SMHI HYDROLOGY

No 27, 1990

APPLICATION OF THE HBV MODEL FOR FLOOD FORECASTING IN SIX CENTRAL AMERICAN RIVERS

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Printed at the SMHI, Norrköping
March 1990

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PREFACE

This report describes the application of a runoff model to six rivers in Central America. It is a part of the project "Streamflow Forecasting and Flood Warning in Central America" for which the Swedish Meteorological and Hydrological Institute (SMHI) has been responsible. The project has been financed by the Swedish International Development Agency (SIDA) and co-ordinated by the Royal Institute of Technology (KTH) in Sweden. The project is one of the efforts to predict and prevent natural disasters in Central America within the duties for Centro de Coordinación para la Prevención de Desastres Naturales en América Central (CEPREDENAC).

In Central America the project activities have been co-ordinated by CEPREDENAC and Comité Regional de Recursos Hidráulicos (CRRH). The counterparting organizations have been:

Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH)	Guatemala
Ministerio Agricultura y Ganadería, Centro de Recursos Naturales	El Salvador
Ministerio de Recursos Naturales, Dirección General de Recursos Hídricos	Honduras
Empresa Nacional de Energía Eléctrica (ENEE)	Honduras
Instituto Nicaragüense de Estudios Territoriales (INETER)	Nicaragua
Instituto Costarricense de Electricidad (ICE)	Costa Rica
Instituto Meteorológico Nacional (IMN)	Costa Rica
Instituto de Recursos Hidráulicos y Electrificacíon (IRHE)	Panamá

The main objectives of the project are:

- To calibrate a rainfall runoff model, the HBV model, for one river in each of the participating countries.

- To install a streamflow forecasting system, based on the HBV model, on a personal computer in each country.

- To train two hydrologists from each country in the calibration and operational use of the forecasting system.

The project was started in September 1988 and had to be completed in less than two years time. During October and November 1988, two hydrologists from the SMHI visited Central America. The purpose of this visit was to select one river in each country and to initiate the compilation of data needed for the HBV model. From mid-April to mid-June 1989 twelve Central Americans were trained in the use of the HBV forecasting system at the SMHI in Norrköping, Sweden. During this training the model was calibrated for each of the selected rivers. A personal computer was purchased for each country and the participants installed the forecasting system on the computers. In November 1989 two hydrologists from the SMHI visited Central America in order to check the installation of the system, to make final adaptions for real-time forecasting, and to give advice on the present and possible future applications of the HBV model.

The project has proceeded approximately according to the original plans. However, the visit to El Salvador in November 1989 had to be cancelled due to the state of emergency in that country. The project is completed with this report besides participation in a follow-up meeting for projects dealing with prevention of natural disasters. The follow-up meeting is to be organized by CEPREDENAC and is planned to take place in Central America in May 1990.

A large number of people have been involved in the project. Mr Arne Forsman (SMHI) and Mr Edgar Robles (CRRH) initiated the project and have also participated in the work. Mr Martin Häggström (SMHI) has been the project leader and responsible for the execution of the project. From the SMHI also the following hydrologists have made significant contributions to the realization of the project: Göran Lindström, Magnus Persson, Katarina Losjö, Jörgen Nilsson, Sten Bergström and Joakim Harlin.

The following professionals from Central America participated in the training course on the HBV model at the SMHI:

Mr Carlos Cobos	INSIVUMEH	Guatemala
Mr Julio Roberto Martínez	INSIVUMEH	"
Mr Leonardo Merlos	Recursos Naturales	El Salvador
Mr Roberto Dimas Alonzo	Recursos Hídricos	Honduras
Ms Glenda Castillo	ENEE	"
Ms Carolina Sirias	INETER	Nicaragua
Mr Douglas Miranda	INETER	"
Mr Jorge Granados	ICE	Costa Rica
Ms Rosario Alfaro	IMN	"
Mr Edgar Robles	CRRH	"
Ms Mercedes Rodríguez	IRHE	Panamá
Ms Rigel Moscote	IRHE	"

Prof. Lars Yngve Nilsson (KTH) assisted by Mr Rodolfo Candia (KTH) and Dr Aristoteles Vergara (CEPREDENAC) have had a co-ordinative responsibility for the project. The latter together with Mr Claude Ginet (CEPREDENAC) have also been helpful with practical arrangements in Central America, such as purchase of personal computers.

The chapters in this report about the application of the forecasting system in each country have principally been written by the participants from the respective country. The text material has been co-ordinated and edited, and the common chapters written, by the undersigned and Mr Göran Lindström. Ms Agneta Lindblad has drawn the figures and Ms Gun Sigurdsson has typed the manuscript.

Many thanks are due to the above mentioned persons and to a great number of other persons both in Sweden and Central America who have contributed to the fulfilment of the project.

Norrköping, January 1990
Martin Häggström

1. INTRODUCTION

Floods and inundations are the natural disasters that most frequently hit the Central American countries. River forecasting and flood warnings are therefore of greatest interest. The monitoring of the flow of potentially dangerous rivers and the issuing of early flood warnings can substantially reduce the property damages and the loss of lives from floods.

A runoff model for continuous computation of river discharge is a useful tool for prediction of floods and it can constitute the basis for a flood warning system. The runoff model computes river discharge from precipitation as main input through a series of mathematical functions. It accounts for the water in storage in the basin and is capable of continuous simulation of flow for as long time as there are input data available. There exist many models with different complexity and varying demands on computer facilities and input data. One of the simplest to use is the Swedish developed HBV model (Bergström 1976). In spite of its relative simplicity the HBV model has proved to yield good results (WMO, 1986).

In this project the HBV model has been applied for flood forecasting purposes to one river in each of the participating Central American countries. The rivers have been selected in co-operation between representatives from the SMHI and the counterparting organizations. Rivers with flood problems were selected, but not necessarily those with the most severe floods. A prerequisite was that the basins have relatively well developed networks of precipitation and streamflow stations, since the selected rivers are to be seen as pilot rivers in the model application. Regard was also paid to the possibility to use the model for a more efficient management of the water resources for hydropower production, irrigation and domestic consumption.

The following rivers were selected:

The Río Samalá in Guatemala, the Río Grande de San Miguel in El Salvador, the Río Choluteca in Honduras, the Río Viejo in Nicaragua, the Río Grande de Tárcoles in Costa Rica and the Río Bayano in Panamá. The geographical location of the river basins can be seen in Figure 1.

Country	River	Basin area (km²)	Area for application of the HBV model (km²)
Guatemala	Río Samalá	1499	861
El Salvador	Río Grande de San Miguel	2300	2237
Honduras	Río Choluteca	7550	6964
Nicaragua	Río Viejo	1519	543 + 1519
Costa Rica	Río Grande de Tárcoles	2168	1745
Panama	Río Bayano	5000	4452

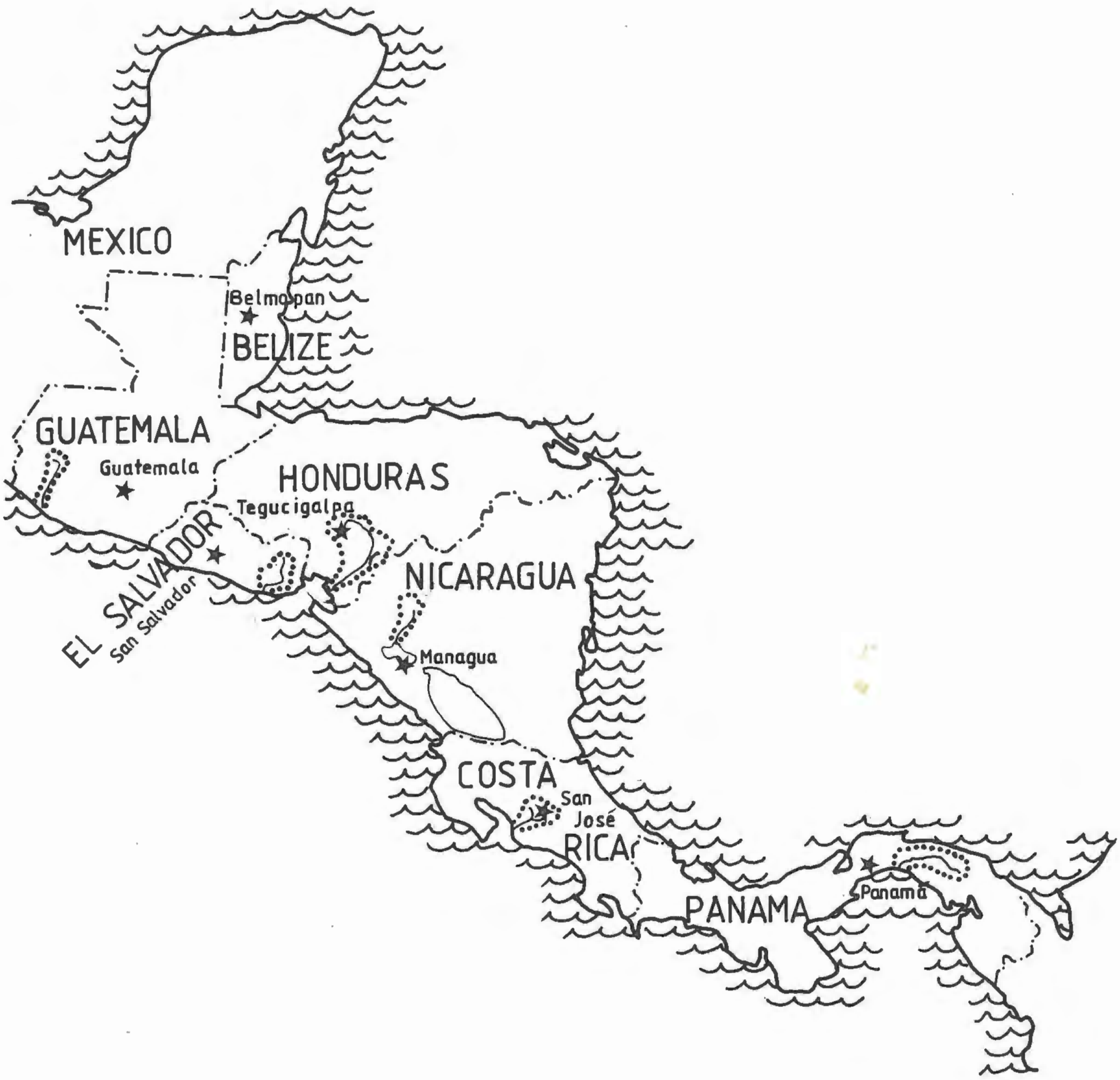
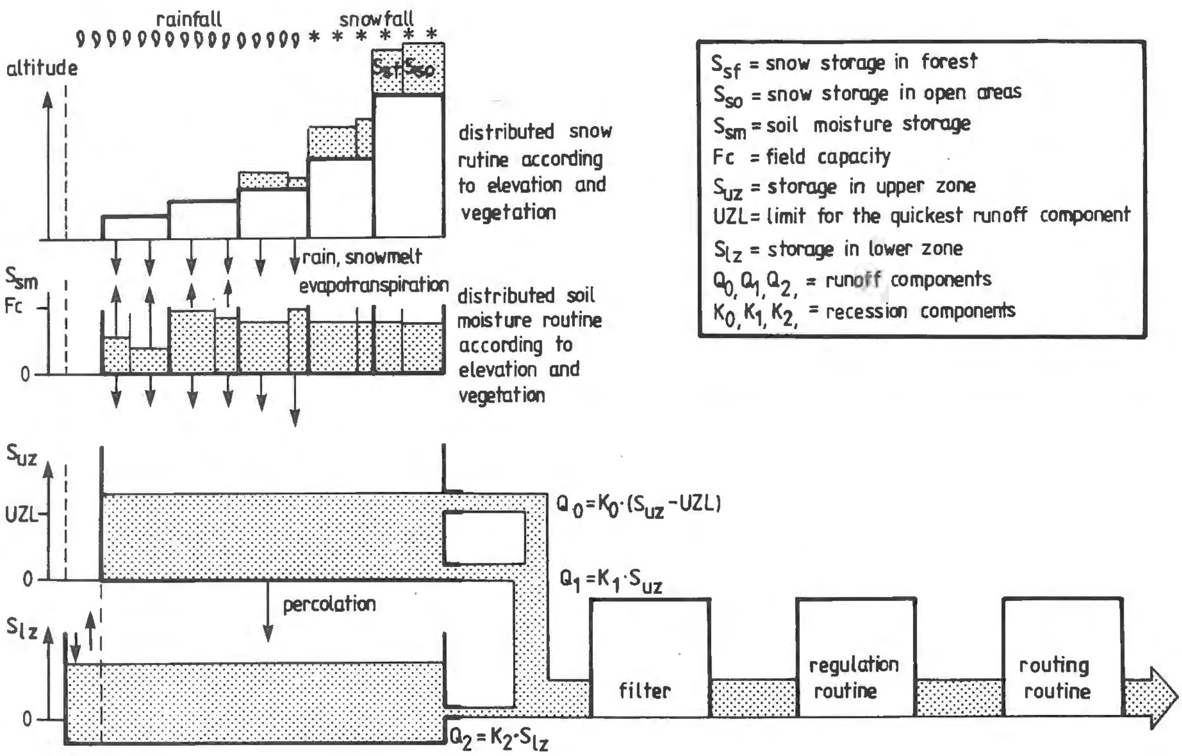


Figure 1. The geographical location of the project areas.

2. THE HBV MODEL

The HBV model is a conceptual runoff model for continuous computation of river discharge. It has been developed at the SMHI (Bergström, 1976) and consists of a number of computation routines that describe the main processes of the hydrological cycle. The structure of the model is relatively simple and computer and input data demands are moderate. A complete forecasting system based on the HBV model has been developed at the SMHI for interactive use on a personal computer.

Large and heterogeneous basins should in the model be divided into subbasins. Each subbasin can be further divided into elevation zones with respect to altitude. The elevation zones can be divided into vegetation zones, and then one usually distinguishes between forest and open land. The structure of the HBV model within a subbasin is shown in Figure 2.



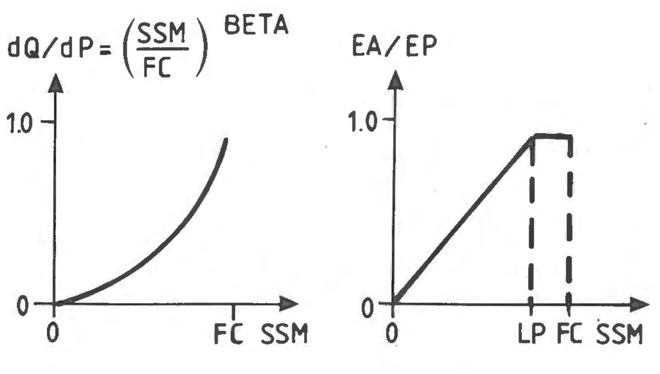
Figur 2. Basic structure of the HBV model.

The HBV model is usually run with daily timesteps, but shorter timesteps down to one hour can be used. Input data is precipitation and in regions with snow also air temperature. These data should be measured over the same periods as the timesteps of the model, and that usually means daily sums of precipitation and daily mean temperature.

A separate weighting of the input data stations is done for each subbasin. The variation of precipitation and temperature with altitude can be accounted for by lapse rate functions. These adjust input data from the weighted mean altitude for the used stations to the mean altitude of the elevation zone. 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 subbasin.

The snow routine of the model controls snow accumulation and melt and works separately for each elevation and vegetation zone. The precipitation accumulates as snow cover when the air temperature is below a threshold value. Snow melt occurs when the temperature is above the threshold value and the rate of the snow melt is controlled by a degree-day parameter.

The soil moisture routine controls the main part of the runoff generation. It runs separately in each elevation and vegetation zone. The routine uses three empirical parameters, BETA, FC and LP, as shown in Figure 3.

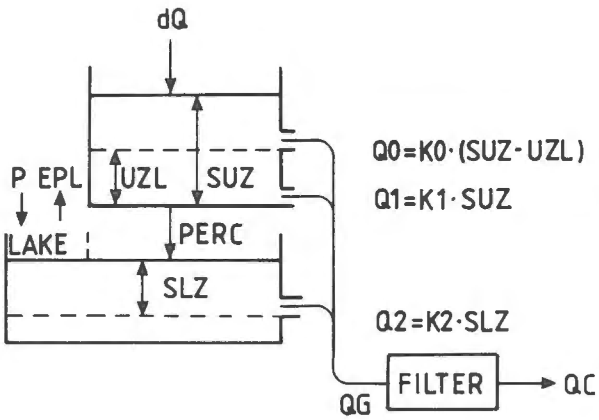


dP = contribution from rain or snowmelt
dQ = outflow to the runoff response routine
SSM = computed soil moisture storage
FC = maximum soil moisture storage
BETA = empirical coefficient
EP = potential evapotranspiration
LP = limit for potential evapotranspiration
EA = computed evapotranspiration

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

The parameter BETA controls the contribution to the runoff response routine (dQ) and the increase in soil moisture storage (1-dQ). In order to avoid problems with non-linearity, the soil moisture routine is fed in millimeter steps by water from rainfall or snowmelt. The routine results in a small contribution to runoff when the soil is dry and a great contribution when conditions are wet. The parameter FC is the maximimum soil moisture storage in the model. The actual evapotranspiration (EA) increases with increasing soil moisture storage accordning to a linear relationship. LP is the value of soil moisture storage above which evapotranspiration reaches its potential value (EP).

The runoff response routine transforms excess water (dQ) from the soil moisture routine to runoff for each subbasin, see Figure 4. The effects of precipitation and evaporation for open water bodies (LAKE) is included. The routine consists of two reservoirs, which by recession coefficients distribute the generated runoff in time, and a filter for smoothing the flow.



dQ = inflow from the soil moisture routine
SUZ = computed storage in upper zone
UZL = limit for highest runoff component
PERC = percolation
LAKE = open water bodies
P = precipitation (on open water bodies)
EPL = evaporation from open water bodies
SLZ = computed storage in lower zone
K0,K1,K2 = recession coefficients
Q0,Q1,Q2 = computed runoff components
QG = Q0+Q1+Q2
QC = computed outflow

Figur 4. The runoff response routine of the HBV model.

The lower reservoir represents the groundwater and lake storage that contributes to base flow. The drainage is controlled by the recession coefficient K2. If the yield 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 groundwater drained through more superficial channels. When the storage exceeds UZL, an even faster drainage will start, controlled by the coefficient K0. The total outflow from the reservoirs (QG) passes through a simple filter with a triangular weight distribution, see Figure 5. This filter describes the distribution of concentration times from different parts of the subbasin to the outflow point.

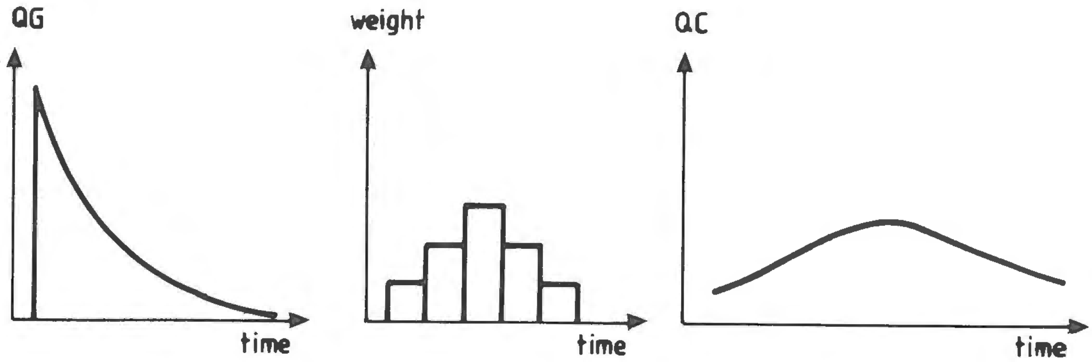


Figure 5. Presentation of the effects of the runoff filter of the HBV model.

Storage in a lake or a reservoir, which is located at the outlet of a subbasin, is taken into account by a special regulation routine. The outflow is controlled by one or a few stage-discharge relationships to which different regulation stipulations can be applied. Varying regulation limits during the year and seasonal dependent release can be considered. The outflow can also be calculated as a fraction of the inflow and further be modified by the storage in the basin.

The outflow from the different subbasins is added in the order that they contribute to the total flow in the water course. The delay and damping of the flow that takes place in the water course down to the outlet of next subbasin is considered by a Muskingum routing routine or a simple time lag.

The HBV model is calibrated by a manual trial and error procedure at which the parameter values are adjusted to improve the correspondence between the model simulated and recorded hydrographs. Usually 5-10 years of observed daily discharge data are sufficient. To judge the fit the three following criteria are mainly used:

1. Visual comparison between the computed and observed hydrographs.

2. A continuous follow-up 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: Qcomp = computed discharge (m^3/s),
Qobs = observed discharge (m^3/s),
t = time variable (usually days),
n = number of timesteps,
$\overline{Qobs}$ = the mean value of the observed discharge for the current period

The visual comparison is the most important criterion and one can especially consider those parts of the hydrograph that are most essential for the current application. For instance it can be flood peaks if the main purpose of the model application is flood forecasts. In addition to the above 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. Such a test will indicate whether the model is valid also outside of the calibration period.

