the southeast during most months (Schwerdtfeger, 1976). These winds are probably the reason for the differing precipitation pattern at high altitudes in the Cordillera Central.

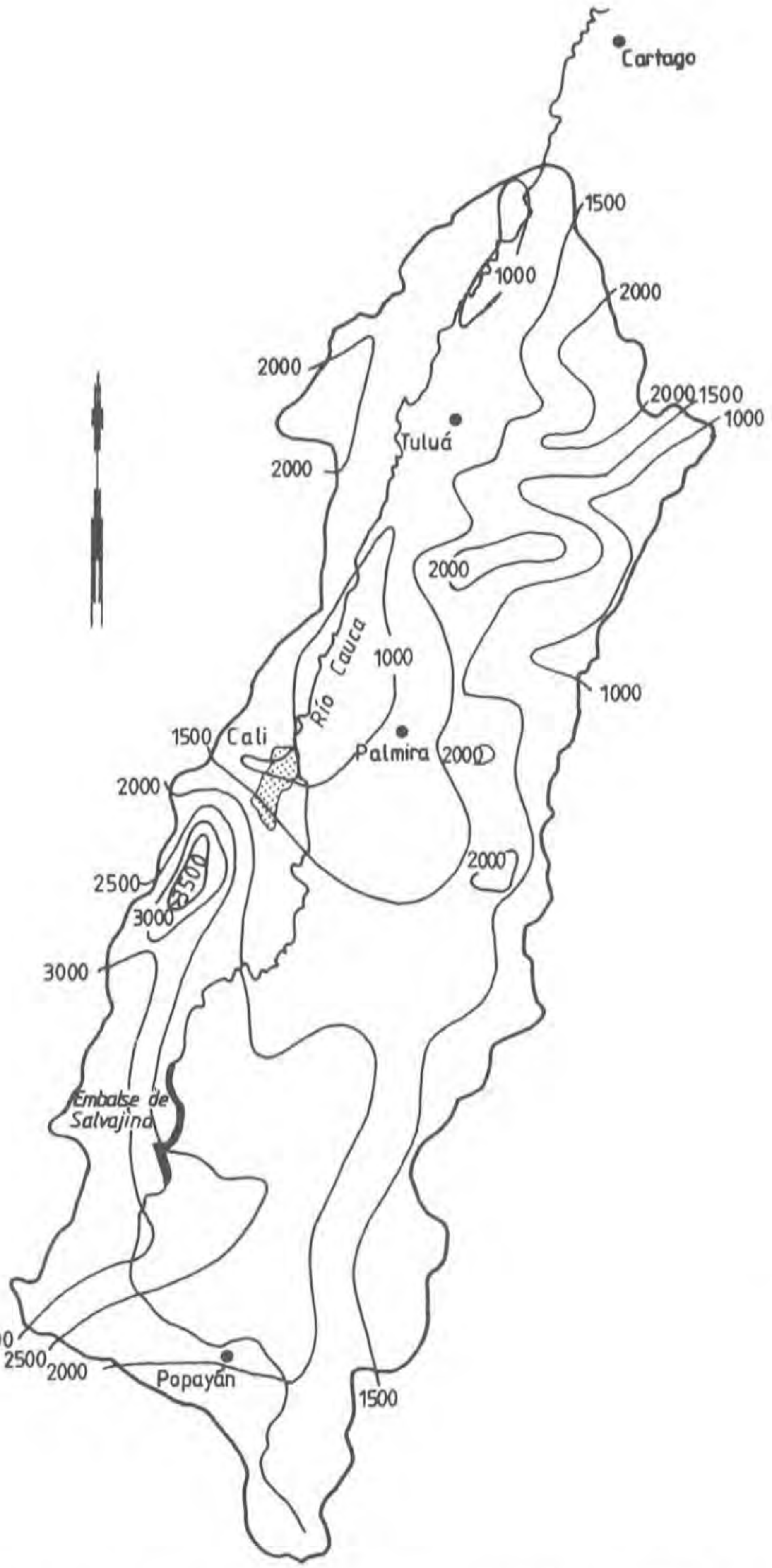


Figure 5. Average annual precipitation in the upper Río Cauca basin (from González, 1984).

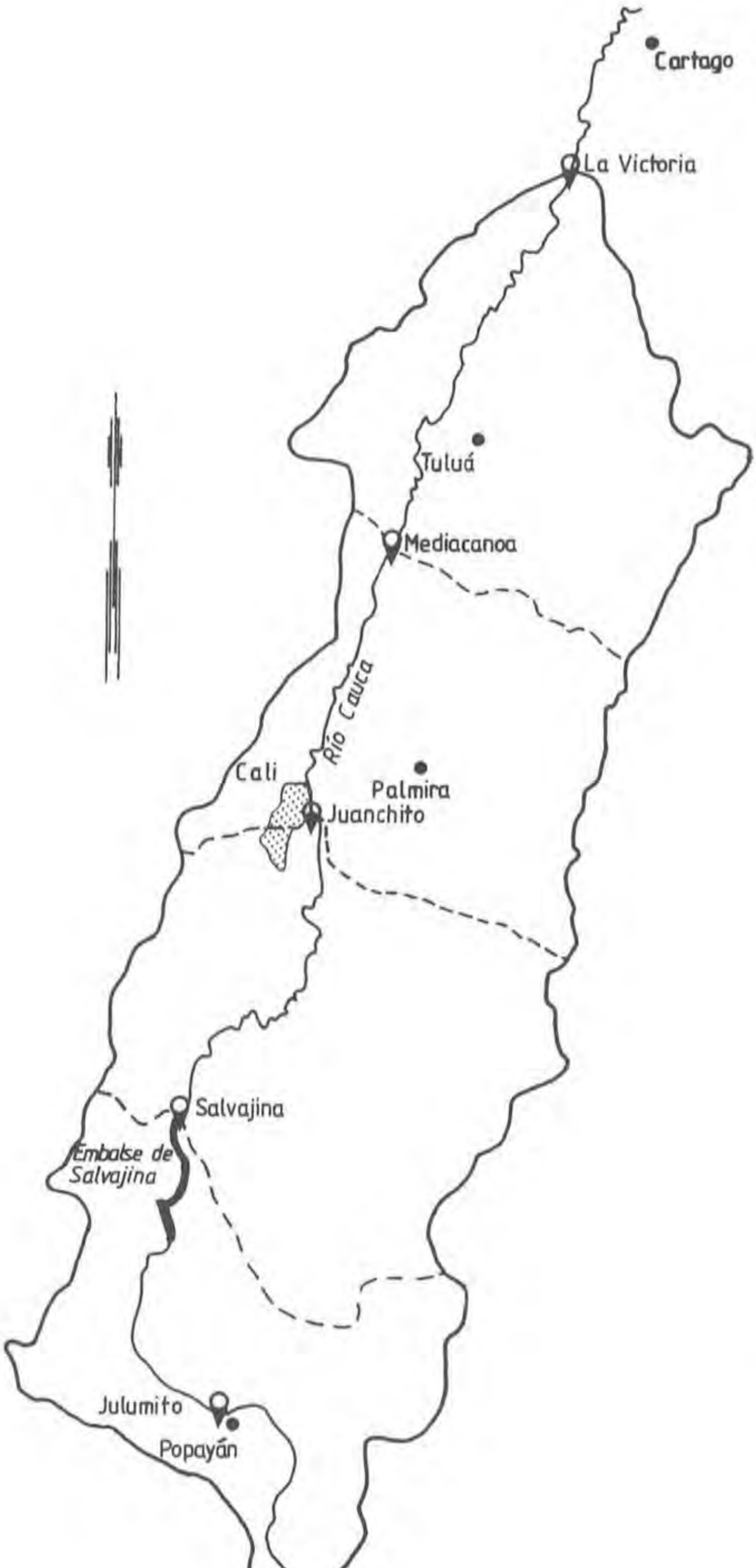
4. MODEL APPLICATION TO THE RIO CAUCA

4.1 Basin subdivision

The HBV model has been calibrated and adapted for forecasting at four streamflow stations in the Río Cauca. They are Salvajina (3 652 km^2), Juanchito (8 584 km^2), Mediacanoa (12 186 km^2) and La Victoria (16 284 km^2). The average annual discharges are 140, 278, 333 and 390 m^3/s respectively. The locations of the stations and their basin divides are shown in Figure 6.

The local basins for the mentioned streamflow stations and for the station Julumito (724 km^2) are natural subbasins in the model. Due to big differences in altitude, vegetation, precipitation and runoff conditions, a further division into subbasins has been done. The borders of these subbasins do not follow hydrological basin divides. The intention has instead been to create more or less homogeneous regions. The possibility to divide into elevation and vegetation zones has not been used due to an irregular precipitation pattern.

Areas along the basin divide in the Cordillera Central with an altitude of more than 3 000 m were treated as separate model subbasins. These subbasins represent the páramo region. They are indicated by No. 1, 4, 9, 13 and 17 in Figure 7. The remaining parts of the slopes of the Cordillera Central are denoted as subbasins No. 2, 5, 8, 10, 14 and 18. The slopes of the Cordillera Occidental have No. 3, 7, 12 and 16. An area close to the Savajina reservoir has No. 6, and subbasins representing the alluvial plain have No. 11, 15 and 19.



Figur 6. Locations in the Río Cauca, for which the HBV model has been adapted for forecasting.

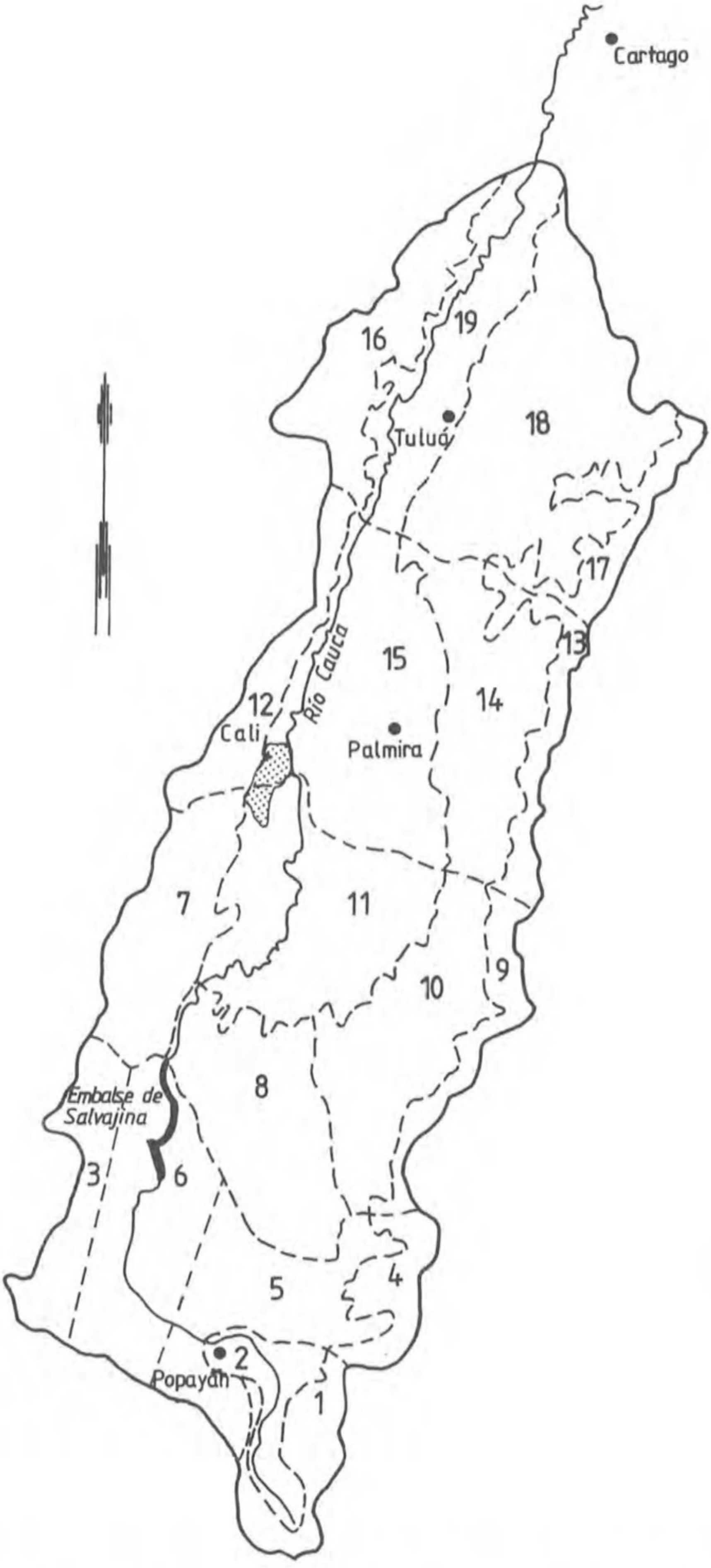


Figure 7. Subbasins in the HBV model of the upper Río Cauca.

