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-

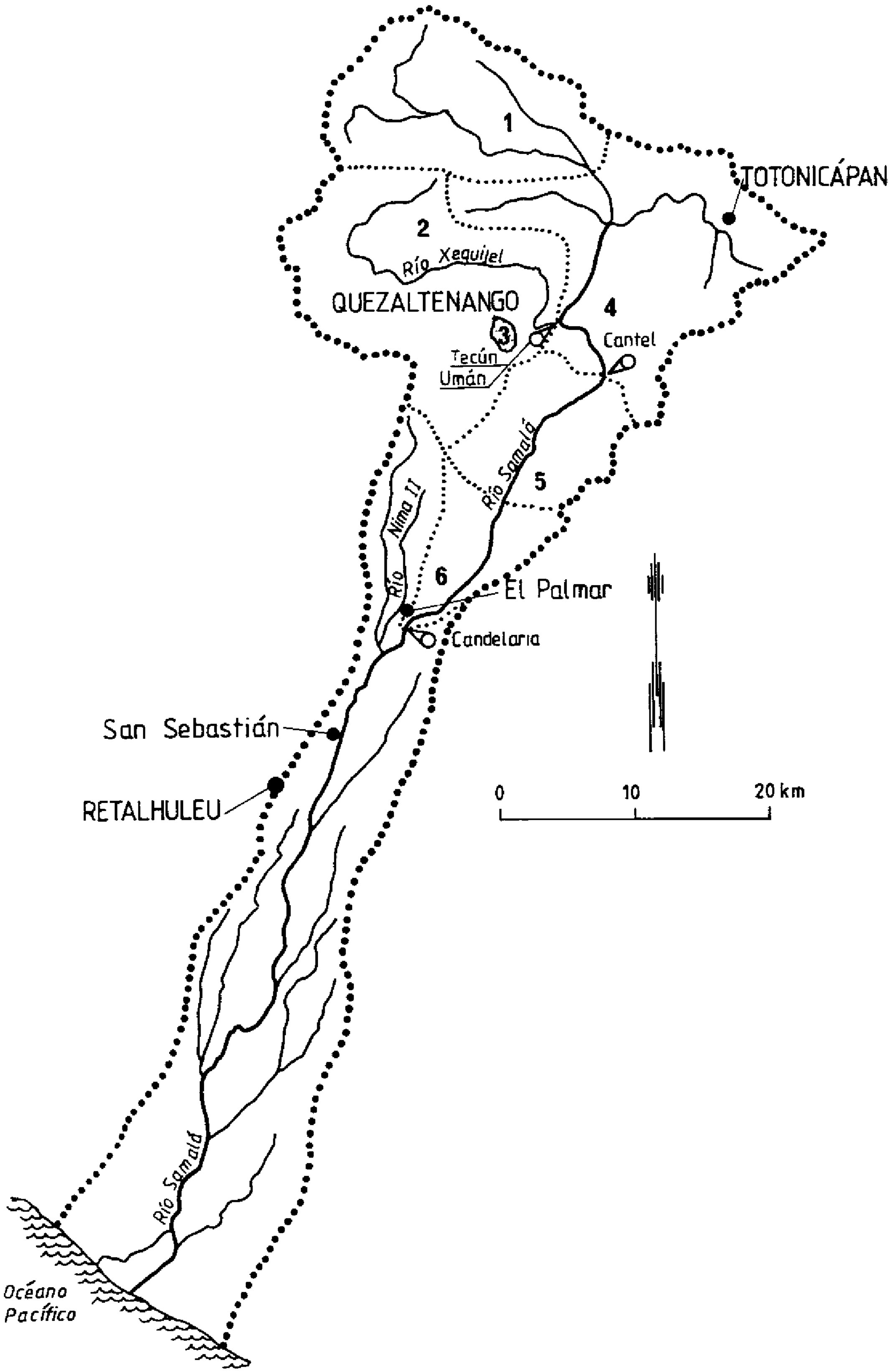

Figure 6. The basin of the Río Samalá.

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 established in order to simulate the peaks produced by urban areas, especially from the city of Quezaltenango. It has an area of 25 km² and is totally impervious. The remaining area down to the Cantel streamflow station forms the forth subbasin and is 239 km². The area between Cantel and Candelaria has been divided into two subbasins of which the upper one is 102 km² and the lower one 58 km². 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.