The HBV model is often used for forecasting purposes. Before a forecast the model is run on observed data until the timestep before the timestep of forecasting. Consequently the forecast is partly based on the state in the model reservoirs at the time of forecast.

Updating of the model is to be considered, if there is a discrepancy between the computed and observed hydrographs during the last days or timesteps before the forecast. 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 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. One ought to be cautious to update, and one should be aware of the fact that the updating can introduce additional uncertainty.

The model has two types of forecasts, called the short range and the long range forecast. The short range forecast is to be used for making predictions of the flow development during the immediate future. Usually the forecast is made for a few days and uses a meteorological forecast as input to the model. The long range forecast is to be used for predictions over such long periods that meteorological forecasts are not available. The forecast is often made for a period of several months and historic climate records are used as input.

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.

The long range forecast is used for prediction of both flow peak and flow volume. For regulation of hydropower reservoirs the expected remaining inflow volume to a given date is the most interesting figure, while in other basins the interest is concentrated towards the distribution of peak flows. The latter aspect is, of course the most important, if flood damages is the main problem. On the other hand, if there are drought problems, low flow forecasts can be the most interesting ones.

For a long range forecast the model uses precipitation and temperature data from the corresponding dates during preceding years as input to give a range of simulations. Usually data from at least 10 years are used, and often from 20 years or more. The distribution of the simulated peaks gives an indication of the probability that a given value will be exceeded. The volume forecast is presented as a statistical interpretation of the distribution of simulations.

3. THE RIO SAMALA, GUATEMALA

For a river of moderate size, the Río Samalá has great flood problems. It flows through an area with frequent volcanic eruptions, that provide big quantities of easily erodable material. A consequence is non-stable river beds and frequent inundations. Several towns and villages are located in the flood risk zones of the Río Samalá and its tributaries. The use of a runoff model can contribute to the understanding of the hydrological processes in the basin. The model can also play a key role in an alert system for floods in the Río Samalá.

3.1 Basin description

The basin of the Río Samalá, see Figure 6, is located between the 14°17′ and 15°03′ north latitude and the 91°17′ and 91°49′ west longitude. The basin area is 1499 km^2 and covers partially the departments of Retalhuleu, Totonicapán and Quezaltenango and borders on the departments of Suchitepequez and Sololá. There are several important cities inside the basin, some of them departmental capitals such as Totonicapán and Quezaltenango. The last one is the second largest city of the country. Also part of the city of Retalhuleu is located inside the basin.

The Río Samalá starts in the volcanic mountain range, that crosses the country from east to west, and ends in a flat valley on the Pacific coast. The length of the basin is about 150 km and there is an elevation difference of 3500 m. The upper part of the basin is a plateau at an altitude of about 2300 m, surrounded by mountains and about 30 km wide. In the middle part the river flows through a gorge and the basin has an average width of 6 km. When the river enters the coastal plain, the basin is widened again to approximately 12 km.

The river channels have very steep slopes in the mountains. Due to abrupt changes of slope, the rivers carry and deposit material produced by erosion. That considerably affects the river courses, making them very sensible to floods.

The agricultural activity in the basin is high and especially in the upper plateau, where wheat, corn and vegetables are the main crops. In the low-

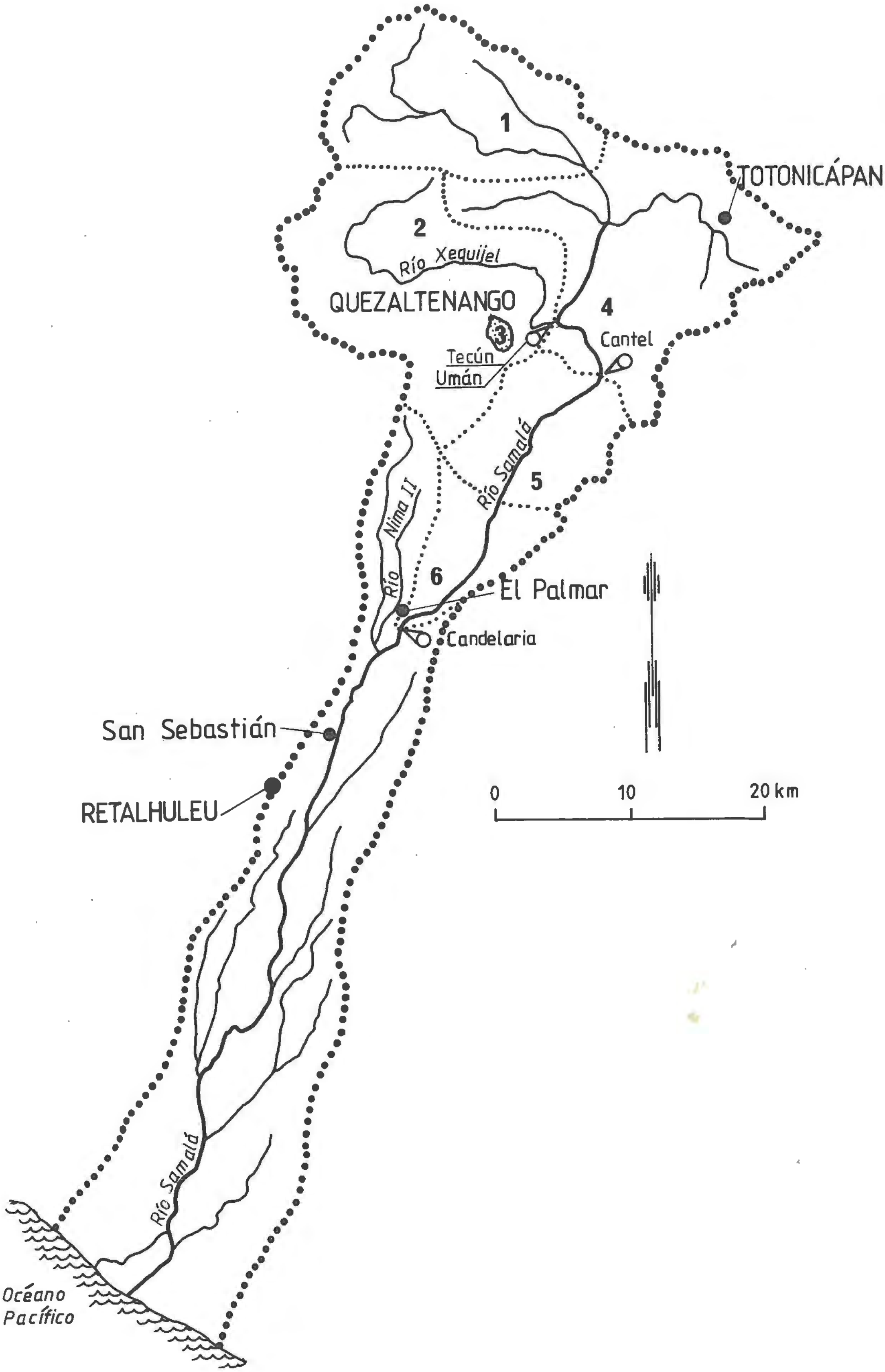


Figure 6. The basin of the Río Samalá.

lands sugarcane is an important crop. In the upper part of the basin there are some forests, which are exploited irregularly. Large areas and even those with very steep slopes are deforested to be used for agriculture.

The main geographic features in the basin are the volcanoes of Santa María (3772 m), the highest elevation for the basin, Santiaguito (2500 m), Siete Orejas (3200 m), Cerro Quemado (2800 m), Zunil (3542 m) and Santo Tomas (3505 m). The Santiaguito volcano is in constant activity and erupts great quantities of ash and volcanic debris.

The recorded history of volcanic disasters in the area started in 1902 when the Santa María volcano erupted and extruded 5.5 km^3 of debris. This has been considered one of the biggest eruptions in the world. In 1922 an explosive eruption from Santa María formed a new crater, which became the present Santiaguito volcano. At least 23 persons died because of this eruption. Seven years later, in 1929, a new eruption from Santa María produced a large devastation zone and in 1973 there was again a similar phenomena. The disasters of this nature have caused great changes of the landscape.

The Río Samalá basin has a rainy season which normally starts in May and ends in October and a dry season from November to April. Most of the precipitation originates from humid air masses coming from the Pacific Ocean and when they are forced up by the mountain range, high and frequent precipitation is produced. The maximum amounts fall on the barrier volcanoes in the middle part of the basin. The area around the Candelaria station thus receives an average annual precipitation of more than 4000 mm. Due to the barrier effect of the volcanoes, the upper part of the basin has considerably less precipitation. The plateau at Quezaltenango has an average annual precipitation of about 800 mm and the surrounding mountain slopes usually between 1000 and 1200 mm.

There are great temperature differences in the basin due to difference in altitude. In the plateau the average daily minimum temperature is about 2 °C and the average maximum about 21 °C. The corresponding figures for the lowlands are 24 °C and 30 °C. The mean relative humidity is about 75 % in the highlands, 80 % in the middle part and more than 90 % in the coastal plain.

3.2 Flood history

The southern part of the basin has serious flood problems, worsened by the constant activity of the Santiaguito volcano located in the middle zone. It erupts large amounts of fine material which is deposited on the volcano slopes and carried away downstream by the runoff. The situation is aggravated by the intense precipitation that occurs in the area. The streams transport large amounts of sediments that are deposited in the lower parts, where the flow has less energy and the rivers form nonstable meanders.

The sedimentation of the river beds in the vicinity of the Santiaguito volcano was very severe in 1983 and especially for the tributary Río Nima II. A lot of sediment was deposited near the town of El Palmar. A combination of a large volcanic eruption and an intense rainfall produced a disaster. The town was flooded and almost destroyed. After the flood, the river bed of the Río Nima II was higher than the level of the town. The place was considered so unsafe that the town population of 2000 inhabitants was moved permanently to a safer place and the old town was declared a disaster zone.

3.3 Model set-up

The HBV model has been calibrated and adapted for forecasting at two streamflow stations in the Río Samalá. They are Cantel and Candelaria with an area of 701 and 861 km^2 respectively. Cantel is located at the outlet of the plateau and has an altitude of 2250 m. Downstream from Cantel, the river drops drastically down to an altitude of 719 m at Candelaria. The mean discharge increases from 5.8 m^3/s at Cantel to 10.1 m^3/s at Candelaria. This last station is the main point of interest for forecasts.

For the model computations the basin of the Río Samalá has been divided into six subbasins. The division is based on homogeneity in vegetation, precipitation, soil type etc. The uppermost subbasin ends at the confluence of the Río Xolcatá and the Río Caquixá, where the river takes the name of Río Samalá and has a basin area of 204 km^2. Subbasin 2 covers the basin of the Río Xequijel and has an area of 233 km^2. A gauging station

Tecún Umán is located at the outlet, but does not have reliable discharge data so the information was only used qualitatively. The third subbasin is geographically not exactly defined, but is establisched in order to simulate the peaks produced by urban areas, especially from the city of Quezaltenango. It has an area of 25 km^2 and is totally impervious. The remaining area down to the Cantel streamflow station forms the forth subbasin and is 239 km^2. The area between Cantel and Candelaria has been divided into two subbasins of which the upper one is 102 km^2 and the lower one 58 km^2. This latter subdivision was decided because of the steep precipitation gradient in the gorge between the volcanoes.

Precipitation data were as far as possible selected from representative stations. However, there are not representative stations in all parts of the basin due to the extreme topography. A double mass test also showed that some precipitation records had serious inhomogeneity. The stations with the greatest homogeneity breaks were disregarded.

Potential evapotranspiration data for the model were calculated from observations in 5 evaporimeter pans of type Class A located in or near the basin. In Figure 7 the evaporation for the different pans has been plotted versus altitude. Average values of monthly mean evaporation for the pans are shown in Table 1.

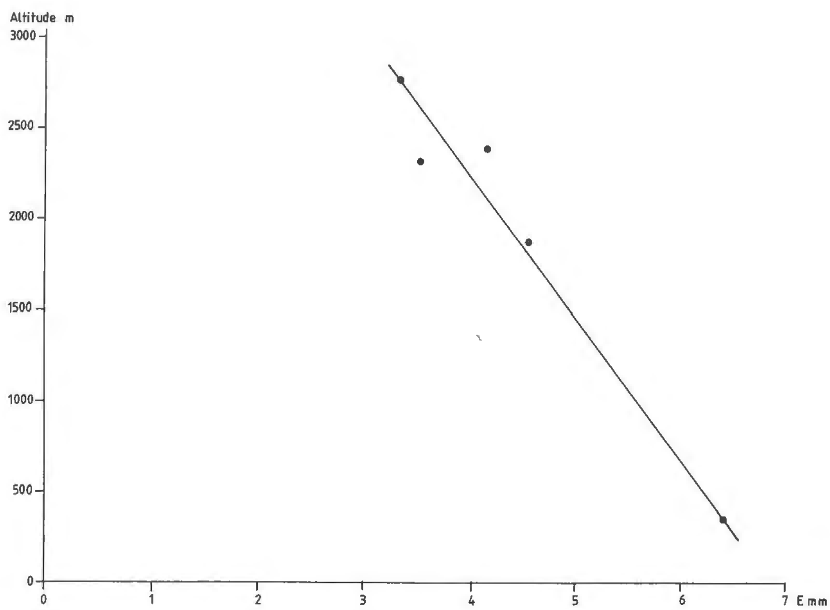


Figure 7. Average daily evaporation for Class A pans versus altitude

Table 1. Monthly mean values of Class A pan evaporation (mm/day)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.1	4.2	5.0	4.7	3.8	3.1	3.9	3.9	3.1	3.4	3.8	4.1

The values in Table 1 were multiplied by a factor 0.85 for correcting pan evaporation to probable potential evapotranspiration. A further correction according to the relationship in Figure 7 was done for taking into account the altitude of each subbasin.

3.4 Calibration results and forecasts

The HBV model for the Río Samalá has been calibrated in two versions; one with computation time-steps of daily length and the other with time-steps of three hours length. The calibration period for daily time-steps was 1979-1987 and input data from 12 precipitation stations were used. For the 3-hours time-steps precipitation from only 5 stations could be used and the calibration period was 1985-1987.

The calibration has been problematic and the model has not always succeded to reproduce the observed streamflow. One reason is that the precipitation network is not dense enough to describe the high spatial variability of rainfall. Especially the high precipitation area between Cantel and Candelaria has not been covered sufficiently. Another reason is that the streamflow records not always seem to be of good quality and that is particularly the case for Tecún Umán. For Cantel and Candelaria there are probably periods with poor data due to sedimentation of the control sections. The regulation of a small reservoir upstream from Candelaria has also caused some problems, since the management policy has not been known.

An example of the model-run results for daily time-steps at Candelaria is shown in Figure 8. The model parameters are listed in Appendix 1. The year of 1983 was chosen for the example, since that year had a very troublesome flood period. However, the flood peaks were not the very highest but the problems were caused by a combination of high discharge and high sediment load.

The calibration for 3-hours time-steps has up to now given unsatisfactory results. The main reason is that too few precipitation stations were available.

A forecast model running with daily time-steps seems to be quite sufficient for modelling the runoff from the upper plateau. However, at Candelaria a great portion of the streamflow fluctuations are caused by runoff from the steep volcano slopes, and the response time for this runoff is a matter of hours. A forecast model running with 3-hours or 6-hours time-steps is therefore prefereable, even if a daily model also is useful, since high flood peaks usually are built up of several days of rain.

Real-time forecasting was tested in November 1989 with the model version for daily time-steps and both short range and long range forecasts were made. Precipitation data from one station, Labor Ovalle near Quezaltenango, were received via radio for the days immediately preceding the forecast. No other data could be collected for this period. Instead of a meteorological forecast a couple of possible precipitation sequences were used as input for the short range forecast.

A forecast based on data measured at only one precipitation station in the plateau is not very useful. It could give an indication of the flow development at Cantel but would not give useful results for Candelaria. Good forecasts for Candelaria would require real-time collection of precipitation data from at least one, but preferably two, stations in the high precipitation area between Cantel and Candelaria. Operational real-time forecasting should, therefore, not be started until real-time collection of precipitation data is arranged from a sufficient number of stations in the basin.

The model can also be extended to the basin area downstream from Candelaria, but without calibration. A first step would be to include the whole area with extremely high precipitation on the volcano slopes, approximately down to the town of San Sebastián. The model parameters could probably be given the same values as for the subbasins between Cantel and Candelaria.

A model application for the lower Río Samalá would be a cheap method to simulate streamflow data. An ordinary streamflow station is very difficult to operate due to the heavy sediment load of the river water.

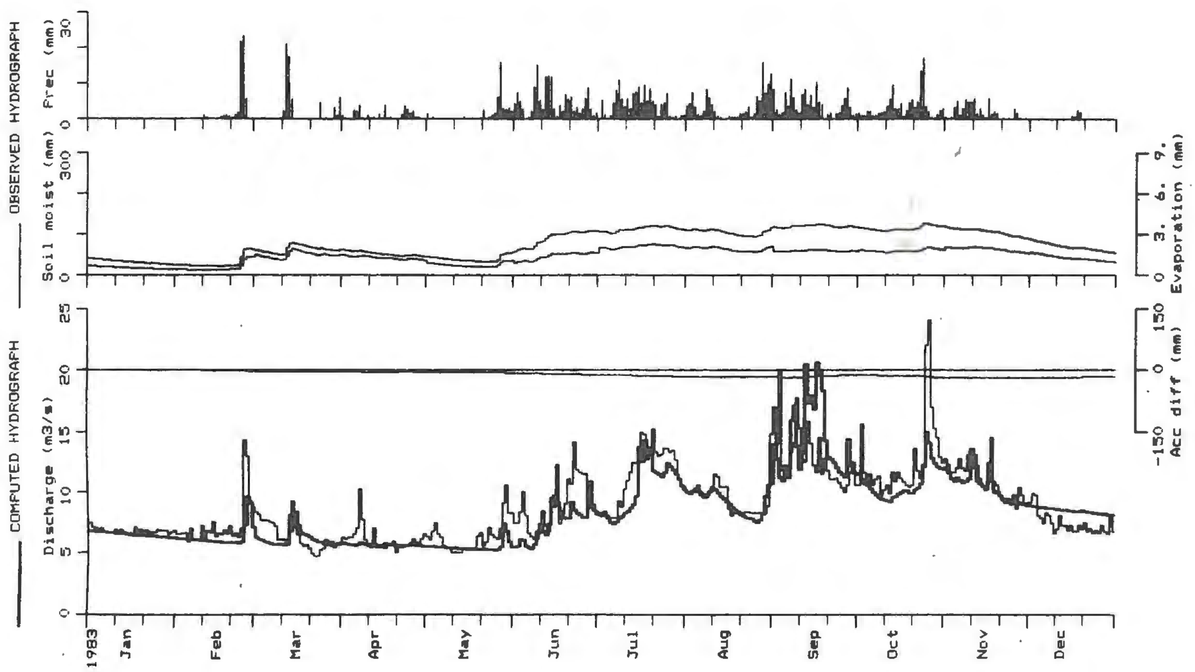


Figure 8. Model results in 1983 for Candelaria.

4. THE RIO GRANDE DE SAN MIGUEL, EL SALVADOR

The Río Grande de San Miguel is a river with frequent and severe flood problems. Large areas of productive agricultural ground are affected by the floods and that seriously restricts the development of the basin. In the 1960s the basin got well developed networks of hydrological and meteorological stations. However, the civil war of the 1980s has brought about a deterioration of the networks and the hydrometric stations have been completely closed down. The use of a runoff model can be a way for reconstructing the hydrographs of the 1980s. In the future when real-time collection of rainfall data can be organized a runoff model will be very useful for flood forecasting purposes.

4.1 Basin description

The basin of the Río Grande de San Miguel, see Figure 9, is located in eastern El Salvador between 13°12′ and 13°47′ north latitude and 87°58′ and 88°28′ west longitude. The basin area is about 2300 km^2 and covers parts of the provinces Morazán, San Miguel, La Unión and Usulután. The most important population concentration is the city of San Miguel with about 150 000 inhabitants.

In the hilly landscape in the northern part of the basin many fast moving streams start to flow. The streams join and form the Río Grande de San Miguel, which first flows southwards and then turns to the west through a broad valley. Finally the river turns again to the south and pours its water into Bahía de Jiquilisco, a mangrove estuary in the Pacific Ocean.

The most dramatic features of the basin are the volcanoes of San Miguel (2130 m) and Usulután (1449 m), which dominate the western part of the basin. The landscape in the northern sector as well as in a narrow strip along the southern basin divide has an abrupt relief with many steep ridges. The middle part of the basin has smoother topography and there are also large plain areas. The volcanoes and the central part of the basin have ground conditions very permeable for infiltration. In the rest of the basin the ground mostly has low infiltration capacity.

