THE DESIGN OF A FLOOD FORECASTING PROCEDURE FOR THE KLANG RIVER AT KUALA LUMPUR

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ABSTRACT

A procedure was required for forecasting the flood level of the Klang river at the city of Kuala Lumpur, Malaysia. Using data from rainfall stations and tributary river stages, flood stage may be predicted by means of a multiple-input, autoregressive, moving-average linear model. This model was calibrated from storm records by means of stepwise multiple regression. The resulting set of equations was developed into a procedure for manual computation.

INTRODUCTION

The city of Kuala Lumpur (the name means 'muddy confluence' in Malay) is centred on the confluence of the Klang river and one of its tributaries, the Gombak. Parts of the city are prone to frequent flooding by the river and the decision to mobilise flood relief services is based on the river stage measured at the Market Street bridge. In order to expedite flood relief it became desirable to have a method of forecasting Market Street river levels. As a compromise between the response time of the catchment and desired forecast times, a period of four hours was selected as the time between reception of input data and time of occurence of the predicted stage. An essential requirement of the flood forecasting technique is that it can be computed manually with the aid of a battery-powered calculator. Night time forecasting at short notice and possible loss of electric power rule out real-time computer use. However, the National Electricity Board IBM 360 was used to develop and calibrate the mathematical model.

FLOOD HYDROLOGY

Malaysia has an equatorial climate and comes within the zone of influence of the north-east and south-west monsoons. The Klang catchment is protected from the south-west monsoon by the landmass of Sumatra and from the north-east monsoon by the central mountain range of the Malay Peninsula. With the exception of rare "spill-over" from the north-east monsoon, most floods are caused by convectional storms which produce intense, but localised, rainfall. The frequency and intensity of these storms varies throughout the year and appears to reach a maximum in October and November, just prior to the onset of the north-east monsoon.

The catchment area above the Market Street bridge is 465km^2. The lower part of the catchment has a high proportion of impervious urban area, but

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the remainder of the catchment, up to the highest point at 1800 m, is covered with plantations and tropical rain forest. Because flood-producing convectional storms have a diurnal pattern, antecedent conditions were assumed to be the same for all events. The rainfall occurring in these storms is of such high intensity (up to 150 mm/hour) that any inaccuracies in assumed loss rates have only a small effect on estimates of rainfall excess.