4.2 Input data

The precipitation input to the model is taken from a number of precipitation stations representing each subbasin. Stations situated within or near the actual subbasin were as far as possible selected, and altogether 58 stations were prepared for use. The homogeneity of the records was tested and some stations were eliminated due to non-homogeneity. Other stations were excluded, because they were considered not to give additional information. Although the precipitation network in the upper Río Cauca basin is rather dense, it is not evenly distributed. At high altitude, there are very few stations, and for some of the subbasins, stations far from the basin had to be used. Also in lower regions, it was found that the high spatial variability of the precipitation caused a great deal of uncertainty in the calculation of areal average precipitation.

The weights of the precipitation stations for each subbasin were derived in a rather subjective manner, but a great deal of effort was spent on adjusting the weights as a way to increase the accuracy of the model simulation. Most of the model calibrations were based on input data from 42 precipitation stations in the total basin. However, for real time forecasting, many of these stations can not be used, as they are not available by telephone or any other way of quick data collection. Therefore, calibration also had to be carried out, based on a reduced precipitation network with 29 stations.

Due to the spatial variability of the precipitation and the uneven distribution of precipitation stations, some stations are more important than others. Unfortunately the remote and less populated areas in the mountains, where the precipitation is particularly irregular, are difficult to reach by telephone. The station Santa Teresa has been given a special role, as it is the only one in the reduced network that has the precipitation pattern of the "Llanos", i.e. it has maximum precipitation in June and July. This station has accordingly been given weight in all subbasins located at high altitude in the Cordillera Central. In the Cordillera Occidental, only two stations can be reached by telephone (El Topacio and Venecia). It was necessary to represent the precipitation in the western subbasins by also using stations on the valley floor. This causes some problems, since the region receives very much rain and there is a considerable variation in the east-west direction in this area.

The measured precipitation had to be multiplied by a correction factor to obtain an areal average precipitation of the right magnitude for each subbasin. The determination of correction factors was based on the precipitation distribution map in Figure 5. For some of the subbasins at high altitude, the correction factor was set as low as 0.6 due to the decrease in precipitation with altitude above 2 000 m. The subbasins in the valley plain have correction factors near 1.0, as the altitudes of the precipitation stations represent the elevation of the subbasins relatively well.

Temperature data were not used as input for this application, since the model only uses temperature in the snow routine. Although snowfall sometimes occurs at high altitude, the snow cover mostly melts quickly and is on the whole negligible.

The HBV model uses potential evaporation as an upper limit for the computation of actual evapotranspiration. Monthly mean values of the potential evaporation are often sufficient as input and were used in this application. These monthly mean values were calculated using data from 15 evaporation pans of type Class A, which have been in operation between 5 and 20 years. The pans were selected from locations representative of the upper Río Cauca basin, and they show a similar seasonal variation pattern. The difference is mainly in magnitude, and it was found that the magnitude is related to altitude, as shown in Figure 8.

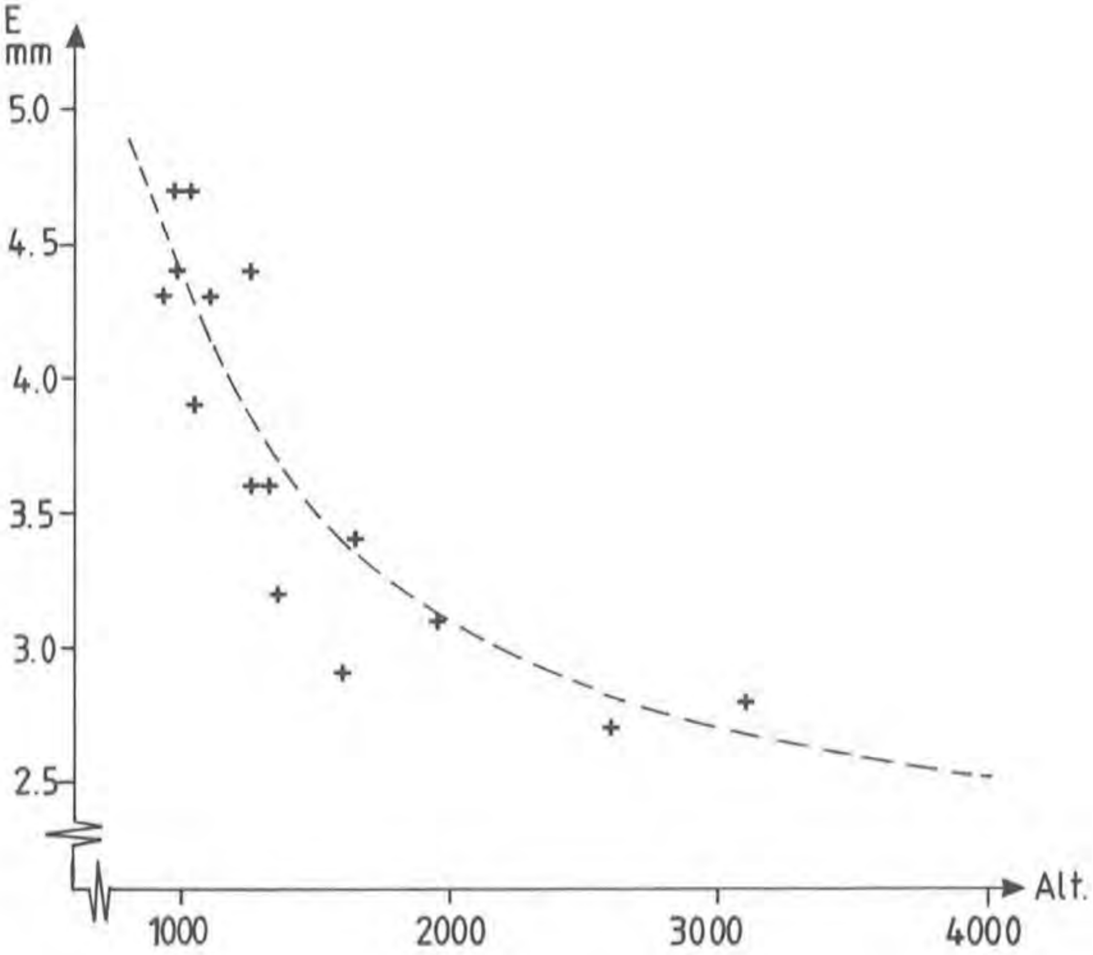


Figure 8. Average daily evaporation for Class A pans in the upper Río Cauca basin versus altitude. The dashed curve is a visually smoothed relation.

The arithmetic means of the monthly mean values from the 15 selected evaporation pans were calculated. These values are shown in Table 1 and represent the pan evaporation at an altitude of about 1 500 m.

Table 1. Average monthly values of Class A pan evaporation (mm/day).

J	F	M	A	M	J	J	A	S	O	N	D
3.8	3.9	3.9	3.6	3.4	3.3	3.9	4.0	3.8	3.6	3.4	3.5

Since the Class A pan generally overestimates the potential evaporation, the values in Table 1 were reduced by multiplying with 0.7 (as recommended by Torres and Yang, 1984). A further correction for altitude was performed for each subbasin according to the smoothed relation of the data shown in Figure 8.

Although the annual mean variation pattern of Class A pan evaporation is rather similar for the whole region, the evapotranspiration varies between individual years. As a test, the monthly mean values actually measured each year at Salvajina were used as input to the model for Salvajina instead of the standard values given in Table 1. However, this did not result in any visible improvement of the model performance, and it was thus concluded that the standard values were sufficient for further model calibration.

4.3 Overflow of river banks

A special problem in the calibration has been overflow of the river banks at high water levels. In the overflow periods, large areas of the upper Cauca plain are inundated, and the dynamics of the flow drastically changes due to storage on the flood plain. In the model, this has been described by simulating the river reach as a series of lakes with variable areas, from which the outflow is controlled by rating curves. Below the critical level of overflow, the lakes were given small areas corresponding to the river area in the subbasin and at higher levels rapidly increasing areas. Thus the flow is routed through lakes, and the Muskingum routing is not used for the subbasins with inundation lakes.

During the calibration period, there were two occasions with extensive overflow: November/December 1975 and October/November 1984. The inundated area in 1984 was largest in subbasin 15 ($\sim 100\ km^2$) and subbasin 19 ($\sim 50\ km^2$) and less in the southern part of the plain. Due to construction of dikes along the river banks the water stage, at which overflow begins, is now higher than in the past. The improvement of the dikes will probably continue, and this makes it difficult to adapt a model which is to be used for forecasting in the future.

The model was calibrated with two inundation lakes: one in subbasin 15 (Mediacanoa) and the other one in subbasin 19 (La Victoria). The less extensive overflow in subbasin 11 has been neglected in the model simulation. Information about the present critical levels for overflow and the maximum inundated areas in the 1984 overflow was used as a base for setting the water stage-area curves of the inundation lakes. Below the critical water stage of overflow the actual rating curves were used, but at higher stages the rating curves were calibrated.

4.4 Irrigation losses

Irrigation of agricultural land in the valley plain has become important during recent years. Most of the irrigation water is taken from small rivers entering the valley from the surrounding mountains, but groundwater is also used. The irrigation modifies the water balance especially due to an increased evapotranspiration during dry periods.

The quantitative influence of the irrigation is not very well known, and therefore it has been necessary to represent it schematically in the model. At low flow conditions, the outflow from subbasins 7, 10, 12, 14, 16 and 18, which are adjacent to the plain, has been reduced 50 % as representing irrigation losses due to increased evapotranspiration. When the outflow exceeds a certain limit, the irrigation loss is decreased linearly until it becomes zero at ten times the limit. The reduction is made separately for each one of the mentioned subbasins, and the limit is set roughly proportional to the area of the plain, that is irrigated from the rivers of the subbasin. The limit for 50 % reduction was set to 5 m^3/s for subbasins 12 and 16, 10 m^3/s for subbasin 7, 15 m^3/s for subbasins 10 and 18 and 25 m^3/s for subbasin 14.

Although the method used for taking irrigation losses into account is not supported by direct observations, it has given satisfactory results. During low flow periods, when the irrigation losses are most important, the computed discharge for the Río Cauca agrees quite well with the observed hydrograph.

4.5 Calibration

The Río Cauca upstream and downstream from Salvajina has been treated as two separate model applications. The upstream application (called Salvajina) has six subbasins, No. 1 to 6 in Figure 7, and the purpose has been to adapt the model for forecasting the net inflow to the Salvajina reservoir. The downstream application (called La Victoria) has thirteen subbasins, No. 7 to 19 in Figure 7. The purpose has been to adapt the model for forecasting the discharge at the stream flow stations Juanchito, Mediacanoa and La Victoria. In this application the model computes the discharge of local origin downstream from Salvajina. To obtain the total discharge, the measured outflow from the Salvajina reservoir is added and routed through the model. The simulated inflow to Salvajina can not be used due to regulation of the reservoir.

Discharge data for five stream flow stations in the Río Cauca were used for the calibration. The stations are Julumito, Salvajina, Juanchito, Mediacanoa and La Victoria, and they are situated at the outlets of the subbasins 2, 6, 11, 15 and 19 respectively, see Figure 7. For Julumito the only purpose was to check the internal behaviour of the model. From 21 January 1985, when the reservoir at Salvajina was taken into use, the calibration was made versus the net inflow to the reservoir. This is calculated from the measured outflow (Salvajina-Efluente) and the change in water level in the reservoir. The net inflow calculated in this manner is, however, very uncertain due to water level fluctuations caused by wind stress, errors in reading etc. The model was therefore set up with an option for calibration versus the natural discharge at Salvajina. This natural discharge (La Mina) is calculated by correlation with the stream flow station Pan de Azúcar upstream from the reservoir.

Separate calibrations were also carried out for some stream flow stations in the tributaries of the Río Cauca. The purpose was to collect information of how to set initial parameter values for different regions due to vegetation, altitude, etc.

To make full use of the hydrographic information available, the internal behaviour of the complete model for the Río Cauca was checked with data from stream flow stations in some of the main tributaries. The computed outflow from five of the subbasins was compared with the tributaries that most closely correspond to the subbasin in consideration, regarding location, size, precipitation and basin characteristics. Thus the following comparisons were made:

Table 2. Internal checkpoints for the HBV model of the upper Río Cauca.

SUBBASIN	STREAM FLOW STATION
7	Timba-Timba
8	Ovejas-Abajo
10	Palo-Puerto Tejada
14	Guachal-Palmaseca
18	Tuluá-Mateguadua

The discharge of the tributary was multiplied by a factor in order to rank the basin area of the tributary on a par with the area of the subbasin. The subbasin was not calibrated with respect to the tributary but slightly adjusted as regards dynamics and volume, keeping in mind that the basins being compared partly represent different areas. With this set-up of the model, information from the main tributaries can be used in a forecasting situation, which facilitates the updating procedure. This is particularly valuable with regard to the Río Palo, which contributes quite significantly to the streamflow at Juanchito, especially at peak flow.