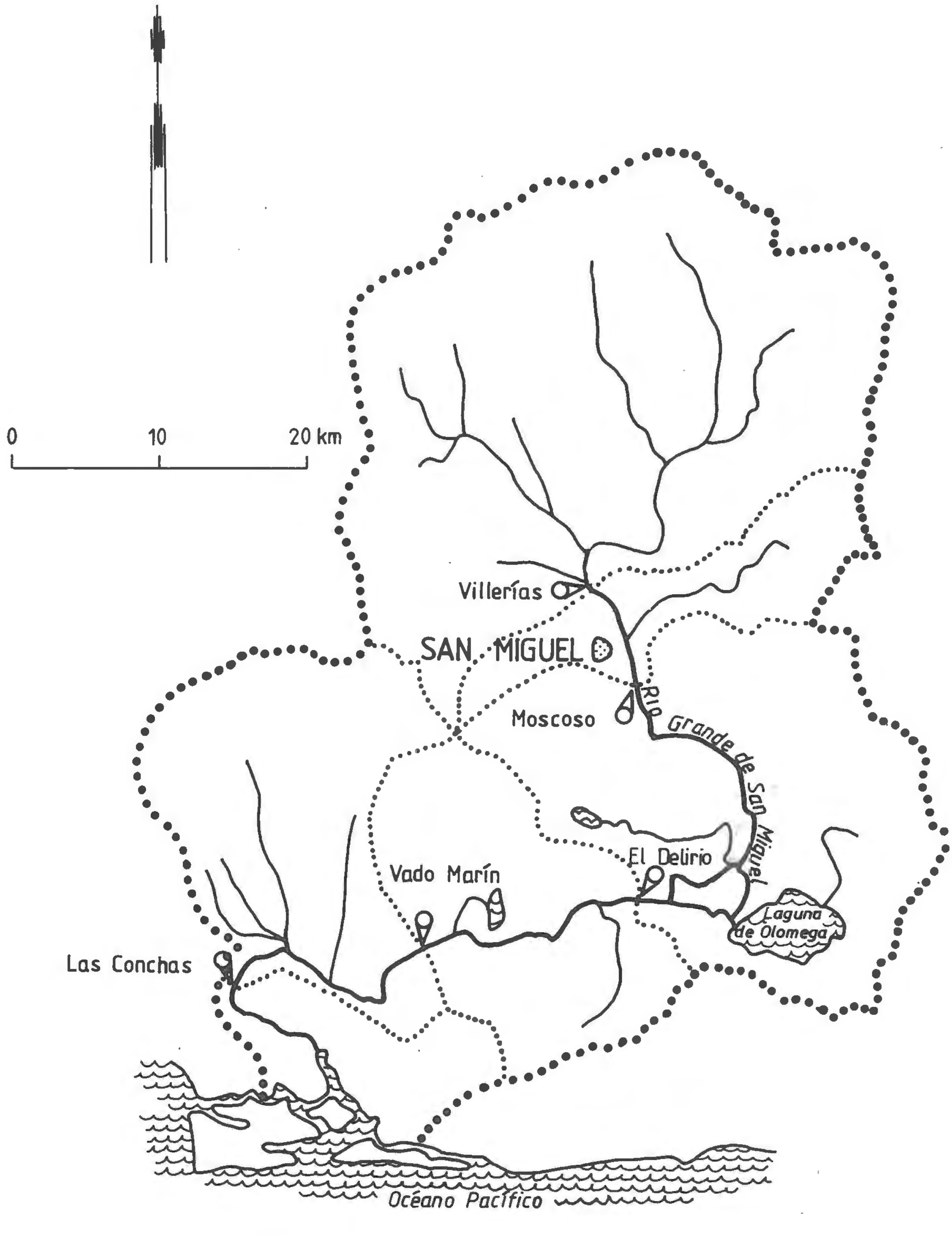


Figure 9. The basin of the Río Grande de San Miguel.

There has been an extensive deforestation and only small spots of forests are left in the basin. The combination of deforestation, steep terraine and in some regions low infiltration capacity results in flash flood problems in the tributaries. This also causes serious erosion and large quantities of fertile soil are washed away.

There are three relatively large lakes located in the lowland part of the basin. The most important is Laguna de Olomega with an area of 25 km^2. This lake has a damping influence on the flow in the river. Water flows into the lake at rising water level in the river and flows out when the river level has fallen below the lake level.

The basin has a tropical savanna climate with a rainy season lasting from May to October and a dry from November to April. The rainiest month is September and the driest are January and February. The annual mean precipitation varies between 1600 mm in the central part of the basin to more than 2300 mm in the northernmost mountains. The average annual precipitation for the whole basin is about 1800 mm.

The annual mean temperature at San Miguel in the central part of the basin is 27 °C with a variation of about 3 °C between the warmest and coolest months. The mean relative humidity is about 70 % and the mean wind velocity around 2 m/s.

4.2 Flood history

In its middle course the Río Grande de San Miguel is surrounded by plain areas, which are frequently flooded by the river and its inflowing tributaries. Insufficient drainage of rain water also contributes to the problems and inundations occur on an average every second year. An area of more than 100 km^2 is frequently flooded and sometimes even more than 200 km^2. Severe floods occurred in 1952, 1954, 1963, 1972, 1974, 1982, 1987 and 1988.

4.3 Model set-up

The HBV model for the Río Grande de San Miguel has been set up for calibration on streamflow data from five stations in the river. The local basins of the stations have been used as subbasins in the model. The stations are Villerías, Moscoso, El Delirio, Vado Marín and Las Conchas. For El Delirio the preparation of data, however, was delayed and calibration has not yet been carried out.

At all the hydrometric stations in the basin the observations were stopped in the end of the 1970s or the beginning of the 1980s. The model should therefore primarily be used for prolongation of the recorded hydrographs. The purpose is also to use the model for forecasting and that should be particularly useful for Moscoso, El Delirio and Vado Marín.

The basin had a relatively dense precipitation network in the 1970s. The intention in this project was to use more or less all the precipitation observations from the 1970s for the calibration of the model. However, due to practical problems only six stations could be used for the calibration, and the distribution of these stations was not very good. No station was located in the two subbasins furthest downstream.

Monthly average values of potential evapotranspiration were calculated from pan evaporation measurements in the region. A correction factor was applied for taking into account that pan evaporation generally exceeds the evapotranspiration.

4.4 Calibration results and forecasts

The calibration of the model for the Río Grande de San Miguel was carried out on daily data from the period 1970-1979. The calibration work was concentrated on Moscoso and Vado Marín. Moscoso gives the flow upstream from the inundation areas and Vado Marín downstream.

Large inundation areas as well as lakes like Laguna de Olomega, with restricted hydraulic connection to the river, cause special problems for the calibration. Their moderating effect on the flow has in the model been described by reservoirs of variable sizes.

An example of the model-run result for Vado Marín is shown in Figure 10. The model parameters are listed in Appendix 2. The year of 1974 had the highest flood peak during the calibration period and has therefore been used for the example. The calibration results are not entirely satisfactory, even if the model has succeeded in simulating most of the flood peaks relatively well. The possibility for improvement of the calibration seems to be considerable. However, when further calibration work is carried out, data from more precipitation stations and streamflow data from El Delirio should be used.

The forecasting procedure of the model has been tested with historical data. Operational forecasting can be carried out only after real-time collection of precipitation data has been arranged.

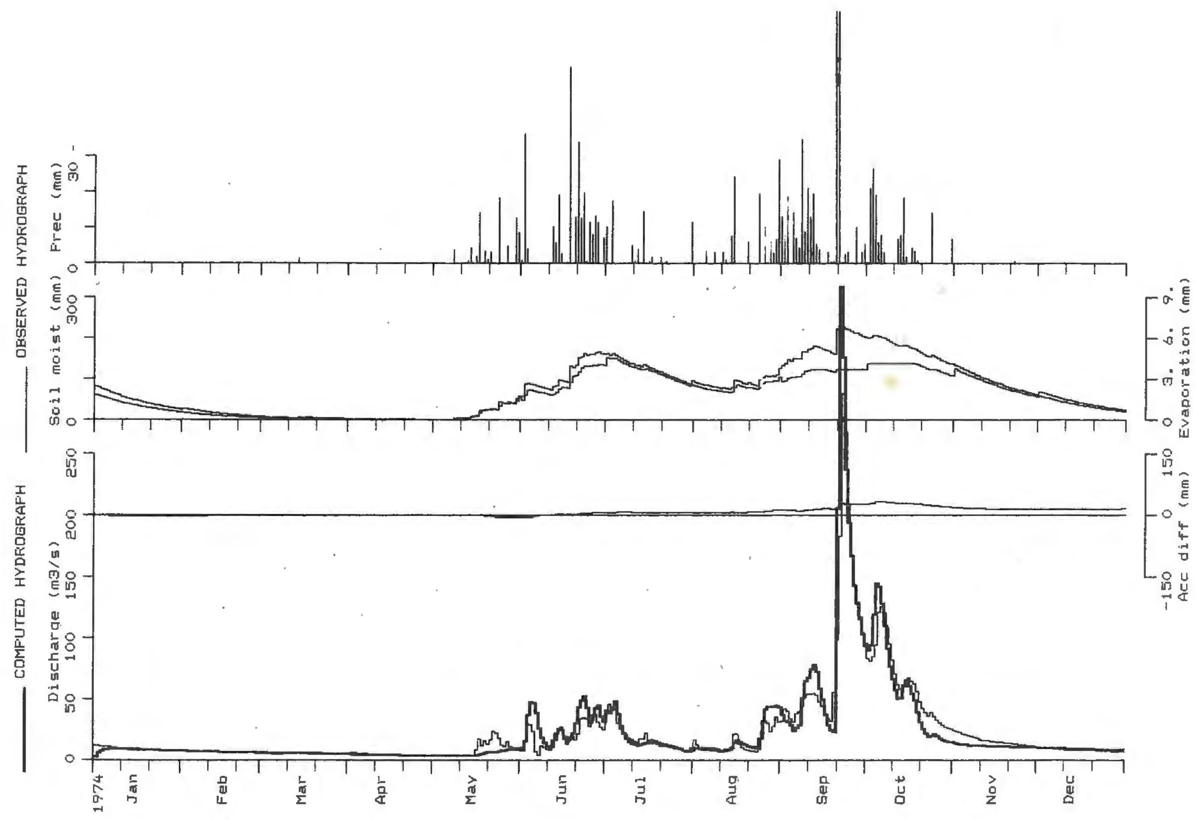


Figure 10. Model results in 1974 for Vado Marín

5. THE RIO CHOLUTECA, HONDURAS

A large number of people live in the basin of the Río Choluteca. On its way to the sea the river passes two main cities: Tegucigalpa, the capital of Honduras, and Choluteca. Agriculture is an important activity in the basin and especially the plain around Choluteca is highly productive. For this plain the floods of the river are a threat but the river is also of vital importance as a source for irrigation water. A runoff model for the river can be used both for prediction of floods and prediction of the water availibility during the dry season.

5.1 Basin description

The basin of the Río Choluteca, see Figure 11, is located in the southern part of Honduras between 13°03′ and 14°23′ north longitude and 86°28′ and 87°29′ west longitude. The basin area is 7550 km^2 of which 280 km^2 are situated in Nicaragua. The main part of the basin is hilly to mountainous and is built up of tertiarian extrusive rocks. It has an average altitude of about 860 m.

The Río Choluteca has its headwaters in the mountains west of Tegucigalpa. From there the river flows in a wide bow to the outlet into Golfo de Fonseca of the Pacific Ocean. In its lowest reach the river has built up an alluvial plain.

The basin is to about 50 % covered by forests, which partly are poor. Under the impact of the population expansion the forests are day by day decreased and substituded by migrate agriculture and grasslands. However, some areas, which are mainly located in the northern part of the basin, are protected as national parks or forest reserves. There is also a project going on for soil conservation, agricultural development and forestation.

The most important agricultural districts are located in the middle and southern part of the basin. The main crops are sugarcane, cotton, corn, fruit and vegetables. The agriculture suffers from frequent drought problems and irrigation is necessary for a good production. In order to increase the availability of water for irrigation, there is an advanced plan for construction of a reservoir near Hernando López, see Figure 11.

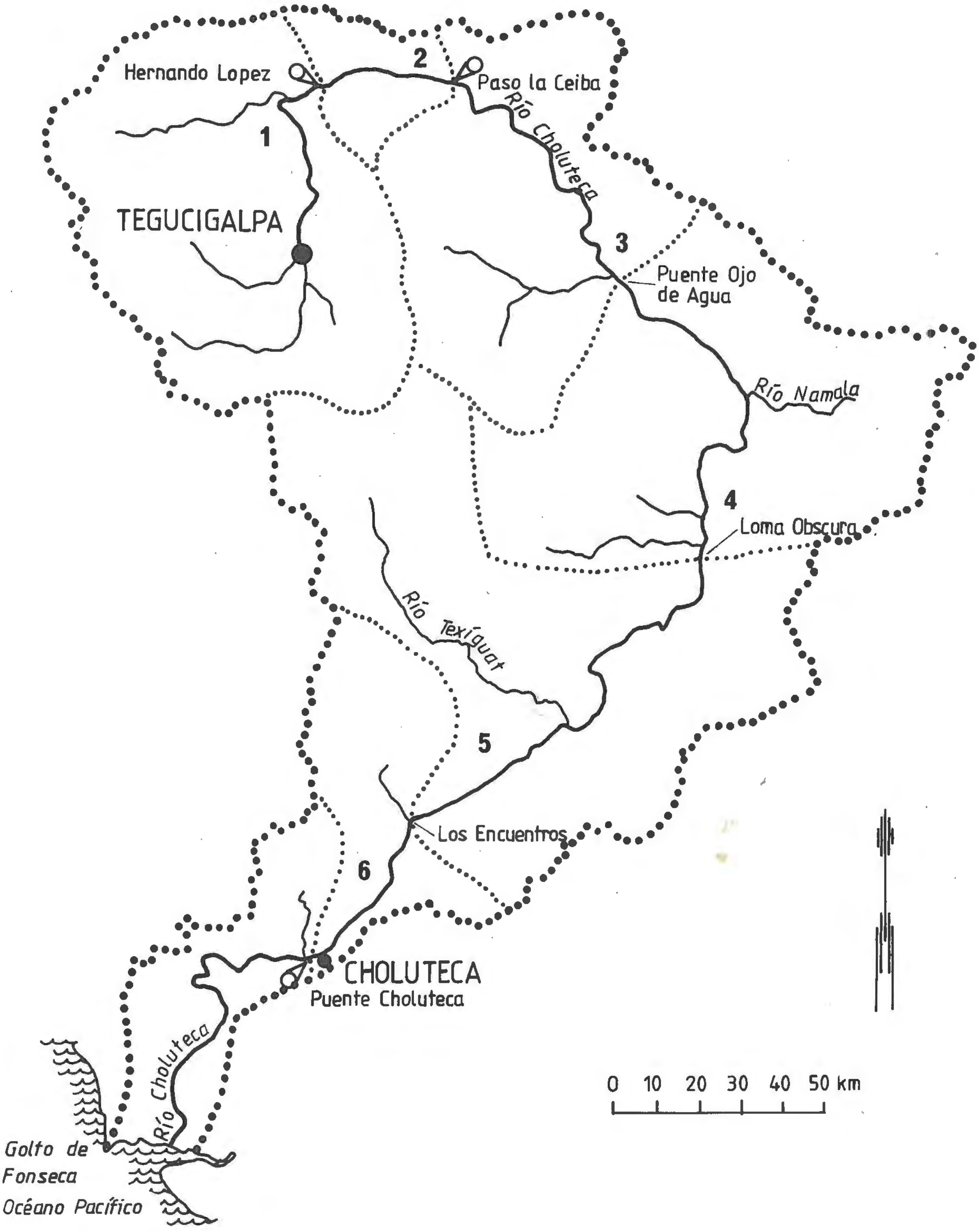


Figure 11. The basin of the Río Choluteca.

The oscillation of the intertropical convergence zone causes a wet season from May to October and a dry one from November to April. The dry season is less severe in the northern part of the basin due to occasional influence of polar air masses during the winter of the northern hemisphere. In general more than 80 % of the annual precipitation is concentrated in the wet season.

Showers are the predominant type of precipitation and thunderstorms are frequent during the pass of the intertropical convergence. The average annual precipitation is about 1000 mm in the upper two thirds of the basin. Due to rain shadow there is a narrow region with annual values as low as 400 mm in the area of the Río Texíguat. Further south the precipitation increases and is about 1800 mm annually at Choluteca.

The highest air temperature usually occurs in April-May and the lowest in December-January. The difference between the highest and lowest monthly value is less than 5 °C. Depending on altitude the annual mean temperature varies between 16 and 28 °C. The annual mean value of the relative humidity is 71 % in the northern part of the basin and 65 % in the southern part. The prevailing wind direction is from the north or the northeast with average velocity between 3 and 4 m/s.

5.2 Flood history

The Río Choluteca causes flood problems mainly in two areas; the city of Tegucigalpa and the Choluteca plain. Last time, a severe flood occurred, was in September 1988 when more than 100 km^2 of the plain were inundated and Tegucigalpa suffered housing damages. The worst flood during recent years was caused by the tropical hurricane Fifi, which passed in September 1974. More than 500 km^2 of the plain were then inundated and large damages were caused in Tegucigalpa. Other severe floods occured in 1962, 1965 and 1982.

5.3 Model set-up

The basin of the Río Choluteca has in the model been divided into six subbasins. Three of them have outlets at streamflow stations and the three others were created in order to get relatively homogeneous areas according to the precipitation pattern. The subbasins named after their outflow points are: Hernando López (1565 km^2), Paso la Ceiba (178 km^2), Puente Ojo de Agua (1228 km^2), Loma Obscura (1540 km^2), Los Encuentros (1859 km^2) and Puente Choluteca (594 km^2). The streamflow stations are located at Hernando López, Paso la Ceiba and Puente Choluteca. The total basin area at Puente Choluteca is 6964 km^2. The subbasin and their water divides can be seen in Figure 11.

The model is to be used for making flood forecasts at the outlets of the subbasins. The main point of interest for forecasts is Puente Choluteca, due to the large areas that are exposed to be flooded in the vicinity of this station. Forecasts could in the future be valueable for Hernando López, if a reservoir for irrigation and hydropower is constructed near that point.

In this project the model has not been adapted for forecasting at Tegucigalpa. The response time for the river is much shorter there than in the lower reach. It would, therefore, be more practical to use a separate model for the uppermost part of the river. That model application should run with time-steps of about 6 hours length.

The precipitation network in the basin of the Río Choluteca is rather dense. However, the stations are not evenly distributed and very few are located in the eastern part of the basin. A complication is also that some stations have missing data and other ones have not been in operation during the whole calibration period. Another complication is that the network is operated by at least three different institutions with different purposes. In order to check the homogeneity of the precipitation series a double mass test was used and a few stations had to be disregarded. Some stations have not been in operation on weekends and were therefore not used. Short gaps in the precipitation series were filled in with data from neighbouring stations.

The weights of the precipitation stations for each subbasin were estimated in a rather subjective manner. However, during the calibration process the weights were adjusted in order to increase the accuracy of the model simulation. Correction factors were used to estimate the areal average precipitation for each subbasin. These correction factors were determined according to the precipitation distribution of a isohyetical map.

Potential evapotranspiration for the model was calculated from evaporation measurements in pans of type Class A. Data from nine pans located in or near the basin were used. The pans had similar seasonal variations but indicated a decrease of evaporation with altitude. This decrease was about 2 mm per day for 500 m altitude increase. Average values of monthly mean pan evaporation are shown in Table 2. These values represent the evaporation at an altitude of about 650 m.

Table 2. Monthly mean values of Class A pan evaporation (mm/day)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.8	5.9	7.1	7.0	5.9	4.5	4.7	4.8	4.3	3.9	3.8	4.0

Since Class A pan evaporation generally exceeds the potential evapotranspiration, the values in Table 1 were multiplied by a correction factor of 0.8. A correction for altitude was also applied for each subbasin.

5.4 Calibration results and forecasts

The HBV model for the Río Choluteca has been calibrated with daily timesteps. The calibration period was 1979-1985 and data from 3 streamflow stations and 20 precipitation stations were used. The model-run results for 1980 are shown in Figure 12. The model parameters are listed in Appendix 3. The year of 1980 had many flood peaks of which the last one was the highest during the calibration period. The calibration result is as a whole satisfactory even if the peak values in 1980 are somewhat understimated.

The procedure of real-time forecasting was tested in November 1989 and short range and long range forecasts were made. Precipitation for the last days before the forecast was collected from 2 synoptic weather stations; one located in Tegucigalpa and the other one in Choluteca. A couple of probable precipitation sequences were used for the coming days in the short range forecast.

Operational real-time forecasting can be started with the installed system. Precipitation from some additional stations in different parts of the basin should, however, be collected. This can probably be done by telephone. Streamflow data from at least Choluteca should also be collected in order to make updating of the model possible. In addition quantitative precipitation forecasts for the basin or at least qualified guesses by an experienced meteorologist should be used as input for the short range forecast. Long range forecasts on the other hand use the already existing data base of historical data.