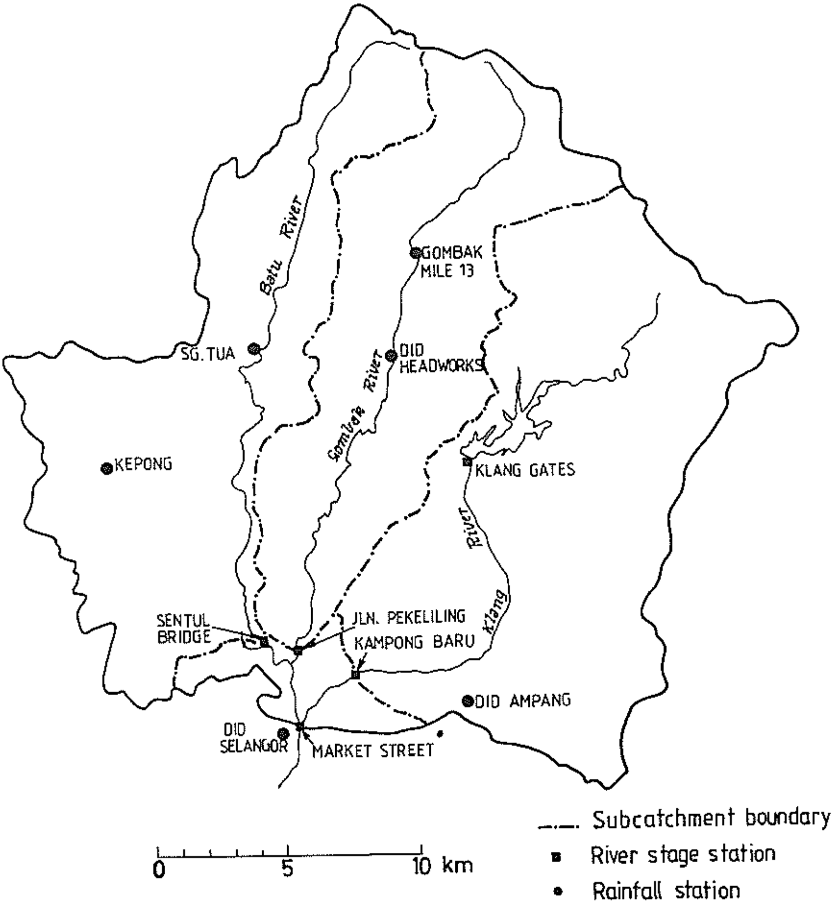

FIG. – 1 The catchment of the Klang River at Kuala Lumpur

DATA INPUT

The catchment can be divided into the three subcatchments of the Batu, Gombak and Klang rivers (Fig. 1). Within each subcatchment the Drainage and Irrigation Division (D.I.D.) has installed rainfall stations and a river level gauge at the downstream end. In addition there is a raingauge in the city centre at the D.I.D. office, and river level gauges at Market Street and at the water supply reservoir in the Klang subcatchment (Fig 1). During a flood alert observers send rainfall or stage readings by telephone or radio to the D.I.D. office. Observers are instructed to contact the office whenever the rainfall total during the day exceeds a certain value. On the basis of these rainfall reports the D.I.D. may alert the remaining observers and data are sent in every hour until the stand-down instruction is given.

On the basis of some crude water balance estimates an initial rainfall loss of 12 mm and a steady loss rate of 5 mm/hour are used. These losses are applied to data from all rainfall stations except the D.I.D. office, for which zero losses are assumed for the impervious areas in the lower part of the catchment.

THE MODEL STRUCTURE

A mathematical model was developed for each subcatchment relating the river stage at the bottom of the subcatchment to the rainfall data for the subcatchment. The river stage at Market Street was then related to the river stage for the three subcatchments. The model was broken into separate parts for several reasons. The subcatchment models should be calibrated separately using the different storms which give the best estimates for each subcatchment. This is necessary because of the high spatial variability of convectional rainfall. Computation of the forecast in separate stages reduces the chance of calculation errors, and stage forecasts for the tributaries provide useful additional information on the possible flood hazard.

Since the river stage is the required information the model relates stage rather than discharge to rainfall. This permits the use of river stations for which there are no rating curves. The model is used only at high river stages and for this restricted range all relationships are assumed to be linear.

A linear relationship between an input time series X_t and an output time series Y_t can be expressed with the least number of parameters by means of the autogressive moving-average (ARMA) process:

$$\begin{aligned} Y_t = {} & A_0 + A_1\, Y_{t-1} + \ldots A_p\, Y_{t-p} \\ & + B_1\, X_{t-b} + \ldots B_q\, X_{t-b-q+1} \\ & + N_t \end{aligned} \tag{1}$$

where A_0, A_1, . . . A_p, B_1 . . . B_q are model parameters, b is delay time of the process and N_t is an error term. The calibration of ARMA processes is discussed by Box and Jenkins (1970). Much of the complexity of the fitting process arises from the reduction of the error (or noise) term N_t to a linear transformation of white noise. Since N_t is not pure white noise (i.e. errors of constant variance with no autocorrelation) the usual multiple regression techniques do not apply and the calibration is an iterative procedure.

The calibration of the flood forecasting model departs from an ideal analytical situation for the following reasons:

(1) The delay parameter b was set equal to the forecast period of four hours. Any runoff caused by rainfall during the forecast period, such as that from the impervious lower part of the catchment, became part of the forecast error.

(2) The properties of the error term N_t are ignored to the extent that multiple regression techniques are used to calibrate the model. This permits the use of standard computer software by engineering hydrologists unfamiliar with the statistics of time series analysis.

(3) p and q, the number of autoregressive and moving-average parameters respectively, were determined using only one autoregressive term, Y_{t-b}, and using stepwise multiple regression to find the required number of moving-average terms.