4.6 Calibration results

The calibration was carried out according to the three main criteria to fit the model that are described in Chapter 2.2. The calibration period was twelve years, 1975 - 1986. One year, 1987, was later added, but since this was a very dry year, it did not give further information of the behaviour of the model. Both the Salvajina and the La Victoria applications were first calibrated with input data selected from all available precipitation stations. The parameter values that were finally determined can be seen in the parameter list in Appendix 1. Forecast versions based on a reduced number of precipitation stations with near real time data collection were later adapted by a few calibration runs, where only the general precipitation correction parameter (PCORR) and the station weight parameter (CP) were adjusted. The explained variance for the four points of interest for forecasting can be seen in Table 3.

Table 3. The explained variance (R^2) for model applications based on precipitation data selected from all available stations and forecast applications based on precipitation data selected from 29 stations.

BASIN	AREA km^2	R^2-VALUE FOR THE CALIBRATION PERIOD 1975 - 1986 Complete model version	Forecast model version
Salvajina	3652	0.78	0.69
Juanchito	8584	0.92	0.92
Mediacanoa	12186	0.91	0.92
La Victoria	16284	0.93	0.93

Examples of the model-run results are shown in Figures 9, 10, 11 and 12. The year of 1984 has been chosen for the examples since it was rainy and there was overflow of the banks of the Río Cauca at the end of the year.

Duration curves of computed and recorded hydrographs for the calibration period 1975 - 1986 are shown in Appendix 2. The model versions based on all available precipitation stations have been used.

The main reason for difficulties in simulating the discharge at Salvajina (Figures 9 a and 9 b) is the spatial variability of the precipitation. A specific difficulty seems to be the simulation of peaks that originate from precipitation with the Llanos pattern (see Chapter 3.2) at high altitudes of the Cordillera Central. In the model application based on all available data there are 11 precipitation stations in the Salvajina basin, of which 2 have the Llanos pattern.

In the forecast version for Salvajina it was necessary to use a station from far outside the basin to represent the Llanos precipitation pattern. The precipitation in the Cordillera Occidental is also poorly represented, since no station in that area of the Salvajina basin can be reached by near real time data collection. The uneven and sparse precipitation network is the reason for the much lower R^2-value for the forecast version, see Table 1.

The R^2-values for Juanchito, Mediacanoa and La Victoria are higher than for Salvajina. This mainly depends on the fact that local rains have less influence due to larger basin areas and that the measured outflow from Salvajina is routed downstream. For the calibration period 1975 - 1986 the forecast versions have practically the same R^2-values as the versions based on all available precipitation stations (see Table 1). This is somewhat surprising, since only a few precipitation stations in the Cordillera Occidental can be used in the forecast version. However, when the model was used for

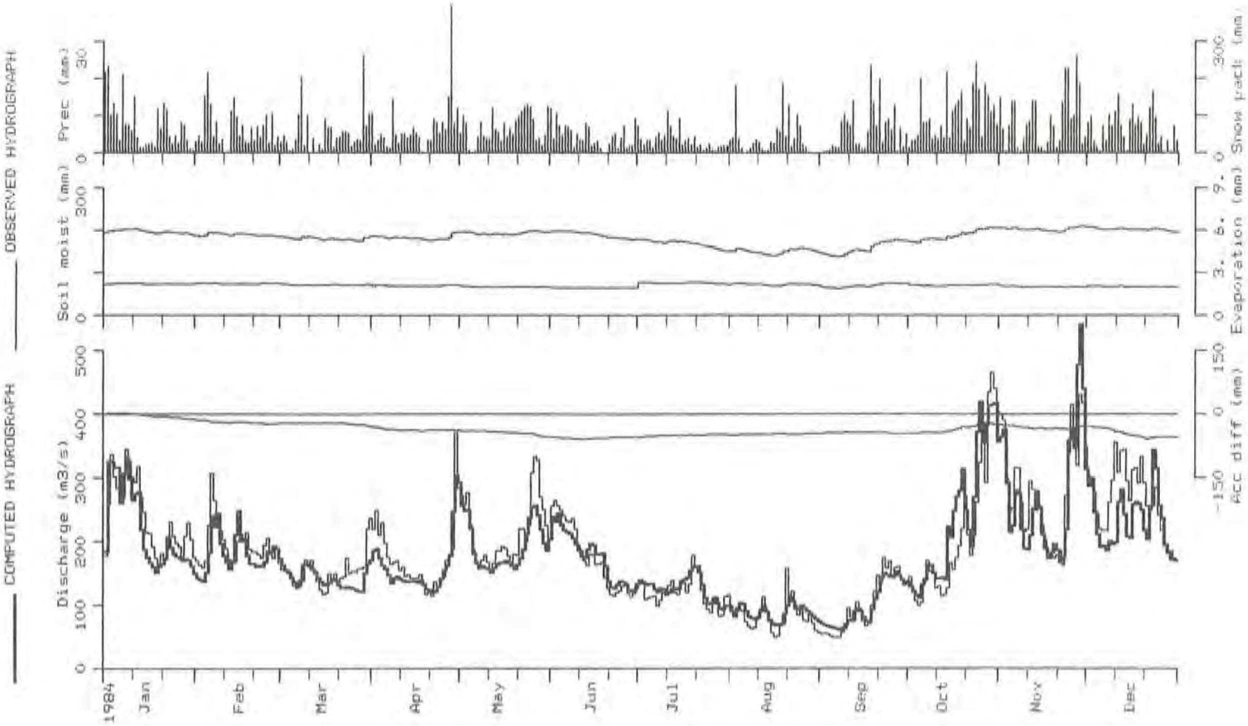


Figure 9 a. Model results in 1984 for Salvajina based on precipitation data from all available stations.

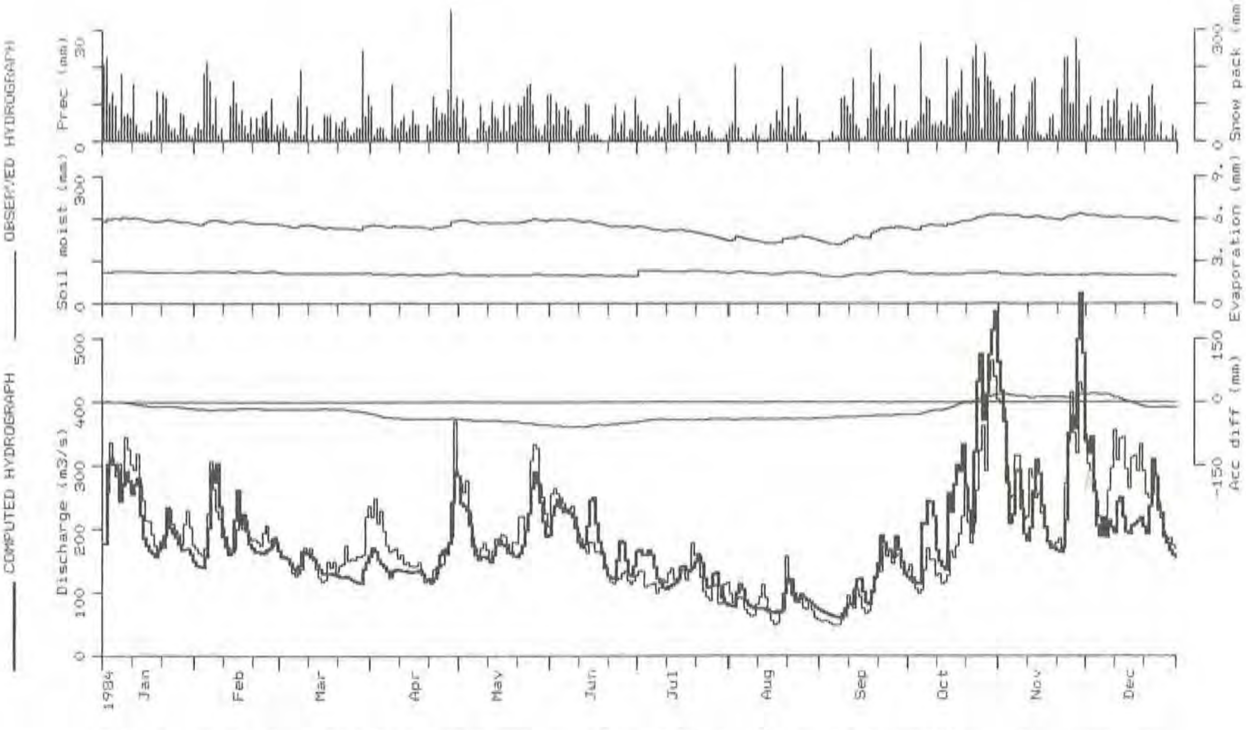


Figure 9 b. Model results in 1984 for Salvajina based on precipitation data that can be collected in a forecasting situation.

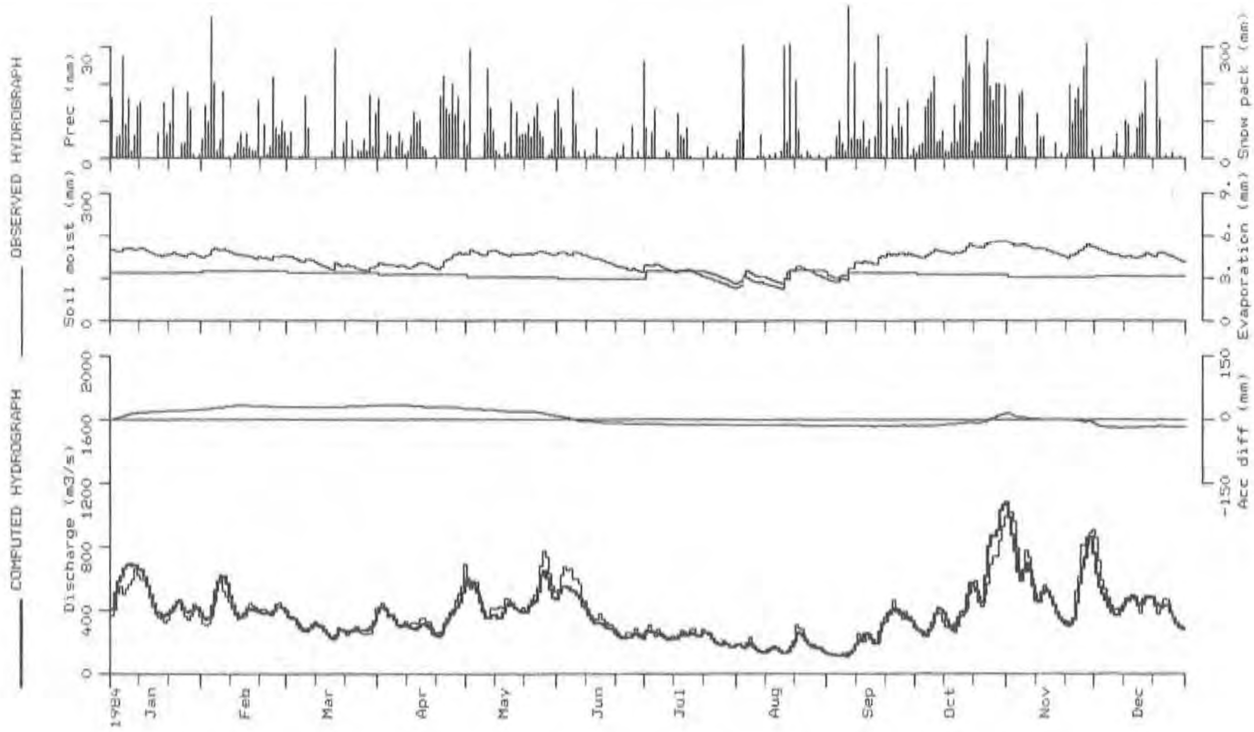


Figure 10 a. Model results in 1984 for Juanchito based on precipitation data from all available stations.

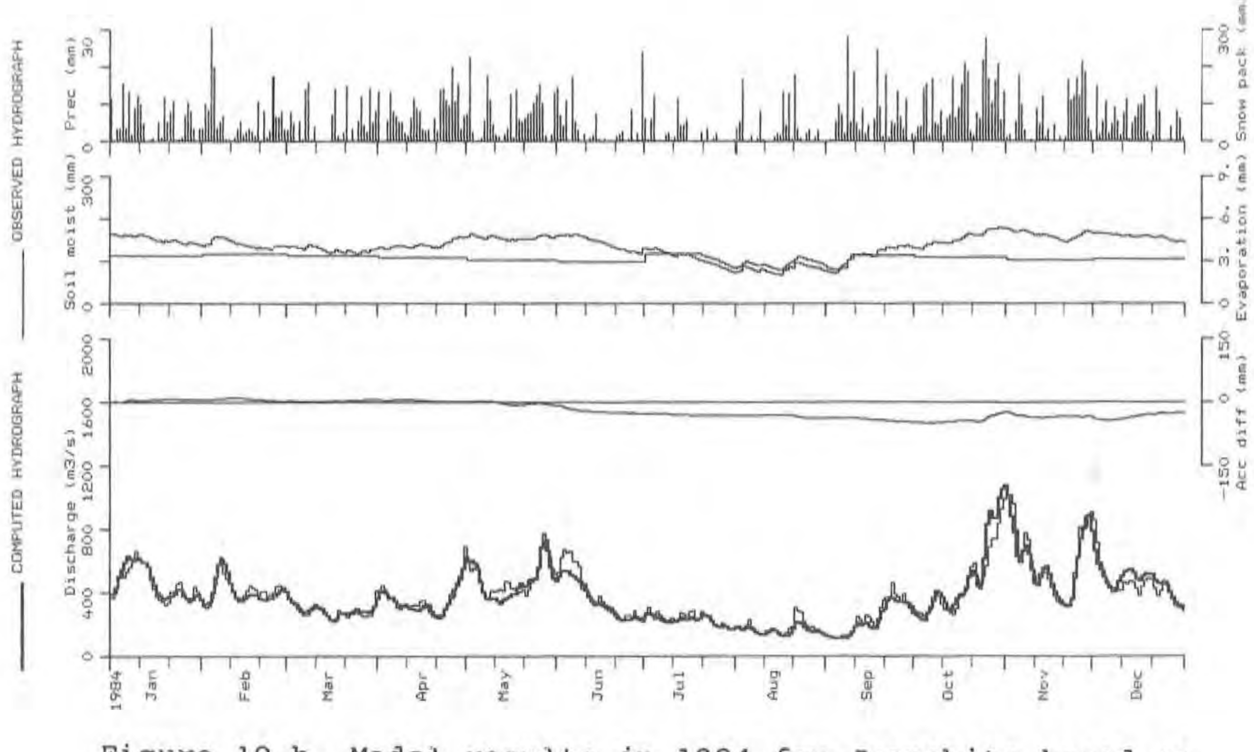


Figure 10 b. Model results in 1984 for Juanchito based on precipitation data that can be collected in a forecasting situation.