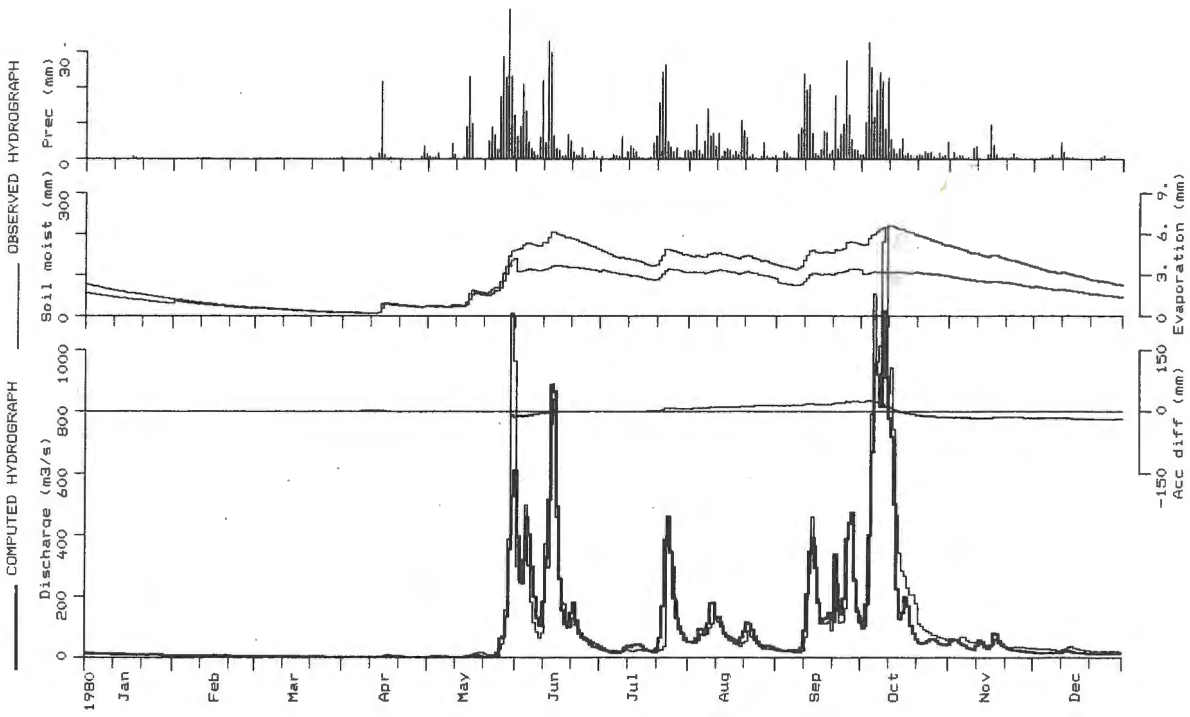


Figure 12. Model results in 1980 for Puente Choluteca.

6. THE RIO VIEJO, NICARAGUA

During the two most recent decades, the Río Viejo basin has become of great importance for the Nicaraguan economy, mainly due to hydropower production and agriculture. The activities in these fields make the basin to a base for the social-economical development of the country. A forecasting system for the river could be very useful for a more efficient exploitation of the water resources. It will also increase the possibilities for issuing flood warnings when necessary.

6.1 Basin description

The Río Viejo basin, see Figure 13, is located in the northwestern part of Nicaragua between 12°28′ and 13°16′ north latitude and 85°59′ and 86°24′ west longitude. The basin area is 1519 km^2 and it has an elongated shape, oriented from the north to the south, with its wider part in the north. The Río Viejo flows into Xolotlán (Lago de Managua), which is a lake belonging to the Atlantic watershed but with only occasional outflow.

The Río Tuma, adjacent to the upper Río Viejo, was in the mid 1960s dammed up at Mancotal and a 50 km^2 large reservoir, Lago de Apanás, was formed. The water from this reservoir passes through a hydropower plant, La Centroamérica, and is released into a small tributary to the Río Viejo. The average release is 10.5 m^3/s. Surplus water from Lago de Apanás can be spilled to the Rio Tuma but that happens only at rare occasions.

In 1989 a new reservoir, Lago de Asturias, in the Río Tuma has been taken into use. From this reservoir water is pumped to Lago de Apanás in order to increase the production at the hydropower plants. The average increase of discharge in the Río Veijo is 2,7 m^3/s.

The Río Viejo is formed by the confluence of the Río Isiquí and the Río San Rafael del Norte at an altitude of about 700 m. From there the Río Viejo flows through a narrow channel down to the Sébaco valley. In this reach the river receives the release water from Lago de Apanás and this water constitutes the main part of the discharge except during floods. In its middle course the Río Viejo runs through the Sébaco valley at an

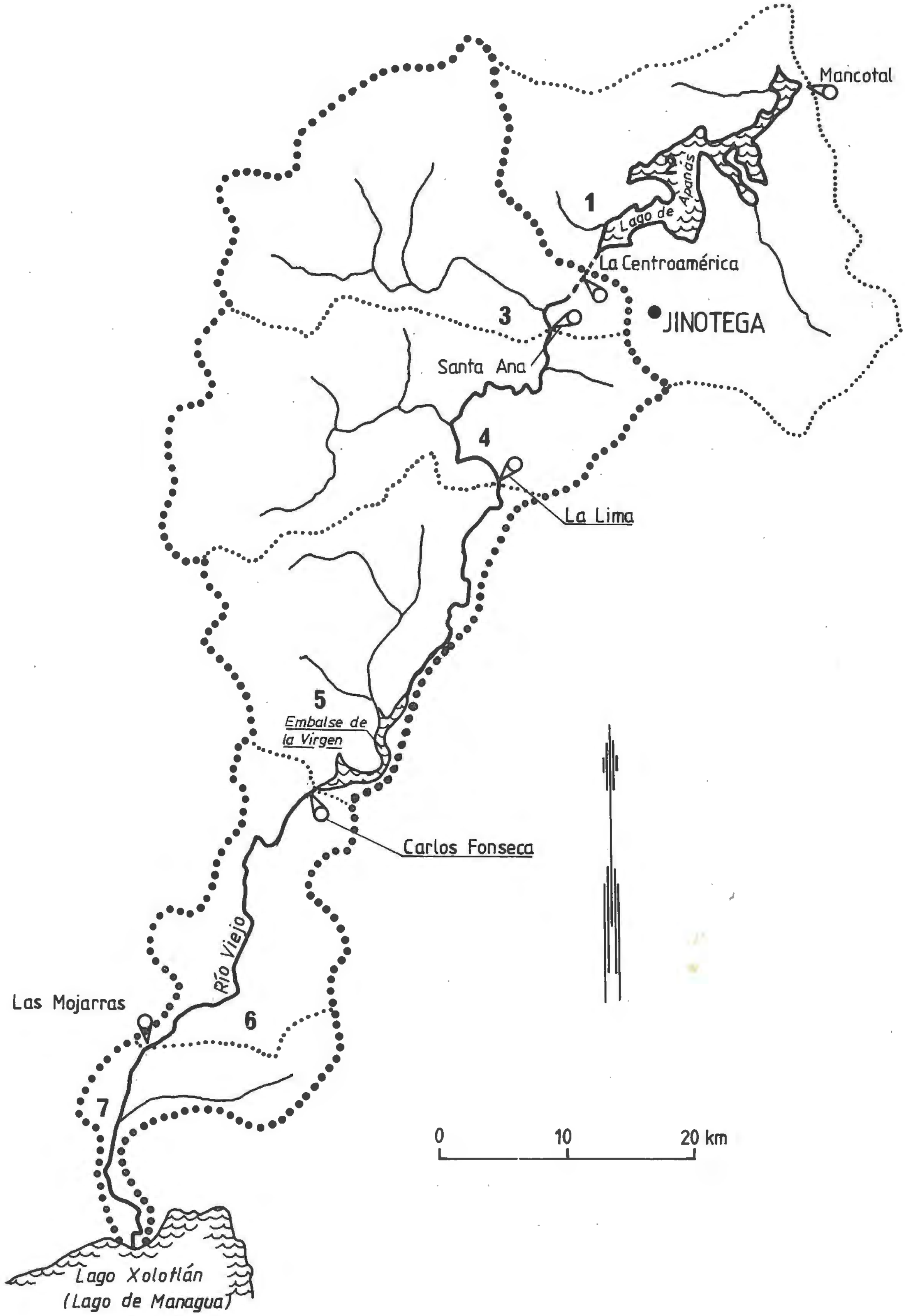


Figure 13. The basin of the Río Viejo and Lago de Apanás

average altitude of about 460 m. This valley, which also is drained by the Río Grande de Matagalpa, is a very important agricultural zone and produces the main part of rice and vegetables for Managua's market. The towns of San Isidro, Ciudad Darío and Sébaco are situated on the outskirts of the valley. The demand of water from the Río Viejo for irrigation and domestic consumption in the Sébaco valley is about 5 m^3/s.

Before 1965, the first year of operation for the power plant La Centroamérica, the Río Viejo usually dried up in the dry season. Agricultural production was, therefore, performed only during the wet season. The regulation of Lago de Apanás made agricultural development possible since water for irrigation was guaranteed all year. At present the cultivated area in the Sébaco valley is about 6 700 ha with a potential agricultural estimate of 30 000 ha.

When leaving the Sébaco valley the Río Viejo runs through a canyon in which a dam has been constructed forming the reservoir La Virgen. This reservoir is about 6 km^2 and has a small regulation capacity of about 1,5 millions of m^3, which is used for regulating the inflow to the power plant Carlos Fonseca on a daily and weekly basis. As a reservoir for reducing floods La Virgen has no practical importance.

Downstream from the Carlos Fonseca power plant the river flows through a narrow channel before it reaches the Sineca plain at an altitude of about 60 m. In this plain bordering Xolotlán (Lago de Managua) an agricultural development has been initiated during the last years.

The basin of the Río Viejo is hilly and mostly covered by bush. The vegetation in the northern half of the basin is of tropical wet type. The southern half has a tropical dry vegetation and in low-lying areas the vegetation is characterized as very dry. The basin of the upper Río Tuma is mountainous and is partly covered by forests of tropical wet type.

The mean annual precipitation in the basin of the Río Viejo is about 950 mm of which 75 % fall during the wet months May to October. Most of the rain is of convective origin but occasionally tropical storms affect the area. The mean annual temperature is about 25 °C with low seasonal variation. The mean annual relative humidity is about 70 %.

6.2 Flood history

The basin of the Río Viejo has occasional flood problems but the damages are usually not very severe. The areas that are in the risk zone of being flooded by river water are located in the Sébaco valley and on the plain near the outlet of the river. The flood problems occur mostly in connection with tropical hurricanes and the last severe flood was caused by the hurricane Joan (Juana), that passed over Nicaragua in October 1988. Another problematic flood during later years occurred in late May 1982.

6.3 Model set-up

The HBV model for the Río Viejo has been set up as three separate applications. The first application is for computing the inflow to Lago de Apanás. In the second application the model computes the regulated discharge downstream from the reservoir, using recorded outlow from Lago de Apanás as input data. The third application combines the two first ones, but the outflow from the reservoir is in this case calculated by a simple regulation routine for Lago de Apanás.

The application for the inflow to Lago de Apanás has two subbasins - the area surrounding the lake and the lake itself. The calibration was carried out on inflow data calculated from records of discharge and the change of water level in the reservoir.

The application for the Río Viejo downstream from Lago de Apanás has five subbasins. The first four of these correspond to the local basins of the stream flow stations Santa Ana, La Lima, the Carlos Fonseca power plant and Las Mojarras. The last subbasin is the area between Las Mojarras and the outlet into Xolotlán. The model has been calibrated on stream flow data from the stations La Lima and Las Mojarras.

The application for the total basin is a combination of the two others and has seven subbasins. A simple strategy for the regulation of Lago de Apanás effects the combination. This makes it possible to simulate the total streamflow of the Río Viejo without manually entering the recorded outflow data from the power plant La Centroamérica.

The basin has relatively many precipitation stations and they have a good geographical distribution. A couple of stations were excluded due to strange and probably erroneous data. Thiessen polygons were used for calculating the station weights.

Monthly average values of potential evapotranspiration were calculated from observations at some evaporimeter pans of type Class A situated in or near the basin. For each subbasin a correction factor was applied for taking into account the decrease of the evapotranspiration with altitude and also for taking into account that pans generally overestimate the evapotranspiration.

6.4 Calibration results and forecasts

The calibration of the model for the Río Viejo was carried out on daily data from the period 1972-1986. Data records from 21 precipitation stations, 4 streamflow stations (including the power plants) and 1 water level station were used. The storage fluctuations in the reservoir La Virgen have been considered as insignificant and has not been taken into account by the model computation.

The application for Lago de Apanás had to be calibrated on inflow data of inferior quality. The reason was that the water level data of the reservoir by mistake were prepared with only decimeter resolution. In spite of this, the calibration results were satisfactory, but should be checked and if necessary modified as soon as corrected water level data are available.

The calibration for the Río Viejo has also been somewhat problematic due to both data errors and strange discharge values. The runoff in the basin downstream from Lago de Apanás seems to be very low and the flow in the river usually is lower than the release from the reservoir.It does not seem possible to explain the whole loss with data errors or outtake of water for irrigation and domestic consumption. A possible reason to the low runoff and loss of water from the river channel is underground infiltration to groundwater that is not drained by the river.

The loss of water has in the model been represented by two functions. The first one is applied on the river reach between Santa Ana and La Lima and reduces the flow according to a relationship more or less found through calibration. The other function represents the loss caused by irrigation and domestic consumption and is applied on the river reach through the Sébaco valley.

A one year model-run result for Las Mojarras is shown in Figure 14. The model parameters are listed in Appendix 4. The year of 1982 was chosen, since it had the highest flood during the calibration period. The release water from Lago de Apanás is given as input for the model-run and routed downstream. The flood peak is simulated fairly well by the model and the result seems as a whole to be satisfactory. The small-scale fluctuations of the observed hydrograph are mostly caused by the regulation of the reservoir La Virgen.

There has not yet been any opportunity to run the model for an independent test period. The year of 1988 would be especially interesting for testing the model due to the flood peak caused by the hurricane Joan.

The Río Viejo responds very quickly to precipitation due to the small capacity of the natural reservoirs. Even in the lower reach of the river the flood peak arrives within the same 24-hours period as the rain. Updating of the model is difficult due to the very quick response.

A forecast model for the Río Viejo should preferably be run with shorter time-steps than the present daily ones. In this project it has not been possible to calibrate the model for shorter time-steps due to lack of precipitation data with such a resolution. The model can yet be useful for forecasting purposes, since the floods are often built up from several days of rain. During a period of heavy rain one can also collect the precipitation several times a day, and for the current day feed the model with the sum of collected and for the rest of the day expected precipitation.

The procedure of real-time forecasting was tested in November 1989 and both long and short range forecasts were made. No meteorological forecast was available as input for the short range forecast, but a couple of possible precipitation sequences were used. The precipitation from the days immediately preceding the forecast could be collected by telephone from only one station.

To be able to make operational real-time forecasting for the Río Veijo, it is necessary to arrange with collection of precipitation data via telephone or radio. Data from at least three stations are probably required for realistic forecasts and the stations must be well distributed over the basin. If forecasts also are to be made for Lago de Apanás precipitation data should be collected from at least two stations in or near its basin.

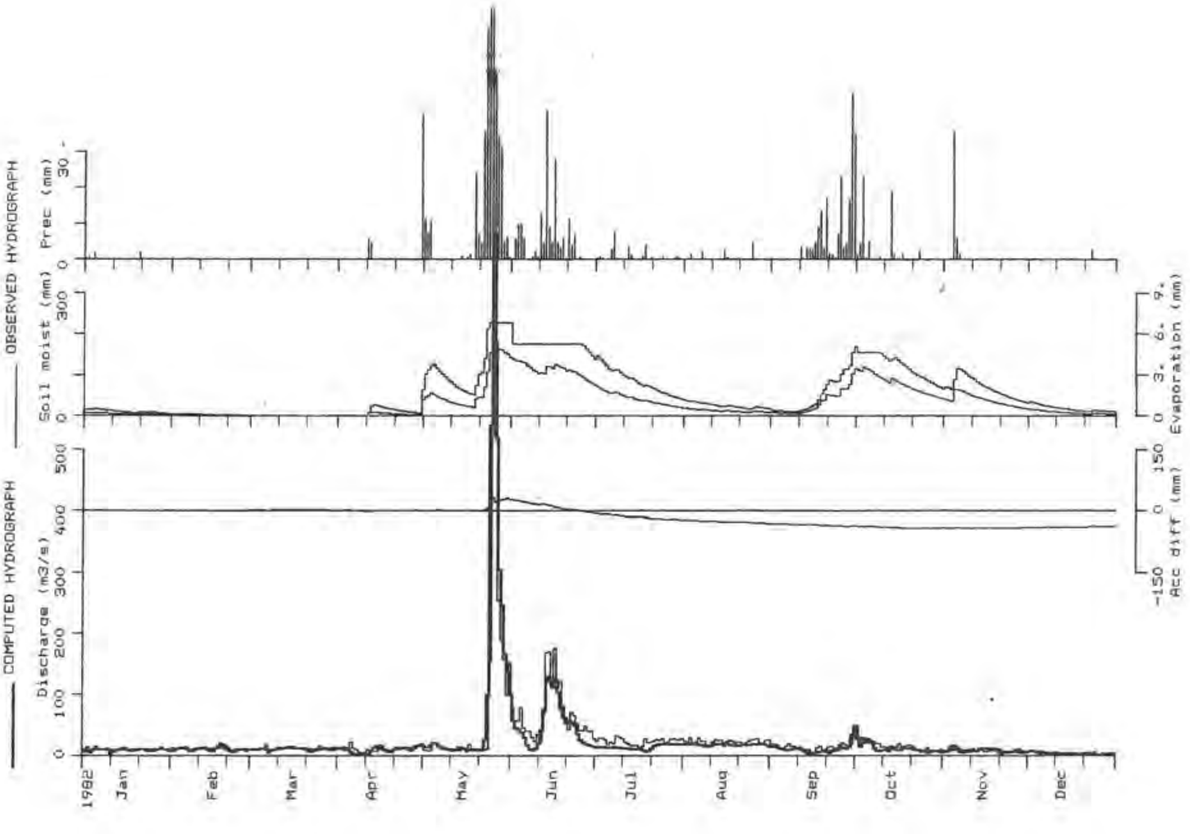


Figure 14. Model results in 1982 for Las Mojarras with the outflow from Lago de Apanás used as input.

7. THE RIO GRANDE DE TARCOLES, COSTA RICA

The basin of the Río Grande de Tárcoles is economically very important for Costa Rica. It includes the most populated and industrialized area of the country and the capital of San José. The basin also has highly productive agricultural zones and the river and its tributaries are important for hydropower production. The use of a runoff model will improve the possibilities to predict floods. It can also be used for long term forecasts of the water availibility during dry periods. Computations of design floods for hydraulic constructions and for flood risk maps are potential applications of a runoff model for the Río Grande de Tárcoles.

7.1 Basin description

The basin of the Río Grande de Tárcoles, see Figure 15, is situated in midwestern Costa Rica between 9°44′ and 10°11′ north latitude and 83°54′ and 84°40′ west longitude. The area of the basin at the outflow into Golfo de Nicoya of the Pacific Ocean is 2168 km^2. The river drains a broad depression which includes the western part of Valle Central (Central Valley) of Costa Rica. This valley is a densely populated region and the cities of San José, Heredia and Alajuela are situated in the basin.

The average altitude of the basin is more than 1000 m with decreasing levels from east to west. The landscape is irregular and flat zones are alternating with mountains, hills and canyons. The highest mountains are situated at the northeastern basin divide in the mountain range of the Cordillera Central with the volcanoes of Poás and Irazú as the highest peaks.

The Río Grande de Tárcoles is formed by the confluence of two main river branches, the Río Virilla and the Río Grande. The biggest is the Río Virilla, which drains the densely populated areas in Valle Central. Most of the tributaries to the two main branches rise on the slopes of the Cordillera Central.

The discharge of both the Río Virilla and the Río Grande is to some extent used for hydropower production. Via tunnels, canals and reservoirs water from the Río Virilla is conveyed to the power plant Ventanas Garita and from the Río Grande to the plant La Garita. Both plants release the water into the Río Grande near the confluence with the Río Virilla. The regulation capacity is small and the reservoirs cannot be used for flood damping.

Due to population increase and industrial development the basin has lost most of its original vegetation. Especially in Valle Central there has been advanced deforestation and the forests are replaced by agricultural fields, grasslands and urban areas. Most of the forests that exist are located near the northeastern divide in the Cordillera Central and in the southwestern part of the basin. Above an altitude of 1500 m in the Cordillera Central the forest can be caracterized as a humid type and in the rest of the basin as dry forest. Large areas of coffee plantations are situated in the basin and it is the most productive coffee-zone of Costa Rica. Other important crops are sugar cane, corn and cereals. The basin also has a well developed dairy industry.

The deforestation, the intense agriculture and the urbanization have brought about serious erosion in the basin. Besides land use problems it has given heavy sediment loads in the rivers. The sediments are a major problem in relation to hydropower production.