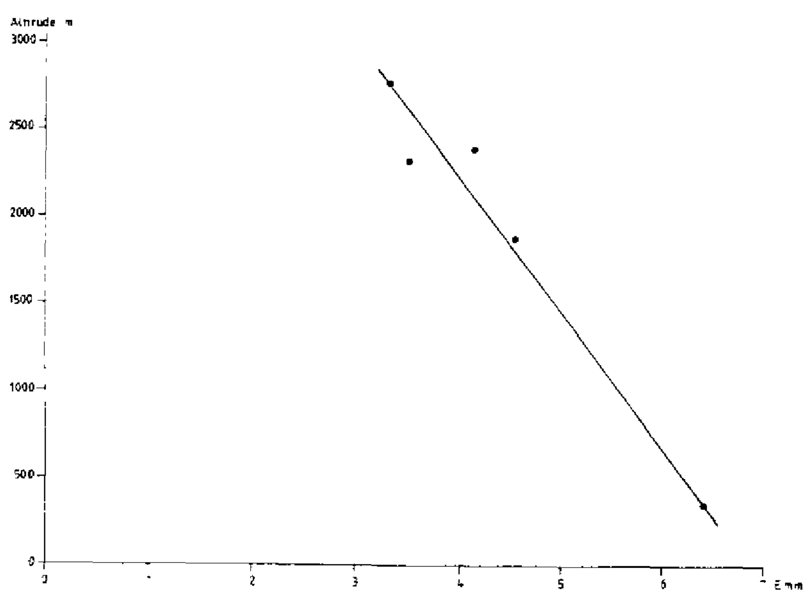

Figure 7. Average daily evaporation for Class A pans versus altitude

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.

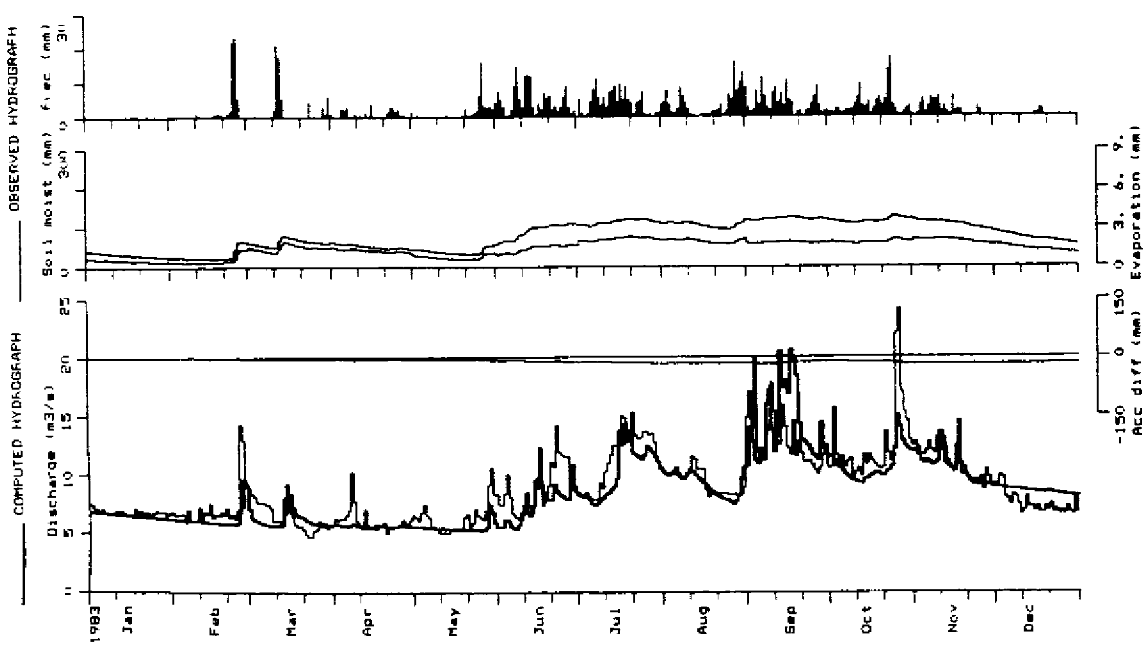

Figure 8. Model results in 1983 for Candelaria.