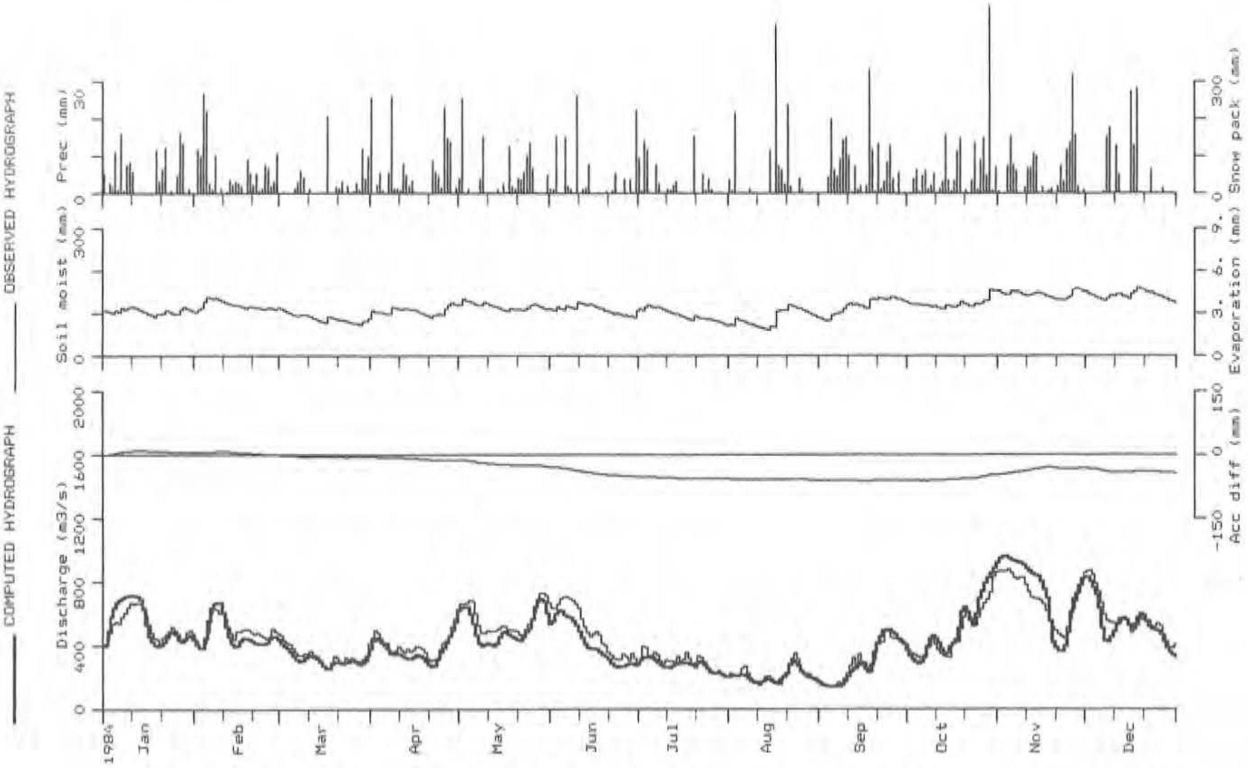


Figure 11 a. Model results in 1984 for Mediacanoa based on precipitation data from all available stations.

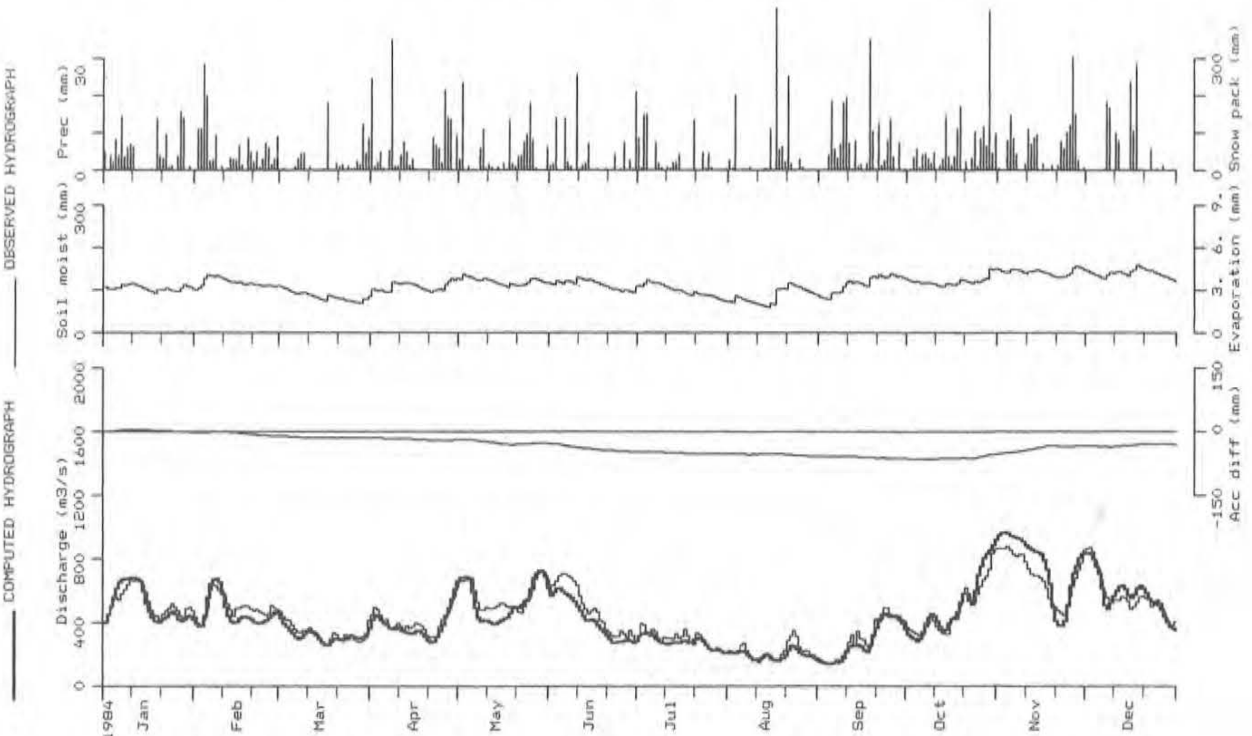


Figure 11 b. Model results in 1984 for Mediacanoa based on precipitation data that can be collected in a forecasting siutation.

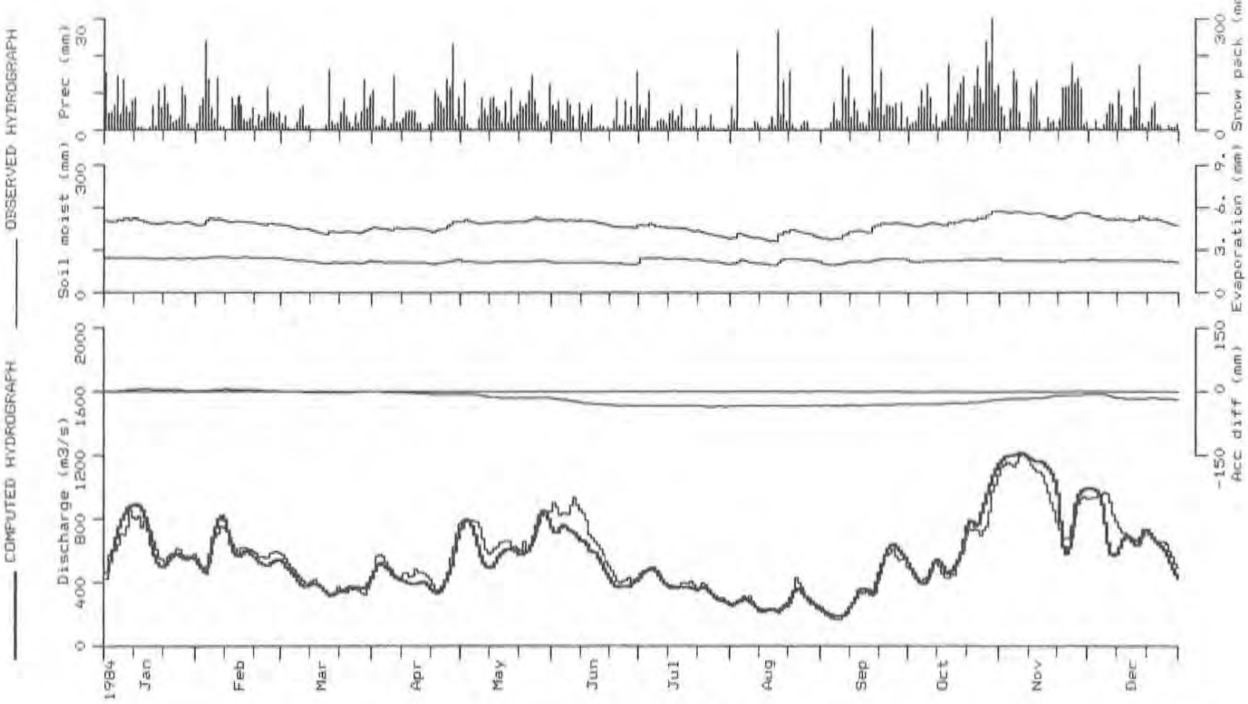


Figure 12 a. Model results in 1984 for La Victoria based on precipitation data from all available stations.

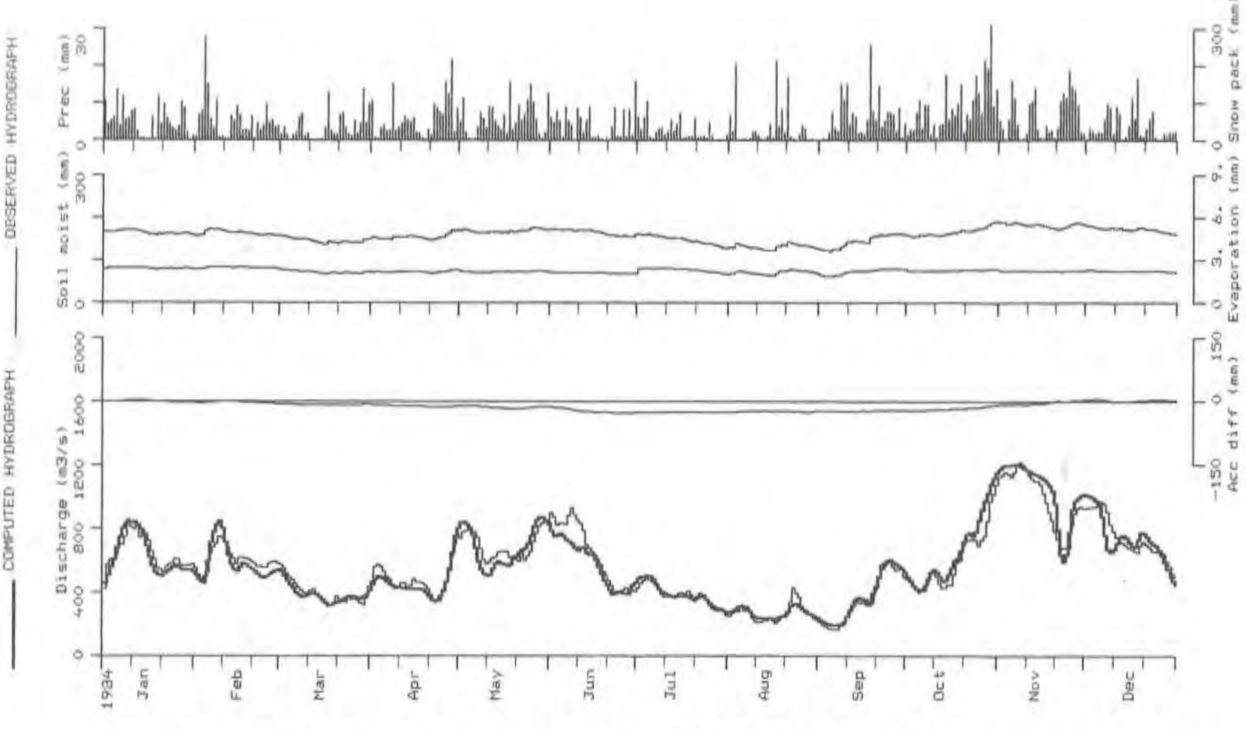


Figure 12 b. Model results in 1984 for La Victoria based on precipitation data that can be collected in a forecasting situation.

simulating the flow during 1987, the forecast versions had lower R^2-values.