Equation (1) now becomes:

$$Y_t = A_0 + A_1 Y_{t-4} + B_1 X_{t-4} \ldots B_q X_{t-3-q} + e_t \tag{2}$$

where e_t is assumed to have the required properties for linear regression.

For each subcatchment the river stage is the output Y_t and there are several input rainfall stations, so that a multiple-input from of equation (2) is:

$$\begin{aligned} Y_t = A_0 + A_1 Y_{t-4} + B_{11} X^{(1)}_{t-4} + \ldots \\ + B_{1q} X^{(1)}_{t-3-q} + \ldots \\ + B_{m1} X^{(m)}_{t-4} + \ldots B_{ms} X^{(m)}_{t-3-s} \\ + e_t \ldots \end{aligned} \tag{3}$$

The stage Z_t at Market Street is predicted from the forecasted stage in each of the three subcatchments by the equation:

$$\begin{aligned} Z_t = A_0 + A_1 Z_{t-4} + C_1 Y^{(1)}_t \\ + C_2 Y^{(2)}_t + C_3 Y^{(3)}_t + e_t \end{aligned} \tag{4}$$

which is also derived by means of multiple regression.

CALIBRATION OF THE MODEL

A total of 39 storms was used to initially calibrate the model; the model is periodically recalibrated as more data become available. Due to the different periods of record of the various hydrological stations the subcatchments were calibrated with different numbers of storms, 6 for the Batu, 8 for the Gombak, and 12 for the Klang. The stage correlation of equation (4) was derived from 12 events. Stepwise multiple regression was permitted to run until all variables were included. Variables which had entered the regression were not allowed to be subsequently rejected. The criteria for inclusion of a variable were that it gave a significant decrease in error variance and did not cause oscillations in the regression coefficients. Serious oscillation of the coefficients indicates intercorrelation of variables which means that little new information is being added to the regression (Johnston, 1963).

A set of coefficients from a calibration is shown in Table 1. The absolute values of the coefficients are not important because they are the result of using a mixture of metric and British units for the input data (the Malaysian metrication program was still in progress). Their relative values, however, show that the weighting of the coefficients is reasonably smooth. The values of the intercept term are a result of all river stages being measured with respect to mean sea level.

APPLICATION OF THE PROCEDURE

In order to facilitate the manual computation of the four equations required for the forecast a cardboard template was constructed (Fig. 2). The template is designed for use with standard computer printer paper. The headings on the template are used as a guide for ruling up the required columns in which the input data are recorded as each station reports. When the template is placed over the data with the time slot aligned correctly the data values appear in the slots adjacent to the appropriate coefficient. The multiplications and additions can then be carried out with the aid of a calculator or entirely by hand.

STATION	t	t−4	t−5	t−6	t−7	t−8	t−9	t−10	t−11
Batu Subcatchment									
Sg. Tua		0.74	0.13	0.36	0.53	0.53			
Kepong		0.44	0.50	0.49	0.35	0.29			
D.I.D. Selangor		0.99	0.35						
Sentul Bridge	F/C	0.72							
Intercept value =	28.93								
Gombak Subcatchment									
Gombak mile 13					0.16	0.15	0.12	0.15	
D.I.D. Headworks		0.60	0.48	0.51	0.51	0.40	0.36	0.28	0.18
D.I.D. Selangor		0.13	0.12	0.13	0.14				
Jln. Pekeliling	F/C	0.78							
Intercept value =	21.40								
Klang Subcatchment									
D.I.D. Ampang		0.27	0.29	0.24	0.21	0.17			
Klang Gates		0.29							
Kampong Baru	F/C	0.81							
Intercept value =	18.69								
Market St. Forecast									
Sentul Bridge	0.17								
Jln. Pekeliling	0.69								
Kampong Baru	0.35								
Market St.	F/C	0.15							
Intercept value =	−43.71								

N.B. F/C = value is forecasted
The time unit is one hour

TABLE 1 — Forecast Equation Coefficients

RESULTS

It is difficult to analyse the errors of the procedure because of the assumptions made in the mathematical structure, the method of solution, and the nature of the data. Forecast records kept since the procedure has been in use show that the river stage at Market Street can be predicted four hours ahead with an error of about 300 mm in a possible 900 mm rise or 600 mm fall during the period. Prediction of the time of occurrence of the maximum stage is usually not more than two hours in error. While not of a high degree of forecast accuracy, these results serve the purpose of the local authorities. Any significant improvement in accuracy cannot be expected because of the effect of runoff from the city area, which can cause changes in river stage within the four hour forecast period.