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.

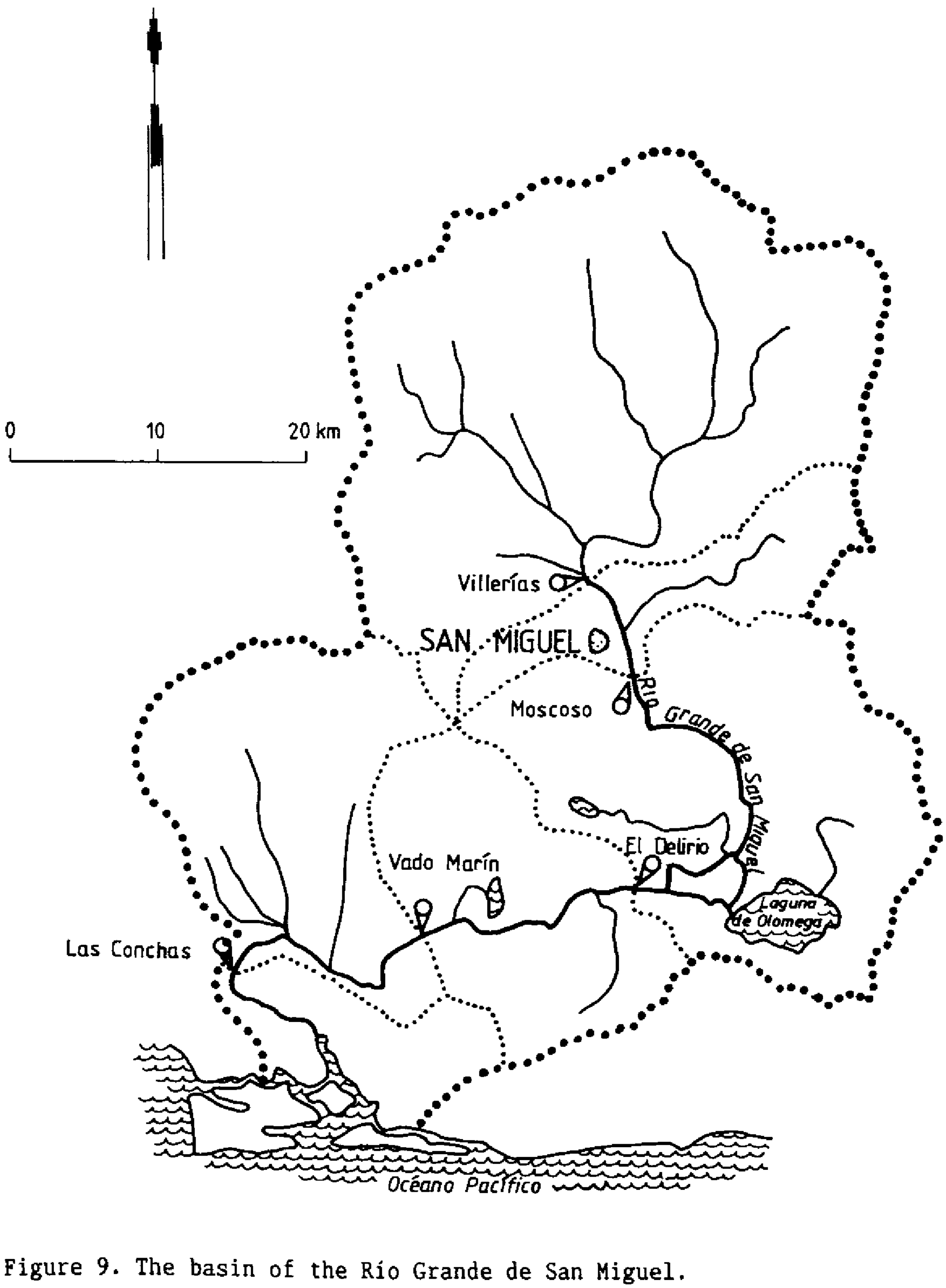

Figure 9. The basin of the Río Grande de San Miguel.

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.