The most difficult to simulate was the overflow of the banks of the Río Cauca. Upstream of Juanchito, however, overflow has been disregarded, since it is less extensive there than further downstream. This can be seen as a small overestimation of the rising limb and the peak value of the flood in Juanchito in October/November 1984 (Figures 10 a and 10 b). The simulations for Mediacanoa (Figures 11 a and 11 b) and for La Victoria (Figures 12 a and 12 b) succeeded relatively well due to the applied inundation lakes.

The effect of artificial levees that are high enough to prevent overflow, has been illustrated by running the model without inundation lakes at Mediacanoa and La Victoria. The result of that simulation for 1984 is shown in Figures 13 and 14. When comparing with the ordinary simulations in Figures 11 a and 12 a, one can see that the overflows have effectively moderated the flow peaks.

The Salvajina reservoir is to be regulated in order to decrease flood peaks and increase the discharge during low flow periods. The effect of the regulation can be illustrated, if the natural computed discharge at Salvajina is fed into the model instead of the regulated outflow. As an example, the ordinary simulation for 1987 at Juanchito is shown in Figure 15 and the simulation based on natural discharge from Salvajina in Figure 16.

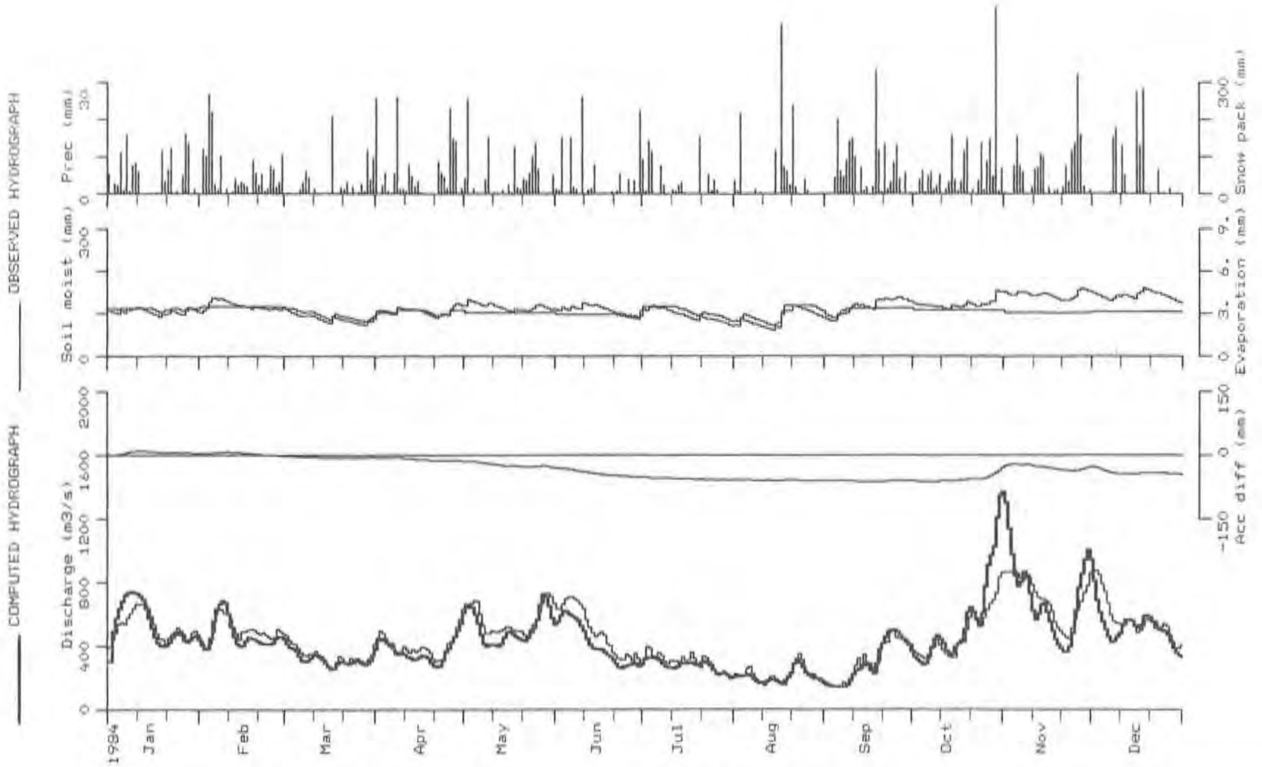


Figure 13. Model results in 1984 for Mediacanoa without simulation of overflow.

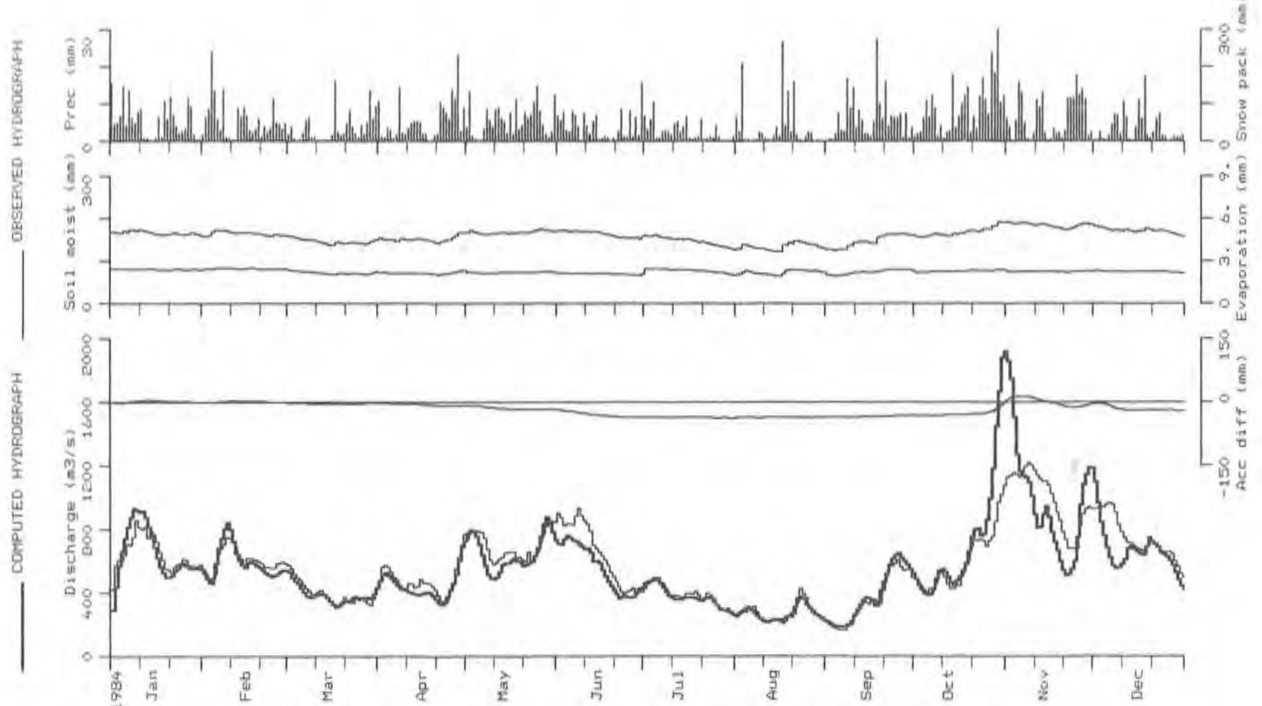


Figure 14. Model results in 1984 for La Victoria without simulation of overflow.

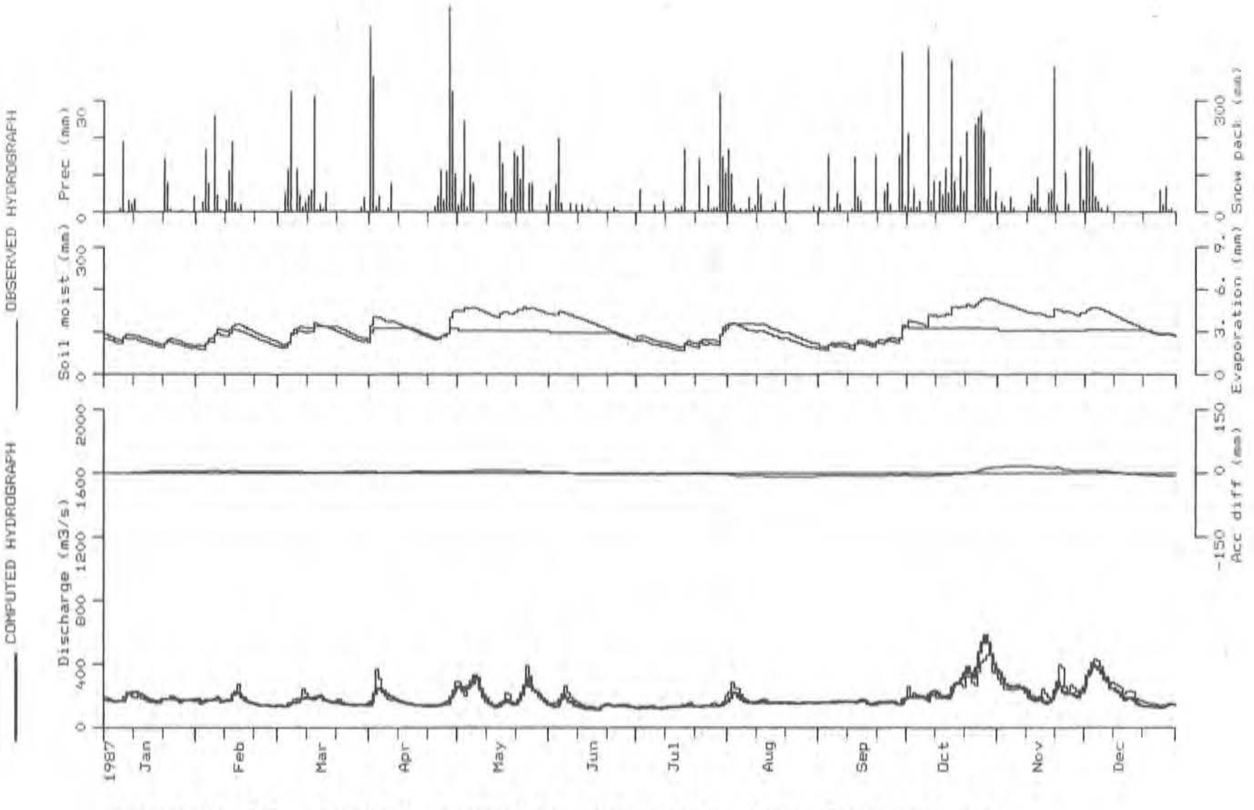


Figure 15. Model results in 1987 for Juanchito.

