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

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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 Rio 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.

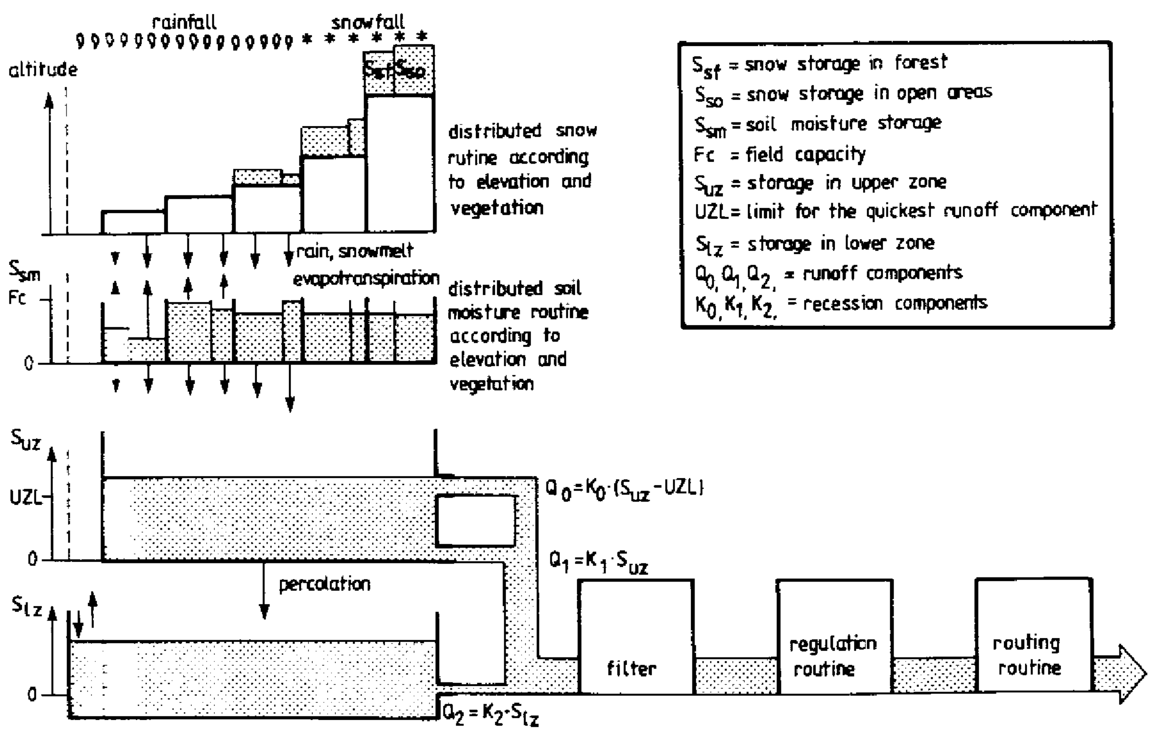
Country	River	Basin area (km^2)	Area for application of the HBV model (km^2)
Guatemala	Río Samalá	1499	861
El Salvador	Río Grande de San Miguel	2300	2237
Honduras	Río Choluteca	7550	6964
Nicaragua	Río Viejo	1519	543 + 1519
Costa Rica	Río Grande de Tárcoles	2168	1745
Panama	Río Bayano	5000	4452

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 time-steps 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 sub-basin. 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.

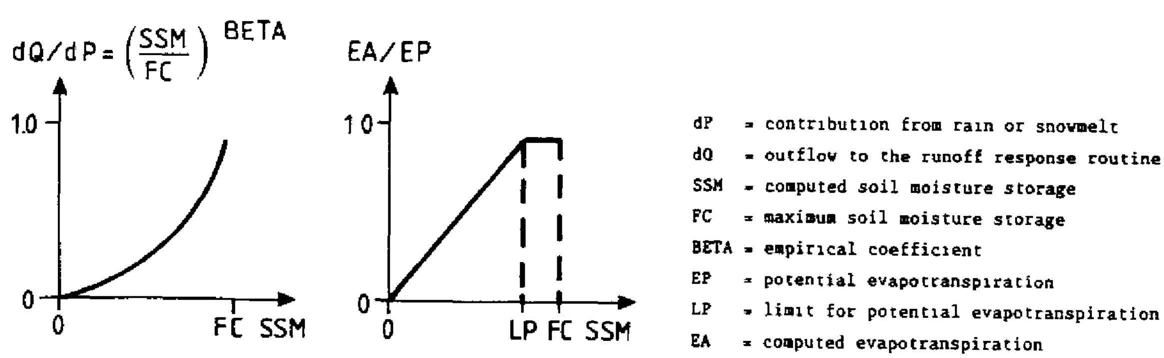
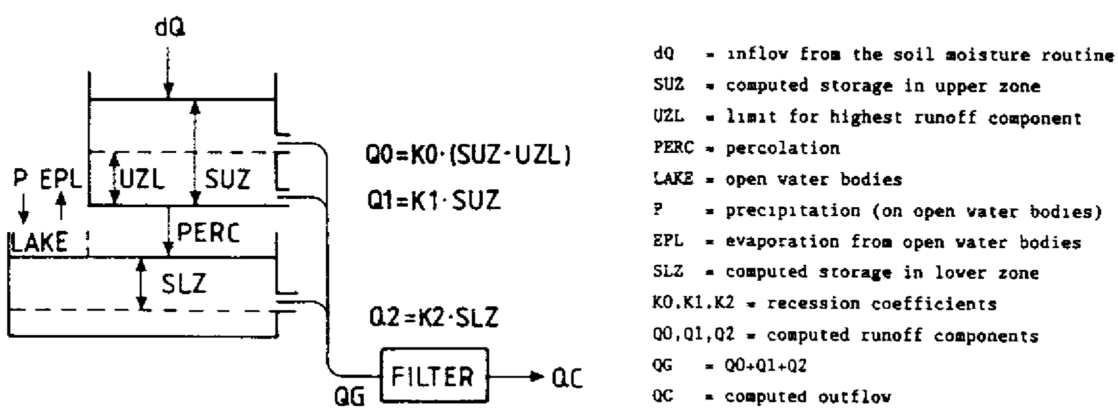


Figure 3. Schematic presentation of the soil moisture accounting in the HBV model.

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.



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.

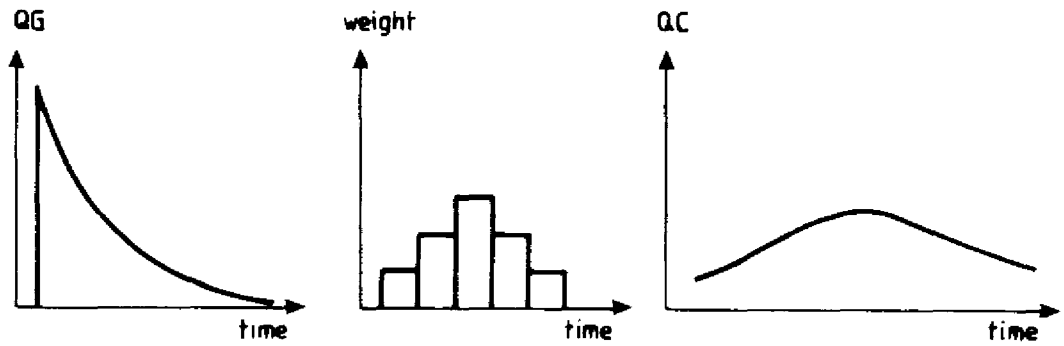


Figure 5. Presentation of the effects of the runoff filter of the HBV model.

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.