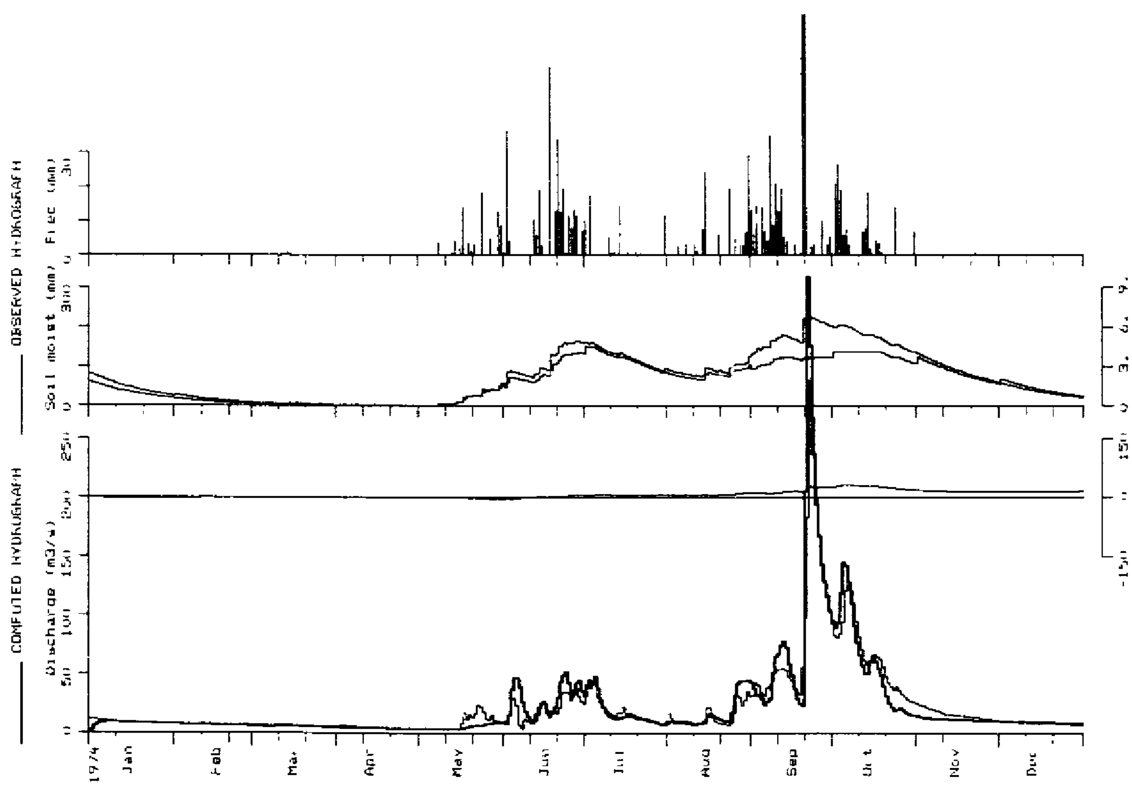

Figure 10. Model results in 1974 for Vado Marín

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.