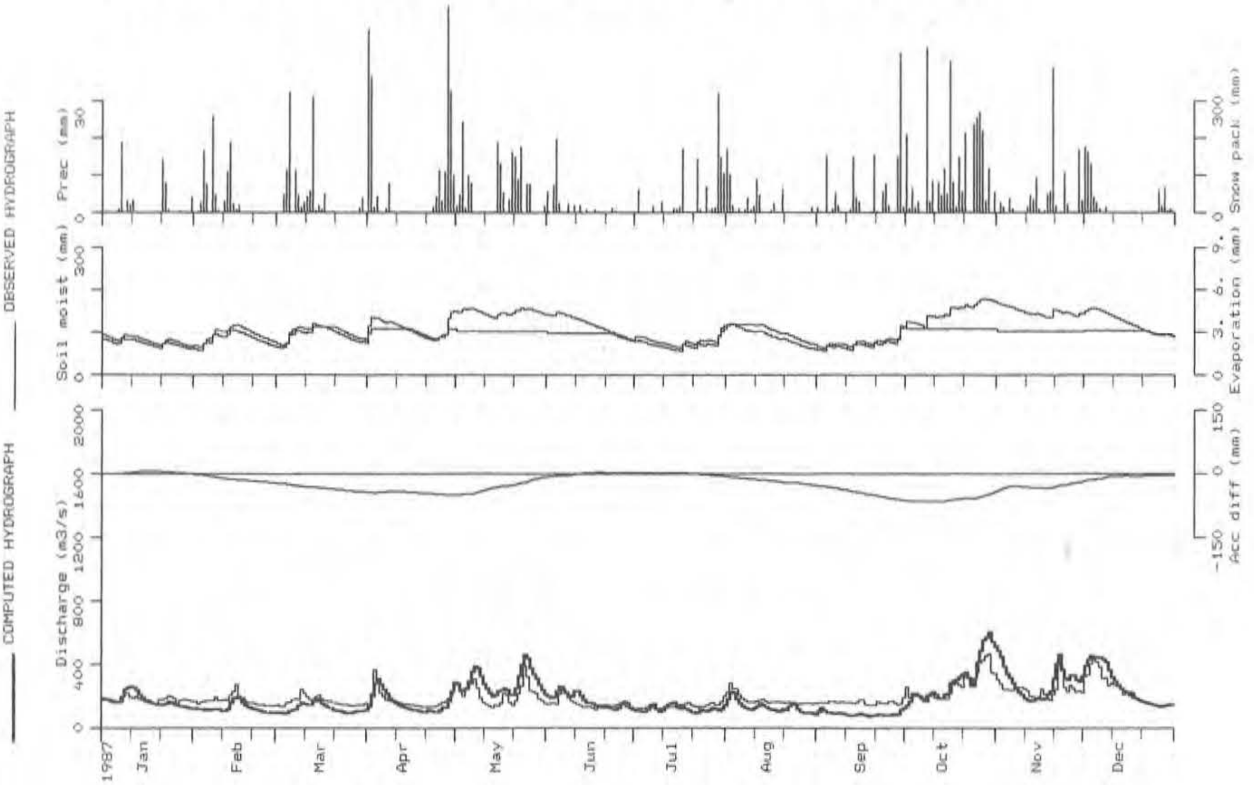


Figure 16. Model results in 1987 for Juanchito, when computed natural discharge at Salvajina is fed into the model instead of regulated outflow.

4.7 Forecasting

When the calibration work was finished in March 1988, the procedure to make real time forecasts was tested. Both short range and long range forecasts were then made. Precipitation input data for the last days up to the day of forecasting were collected by telephone or radio communication. The collection process worked relatively well, bearing in mind that some precipitation observers were not used to the new routines.

The forecasts for Juanchito, made the 8th of March 1988, are shown in Appendix 3 as examples. The forecast version of the model was run on actual data from the 1st of January to the 7th of March. No updating was necessary, since the simulated flow was in good accordance with the observations.

A short range forecast was made for five days, Figure A 3.1, and the regulated outflow from Salvajina, according to the regulation plan, was fed into the model. Three alternative sequences of precipitation input were used:

1. Forecasted precipitation according to the global forecasts from the European Center for Medium Range Weather Forecasts (ECMWF) in Reading, United Kingdom. This forecast for the five days was 0, 0, 0, 0 and 26 mm.
2. Ten millimetres of precipitation each day.
3. Twenty millimetres of precipitation each day.

The precipitation sequence according to the ECMWF gave the lowest forecasted flow, see Figure A 3.1. Later it turned out that the predicted precipitation sum for the 5-day period was too low and that most of the rain came during the two first days while the remaining days were almost dry. The precipitation sequences with 10 and 20 mm each day were used for illustrating the effect of the beginning of a more rainy period. With 10 mm each day the model gave a slightly increased flow, but with 20 mm the flow increased rapidly.

A long range forecast was made from the 8th of March to the 31st of May 1988. Precipitation data from the corresponding dates during the period 1975 to 1987 were used as input. The result of the thirteen different simulations with tabulated values of the highest peak for each simulation is shown in Figure A 3.2. The forecasted accumulated volume is given in Figure A 3.3.

Volume forecasts are primarily of interest for the regulation of the Salvajina reservoir. Downstream of Salvajina, the distribution of peaks is more interesting than the volume forecast. From Appendix 3 it can be seen that for Juanchito the probability of exceeding 500 m^3/s and 600 m^3/s was predicted as roughly 40 % and 10 % respectively during the period from the 8th of March to the 31st of May, 1988. The peak also seemed more likely to occur in May than in April or March.

When in a forecasting situation there is a considerable discrepancy between the observed and simulated flow, it is advisable to update the model. The set-up of the model for the upper Río Cauca, with a number of internal check points at some main tributaries and at Juanchito and Mediacanoa, simplifies the updating procedure. It is thus possible to discern the geographical location of an error and make a proper correction. This type of updating will imply that one should adjust the model state in the subbasin of interest instead of adjusting the input data. The latter is the most common way of updating the HBV model, but it has in this case the drawback of affecting the whole basin, rather than only the subbasins, from which the error originates. Updating of the model state will mainly involve adjustments of the storage in the soil moisture zone and in the upper or the lower zone some days before the date of a forecast.

The limited number of forecasts carried out at the time of writing this report makes it difficult to evaluate the capability of the HBV model to predict the flow in the upper

Río Cauca. The fact that the measured flow is reproduced fairly well by the model indicates that the forecasts should be useful. However, the accuracy of a hydrological forecast is highly dependent on the accuracy of the precipitation forecast, and quantitative precipitation forecasts are not very trustworthy. The forecasts made by ECMWF could further be tested as input to the HBV model for the upper Río Cauca.

5. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The application of the HBV model to the upper Río Cauca shows that the model accounts for a large part of the variance of the observed runoff. The explained variance for the calibration period is almost 80 % for the inflow to the reservoir at Salvajina and over 90 % at the three points of interest downstream of Salvajina, namely Juanchito, Mediacanoa and La Victoria. The volume errors are small, and the simulated peaks are in good agreement with observations. The model should, therefore, be a valuable tool for forecasting the flow in the upper Río Cauca.

The model is also a convenient tool for simulating the flow in the Río Cauca, as if the reservoir at Salvajina had never been built. It can further be used to investigate the effects of the construction of dikes.

The results were encouraging, when the density of the precipitation network was decreased from 42 to 29 stations in the total basin. The reduction had negligible effect on the model performance downstream from Salvajina, and this indicates that it may be possible further to reduce the number of stations that are needed in a forecasting situation. A continued removal of stations could also identify key stations, from which reliable data transfer is most important. However, in some parts of the basin there is a need for more precipitation stations that can be reached in a forecasting situation.

The climate of the upper Río Cauca basin is to some extent influenced by the southern atmospheric oscillations, which cause the ocurrence of the warm ocean current "El Niño" along the Peruvian coast. When the atmospheric oscillations are favourable to "El Niño", the flow of the Río Cauca is low and vice versa (Riehl, 1984). This knowledge could be used for improving the long term forecasts. For example, years with clearly different states of the oscillations could be excluded from the statistical analysis.

By studying the effects of changes in land use practice on small reference basins, one can gather experience on how the model parameters should be changed to represent the old and new conditions. Examples of such land use changes are clear-felling and afforestation.

Due to its conceptual structure, it has been possible to use the HBV model for simulations of groundwater recharge and groundwater levels (Bergström and Sandberg, 1983). The model can therefore be used as a reference to distinguish short term variations in groundwater storage, caused by weather fluctuations, from long term changes, caused by for example irrigation.

The soil moisture routine of the HBV model performs a water balance calculation. A further development and verification against soil moisture measurements was carried out by Andersson (1988). As the model gives daily estimates of the soil moisture deficit, it could probably be used for assessments of the need for irrigation.

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APPENDIX 1

PARAMETERFILE

Nr	Name	Valid from												
1	AREA	1975 1 1	450.00	274.00	400.00	350.00	1150.00	1028.00						
2	ELEV	1975 1 1	3500.00	2500.00	2200.00	3500.00	2000.00	1600.00						
3	VEG	1975 1 1	1.00	1.00	1.00	1.00	1.00	1.00						
4	LAKE	1975 1 1	0.00	0.00	0.00	0.00	0.00	0.00						
5	PELEV	1975 1 1	3420.00	2300.00	1700.00	1300.00	2540.00	1840.00	1200.00	1160.00	2320.00	1470.00	2900.00	1730.00
			1646.00	3690.00	2430.00									
7	QFACT	1975 1 1	1.00	1.00	1.00	1.00	0.00							
10	CQ	1975 1 1	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00		
11	EVAP	1975 1 1	3.80	3.90	3.80	3.60	3.40	3.30	3.90	4.00	3.80	3.60	3.40	3.50
13	REPL	1975 1 1	11.00	12.00	4.00	3.00	2.00	5.00	8.00	7.00	1.00	0.00	1.00	2.00
			15.00	1.00	4.00									
16	SUBQR	1975 1 1	0.00	1.00	0.00	0.00	0.00	0.00						
19	FELEV	1975 1 1	0.00											
20	PCORR	1975 1 1	0.75000	0.90000	1.00000	0.80000	0.90000	0.95000						
21	PCALT	1975 1 1	0.00000											
27	FC	1975 1 1	50.00000	200.00000	300.00000	50.00000	300.00000	300.00000						
28	LP	1975 1 1	50.00000	150.00000	200.00000	50.00000	200.00000	200.00000						
29	BETA	1975 1 1	1.00000	1.50000	2.00000	1.00000	2.00000	2.00000						
36	PERC	1975 1 1	1.50000	4.00000	4.00000	1.50000	4.00000	4.00000						
37	UZL	1975 1 1	5.00000	30.00000	30.00000	5.00000	30.00000	30.00000						
38	K0	1975 1 1	0.60000	0.40000	0.40000	0.60000	0.40000	0.40000						
39	K1	1975 1 1	0.10000	0.07000	0.07000	0.10000	0.07000	0.07000						
40	K2	1975 1 1	0.03500	0.03500	0.03500	0.03500	0.03500	0.03500						
41	DAMP	1975 1 1	0.00000	0.20000	0.00000	0.20000	0.00000	0.00000						
43	CEVP	1975 1 1	0.50000	0.55000	0.60000	0.50000	0.65000	0.70000						
46	MAXBAS	1975 1 1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000						
47	BLAG	1975 1 1	0.50000	0.50000	0.50000	0.50000	0.50000	0.00000						
49	PATH	1975 1 1	2.00000	6.00000	6.00000	5.00000	6.00000	0.00000						
3	VEG	1985 1 21	1.00	1.00	1.00	1.00	1.00	0.95						
4	LAKE	1985 1 21	0.00	0.00	0.00	0.00	0.00	0.05						
7	QFACT	1985 1 21	1.00	1.00	1.00	1.00	-5.00							
10	CQ	1985 1 21	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	-1.00		

Total weights corrected by multiplication with PCORR

		Subcatcment nr:						
Nr	Name	1	2	3	4	5	6	Total (%)
1	Laguna San Rafael	0.40	0.25	0	0.40	0	0	9.42
2	Coconuco	0.20	0.30	0	0.10	0.15	0	9.91
3	El Tambo	0	0	0.20	0	0.10	0.30	14.55
4	Dinde	0	0	0.50	0	0	0.10	9.09
5	Silvia	0	0	0	0.15	0.20	0	7.60
6	Piendamo	0	0	0	0	0.30	0.10	12.46
7	Pan de Azucar	0	0	0.10	0	0	0.30	10.17
8	Salvajina	0	0	0.20	0	0	0.20	8.40
9	Jambalo	0	0	0	0	0	0	0
10	Mondomo	0	0	0	0	0	0	0
11	Paletara	0.40	0.25	0	0	0	0	6.00
12	Aeropuerto Machangara	0	0.20	0	0	0.25	0	9.40
13	El Topacio	0	0	0	0	0	0	0
14	Santa Teresa	0	0	0	0.35	0	0	2.99
15	Hacienda Carpenteria	0	0	0	0	0	0	0

Figure A 1.1 Parameter list for the Salvajina application of the HBV model. The CP-parameters (weight coefficients of precipitation stations) are given in the lower table.