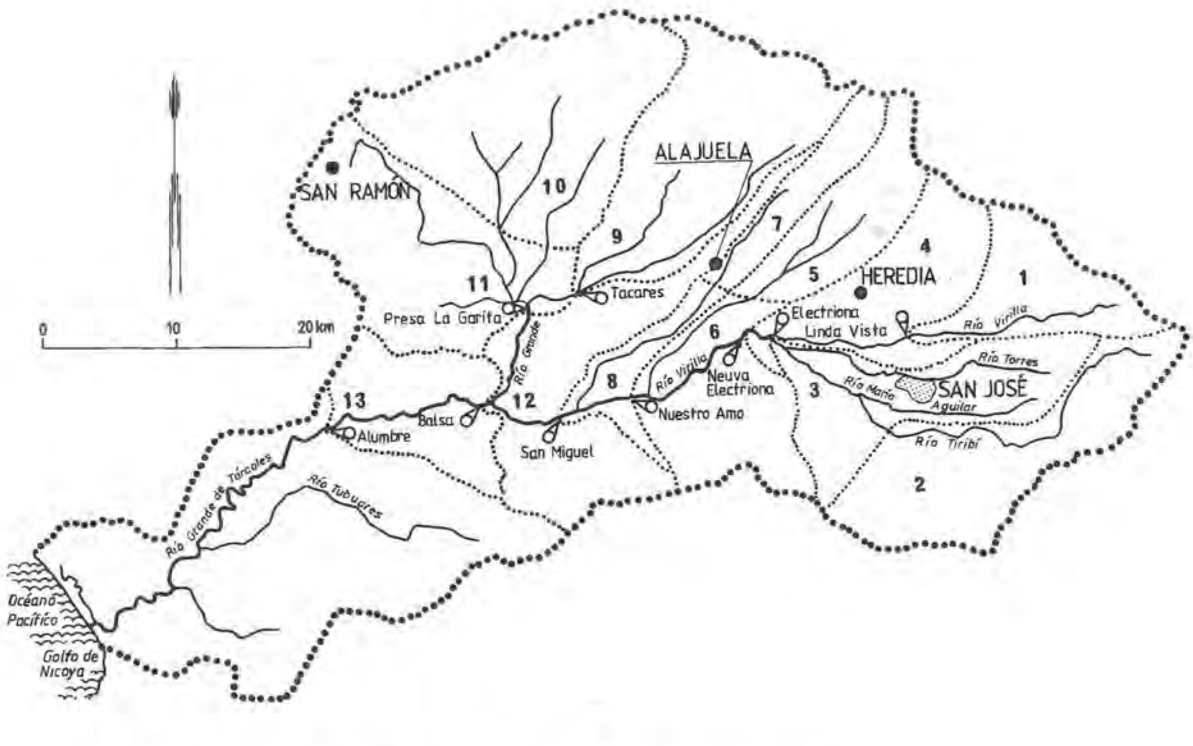


Figure 15. The basin of the Río Grande de Tárcoles.

The basin of the Río Grande de Tárcoles is influenced by the intertropical convergence and has a rainy season from May to October and a dry one from December to March. April and November are transition months, which are characterized by an alternation of wet and dry periods. In July or August the rainy season has a recession, called "veranillo" during which conditions of the dry season are experienced. The start of this recession varies from one year to another and it can last from some days to several weeks.

The Cordillera Central at the northern basin divide is an obstacle for northerly winds in the lower atmosphere. However, the depression of La Palma between the Irazú and Barva volcanoes allows the influence of the Caribbean rainy regime in December and January. This influence is associated with the displacement of cold fronts from higher latitudes. The cold fronts produce drizzle and moderate rain in the Valle Central, phenomena known as "temporales". The periods of continuos rain caused by the "temporales" can sometimes produce floods.

Annual precipitation of more than 3000 mm occurs along the northern basin divide and in an area in the southwestern part of the basin. Least precipitation with about 1800 mm annually has the central area of the basin. The mean annual precipitation in San José is around 1900 mm and 335 mm of that fall in September which is the rainiest month.

The temperature has low seasonal variation with less than 5 °C between the highest and lowest monthly mean values. The annual average of daily maximum temperature varies from 30 °C in the coastal zone to 26 °C in San José and about 15 °C in the mountain regions. Corresponding values for the daily minimum temperature are 20 °C, 15 °C and 5 °C.

The trade winds predominate throughout the year. In general the maximum wind speeds occur during the dry season and the "veranillo". The relative humidity is around 80 % during the whole year.

7.2 Flood history

In the region of San José, there are frequent flood problems. The upper Río Virilla and its tributaries Río Torres, Río María Aguilar and Río Tiribí often overflow. The main part of the floods occur during the rainy season and most frequently in October, but some floods occur in December - January associated with cold fronts from the north. The most recent severe flood was caused by the tropical hurricane Joan (Juana) in October 1988. There are also occasional flood problems in other parts of the basin and a region with relatively frequent floods is the lower reach of the Río Grande de Tárcoles. The floods cause inundations of both rural and urban areas and the main damages occur in residential districts and industrial zones.

7.3 Model set-up

The HBV model has been adapted for the upper 80 % of the basin of the Río Grande de Tárcoles. That means an area of 1745 km^2 upstream from Alumbre. For the model computation the basin of the river has been divided into 13 subbasins, se Figure 15. Nine of these subbasins have outlets at existing or former streamflow stations. The other subbasins were created in order to get fairly homogeneous regions as regards altitude, vegetation and precipitation.

Streamflow forecasts are mainly of interest at the outlets of the subbasins no 3, 6 and 13. At these points the streamflow stations Electriona, Nuestro Amo and Alumbre are located respectively. For Electriona the forecasts will give an indication of the flood risk in the San José urban area. At Nuestro Amo the forecasts are important for the management of the intake gates to the power plant Ventanas Garita. The reason is that garbage and other debris is carried by the river at rising water stage and can interrupt the production. Forecasts for Alumbre give information about flood risk in the lower reach of the Río Grande the Tárcoles.

The model has been calibrated on streamflow data for the stations Electriona, Nuestro Amo, San Miguel, Tacares, Presa la Garita, Balsa and Alumbre. Their respective total basin areas are 302, 734, 829, 202, 649, 1638 and 1745 km^2 with annual mean discharge of 12, 27, 36, 13, 35, 78 and 81 m^3/s.

The basin has a relatively dense precipitation network although not uniformely distributed, and few stations are located in the higher parts of the mountains. The weights for the stations were calculated by Thiessen polygons but with subjective modifications. Some effort was spent on adjusting the weights in order to increase the accuracy of the model simulation.

A network of seven telemetric precipitation stations is under installation in the upper part of the basin. These stations will facilitate the collection of precipitation data for real-time forecasting with the HBV model. They will also make it possible to forecast shorter intervals than one day.

Potential evapotranspiration for the basin has been calculated by the IMN of Costa Rica using the Penman formula. The monthly mean values used for the model computations are shown in Table 3. These values represent the central part of the basin.

Table 3. Monthly mean values of potential evapotranspiration (mm/day) according to the Penman formula.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.0	4.7	5.2	5.0	4.0	3.5	3.5	4.0	3.7	3.5	3.5	3.7

7.4 <u>Calibration results and forecasts</u>

The HBV model for the Río Grande de Tárcoles was first calibrated with daily computation time-steps. The calibration period was 1972-1986 and data from 36 precipitation stations and 7 streamflow stations were used. The model-run results for 1984 at Alumbre are shown as an example in Figure 16. The model parameters are listed in Appendix 5. The year 1984 was one of the rainiest, but also a year for which the model simulation succeeded relatively well.

The calibration results are as a whole acceptable, but there seems to be a possibility for improvement. The weights of the precipitation stations is one factor that could be further considered. It seems that precipitation near the basin divide in the Cordillera Central is not always well represented. Another factor is the great variability of the response time. Some parts of the basin, for instance subbasin 9, react very slowly on precipitation, while other parts react quickly.

For the period immediately before a forecast, collection of precipitation data cannot be done for all the 36 stations, but only from those that can be reached by telephone. Therefore, forecast model versions using data from fewer precipitation stations are needed. Special care must be taken to include good and representative stations near the northern and eastern parts of the basin divide.

For the Río Virilla in the upper part of the basin, real-time input data are to be measured with the telemetric precipitation network that is under installation. This network covers the uppermost 6 subbasins down to the streamflow station Nuestro Amo. The forecast version of the model for this part of the basin has been calibrated on data from the seven precipitation stations that most closely correspond to the telemetric stations. The result has up to now not been quite as good as with all stations but the calibration can probably be improved. The results of the calibration will also give an indication whether the telemetric stations give a good representation of the areal rainfall or if any station should be relocated.

The model for the Río Virilla is also being adapted for 6-hours time-steps in order to get earlier predictions of the floods. Precipitation and streamflow data have been prepared on 6-hours intervals for the years 1983 and 1984 and some calibration has up to now been carried out. The model parameters that affect the time distribution of the flow are to be changed in this calibration, while the others are to be left the same as in the calibration on daily data.

The procedure of real-time forecasting has been tested with daily data. In November 1989 short and long range forecasts were made for Nuestro Amo. Precipitation data for the last days before the forecast were collected from 3 stations. Streamflow data could not be collected and therefore updating of the model was not considered. No meteorological forecast was available but 3 possible precipitation sequences were used as input data for a short range forecast of 5 days. Forecasting for the whole basin was later done with data from 11 precipitation stations.

Operational real-time forecasting for the Río Virilla will be possible thanks to the recently started telemetric transfer of precipitation data. This transfer also allows forecasting with the model version for 6-hours time-steps. A procedure for collection of streamflow data should be introduced in order to make updating of the model possible. Precipitation data for the immediate future should be taken from a quantitative precipitation forecast or at least be estimated by an experienced meteorologist.

The telemetric network only covers the basin of the Río Virilla. Further downstream in the Río Grande de Tárcoles operational forecasting require input data from additional precipitation stations. Data from these stations have to be collected by telephone or radio.

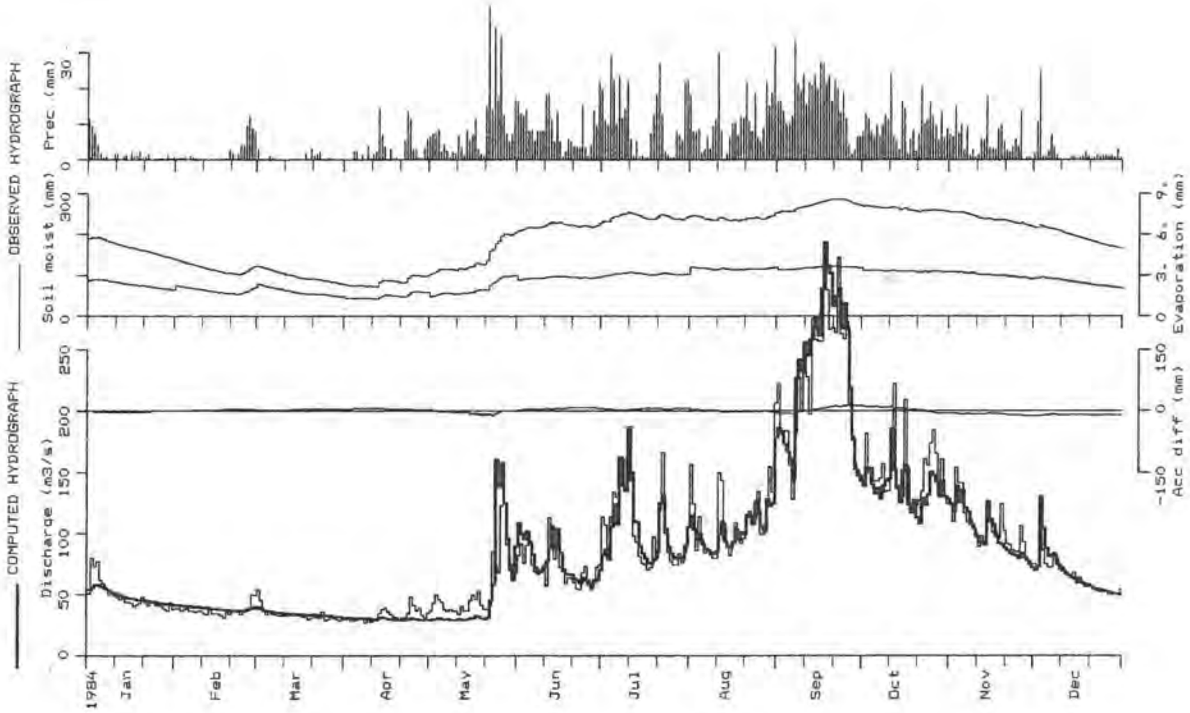


Figure 16. Model results in 1984 for Alumbre.

8. THE RIO BAYANO, PANAMA

The Río Bayano is one of the biggest and most important rivers in Panama. It has been regulated since 1976 for hydropower production and has a water reservoir with a considerable storage capacity. About 20 % of the electricity production in Panama is generated by the river. A forecast system for the river can be used for a better management of the regulation reservoir, which can both increase the hydropower production and decrease the risk for floods downstream from the reservoir. The forecast will also increase the possibilities to issue flood warnings when necessary.

8.1 Basin description

The basin of the Río Bayano, see Figure 17, is located in the eastern part of the Panamanian isthmus, between 8°48′ and 9°23′ north latitude and 78°04′ and 79°16′ west longitude. The headwaters of the river are in the hills that separate the provinces of Panama and Darién. The northern basin divide follows the Serranía de San Blas, that separates the basin from the narrow strip of wetland that borders the Caribbean Sea. To the south the basin is limited by the mountains in the Serranía de Majé. In the central part of the basin the reservoir Lago Bayano has been constucted.

The Río Bayano follows a general east to west direction, meandering for approximately 215 km. It pours its water into the Pacific Ocean and has a basin area of about 5000 km^2. The central part of the basin is relatively flat. The areas close to the river have deep alluvial deposits and the main part of the basin is formed by sedimentary rocks. The mean elevation is 267 m and the average slope is 0,4 %. The highest peak is Cerro Chucanti in the southwest with an elevation of 1300 m.

The basin is still to a large extent covered by forests, especially upstream from the Bayano dam where primeval forests cover about three fourths of the area. The primeval forests are most predominant north of the reservoir and near the southern basin divide. The rest of the land is covered by a mixture of bushes, secondary forests, cattle raising pastures and agricultural fields.

The basin population is about 23000 inhabitants of which approximately

10 % are indigenous to the area. The population cultivates mainly for subsistence using the traditional method of slash and burn. Downstream from the dam there are commercial plantations of corn, rice and plantains and also cattle is raised for commercial purposes.

The conditions for soil erosion are very different in the southern part of the basin compared to the northern part. That is caused both by geology and vegetation cover. The most susceptible regions for soil erosion are located in the southern and western parts, which have suffered most changes with respect to the natural conditions, and there a fast rate of erosion due to human activities can be observed.

There are great differences in the runoff between different parts of the basin. The northern tributaries have highest runoff since their headwaters are in the Serranía San Blas, which is one of the most rainy areas in Panama. Their runoff is almost 100 $l/s^{x}km^{2}$, while the southern tributaries have runoff values ranging from 50 to 85 $l/s^{x}km^{2}$. The lowland area between the mountain ranges has a runoff of 30-35 $l/s^{x}km^{2}$.

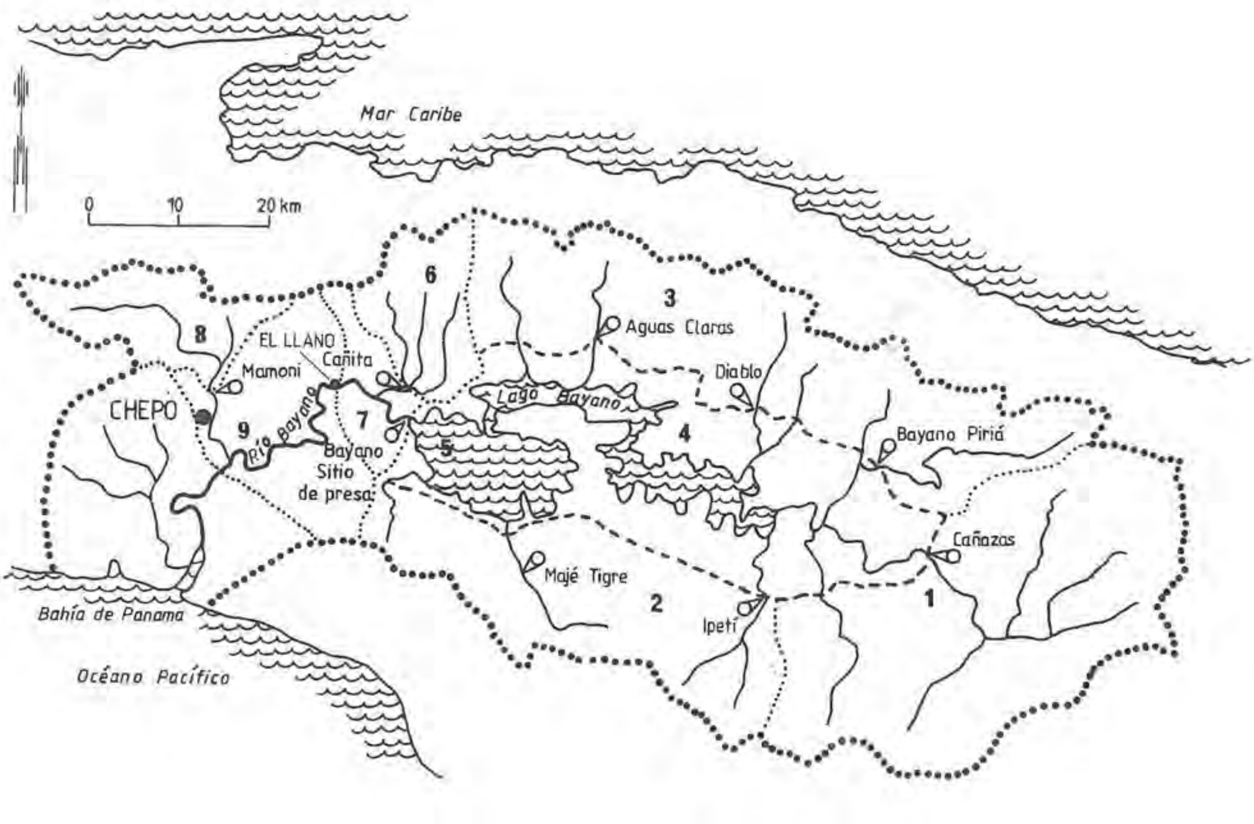


Figure 17. The basin of the Río Bayano.

The construction of the civil structures of the hydropower plant started in December 1971 and the closing of the gates was on the 16th of March 1976. The reservoir Lago Bayano has, at its maximum level 62,5 m, an area of about 360 km^2. The maximum regulation volume is 3100 millions of m^3 and the reservoir is used for the annual regulation of the discharge for electricity generation. About 4700 millions of m^3 water are turbinated annually and the mean discharge amounts to 150 m^3/s.

The Río Bayano basin is influenced by the intertropical convergence zone which is characterized by irregular winds of different intensity with frequent and strong precipitation. Towards late April, when the northern trade wind intensity diminishes, the intertropical convergence zone arrives to Panama, on its way up north, producing the rainy season which ends in late December. The maximum amount of precipitation falls in October and November. In January, when the northern trade winds dominate and move the rain strata toward the southern hemisphere, the dry season begins. In the mountain ranges of the basin it is not so severe and showers are frequent the whole year.

The average annual precipitation in the basin is around 2500 mm. The maximum precipitation takes place in the northern part of the basin and there are areas near the basin divide where the annual precipitation has been estimated to be more than 5000 mm. Minimum precipitation falls in the central part of the basin, where the annual amount is less than 2000 mm. The average annual temperature is approximately 25 °C and the seasonal temperature variation is insignificant. The mean relative humidity is around 85 %.

Using Thornwaite climate classification, 60 % of the basin has humid megathermal climate without humidity deficit, 30 % is perhumid megathermal and the remaining 10 % is perhumid mesothermic. According to the Holdridge system the Bayano basin has been classified as a wet tropical forest which overlaps with the dry tropical forest characteristics.

8.2 Flood history

The lower reach of the Río Bayano is surrounded by low-lying areas that are susceptible to floods. The town of El Llano located 56 km from the river mouth and a number of villages along the river are exposed. There are also fields with comercial plantations of corn, rice and plantains that are threatened by inundation. The flood problems are sometimes made worse by high sea level. In the river mouth the tide can be up to 6 m and influence the water level the whole way up to El Llano.

Before the construction of the reservoir Lago Bayano, the river flooded the low-lying areas frequently and at El Llano flood problems appeared on an average every second year. The last times that severe floods occured were in October 1975 and in November 1966 when the rising water of the Rio Bayano and its tributaries the Río Mamoni and the Río Majecito caused big damages.

Since the regulation was taken into use there has not been serious flood problems. However, the risk for flooding has not been eliminated. Flood problems will under the present conditions occur mainly when the reservoir is full and a heavy rain causes a great inflow that must be spilled at the same time as the discharge is high in the tributaries downstream from the reservoir. During the last years the risk has somewhat increased, caused by changes in operation of the reservoir in order to keep a high water level, which is more advantageous for the power production.

8.3 Model set-up

The HBV model for the Río Bayano has been set up as two applications - one for computing the net inflow to the reservoir and the other one for computing the discharge in the lower reach of the river. The purpose for the first application is to make forecasts in order to improve the management of the reservoir for the hydropower production. The second application is to be used for forecasting floods and has a routine that estimates the spill according to a probable operation of the gates.

The basin of the reservoir Lago Bayano has in the model been divided into five subbasins. The division has been made with the intention of creating as homogeneous areas as possible, especially for precipitation. Subbasin 1 is formed by the easternmost part of the basin, which is mainly lowland covered with tropical forest. Subbasin 2 consists of the mountain slopes south of the reservoir and is to some extent affected by human activities.