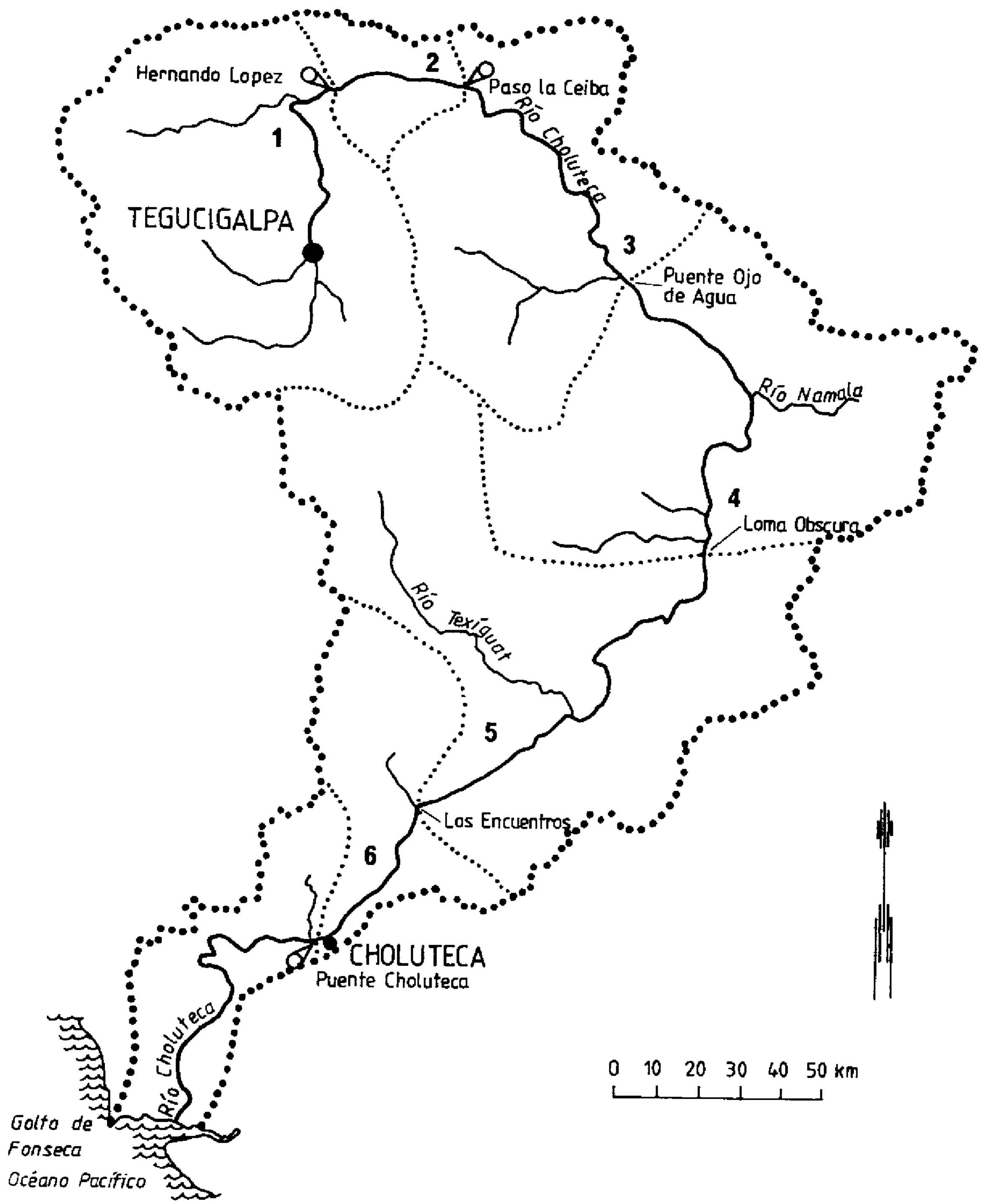

Figure 11. The basin of the Río Choluteca.

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.