Two other benefits derive from the forecasting procedure. A rational method for making estimates of river stage, on which decisions to alert flood relief services can be based, relieves the decision maker of considerable stress

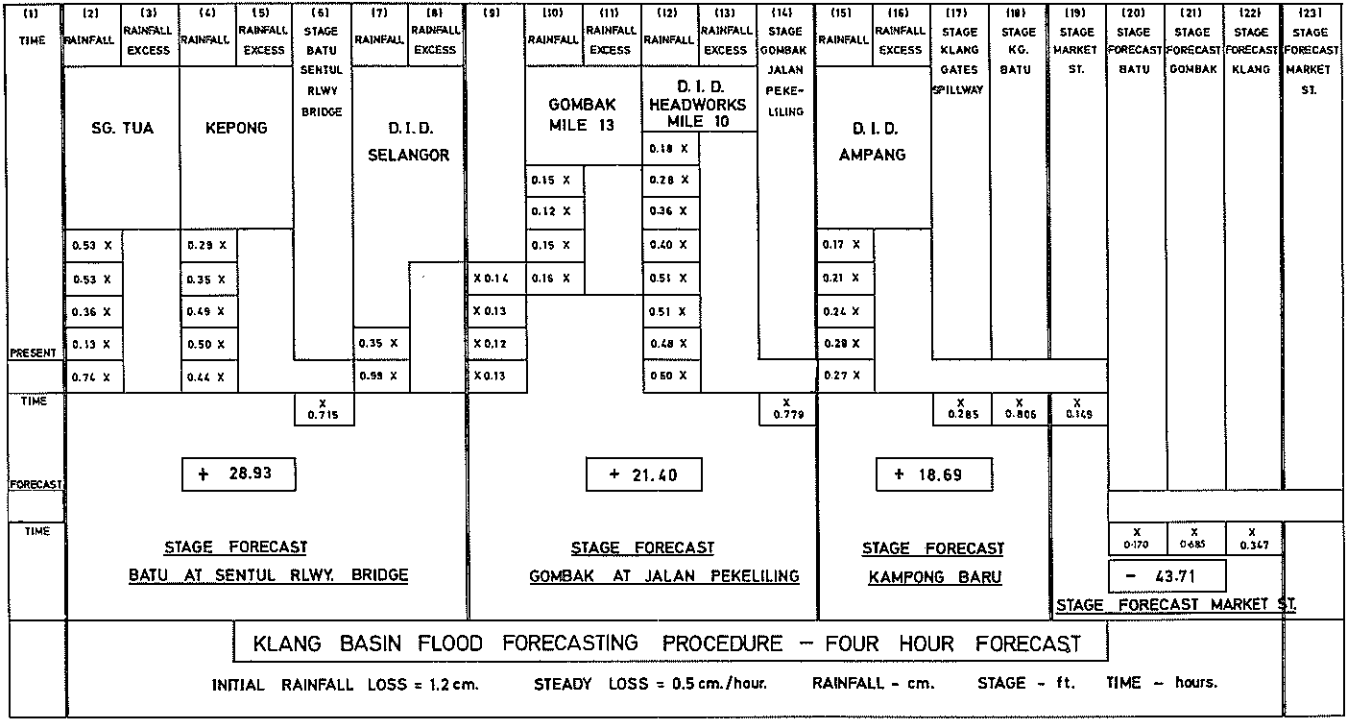

FIG. – 2 The template used for flood forecasting during a period of emergency. The procedure also provides a framework for the planning of the data network and the organisation of observers during a flood alert.

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