The forest covered mountain slopes north of the reservoir form subbasin 3 and the lowland area around the reservoir is subbasin 4. Finally subbasin 5 is formed by the reservoir.

The calibration of the model has been carried out on inflow data for Lago Bayano. These data have been calculated from discharge at the power plant including spill and the change of water level in the reservoir. The behaviour of the model for the three first subbasins has been checked against streamflow data from stations in these areas. For subbasin 1 it is the station Cañazas with a basin area that covers 69 % of the subbasin. The stations Ipetí and Majé Tigre together cover 46 % of subbasin 2 and Bayano Piría, Diablo Ante Embalse and Aguas Claras 41 % of subbasin 3.

The basin area downstream from Lago Bayano has been divided into four subbasins of which two correspond to the catchment areas of streamflow stations in the tributaries. They are subbasin 6 for the Río Cãnita and no 8 for the Río Mamoní. Subbasin 7 has its outlet at the flood susceptible town of El Llano and no 9 downstream of the Rio Mamoni. The model behaviour for the two subbasins with streamflow data has been calibrated. Since there are no streamflow data for the lower Río Bayano, the model parameter values for the two remaining subbasins had to be guessed.

The precipitation network in the Río Bayano basin is sparse and all stations are located at relatively low altitude. Some stations have data records of low quality and there are many periods with missing data. Initially 15 precipitation stations were selected but already before the calibration 4 were excluded mainly due to homogeneity problems.

For each subbasin a number of stations were chosen to represent the precipitation. The initial weighting had to be very subjective due to the spatial distribution of the precipitation stations. For the subbasins 3, 6 and 8 all the stations were located outside or at the border of the subbasin. During the calibration some effort was spent on adjusting the station weights by trial and error.

At seven streamflow stations around Lago Bayano there is equipment for telemetric real-time transmission of data via satellite. These stations also measure and transmit precipitation data. In most cases the telemetric stations are located relatively close to the ordinary precipitation stations and give approximately the same rainfall as these. Even if it is considered that most of the telemetric stations have worked relatively well, they have a lot of missing data and are therefore not suitable for calibration of the model. However, they provide input data in a forecast situation.

Potential evapotranspiration for the basin has been calculated from earlier evaporation measurements carried out in the basin of the Río Bayano. At a place that is now inundated by the reservoir the evaporation from a Class A pan was observed during the period 1963-1972. These values were compared to evaporation measurements from a lake pan in Lago Gatún in the Panama Canal Zone and monthly correction factors were calculated. Using these correction factors the records for the Class A pan were extended until 1988. The average values of the old and new period were calculated and used as potential evaporation input to the model.

8.4 Calibration results and forecasts

The HBV model for the Río Bayano has been calibrated on data records from the period 1977-1988. For the application for Lago Bayano data from 8 precipitation stations were used and altogether 11 stations for the whole basin. An example of the model-run results for Lago Bayano is shown in Figure 18. The model parameters are listed in Appendix 6. The year of 1988 has been chosen for the example, since it is the most recent year with complete data. It is also the only year after 1981 with spill from the reservoir. This spill was caused by the hurricane Joan (Juana), which passed north of Panama but nevertheless gave rain in the basin of the Río Bayano.

The recorded hydrograph in Figure 18 is calculated from water level and discharge data. A small error in the recorded water level results in big errors in the calculated inflow, which cause apparent inflow changes, that in fact should be distributed over many days. Thus, the model shall not simulate these fluctuations but give an average curve through them.

The model simulation for Lago Bayano is acceptable when one takes into consideration the distribution of precipitation stations. All the stations are located around the reservoir and no station is situated in the areas with high precipitation. For 1988 the model underestimates the inflow during the end of the dry season and the reason is probably rain in areas without precipitation stations.

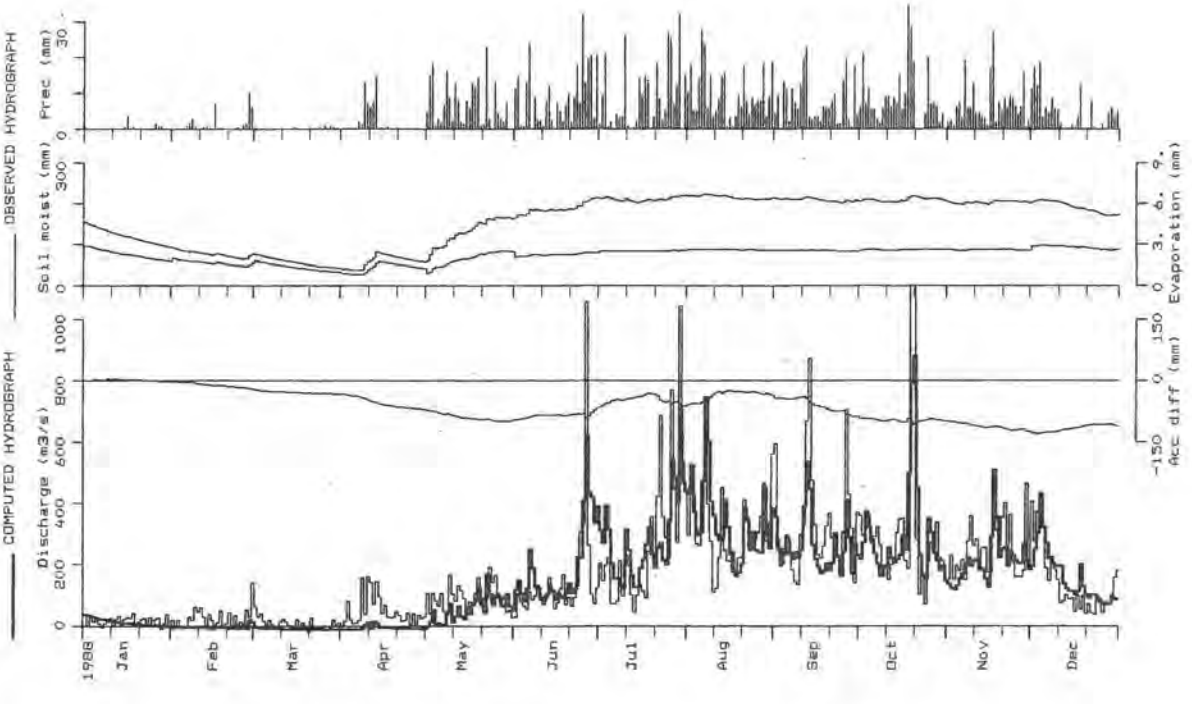


Figure 18. Model results in 1988 for the inflow to Lago Bayano.

The data transmission from the telemetric network is not always working for all stations. In order to find out how much missing data deteriorate the model performance, recalibration has been carried out with a decreasing number of precipitation stations. This was done by removing the stations one by one, always keeping the most reliable ones in the model. Figure 19 shows that with 5 stations the model performance is almost as good as with all stations. The result indicates that the present network in the lowland areas around the reservoir is sufficient. Additional stations should be located in more remote areas closer to the basin divide.

The procedure of real-time forecasting was tested in November 1989 and both short range and long range forecasts were made. The telemetric network provided precipitation data for the last two months before the forecasts.

A short range forecast for seven days is shown as an example in Figure 20. The model was updated before the forecast. Since no meteorological forecast was available, three possible precipitation sequences were used. These sequences were 0, 10 and 20 mm each day. The first sequence gave decreasing inflow to the reservoir, the second almost unchanged inflow and the last one increasing inflow.

A long range forecast was made to April 15, that is to the end of the dry season. Precipitation data from the corresponding dates during the period 1977 to 1988 were used as input. The result of the 12 different simulations with tabulated values of the highest peak for each simulation is shown in Figure 21. The forecasted accumulated volume is given in Figure 22.

Operational real-time forecasting of the inflow to the Lago Bayano can be started at any time. A quantitative forecast of the areal precipitation should be provided as input for taking full advantage of the short range forecast. If no regular meteorological forecast is available, a qualified estimate by an experienced meteorologist could be used.

Forecasts of the flow in the river reach downstream from the reservoir require real-time data from at least one precipitation station in that part of the basin. The collection of these data could be done by telephone. Operational forecasting in this area is useful only during periods with flood threats.

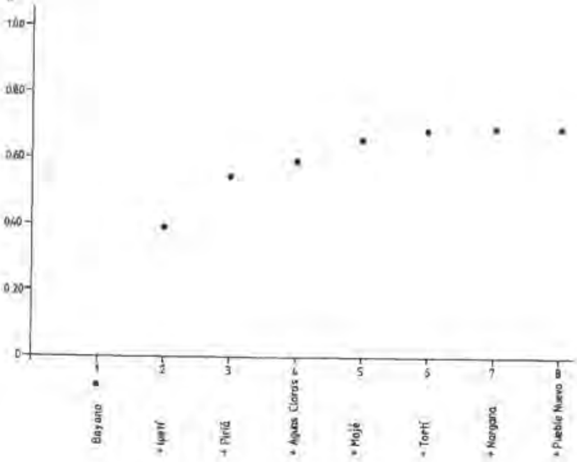
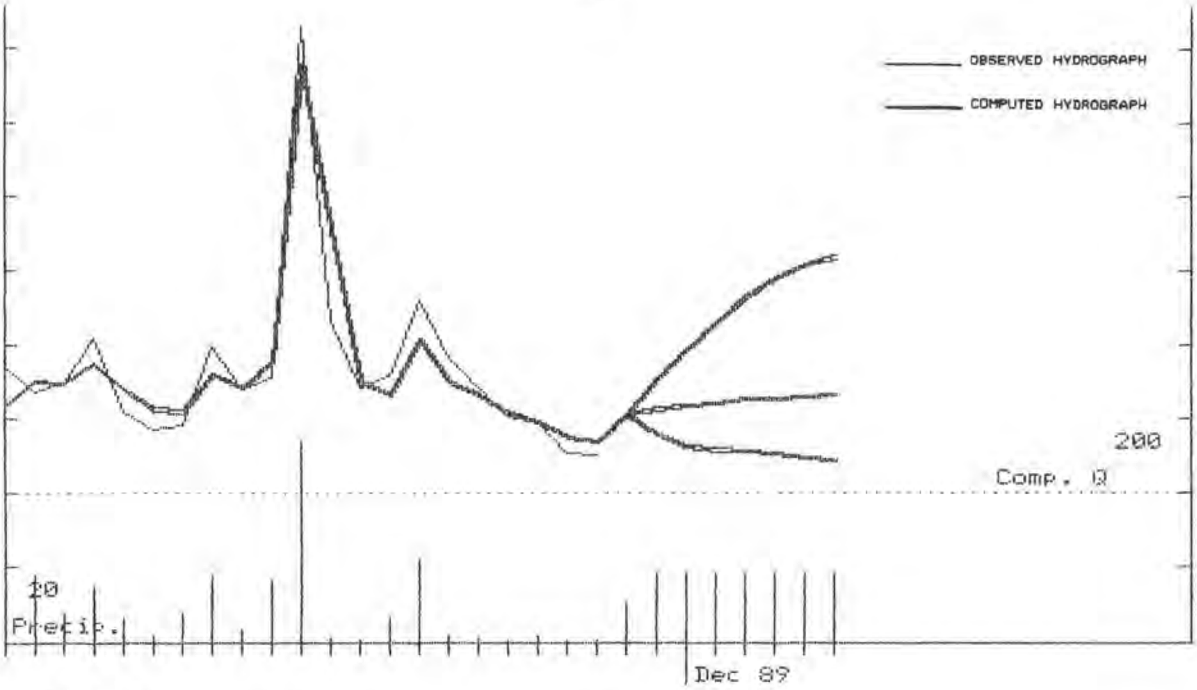


Figure 19. Model performance for the inflow to Lago de Bayano versus number of precipitation stations.



FORECAST 1

DATE	Precip.	Soilmois	Upp.zone	Low.zone	Comp. Q	Rec. Q	Acc.dif	Evap.	Pcorr
891130	0.0	202.4	0.8	50.1	156.9			2.6	
891201	0.0	199.5	0.0	47.8	127.5			2.9	
891202	0.0	196.6	0.0	44.9	114.2			2.9	
891203	0.0	193.8	0.0	42.3	106.9			2.9	
891204	0.0	190.9	0.0	39.7	100.1			2.8	
891205	0.0	188.1	0.0	37.3	93.6			2.8	
891206	0.0	185.4	0.0	35.1	87.6			2.8	

BASIN: BAYANO MONTH: Nov 1989

FORECAST 2

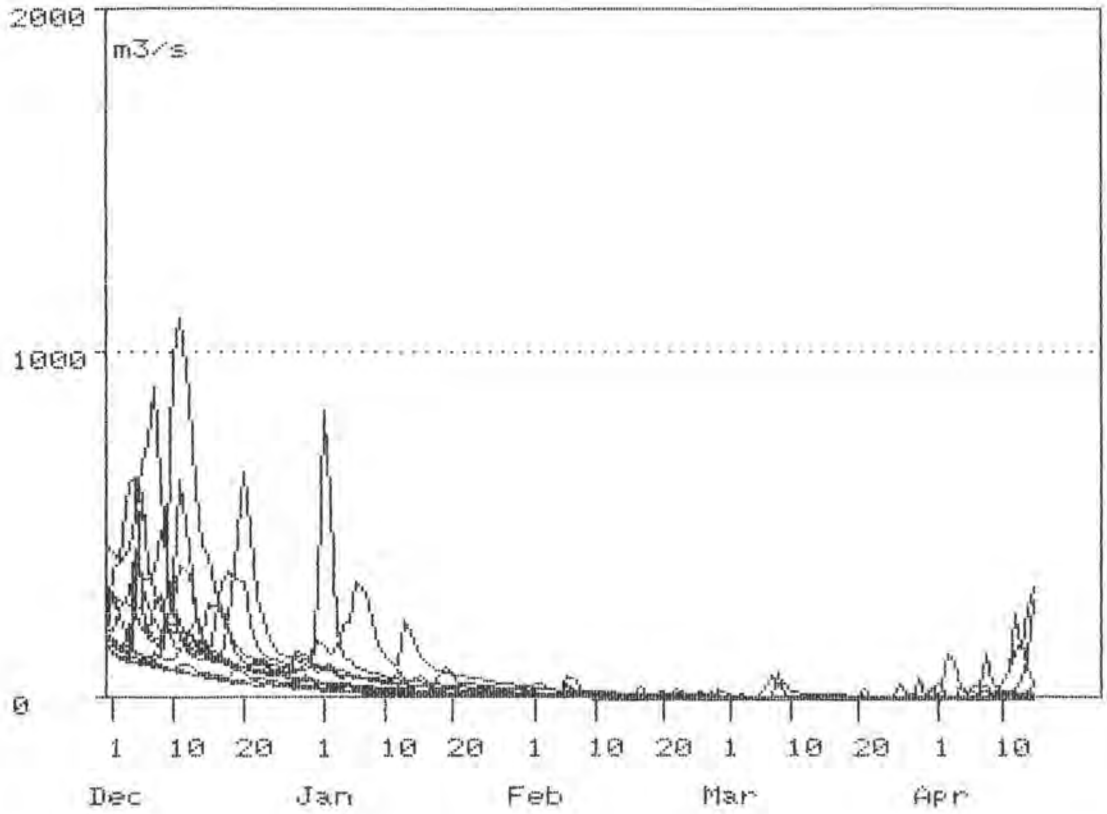
DATE	Precip.	Soilmois	Upp.zone	Low.zone	Comp. Q	Rec. Q	Acc.dif	Evap.	Pcorr
891130	10.0	205.8	4.0	52.0	223.9			2.6	
891201	10.0	206.1	4.5	52.6	233.7			2.9	
891202	10.0	206.4	4.9	53.1	242.0			2.9	
891203	10.0	206.7	5.2	53.7	248.6			2.9	
891204	10.0	206.9	5.4	54.2	253.9			2.9	
891205	10.0	207.2	5.6	54.6	258.4			2.9	
891206	10.0	207.4	5.7	55.1	262.1			2.9	

BASIN: BAYANO MONTH: Nov 1989

FORECAST 3

DATE	Precip.	Soilmois	Upp.zone	Low.zone	Comp. Q	Rec. Q	Acc.dif	Evap.	Pcorr
891130	20.0	208.8	8.8	52.0	303.8			2.7	
891201	20.0	211.7	13.1	52.6	382.6			3.0	
891202	20.0	214.1	15.8	53.1	455.1			3.0	
891203	20.0	216.0	17.4	53.7	528.1			3.0	
891204	20.0	217.6	18.2	54.2	576.0			3.0	
891205	20.0	219.0	18.4	54.6	611.1			3.0	
891206	20.0	220.1	18.5	55.1	634.9			3.0	

Figure 20. An updated model simulation of the inflow to Lago Bayano followed by a 7-day forecast commencing 1989-11-30. Three alternatives of input data were used for the forecast.



Forecast 1989 11 30 using data from the 12 previous years

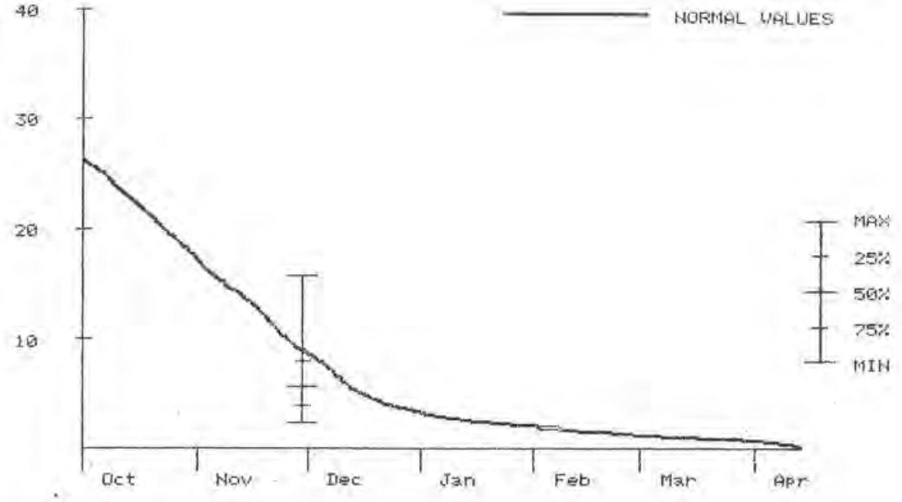
CRONOLOGICAL ORDER

Seq nr	Year	Peak m3/s	Month /Day
1	1977	629	12 11
2	1978	381	12 11
3	1980	832	1 1
4	1981	317	4 16
5	1981	1103	12 11
6	1982	159	11 30
7	1983	595	12 5
8	1984	191	11 30
9	1985	907	12 7
10	1986	157	11 30
11	1987	296	12 8
12	1988	433	12 4

ORDER OF MAGNITUDE

Year	Peak m3/s	Month /Day
1981	1103	12 11
1985	907	12 7
1980	832	1 1
1977	629	12 11
1983	595	12 5
1988	433	12 4
1978	381	12 11
1981	317	4 16
1987	296	12 8
1984	191	11 30
1982	159	11 30
1986	157	11 30

Figure 21. A long range forecast of the inflow to Lago Bayano for the period 1989-11-30--1990-04-15 based on input data from the corresponding dates during the preceding 12 years. The upper figure shows the different simulations and below the peak values are tabulated.



Forecast 1989 11 30 using data from the 12 previous years

VOLUME UNIT: accumulated daily mean discharge in m3/s

DATE	MIN	75%	50%	25%	MAX	DIFF(50%)
12 7	892	1086	1468	2283	4248	196
12 17	1570	2502	3595	4784	8014	105
12 27	1952	3286	4368	6493	10817	57
1 6	2153	3992	4780	7468	12505	32
1 16	2236	4157	5053	7854	14150	29
1 26	2265	4217	5246	7977	14797	12
2 5	2281	4219	5320	8016	15100	4
2 15	2282	4188	5334	8051	15215	1
2 25	2241	4145	5338	8031	15351	-1
3 6	2179	4134	5322	8010	15383	0
3 16	2090	4065	5460	7973	15354	2
3 26	1991	3986	5473	7907	15288	1
4 5	1937	3905	5491	7958	15204	-2
4 15	**2181**	**3894**	**5641**	**7932**	**15752**	**NORMAL VOLUME: 8793**

ACCUMULATED VOLUME LAST DAY

CRONOLOGICAL ORDER Year	Volume	ORDER OF MAGNITUDE Year	Volume
1978	5419	1982	15752
1979	5035	1980	10194
1980	10194	1984	8434
1981	6512	1986	7765
1982	15752	1981	6512
1983	2181	1989	5863
1984	8434	1978	5419
1985	2272	1979	5035
1986	7765	1988	4435
1987	2230	1985	2272
1988	4435	1987	2230
1989	5863	1983	2181

Figure 22. A long range forecast of the inflowing volume to Lago Bayano for the period 1989-11-30--1990-04-15.

9. DISCUSSION AND CONCLUSIONS

The project on "Streamflow Forecasting and Flood Warning in Central America" has aimed at establishing a flood warning system on the national level as well as to promote regional cooperation. One river in each of the countries of Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama has been selected for the project. The flood warning system based on the HBV runoff model has been calibrated and adapted to each of the rivers. Twelve Central American engineers have been trained in the use of the HBV model system.