PARAMETERFILE

Nr	Name	Valid from												
1	AREA	1975 1 1	850.00	1200.00	500.00	1100.00	1282.00	550.00	450.00	1000.00	1602.00	800.00	450.00	2000.00
			848.00											
2	ELEV	1975 1 1	2000.00	1900.00	3500.00	1900.00	1000.00	1700.00	3500.00	2100.00	1000.00	1800.00	3000.00	1700.00
			1000.00											
3	VEG	1975 1 1	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	0.95	1.00	1.00	1.00
			0.95											
4	LAKE	1975 1 1	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.00
			0.05											
5	PELEV	1975 1 1	2650.00	1840.00	1100.00	2322.00	1470.00	986.00	1500.00	980.00	1527.00	1676.00	970.00	1871.00
			2380.00	1038.00	3690.00	1272.00	1698.00	972.00	1069.00	961.00	1433.00	2609.00	960.00	1644.00
			2783.00	1861.00	1014.00	1683.00	1532.00	951.00	1540.00	920.00	1233.00	3100.00	1600.00	913.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00					
7	QFACT	1975 1 1	1.00	1.00	1.00	1.00	1.00	1.00	2.12	1.66	3.36	1.26	0.00	1.98
			0.97	0.00	0.00	0.00	0.00							
10	CQ	1975 1 1	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00		
11	EVAP	1975 1 1	3.80	3.90	3.80	3.60	3.40	3.30	3.90	4.00	3.80	3.60	3.40	3.50
13	REPL	1975 1 1	2.00	3.00	6.00	1.00	0.00	3.00	0.00	43.00	0.00	6.00	8.00	0.00
			42.00	42.00	13.00	0.00	0.00	20.00	8.00	18.00	0.00	26.00	18.00	28.00
			0.00	27.00	23.00	24.00	10.00	0.00	28.00	27.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	14.00	19.00					
16	SUBQR	1975 1 1	7.00	1.00	0.00	13.00	3.00	0.00	0.00	10.00	4.00	0.00	0.00	9.00
			0.00											
17	QADD	1975 1 1	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00											
20	PCORR	1975 1 1	1.05000	0.92000	0.60000	0.85000	0.95000	0.70000	0.60000	0.85000				
			0.95000	0.85000	0.60000	0.90000	0.90000							
21	PCALT	1975 1 1	0.00000											
27	FC	1975 1 1	200.00000	300.00000	50.00000	300.00000	200.00000	200.00000	50.00000	300.00000				
			200.00000	200.00000	50.00000	300.00000	200.00000							
28	LP	1975 1 1	150.00000	250.00000	50.00000	250.00000	100.00000	150.00000	50.00000	250.00000				
			100.00000	150.00000	50.00000	250.00000	100.00000							
29	BETA	1975 1 1	2.00000	2.00000	1.00000	2.00000	2.00000	2.00000	1.00000	2.00000				
			2.00000	2.00000	1.00000	2.00000	2.00000							
36	PERC	1975 1 1	3.00000	3.00000	1.00000	2.00000	2.00000	2.00000	1.00000	2.00000				
			2.00000	2.00000	1.00000	2.00000	2.00000							
37	UZL	1975 1 1	30.00000	30.00000	10.00000	20.00000	30.00000	20.00000	10.00000	20.00000				
			30.00000	20.00000	10.00000	20.00000	30.00000							
38	K0	1975 1 1	0.30000											
39	K1	1975 1 1	0.10000											
40	K2	1975 1 1	0.03000	0.01500	0.04000	0.03000	0.01000	0.03000	0.04000	0.03000				
			0.01000	0.03000	0.04000	0.03000	0.01000							
41	DAMP	1975 1 1	0.20000	0.30000	0.00000	0.20000	0.30000	0.20000	0.00000	0.20000				
			0.30000	0.20000	0.00000	0.20000	0.00000							
43	CEVP	1975 1 1	0.60000	0.65000	0.50000	0.65000	0.85000	0.65000	0.50000	0.60000				
			0.85000	0.65000	0.50000	0.60000	0.85000							
44	LAREA	1975 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			-11.00000	0.00000	0.00000	0.00000	-19.00000							
46	MAXBAS	1975 1 1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000				
			1.00000	1.00000	1.00000	1.00000	1.00000							
47	BLAG	1975 1 1	0.50000	1.20000	0.50000	1.00000	0.00000	0.00000	0.50000	0.00000				
			0.00000	0.00000	0.50000	0.00000	0.00000							
48	WQREL	1975 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			2.00000	0.00000	0.00000	0.00000	8.00000							
49	PATH	1975 1 1	5.00000	5.00000	4.00000	5.00000	9.00000	9.00000	8.00000	9.00000				
			13.00000	13.00000	12.00000	13.00000	0.00000							
50	QRED	1975 1 1	4.00000	0.00000	0.00000	5.00000	0.00000	3.00000	0.00000	7.00000				
			0.00000	3.00000	0.00000	5.00000	0.00000							
16	SUBQR	1985 1 21	7.00	2.00	0.00	13.00	3.00	0.00	0.00	10.00	4.00	0.00	0.00	9.00
			0.00											
17	QADD	1985 1 21	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00											

Figure A 1.2 Parameter list for the La Victoria application of the HBV model. CP-parameters in separate figure.

LA VICTORIA
Total weights corrected by multiplication with PCORR

Subcatcment nr:

Nr	Name	1	2	3	4	5	6	7	8	9	10	11	12	13	Total (%)
1	Silvia	0	0.15	0	0	0	0	0	0	0	0	0	0	0	1.44
2	Piendamo	0	0.20	0	0	0	0	0	0	0	0	0	0	0	1.92
3	Salvajina	0.30	0.15	0	0	0	0	0	0	0	0	0	0	0	3.37
4	Jambalo	0	0	0.25	0.30	0	0	0	0	0	0	0	0	0	3.16
5	Mondomo	0	0.30	0	0	0	0	0	0	0	0	0	0	0	2.88
6	La Balsa	0	0.15	0	0	0.20	0	0	0	0	0	0	0	0	3.72
7	El Trapiche	0	0	0	0.30	0	0	0	0	0	0	0	0	0	2.50
8	Villarica	0	0	0	0	0.30	0	0	0	0	0	0	0	0	3.42
9	Samarkanda	0.40	0	0	0	0	0	0	0	0	0	0	0	0	2.57
10	El Topacio	0.30	0	0	0	0	0.10	0	0	0	0	0	0	0	2.35
11	Univalle	0	0	0	0	0.20	0	0	0	0.15	0	0	0	0	4.42
12	San Pablo	0	0	0	0	0	0.40	0	0	0	0	0	0	0	1.66
13	Los Alpes	0	0	0.25	0.20	0	0	0.20	0.25	0	0	0	0	0	4.70
14	Florida	0	0	0	0	0.10	0	0	0	0.20	0	0	0	0	3.99
15	Santa Teresa	0	0	0.50	0	0	0	0.60	0	0	0	0.50	0	0	4.18
16	San Emigdio	0	0	0	0	0	0	0	0.35	0	0	0	0	0	2.65
17	Villamaria	0	0	0	0	0	0.25	0	0	0	0	0	0	0	1.04
18	Guacari	0	0	0	0	0	0	0	0	0.20	0	0	0	0	2.85
19	Bocatoma	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0.48
20	Aeropuerto Palmaseca	0	0	0	0	0	0	0	0	0.35	0	0	0	0	4.99
21	El Caney	0	0	0	0	0	0.25	0	0	0	0.25	0	0	0	2.96
22	Tenerife	0	0	0	0	0	0	0.20	0.30	0	0	0	0	0	2.75
23	Acueducto Buga	0	0	0	0	0	0	0	0.10	0.10	0	0	0	0.20	3.69
24	La Primavera	0	0	0	0	0	0	0	0	0	0	0	0.15	0	2.27
25	La Gitana	0	0	0	0	0	0	0	0	0	0	0.20	0.15	0	2.83
26	Monteloro	0	0	0	0	0	0	0	0	0	0	0	0.10	0	1.51
27	Acueducto Tulua	0	0	0	0	0	0	0	0	0	0	0	0	0.30	2.26
28	Puerto Frazadas	0	0	0	0	0	0	0	0	0	0	0	0.20	0	3.03
29	Venecia	0	0	0	0	0	0	0	0	0	0.50	0	0	0	3.84
30	La Herradura	0	0	0	0	0	0	0	0	0	0.25	0	0	0.30	4.19
31	Heraclio Uribe	0	0	0	0	0	0	0	0	0	0	0	0.20	0	3.03
32	La Union (Centro Adm)	0	0	0	0	0	0	0	0	0	0	0	0	0.20	1.51
33	Miravalles	0	0	0	0	0	0	0	0	0	0	0	0.10	0	1.51
34	Barragan	0	0	0	0	0	0	0	0	0	0	0.30	0.10	0	2.35
35	Argelia El Recreo	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	Santana	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	Tesorito	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	Caloto	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	Corinto	0	0	0	0.20	0.20	0	0	0	0	0	0	0	0	3.95
40	La Selva	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	Venus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	Planta Nima No.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	Inst. Tec. Santander	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure A 1.3 CP-parameters (weight coefficients of precipitation stations) for the La Victoria application of the HBV model.

APPENDIX 2

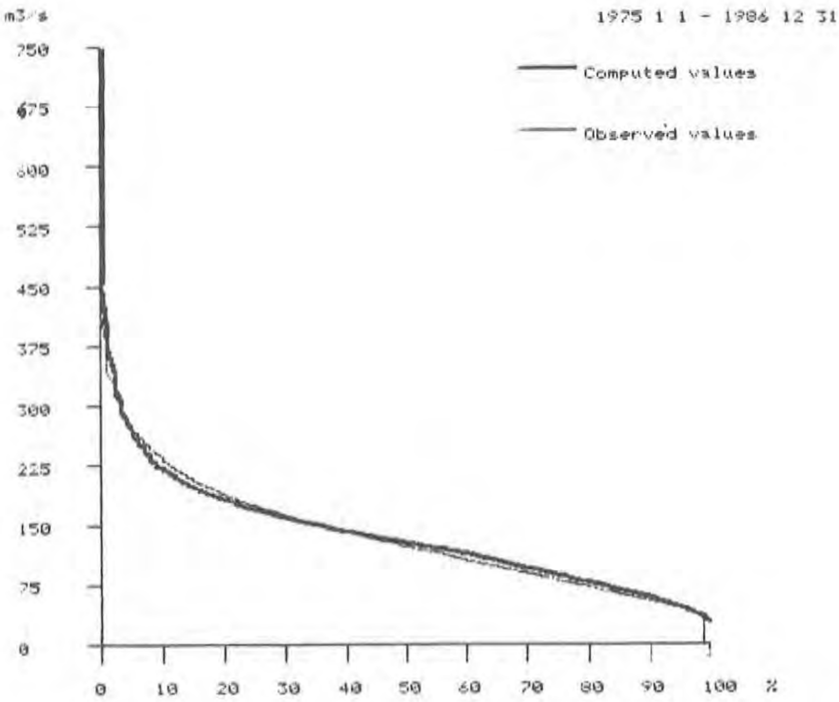


Figure A 2.1 Duration curves 1975 - 1986 of computed and recorded hydrographs for Salvajina.

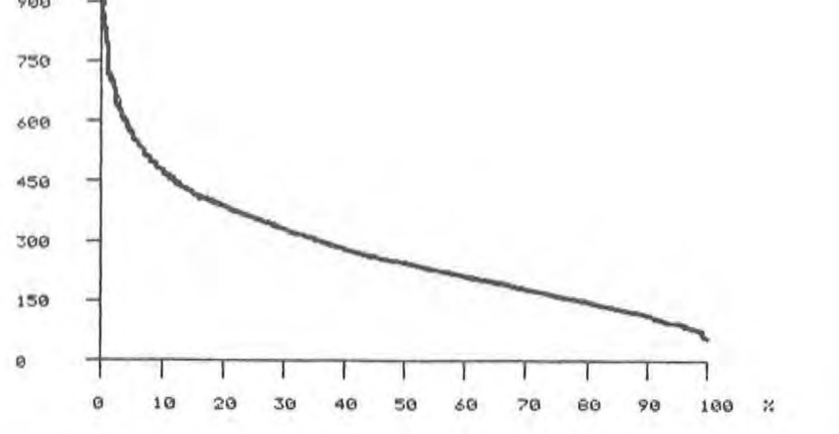


Figure A 2.2 Duration curves 1975 - 1986 of computed and recorded hydrographs for Juanchito.

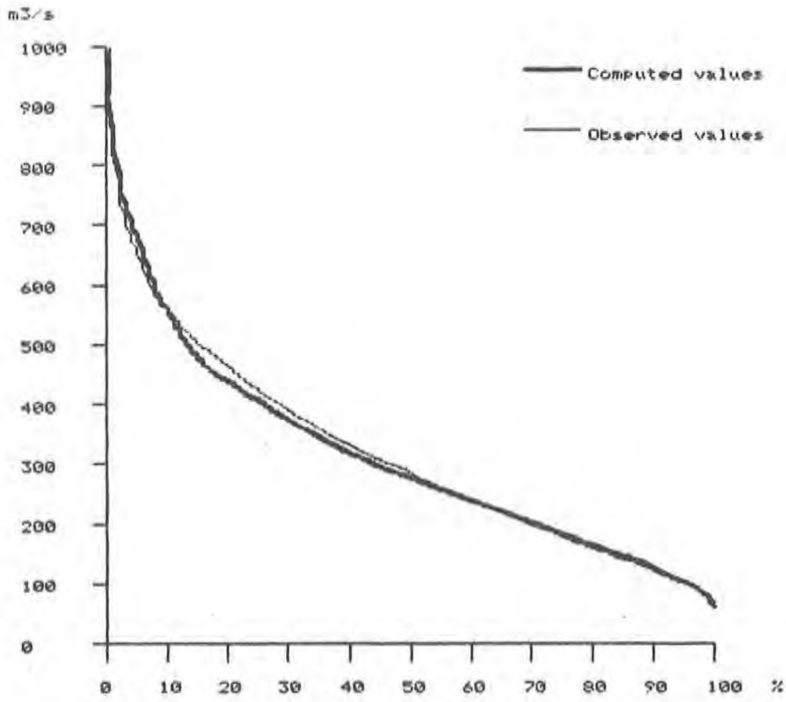


Figure A 2.3 Duration curves 1975 - 1986 of computed and recorded hydrographs for Mediacanoa.