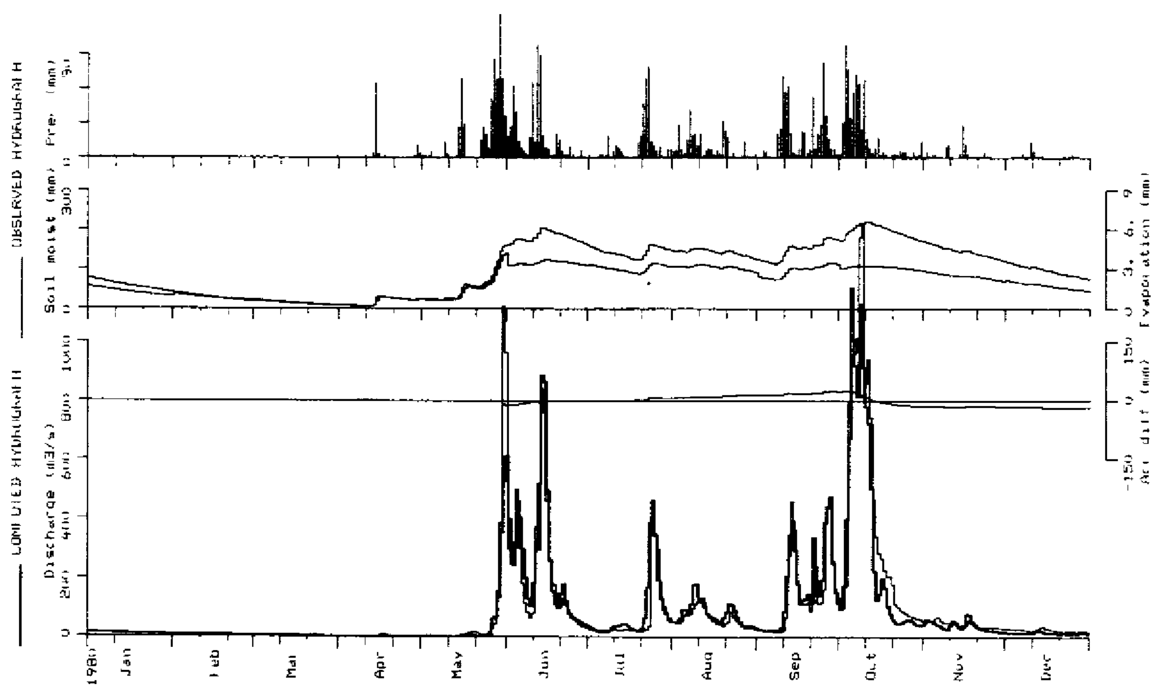

Figure 12. Model results in 1980 for Puente Choluteca.