The six river basins that were selected for the project differ very much in size, topography, vegetation and land use. The calibration results also vary and generally the small river basins, and basins with uneven precipitation were more difficult to model. In general the results were satisfactory, but in some of the countries the calibration of the model was complicated due to poor data quality. The calibration results for each country are discussed in more detail in the chapters on the individual countries.

The HBV model has been applied in many countries all over the world and in climates ranging from artic to tropical. It has proved to give good results in spite of a relatively simple structure (WMO, 1986). In Latin America, the model has earlier been calibrated and installed in Costa Rica (Johansson, Persson, Sandberg and Robles, 1985), Bolivia (Johansson, Persson, Aranibar and Llobet, 1987) and Colombia (Häggström, Lindström, Sandoval and Vega, 1988). In the application to the six Central American basins, we feel that the calibration results have been more dependent on the quality of the input data than on the model structure.

Most of the rivers in this project flow through steep areas, and the response time is short. A proper description of flood damping due to inundation is in most cases not critial. To be able to utilize the forecast it is sufficient with knowledge about the flood problems that are caused by different discharge magnitudes. Flood-risk maps are useful complements for the estimation of flooded areas for a given calculated discharge.

The conditions and possibilities for real-time forecasting vary much between the participating countries. A network for real-time transmission of precipitation data, really only exists in Panama at the time being. In Costa Rica, a similar system is being installed. Generally, more effort needs to be spent on rapid collection of both precipitation and streamflow data to make real-time flood forecasting possible and meaningful. The streamflow data are needed in order to check that the model state at the beginning of the forecast corresponds to the real conditions. To minimize the costs, a few stations in each of the river basins can be selected and equipped with telephone or radio communication. Both in Panama and Costa Rica, the model was recalibrated with fewer precipitation stations representing the real-time networks. The results were quite acceptable also with these reduced networks.

The possibility to use the HBV model for forecasting also depends on the response time of the basin. Some of the modelled basins are relatively small and the response to rainfall can occur very quickly, making forecasting rather difficult. In some of the basins a daily time-step is not sufficiently short and the model should be run with for example six hours time-steps. This has been tested in both Guatemala and Costa Rica. The problems with short time-steps is the data transfer in real time, the increasing data amount and the limited number of stations with such a time resolution.

Quantitative precipitation forecasts are in general rather unreliable. At the Central American institutions involved in this project, such forecasts are not produced or used on a routine basis. However, even without reliable forecasts of precipitation, the HBV model can be useful for flood warnings, since it keeps track of the present wetness status in the basin and thus give an indication of the flood risk. When no quantitative precipitation forecast can be obtained, a probabilistic precipitation forecast or even a qualified judgement by a meteorologist can be used.

Besides for flood forecasts, the HBV model can be used for many other purposes. In some of the countries, a major interest in the selected basin is to make long range volume forecasts. Such forecast can be used for optimization of the reservoir regulation or assessments of the resources available for irrigation during dry periods. The model can further be used for a check of discharge data, and filling in gaps in the records, as well as for extension of short runoff records for design purposes. The model also has a potential for simulation of groundwater levels (Bergström and Sandberg, 1983), soil moisture conditions (Andersson, 1988) or the effects of clear-cutting (Brandt, Bergström and Gardelin, 1988).

The HBV model can be used for spillway design (Bergström, Lindström and Sanner, 1989). An estimate of the PMP (Probable Maximum Precipitation) can be used as input and the model converts the design precipitation to a design inflow hydrograph. The inflow is then routed through the reservoir and further downstream, and the model can be used for design calculations in a whole system of reservoirs. The method is useful for the design of spillways of new dams and for the evaluation of the risk of overtopping of existing dam structures. If the model is to be used for design calculations, effort must be spent on checking its performance for high peaks.

Thanks to the simplicity of the HBV model, it is quite easy to understand and learn. The data requirements are also moderate. A two month training course gives the necessary background for an operational use of the forecasting system. However, the course could preferably be repeated with new participants to increase the total knowledge in each country and thus guarantee that a sufficient number of people are trained for a continued use of the model and its application to other river basins. The limited resources needed for using the HBV model means that it has a potential for becoming a valuable hydrological tool in Central America.

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BASIN: RIO SAMALA

PARAMETERFILE VALID DATE: 02-14-1990
TIME: 09:32:43

Nr	Name	Valid from											
1	AREA	1979 1 1	204.30	246.00	25.00	225.70	102.08	58.00						
2	ELEV	1979 5 1	2700.00	2600.00	2500.00	2600.00	2000.00	1200.00						
3	VEG	1979 5 1	1.00	1.00	1.00	1.00	1.00	1.00						
4	LAKE	1979 5 1	0.00	0.00	0.00	0.00	0.00	0.00						
5	PELEV	1979 5 1	500.00	2490.00	2700.00	2960.00	345.00	760.00	500.00	2599.00	2800.00	500.00	2300.00	2440.00
			2760.00	1550.00	2316.00	2500.00	2560.00	2440.00	2680.00	2400.00	2380.00	2320.00		
7	QFACT	1979 5 1	0.10	0.10	0.10	0.10								
8	CP	1979 5 1	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.25	0.25	0.25	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.20	0.00	0.30	0.30	0.20	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.35	0.15	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.20	0.00	0.00	0.30	0.40	0.00	0.00	0.10	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.60	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	CQ	1979 5 1	0.00	1.00	0.00	0.00								
11	EVAP	1979 5 1	4.10	4.20	5.00	4.70	3.80	3.10	3.90	3.90	3.10	3.40	3.80	4.10
13	PREPL	1979 5 1	0.00	0.00	16.00	0.00	14.00	5.00	0.00	0.00	0.00	0.00	21.00	0.00
			3.00	15.00	11.00	21.00	18.00	21.00	0.00	22.00	22.00	21.00		
14	PREPC	1979 5 1	0.00	0.00	1.09	0.00	1.03	1.43	0.00	0.00	0.00	0.00	1.15	0.00
			0.97	3.13	1.04	1.15	1.05	1.20	0.00	1.35	1.16	0.86		
16	SUBQR	1979 5 1	0.00000	3.00000	3.00000	1.00000	0.00000	2.00000						
19	FELEV	1979 5 1	0.00000											
20	PCORR	1979 5 1	0.75000	0.80000	0.75000	0.75000	0.75000	0.75000						
21	PCALT	1979 5 1	0.00000											
27	FC	1979 5 1	250.00000	250.00000	20.00000	250.00000	100.00000	100.00000						
28	LP	1979 5 1	200.00000	200.00000	20.00000	200.00000	80.00000	80.00000						
29	BETA	1979 5 1	1.50000	1.50000	1.00000	1.50000	1.00000	1.00000						
36	PERC	1979 5 1	1.00000	1.00000	0.00000	1.00000	4.00000	6.00000						
37	UZL	1979 5 1	30.00000	30.00000	0.00000	30.00000	50.00000	50.00000						
38	K0	1979 5 1	0.40000	0.40000	1.00000	0.40000	0.40000	0.40000						
39	K1	1979 5 1	0.03000	0.03000	0.00000	0.03000	0.02000	0.02000						
40	K2	1979 5 1	0.00200	0.00200	0.00000	0.00200	0.00400	0.00400						
43	CEVP	1979 5 1	0.70000	0.80000	0.90000	0.80000	0.90000	1.00000						
44	LAREA	1979 5 1	0.00000											
46	MAXBAS	1979 5 1	5.00000	5.00000	1.00000	5.00000	1.00000	1.00000						
47	BLAG	1979 5 1	1.50000	0.00000	1.00000	0.30000	0.20000	0.00000						
48	WQREL	1979 5 1	0.00000											
49	PATH	1979 5 1	4.00000	3.00000	4.00000	5.00000	6.00000	0.00000						

Figure A 1.1. Parameter list of the HBV model for the Río Samalá (see also Figure A 1.2.).

Basin: RIO SAMALA
Number of stations for precipitation: 22
Precip. weights Valid Date: 02-14-1990
Time: 09:32:00

Total weights corrected by multiplication with PCORR

Subcatcment nr:

Nr	Name	1	2	3	4	5	6	Total (%)
1	EL TAMBOR	0	0	0	0	0	0	0
2	JUCHANEP	0	0	0	0	0	0	0
3	PACHUTE	0.40	0	0	0	0	0	9.31
4	RANCHO DE TEJA	0	0	0	0	0	0	0
5	BRILLANTES	0	0	0	0	0	0	0
6	SANTA MARTA	0	0	0	0	0	0.20	1.32
7	LAS FUENTES	0	0	0	0	0	0	0
8	SN. FCO. EL ALTO	0	0	0	0	0	0	0
9	LAS LAGUNAS	0	0	0	0	0	0	0
10	SAN LUIS	0	0	0	0	0	0	0
11	CANTEL PREC.	0	0	0	0.20	0.20	0	7.47
12	SIGÜILA	0	0	0	0	0	0	0
13	RECUERDO BARRIOS	0.45	0	0	0	0	0	10.48
14	STA. MARIA JESUS	0	0	0	0	0.30	0.60	7.46
15	ZUNIL	0	0	0	0	0.40	0.20	5.98
16	CAJOLA	0	0.25	0	0	0	0	7.48
17	CHIQUIRICHAPARA	0	0.25	0	0	0	0	7.48
18	LLANOS DEL PINAL	0	0.25	0.20	0	0.10	0	9.21
19	SAN ANTONIO SIJA	0	0	0	0	0	0	0
20	TOTONICAPAN	0	0	0.30	0.35	0	0	9.86
21	LABOR OVALLE	0	0.25	0.30	0.15	0	0	12.19
22	CUATRO CAMINOS	0.15	0	0.20	0.30	0	0	11.78

Figure A 1.2. Weight coefficients of the precipitation stations (CP-parameters) for the Río Samalá.

BASIN: RIO GRANDE DE SAN MIGUEL

PARAMETERFILE VALID DATE: 01-25-1990
TIME: 10:47:11

Nr	Name	Valid from												
1	AREA	1970 1 1	910.00	164.00	527.00	298.00	338.00							
2	ELEV	1970 1 1	426.00	320.00	257.00	324.00	420.00							
3	VEG	1970 1 1	1.00	1.00	0.95	0.99	1.00							
4	LAKE	1970 1 !	0.00	0.00	0.05	0.01	0.00							
5	PELEV	1970 1 1	350.00	80.00	860.00	80.00	140.00	105.00						
7	QFACT	1970 1 1	0.10	0.10	0.10	0.10								
8	CP	1970 1 1	0.40	0.00	0.30	0.00	0.30	0.00	0.00	0.00	0.00	0.20	0.40	0.40
			0.00	0.40	0.00	0.40	0.00	0.20	0.00	0.70	0.00	0.30	0.00	0.00
			0.00	0.50	0.00	0.30	0.20	0.00						
10	CQ	1970 1 1	0.00	0.00	1.00	0.00								
11	EVAP	1970 1 1	7.19	8.33	8.16	7.35	5.25	4.50	5.11	4.82	3.88	4.31	4.97	6.26
13	PREPL	1970 1 1	2.00	1.00	1.00	6.00	6.00	5.00						
14	PREPC	1970 1 1	1.40	0.70	1.00	1.00	1.10	0.90						
16	SUBQR	1970 1 1	4.00000	1.00000	0.00000	2.00000	3.00000							
19	FELEV	1970 1 1	0.00000											
20	PCORR	1970 1 1	0.65000	0.75000	0.75000	0.85000	0.90000							
21	PCALT	1970 1 1	0.00000											
27	FC	1970 1 1	225.00000	225.00000	275.00000	250.00000	275.00000							
28	LP	1970 1 1	175.00000	175.00000	195.00000	175.00000	195.00000							
29	BETA	1970 1 1	1.00000	1.00000	2.50000	1.80000	1.80000							
36	PERC	1970 1 1	0.55000	0.55000	4.00000	1.50000	2.00000							
37	UZL	1970 1 1	8.00000	8.00000	20.00000	20.00000	20.00000							
38	K0	1970 1 1	0.60000	0.60000	0.60000	0.60000	0.40000							
39	K1	1970 1 1	0.08000	0.08000	0.07000	0.07000	0.07000							
40	K2	1970 1 1	0.00600	0.00600	0.00500	0.00500	0.00400							
43	CEVP	1970 1 1	0.95000											
44	LAREA	1970 1 1	0.00000	0.00000	-102.00000	0.00000	0.00000							
46	MAXBAS	1970 1 1	1.00000	1.00000	2.00000	2.00000	2.00000							
48	WQREL	1970 1 1	0.00000	0.00000	1.00000	0.00000	0.00000							
49	PATH	1970 1 1	2.00000	3.00000	4.00000	5.00000	0.00000							
8	CP	1974 1 1	0.40	0.00	0.21	0.00	0.30	0.00	0.00	0.00	0.00	0.17	0.40	0.40
			0.00	0.40	0.00	0.35	0.00	0.20	0.00	0.70	0.00	0.26	0.00	0.00
			0.00	0.50	0.00	0.26	0.20	0.00						

Figure A 2.1. Parameter list of the HBV model for the Río Grande de San Miguel (see also Figure A 2.2).

Basin: RIO GRANDE DE SAN MIGUEL
Number of stations for precipitation: 6
Precip. weights Valid Date: 01-25-1990
Time: 10:48:23

Total weights corrected by multiplication with PCORR

Subcatcment nr:

Nr	Name	1	2	3	4	5	Total (%)
1	SAN FRANCISCO GOTERA	0.40	0	0	0	0	14.19
2	OLOMEGA	0	0	0.40	0.70	0.50	29.24
3	CIUDAD BARRIOS	0.30	0	0	0	0	10.64
4	EL PAPALON	0	0.20	0.40	0.30	0.30	20.99
5	BFCIO EL SITIO	0.30	0.40	0	0	0.20	17.24
6	SAN MIGUEL FENADESAL	0	0.40	0.20	0	0	7.69

Figure A 2.2. Weight coefficients of the precipitation stations (CP-parameters) for the Río Grande de San Miguel.

BASIN: RIO CHOLUTECA

PARAMETERFILE VALID DATE: 01-25-1990
TIME: 10:44:10

Nr	Name	Valid from												
1	AREA	1979 1 1	1565.00	178.00	1228.00	1540.00	1859.00	594.00						
2	ELEV	1979 1 1	1170.00	1130.00	1000.00	850.00	750.00	450.00						
3	VEG	1979 1 1	1.00	1.00	1.00	1.00	1.00	1.00						
4	LAKE	1979 1 1	0.00	0.00	0.00	0.00	0.00	0.00						
5	PELEV	1979 1 1	1010.00	1580.00	1070.00	1360.00	960.00	890.00	1500.00	1320.00	1177.00	665.00	1250.00	790.00
			960.00	950.00	750.00	970.00	1315.00	600.00	1250.00	480.00	700.00	340.00	230.00	100.00
			50.00	50.00										
7	QFACT	1979 1 1	0.10	0.10	0.10									
8	CP	1979 1 1	0.00	0.10	0.00	0.30	0.35	0.15	0.00	0.10	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.50	0.20
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.10	0.20	0.20	0.30	0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.40	0.00	0.10	0.00
			0.05	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30
			0.00	0.00	0.05	0.00	0.00	0.10	0.25	0.10	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.30	0.10	0.05
10	CQ	1979 1 1	0.00	0.00	1.00									
11	EVAP	1979 1 1	4.80	5.90	7.10	7.00	5.90	4.50	4.70	4.80	4.30	3.90	3.80	4.00
13	PREPL	1979 1 1	0.00	7.00	0.00	0.00	0.00	0.00	18.00	16.00	25.00	6.00	5.00	16.00
			5.00	17.00	20.00	15.00	14.00	16.00	0.00	19.00	20.00	0.00	22.00	23.00
			14.00	25.00										
14	PREPC	1979 1 1	0.00	1.01	0.00	0.00	0.00	0.00	0.98	0.94	0.82	0.84	0.40	1.00
			1.65	1.04	0.96	1.17	0.96	1.13	0.00	1.18	1.15	0.00	1.07	0.93
			1.41	1.05										
16	SUBQR	1979 1 1	1.00000	2.00000	0.00000	0.00000	0.00000	3.00000						
20	PCORR	1979 1 1	0.85000	1.05000	1.00000	0.95000	0.65000	0.95000						
27	FC	1979 1 1	250.00000	300.00000	300.00000	300.00000	300.00000	300.00000						
28	LP	1979 1 1	160.00000	200.00000	180.00000	180.00000	200.00000	200.00000						
29	BETA	1979 1 1	2.00000	1.50000	1.50000	2.00000	2.00000	1.50000						
36	PERC	1979 1 1	0.40000	0.40000	0.35000	0.30000	0.25000	0.25000						
37	UZL	1979 1 1	10.00000	10.00000	5.00000	5.00000	5.00000	5.00000						
38	K0	1979 1 1	0.70000	0.80000	0.90000	0.90000	0.90000	0.90000						
39	K1	1979 1 1	0.30000	0.30000	0.20000	0.20000	0.15000	0.15000						
40	K2	1979 1 1	0.00900	0.00900	0.01200	0.01500	0.02000	0.02000						
41	DAMP	1979 1 1	0.30000											
43	CEVP	1979 1 1	0.75000	0.70000	0.80000	0.80000	0.90000	1.00000						
46	MAXBAS	1979 1 1	2.00000	1.00000	2.00000	2.00000	2.00000	1.00000						
47	BLAG	1979 1 1	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000						
49	PATH	1979 1 1	2.00000	3.00000	4.00000	5.00000	6.00000	0.00000						
50	QRED	1979 1 1	0.00000	1.00000	1.00000	0.00000	0.00000	0.00000						
7	QFACT	1986 1 1	1.00	1.00	1.00									
13	PREPL	1986 1 1	0.00	5.00	0.00	6.00	25.00	5.00	0.00	2.00	5.00	6.00	5.00	5.00
			0.00	17.00	12.00	12.00	16.00	0.00	22.00	22.00	0.00	23.00	25.00	23.00
			5.00	25.00										
14	PREPC	1986 1 1	0.00	1.43	0.00	0.97	0.51	1.14	0.00	0.80	1.62	0.89	0.42	1.22
			0.00	1.04	0.87	1.01	1.20	0.00	1.37	0.84	0.00	0.96	0.69	0.95
			1.97	1.15										

Figure A 3.1. Parameter list of the HBV model for the Río Choluteca (see also Figure A 3.2.).

Basin: RIO CHOLUTECA
Number of stations for precipitation: 26
Precip. weights Valid Date: 01-25-1990
Time: 10:45:24

Total weights corrected by multiplication with PCORR

Subcatcment nr:

Nr	Name	1	2	3	4	5	6	Total (%)
1	BATALLON	0	0	0	0	0	0	0
2	LA BREA	0.10	0	0	0	0	0	2.22
3	REVENTON	0	0	0	0	0	0	0
4	ZAMBRANO	0.30	0	0	0	0	0	6.67
5	TONCONTIN	0.35	0	0	0	0	0	7.78
6	LA VENTA	0.15	0.30	0	0	0	0	4.27
7	LEPATERIQUE	0	0	0	0	0	0	0
8	EL SAUCE	0.10	0	0	0	0.20	0	6.26
9	NUEVO ROSARIO	0	0.50	0.10	0	0	0	3.62
10	EL PORVENIR	0	0.20	0.20	0	0	0	4.73
11	LAS CANAS	0	0	0.20	0	0	0	4.11
12	ZAMORANO	0	0	0.30	0	0	0	6.16
13	SABANAGRANDE	0	0	0	0	0	0	0
14	YUSCARAN	0	0	0	0.05	0	0	1.22
15	POTRERILLOS	0	0	0	0.40	0	0	9.78
16	MARAITA	0	0	0.10	0	0.30	0	8.11
17	GUINOPE	0	0	0.10	0.10	0	0	4.50
18	NUEVA ARMENIA	0	0	0	0	0	0	0
19	SAN LUCAS	0	0	0	0.05	0.05	0	2.23
20	OROPOLI	0	0	0	0.40	0	0	9.78
21	DANLI	0	0	0	0	0	0	0
22	TEXIGUAT	0	0	0	0	0.10	0	2.02
23	LIURE	0	0	0	0	0.25	0.55	10.24
24	LOS ENCUENTROS	0	0	0	0	0.10	0.30	4.85
25	CHOLUTECA	0	0	0	0	0	0.10	0.94
26	YUSGUARE	0	0	0	0	0	0.05	0.47

Figure A 3.2. Weight coefficients of the precipitation stations (CP parameters) for the Río Choluteca).