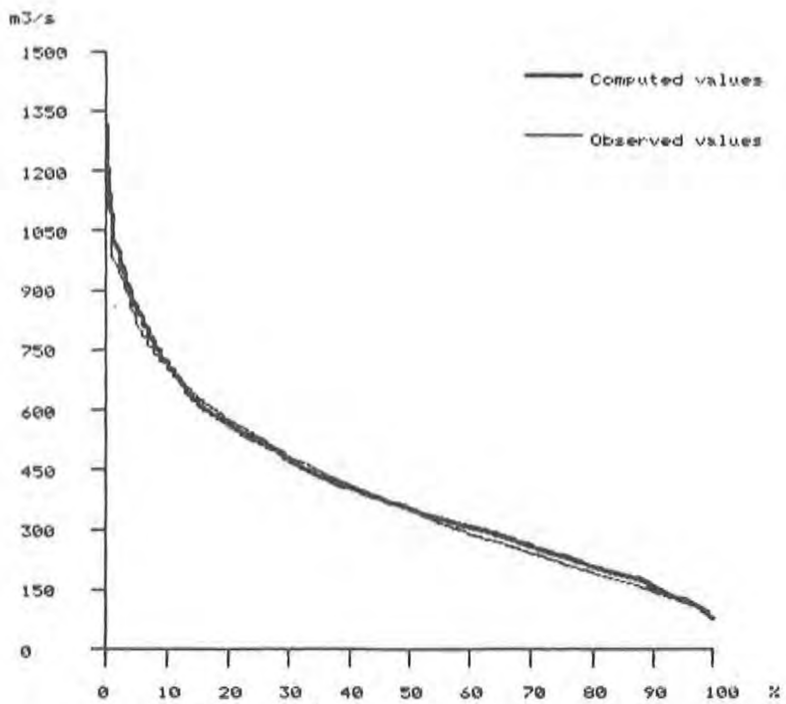
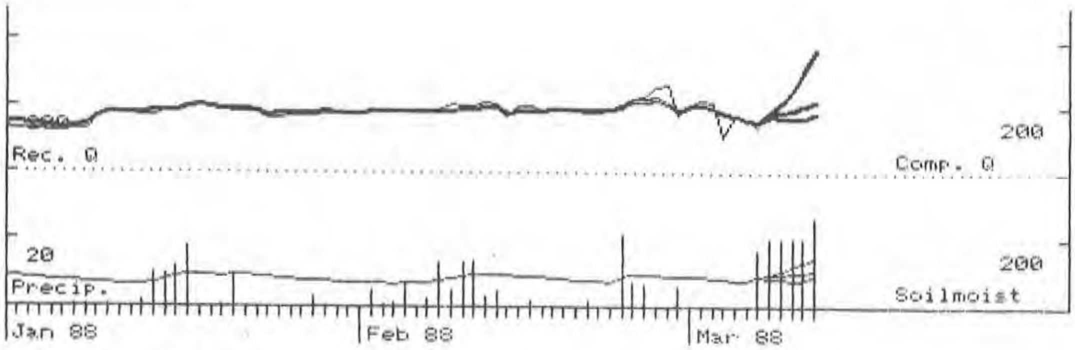


Figure A 2.4 Duration curves 1975 - 1986 of computed and recorded hydrographs for La Victoria.

APPENDIX 3



BASIN: LA VICTORIA
SUBBASIN 5

DATE	PREC	SOIL	UZ	LZ	QCOMP	QREC	ACCDIFF	EVAP	CORR OF P
880301	0.2	85.7	0.0	62.7	199.7	208.0	-1.6	2.9	
880302	0.0	83.0	0.0	62.0	200.1	220.0	-2.0	2.8	
880303	0.0	80.3	0.0	61.2	193.6	215.0	-2.4	2.7	
880304	0.0	77.7	0.0	60.4	179.5	108.0	-1.1	2.6	
880305	0.0	75.2	0.0	59.6	171.5	177.0	-1.2	2.5	
880306	0.0	72.7	0.0	58.9	160.5	163.0	-1.3	2.4	
880307	16.3	84.8	0.2	60.1	156.0	145.0	-1.1	2.6	

BASIN: LA VICTORIA
SUBBASIN 5

DATE	PREC	SOIL	UZ	LZ	QCOMP	QREC	ACCDIFF	EVAP	CORR OF P
880308	0.0	82.1	0.0	59.6	172.1	FORECAST	1		
880309	0.0	79.4	0.0	58.8	168.2				
880310	0.0	76.9	0.0	58.0	166.4				
880311	0.0	74.4	0.0	57.3	165.0				
880312	26.0	94.4	2.0	58.6	175.6				

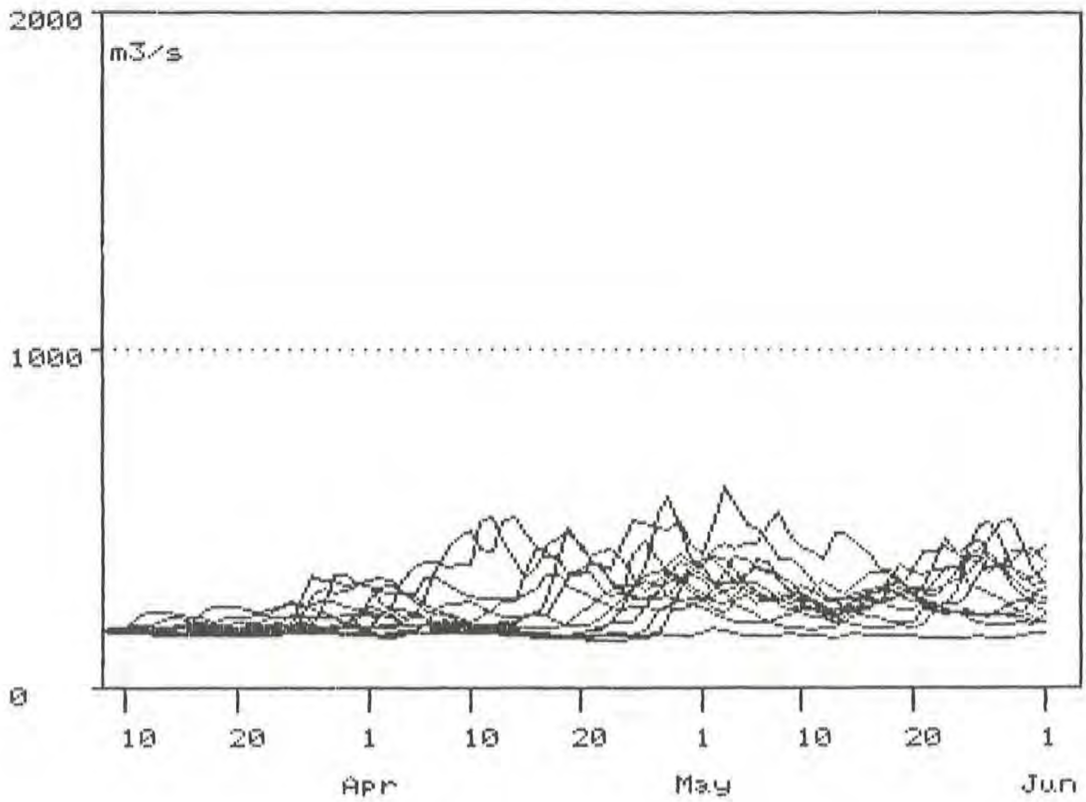
BASIN: LA VICTORIA
SUBBASIN 5

DATE	PREC	SOIL	UZ	LZ	QCOMP	QREC	ACCDIFF	EVAP	CORR OF P
880308	10.0	90.6	0.0	61.2	175.5	FORECAST	2		
880309	10.0	96.0	0.0	62.3	181.7				
880310	10.0	100.9	0.1	63.5	190.4				
880311	10.0	105.4	0.4	64.7	200.9				
880312	10.0	109.7	0.9	65.9	213.9				

BASIN: LA VICTORIA
SUBBASIN 5

DATE	PREC	SOIL	UZ	LZ	QCOMP	QREC	ACCDIFF	EVAP	CORR OF P
880308	20.0	98.8	1.8	61.3	183.2	FORECAST	3		
880309	20.0	111.0	4.3	62.5	210.8				
880310	20.0	122.1	7.7	63.7	250.8				
880311	20.0	131.9	11.7	64.9	301.3				
880312	20.0	140.5	16.4	66.1	370.1				

Figure A 3.1 Model simulation 1988-01-01--03-07 for Juanchito, followed by a 5-day forecast. Three alternatives of input data were used for the forecast.



Forecast 1988 3 8 using data from the 13 previous years

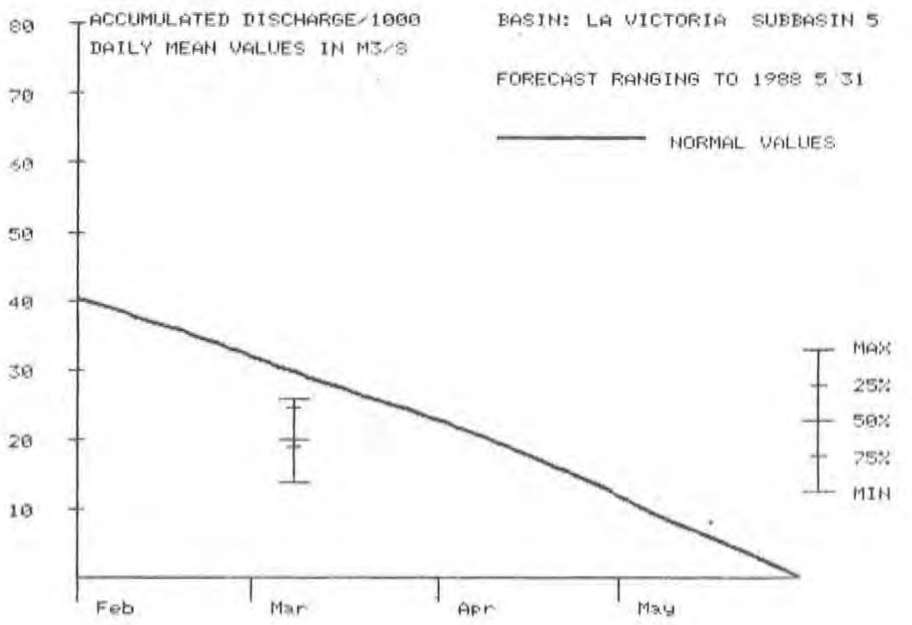
CRONOLOGICAL ORDER

Seq nr	Year	Peak m3/s	Month /Day
1	1975	396	5 4
2	1976	356	5 6
3	1977	337	3 29
4	1978	600	5 3
5	1979	565	4 28
6	1980	180	5 2
7	1981	517	5 8
8	1982	504	4 12
9	1983	501	4 14
10	1984	485	5 27
11	1985	351	5 18
12	1986	440	4 26
13	1987	385	5 6

ORDER OF MAGNITUDE

Year	Peak m3/s	Month /Day
1978	600	5 3
1979	565	4 28
1981	517	5 8
1982	504	4 12
1983	501	4 14
1984	485	5 27
1986	440	4 26
1975	396	5 4
1987	385	5 6
1976	356	5 6
1985	351	5 18
1977	337	3 29
1980	180	5 2

Figure A 3.2 Long range forecast 1988-03-08--05-31 for Juanchito based on input data from the corresponding dates during the period 1975 - 1987. The upper figure shows the different simulations, and below the peak values are tabulated.



Forecast 1988 3 8 using data from the 13 previous years

VOLUME UNIT: accumulated daily mean discharge in m3/s

DATE	MIN	75%	50%	25%	MAX
3 8	172	172	174	176	180
3 15	1325	1371	1400	1480	1631
3 22	2492	2652	2695	2730	3090
3 29	3739	3987	4087	4210	4796
4 5	4891	5394	5512	6188	6630
4 12	6101	6749	6993	7633	9465
4 19	7249	8214	8545	8883	12305
4 26	8373	9498	10279	11176	14616
5 3	9544	11332	12561	13725	17086
5 10	10685	13727	14634	16885	19890
5 17	11799	15644	16350	19783	21613
5 24	12891	17438	18178	21931	23374
5 31	**13993**	**18932**	**20010**	**24643**	**25892**

NORMAL VOLUME: 29830

ACCUMULATED VOLUME LAST DAY

CRONOLOGICAL ORDER Year	Volume	ORDER OF MAGNITUDE Year	Volume
1975	19017	1982	25892
1976	19821	1978	25786
1977	18932	1983	25033
1978	25786	1981	24643
1979	21185	1984	21657
1980	13993	1979	21185
1981	24643	1986	20010
1982	25892	1976	19821
1983	25033	1975	19017
1984	21657	1977	18932
1985	18175	1987	18401
1986	20010	1985	18175
1987	18401	1980	13993

Figure A 3.3 Long range forecast 1988-03-08--05-31 for Juanchito.

SMHI
Swedish meteorological and hydrological institute
S-60176 Norrköping, Sweden. Tel. +46 11 15 80 00. Telex 644 00 smhi s.