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

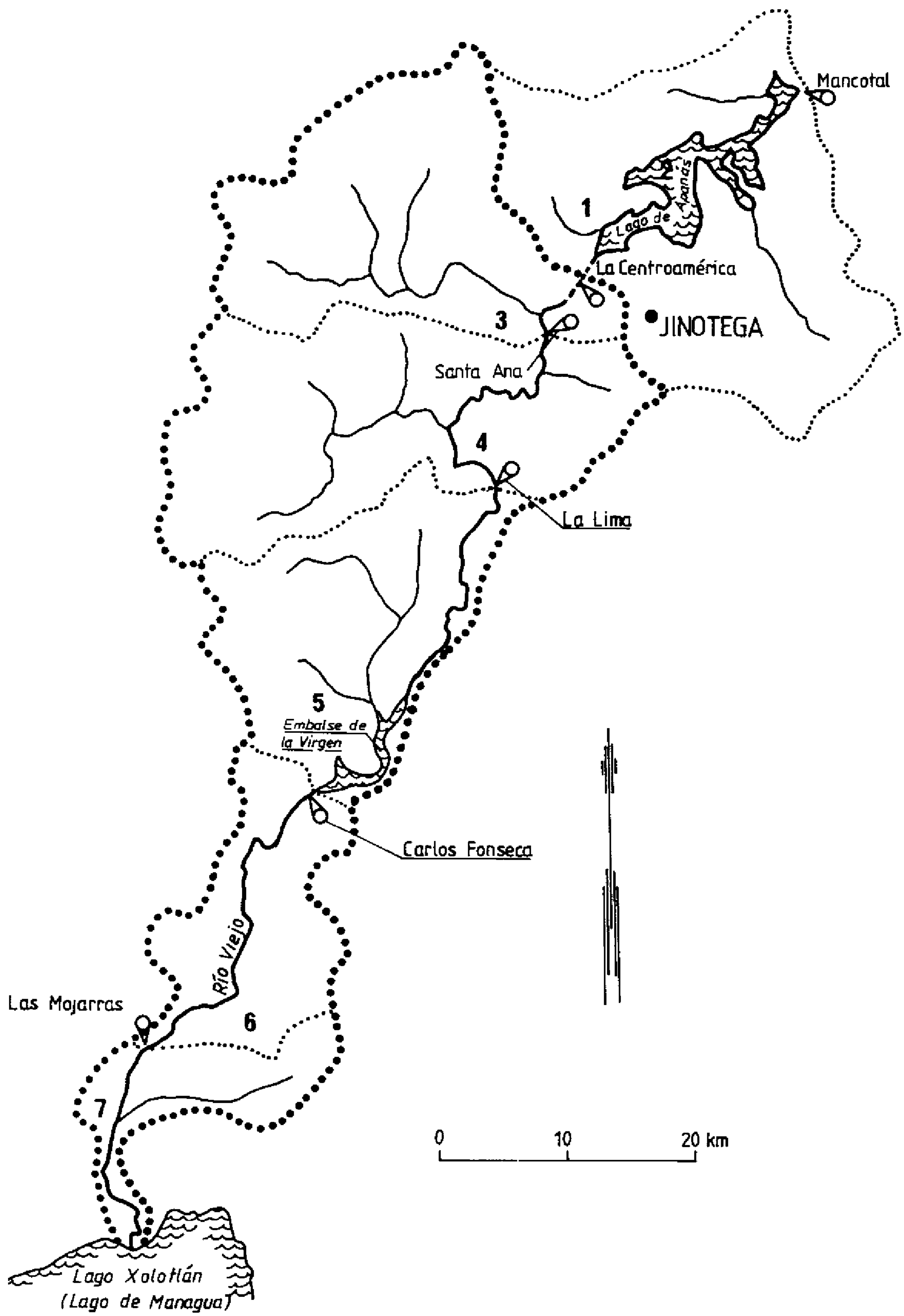

Figure 13. The basin of the Río Viejo and Lago de Apanás

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 overstimate 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.

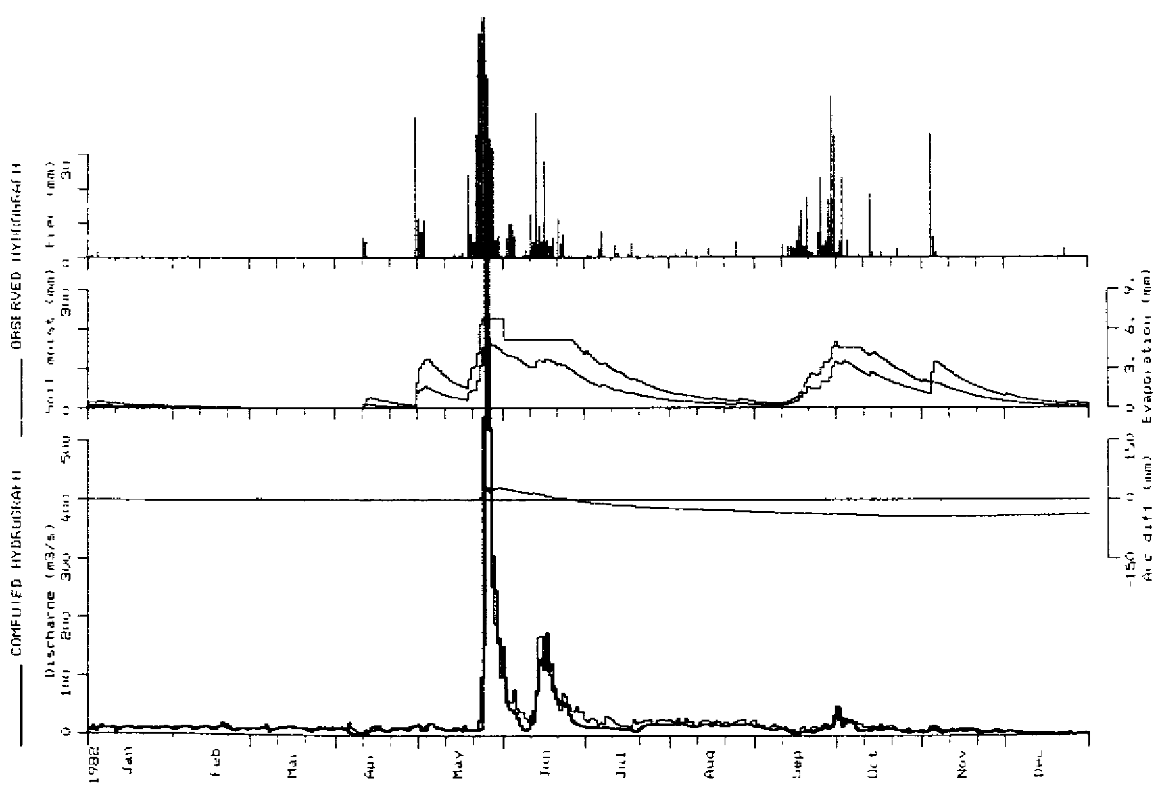

Figure 14. Model results in 1982 for Las Mojarras with the outflow from Lago de Apanás used as input.