BASIN: RIO VIEJO CON LAGO DE APANAS

PARAMETERFILE VALID DATE: 01-25-1990
TIME: 14:38:25

Nr	Name	Valid from												
1	AREA	1972 1 1	493.00	0.00	381.00	469.00	347.00	200.00	122.00					
2	ELEV	1972 1 1	1153.00	900.00	950.00	850.00	656.00	435.00	180.00					
3	VEG	1972 1 1	1.00	0.00	1.00	1.00	0.99	1.00	1.00					
4	LAKE	1972 1 1	0.00	1.00	0.00	0.00	0.01	0.00	0.00					
5	PELEV	1972 1 1	1020.00	950.00	1320.00	990.00	970.00	1280.00	1032.00	1380.00	1078.00	900.00	840.00	540.00
			1010.00	600.00	510.00	480.00	457.00	480.00	100.00	402.00	400.00	400.00	45.00	
7	QFACT	1972 1 1	0.10	0.10	0.10	1.00	1.00	0.10	0.10					
8	CP	1972 1 1	0.10	0.10	0.10	0.15	0.10	0.15	0.15	0.10	0.05	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
			0.20	0.00	0.50	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.15	0.00	0.05	0.00	0.15	0.00	0.45	0.10	0.05	0.05
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.30	0.25	0.20	0.00
			0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.40
			0.15	0.05	0.05	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.40	0.30	0.05	0.25	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.10	0.10	0.10	0.10	0.60							
10	CQ	1972 1 1	0.00	0.00	1.00	0.00	0.00	0.00	0.00					
11	EVAP	1972 1 1	7.30	8.40	8.90	9.40	7.20	5.50	6.10	6.30	5.30	4.90	5.50	6.40
13	PREPL	1972 1 1	2.00	4.00	9.00	0.00	7.00	8.00	4.00	7.00	0.00	9.00	10.00	13.00
			16.00	12.00	16.00	17.00	18.00	20.00	21.00	18.00	20.00	20.00	22.00	
14	PREPC	1972 1 1	1.19	1.19	1.30	1.00	0.82	1.38	0.81	1.57	1.00	0.62	1.00	1.07
			1.16	0.75	0.90	1.21	0.91	0.85	1.26	1.17	1.02	0.81	1.21	
16	SUBQR	1972 1 1	0.00000	7.00000	0.00000	1.00000	6.00000	3.00000	0.00000					
18	QREG	1972 1 1	0.00000	4.00000	0.00000	0.00000	0.00000	0.00000	0.00000					
20	PCORR	1972 1 1	1.00000	1.00000	0.80000	0.80000	0.95000	0.95000	0.95000					
21	PCALT	1972 1 1	0.00000											
27	FC	1972 1 1	150.00000	1.00000	180.00000									
28	LP	1972 1 1	100.00000	1.00000	100.00000									
29	BETA	1972 1 1	1.70000											
34	RSTEP	1972 1 1	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000					
36	PERC	1972 1 1	2.00000	0.00000	1.00000									
37	UZL	1972 1 1	20.00000											
38	K0	1972 1 1	1.00000	1.00000	1.00000	1.00000	0.80000	0.80000	0.80000					
39	K1	1972 1 1	0.07000	1.00000	0.50000									
40	K2	1972 1 1	0.03000	1.00000	0.00500									
43	CEVP	1972 1 1	0.70000	0.80000	0.75000	0.80000	0.90000	0.95000	1.00000					
44	LAREA	1972 1 1	0.00000	50.00000	0.00000	0.00000	0.00000	0.00000	0.00000					
46	MAXBAS	1972 1 1	3.00000	1.00000	2.00000	2.00000	1.00000	1.00000	1.00000					
47	BLAG	1972 1 1	0.00000	0.10000	0.30000	0.30000	0.35000	1.00000	0.00000					
49	PATH	1972 1 1	2.00000	3.00000	4.00000	5.00000	6.00000	7.00000	0.00000					
50	QRED	1972 1 1	0.00000	1.00000	0.00000	2.00000	0.00000	0.00000	0.00000					

Figure A 4.1. Parameter list of the HBV model for the Río Viejo including Lago de Apanás (see also Figure A 4.2.).

Basin: RIO VIEJO CON LAGO DE APANAS
Number of stations for precipitation: 23
Precip. weights Valid Date: 01-25-1990
Time: 12:53:40

Total weights corrected by multiplication with PCORR

Subcatcment nr:

Nr	Name	1	2	3	4	5	6	7	Total (%)
1	La Porra	0.10	0.10	0	0	0	0	0	2.73
2	Mancotal	0.10	0.20	0	0	0	0	0	2.73
3	Los Horcones	0.10	0	0	0	0	0	0	2.73
4	Los Robles	0.15	0.50	0	0	0	0	0	4.09
5	La Porfia	0.10	0.20	0.15	0	0	0	0	5.25
6	El Vigia	0.15	0	0	0	0	0	0	4.09
7	Jinotega	0.15	0	0.05	0.15	0	0	0	8.04
8	Emp.Aranjuez	0.10	0	0	0	0	0	0	2.73
9	Sn.Raf.Norte	0.05	0	0.15	0	0	0	0	3.89
10	La Concordia	0	0	0	0	0	0	0	0
11	Los Potrerios	0	0	0.45	0	0	0	0	7.58
12	Sn.Lorenzo	0	0	0.10	0.30	0.05	0	0	8.82
13	Valle Sta.Cruz	0	0	0.05	0.25	0.05	0	0	6.94
14	Aguas Zarcas	0	0	0.05	0.20	0.05	0	0	5.90
15	La Lima	0	0	0	0	0	0	0	0
16	Sn.Isidro barba.	0	0	0	0.10	0.40	0	0	9.37
17	El Naranjo	0	0	0	0	0.15	0	0	2.73
18	Sebaco	0	0	0	0	0.05	0	0	0.91
19	Sta.Rosa Peñon	0	0	0	0	0.05	0	0.10	1.55
20	Sta.Barbara	0	0	0	0	0.20	0.40	0.10	8.49
21	Mina La India	0	0	0	0	0	0.30	0.10	3.79
22	Dario	0	0	0	0	0	0.05	0.10	1.17
23	Sn.Fco.Carnicero	0	0	0	0	0	0.25	0.60	6.47

Figure A 4.2. Weight coefficients of the precipitation stations (CP-parameters) for the Río Viejo including Lago de Apanás

BASIN: RIO GRANDE DE TARCOLES

PARAMETERFILE VALID DATE: 01-26-1990
TIME: 16:38:12

Nr	Name	Valid from												
1	AREA	1969 1 1	93.30	136.10	166.30	69.90	120.80	147.60	57.10	38.00	201.50	217.90	217.80	171.70
			107.40											
2	ELEV	1969 1 1	1450.00	1580.00	1170.00	1150.00	1180.00	850.00	1320.00	620.00	1300.00	1245.00	1020.00	910.00
			450.00											
3	VEG	1969 1 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			1.00											
4	LAKE	1969 1 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00											
5	PELEV	1969 1 1	1172.00	760.00	696.00	1870.00	1320.00	909.00	639.00	1017.00	1042.00	1780.00	1240.00	932.00
			1162.00	840.00	850.00	1050.00	1290.00	1380.00	1100.00	1300.00	1280.00	1450.00	1260.00	1700.00
			700.00	1177.00	1250.00	1460.00	2140.00	1100.00	2120.00	450.00	2000.00	1061.00	460.00	1320.00
			471.00	1580.00	2564.00	1120.00	40.00	328.00	900.00	880.00	1020.00			
7	QFACT	1969 1 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
10	CQ	1969 1 1	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00		
11	EVAP	1969 1 1	4.00	4.70	5.20	5.00	4.00	3.50	3.50	4.00	3.70	3.50	3.50	3.70
13	PREPL	1969 1 1	2.00	3.00	2.00	10.00	1.00	12.00	12.00	9.00	8.00	22.00	1.00	14.00
			1.00	12.00	12.00	36.00	1.00	1.00	12.00	1.00	1.00	10.00	10.00	10.00
			12.00	12.00	3.00	22.00	10.00	9.00	22.00	3.00	1.00	8.00	12.00	12.00
			1.00	1.00	22.00	1.00	42.00	1.00	1.00	1.00	1.00			
14	PREPC	1969 1 1	0.95	1.03	0.97	1.00	1.22	0.86	0.96	0.76	1.30	1.03	1.11	1.04
			0.98	0.96	0.95	0.97	1.08	1.06	0.80	1.03	0.98	0.97	1.24	1.21
			1.30	1.06	1.65	1.73	0.88	0.97	2.00	0.97	0.77	0.97	1.01	1.60
			1.07	1.05	1.50	0.94	0.87	1.38	1.98	1.87	1.18			
16	SUBQR	1969 1 1	0.00000	0.00000	4.00000	10.00000	0.00000	9.00000	0.00000	2.00000				
			1.00000	0.00000	8.00000	3.00000	5.00000							
18	QREG	1969 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			0.00000	0.00000	0.00000	0.00000	0.00000							
19	FELEV	1969 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			0.00000	0.00000	0.00000	0.00000	0.00000							
20	PCORR	1969 1 1	1.00000	1.00000	1.00000	0.95000	0.95000	0.95000	0.95000	0.95000				
			0.95000	1.00000	1.00000	1.00000	1.00000							
21	PCALT	1969 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			0.00000	0.00000	0.00000	0.00000	0.00000							
27	FC	1969 1 1	400.00000	400.00000	100.00000	400.00000	400.00000	400.00000	400.00000	400.00000				
			400.00000	400.00000	400.00000	400.00000	400.00000							
28	LP	1969 1 1	300.00000	300.00000	50.00000	300.00000	300.00000	300.00000	300.00000	300.00000				
			300.00000	300.00000	300.00000	300.00000	300.00000							
29	BETA	1969 1 1	1.00000											
36	PERC	1969 1 1	3.00000	3.00000	2.00000	3.00000	3.00000	3.00000	3.00000	3.00000				
			4.00000	3.00000	3.00000	3.00000	3.00000							
37	UZL	1969 1 1	80.00000	80.00000	20.00000	60.00000	160.00000	40.00000	160.00000	40.00000				
			160.00000	160.00000	160.00000	40.00000	40.00000							
38	K0	1969 1 1	0.40000	0.40000	0.60000	0.40000	0.10000	0.40000	0.10000	0.40000				
			0.10000	0.10000	0.10000	0.40000	0.40000							
39	K1	1969 1 1	0.05000	0.05000	0.10000	0.05000	0.03000	0.05000	0.03000	0.05000				
			0.03000	0.03000	0.03000	0.05000	0.05000							
40	K2	1969 1 1	0.00500	0.01000	0.01000	0.00500	0.00500	0.00500	0.00500	0.00500				
			0.00500	0.00500	0.00500	0.00500	0.00500							
41	DAMP	1969 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			0.00000	0.00000	0.00000	0.00000	0.00000							
43	CEVP	1969 1 1	1.00000											
44	LAREA	1969 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			0.00000	0.00000	0.00000	0.00000	0.00000							
46	MAXBAS	1969 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	1969 1 1	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000				
			0.00000	0.00000	0.00000	0.00000	0.00000							
49	PATH	1969 1 1	4.00000	3.00000	4.00000	6.00000	6.00000	8.00000	8.00000	12.00000				
			11.00000	11.00000	12.00000	13.00000	0.00000							

Figure A 5.1. Parameter list of the HBV model for the Río Grande de Tárcoles (except CP-parameters that are given in Figure A 5.2.).

Basin: RIO GRANDE DE TARCOLES
Number of stations for precipitation: 45
Precip. weights Valid Date: 01-26-1990
Time: 16:40:43

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	San Jose	0	0	0.10	0.05	0	0	0	0	0	0	0	0	0	1.16
2	La Argentina	0	0	0	0	0	0	0	0	0	0.15	0.25	0	0	5.08
3	Atenas	0	0	0	0	0	0	0	0	0	0	0.20	0.10	0	3.54
4	Avance	0	0.10	0.07	0	0	0	0	0	0	0	0	0	0	1.47
5	Hda Concepcion	0	0.15	0.08	0	0	0	0	0	0	0	0	0	0	1.97
6	Lornessa	0	0	0.10	0.05	0	0.15	0	0	0	0	0	0	0	2.39
7	Turrucares	0	0	0	0	0	0	0	0.55	0	0	0	0.15	0	2.66
8	Palmares	0	0	0	0	0	0	0	0	0	0	0.50	0	0	6.35
9	Naranjo	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	Rancho Redondo	0.35	0.05	0.02	0	0	0	0	0	0	0	0	0	0	2.50
11	Hda La Laguna	0	0.15	0.05	0	0	0	0	0	0	0	0	0	0	1.68
12	Aeropuerto	0	0	0	0.05	0.20	0.15	0.25	0.25	0	0	0	0.05	0	4.58
13	Desamparados	0	0.10	0.03	0	0	0	0	0	0	0	0	0	0	1.09
14	Fabio Baudrit	0	0	0	0	0	0	0	0	0.20	0.05	0	0.10	0	3.87
15	Ojo de Agua	0	0	0	0	0	0.25	0	0	0	0	0	0	0	2.05
16	Tacacori	0	0	0	0	0	0	0.10	0	0.30	0	0	0.05	0	4.17
17	Los Sitios	0.10	0	0.05	0.15	0	0	0	0	0	0	0	0	0	1.61
18	San Antonio	0	0.05	0.20	0	0	0	0	0	0	0	0	0	0	2.34
19	Salitral	0	0	0.05	0	0	0.20	0	0	0	0	0	0	0	2.12
20	San Juan de Dios	0	0.30	0	0	0	0	0	0	0	0	0	0	0	2.38
21	Guadalupe	0.15	0	0.15	0	0	0	0	0	0	0	0	0	0	2.27
22	San Jos. de Heredia	0.25	0	0	0.15	0	0	0	0	0	0	0	0	0	1.94
23	Sacramento	0	0	0	0	0.05	0	0.30	0	0.20	0	0	0	0	3.52
24	Monte de La Cruz	0	0	0	0.10	0.25	0	0	0	0	0	0	0	0	2.06
25	Villa Colon	0	0	0	0	0	0.25	0	0.20	0	0	0	0.10	0	3.47
26	Telegrafo Barva	0	0	0	0.30	0.25	0	0	0	0	0	0	0	0	2.84
27	La Luisa	0	0	0	0	0	0	0	0	0.05	0.35	0	0	0	5.01
28	La Palma	0.15	0	0	0.05	0	0	0	0	0	0	0	0	0	1.01
29	Corralillo	0	0.10	0	0	0	0	0	0	0	0	0	0	0	0.79
30	Coop. Naranjo	0	0	0	0	0	0	0	0	0	0.25	0	0	0	3.18
31	El Gallito	0	0	0	0.05	0.15	0	0.05	0	0	0	0	0	0	1.36
32	Esc. C. Ganaderia	0	0	0	0	0	0	0	0	0	0	0.05	0	0.80	5.65
33	El Alto Uba	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	Sub. San Ramon	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0.64
35	Emb. La Garita	0	0	0	0	0	0	0	0	0	0	0	0.40	0.20	5.26
36	Sto. Dom. del Roble	0	0	0	0	0.10	0	0.30	0	0.05	0	0	0.05	0	2.68
37	Presa La Garita	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	Tres Rios	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	Volcan Poas	0	0	0	0	0	0	0	0	0.20	0.15	0	0	0	4.14
40	Sabana Norte	0	0	0.10	0.05	0	0	0	0	0	0	0	0	0	1.16
41	Bajo Laguna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	San Pedro Turrubares	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	San Rafael Turrubares	0	0	0	0	0	0	0	0	0	0	0	0	0	0
44	La Vibora	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	Sub Naranjo	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure A 5.2. Weight coefficients of the precipitation stations (CP-parameters) for the Río Grande de Tárcoles.

BASIN: RIO BAYANO

PARAMETERFILE VALID DATE: 01-26-1990
TIME: 19:52:16

Nr	Name	Valid from												
1	AREA	1973 1 1	1058.00	619.00	972.00	632.00	0.00	201.00	150.00	214.00	322.00			
2	ELEV	1973 1 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
3	VEG	1973 1 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
4	LAKE	1973 1 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			
5	PELEV	1973 1 1	30.00	70.00	80.00	85.00	60.00	15.00	100.00	30.00	5.00	50.00	400.00	10.00
			100.00	40.00	100.00	385.00	0.00	0.00						
7	QFACT	1973 1 1	0.15	0.10	0.10	0.10	0.10	0.10	0.25	0.10	0.19	-1.00	0.10	0.10
			0.00	0.00	0.00									
10	CQ	1973 1 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			0.00	0.00	0.00	0.00	0.00	0.00						
11	EVAP	1973 1 1	3.85	4.41	4.76	4.47	3.09	2.56	2.67	2.75	2.73	2.80	2.81	3.11
14	PREPC	1973 1 1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.33	1.40
			0.75	1.00	0.94	1.00	1.00	1.00						
16	SUBQR	1973 1 1	1.00000	9.00000	7.00000	0.00000	4.00000	5.00000	0.00000	2.00000				
			0.00000											
18	QREG	1973 1 1	0.00000	0.00000	0.00000	0.00000	10.00000	0.00000	0.00000	0.00000				
			0.00000											
20	PCORR	1973 1 1	0.90000	1.20000	1.00000	0.90000	0.90000	1.30000	1.00000	1.20000				
			1.00000											
21	PCALT	1973 1 1	0.00000											
27	FC	1973 1 1	260.00000	260.00000	200.00000	280.00000	280.00000	250.00000	250.00000	200.00000				
			250.00000											
28	LP	1973 1 1	210.00000	210.00000	200.00000	210.00000	210.00000	200.00000	200.00000	150.00000				
			200.00000											
29	BETA	1973 1 1	4.00000	1.30000	1.30000	3.50000	3.50000	1.00000	1.00000	1.00000				
			1.00000											
36	PERC	1973 1 1	4.00000	4.00000	5.00000	4.00000	4.00000	6.00000	7.00000	6.00000				
			7.00000											
37	UZL	1973 1 1	25.00000	25.00000	25.00000	25.00000	25.00000	25.00000	20.00000	20.00000				
			20.00000											
38	K0	1973 1 1	0.80000											
39	K1	1973 1 1	0.30000	0.30000	0.30000	0.30000	0.30000	0.10000	0.20000	0.20000				
			0.20000											
40	K2	1973 1 1	0.06000	0.06000	0.06000	0.06000	0.06000	0.06000	0.06000	0.04000				
			0.06000											
43	CEVP	1973 1 1	1.00000	1.00000	1.00000	1.00000	0.71000	1.00000	1.00000	1.00000				
			1.00000											
44	LAREA	1973 1 1	0.00000	0.00000	0.00000	0.00000	-1.00000	0.00000	0.00000	0.00000				
			0.00000											
46	MAXBAS	1973 1 1	2.00000	2.00000	2.00000	1.00000	1.00000	1.00000	1.00000	2.00000				
			1.00000											
49	PATH	1973 1 1	5.00000	5.00000	5.00000	5.00000	7.00000	7.00000	9.00000	9.00000				
			0.00000											
13	PREPL	1977 1 1	3.00	3.00	1.00	12.00	2.00	0.00	1.00	0.00	3.00	0.00	13.00	14.00
			11.00	3.00	5.00	0.00	0.00	0.00						
20	PCORR	1978 1 1	1.00000	1.20000	1.30000	1.00000	0.90000	1.30000	1.00000	1.20000				
			1.00000											
20	PCORR	1983 1 1	1.00000	1.20000	1.30000	1.00000	0.90000	1.40000	1.00000	1.00000				
			1.00000											
13	PREPL	1985 1 1	3.00	5.00	5.00	5.00	3.00	0.00	0.00	0.00	3.00	0.00	13.00	4.00
			1.00	3.00	5.00	0.00	0.00	0.00						
14	PREPC	1985 1 1	1.00	0.94	0.96	1.18	1.37	1.00	1.00	1.00	1.10	1.00	1.35	0.70
			1.03	0.87	0.82	0.00	0.00	0.00						
20	PCORR	1985 5 1	0.90000	1.20000	1.00000	0.90000	0.90000	1.40000	1.00000	1.00000				
			1.00000											

Figure A 6.1. Parameter list of the HBV model for the Río Bayano (except CP-parameters that are given in Figure A 6.2.).

Basin: RIO BAYANO
Number of stations for precipitation: 18
Precip. weights Valid Date: 01-26-1990
Time: 19:54:15

Total weights corrected by multiplication with PCORR

Subcatcment nr:

Nr	Name	1	2	3	4	5	6	7	8	9	Total (%)
1	CHEPO	0	0	0	0	0	0	0.50	0.20	0.50	6.80
2	MAJE	0	0.40	0	0.10	0	0	0	0	0	8.38
3	BAYANO CAMPAMENTO	0	0.20	0.10	0.10	0.50	0.40	0.50	0	0.50	15.22
4	PIRIA	0.15	0	0.30	0.10	0	0	0	0	0	11.63
5	IPETI	0.25	0.30	0	0.35	0.25	0	0	0	0	15.62
6	TANARA	0	0	0	0	0	0	0	0	0	0
7	CHARARE	0	0	0	0	0	0	0	0	0	0
8	PACORA	0	0	0	0	0	0	0	0	0	0
9	PUEBLO NUEVO	0	0.10	0	0	0	0	0	0	0	1.76
10	CANAZAS ANTE EMBALSE	0	0	0	0	0	0	0	0	0	0
11	ALTOS DE PACORA	0	0	0	0	0	0	0	0.40	0	2.43
12	NARGANA	0	0	0.20	0	0	0.20	0	0	0	5.84
13	LOMA BONITA	0	0	0	0	0	0	0	0.20	0	1.22
14	AGUAS CLARAS	0	0	0.40	0.35	0.25	0.40	0	0.20	0	17.60
15	TORTI	0.60	0	0	0	0	0	0	0	0	13.52
16	CARTI	0	0	0	0	0	0	0	0	0	0
17	....	0	0	0	0	0	0	0	0	0	0
18	....	0	0	0	0	0	0	0	0	0	0

Figure A 6.2. Weight coefficients of the precipitation stations (CP-parameters) for the Río Bayano.

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