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# A CONCEPTUAL MODEL FOR THE ESTIMATION OF HISTORIC FLOWS

by

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## ABSTRACT

A lumped conceptual model is described which has the objective of determining the extent to which acceptable accuracy of prediction of daily, pentad and monthly flows can be achieved from daily inputs, the minimum data interval normally available in historic data.

The model has been developed on two catchments: the 19 $km^2$ Ray catchment above Grendon Underwood on the Oxford clays and the 197 $km^2$ Cam catchment above Dernford Mill containing a chalk aquifer partly overlain by Boulder Clay.

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## PREFACE

*This report is an account of work carried out on a commissioned research project funded by the Central Water Planning Unit as part of a programme to develop a method for estimating historic river flows from catchment models and historic weather data. The project had two parts: the development of a conceptual model to simulate flows on a calibration period and the testing of the model in prediction mode using the 'split record' approach.*

*The data runs used in this work were from the headwater catchments of the Cam and Ray rivers, and the time base of the rainfall and Penman potential evaporation estimation data input was one day. With these data the conceptual model was used to simulate river flows at daily, pentad and monthly time intervals. The precision of fit of the conceptual models developed for each catchment were assessed by a statistical program which included the equivalent in terms of the model of the coefficient of correlation, coefficient of variation, standard error of estimate, and analyses of the serial correlation of the residuals were made using the Durbin-Watson statistic. The statistical evaluation of the performance of the models was particularly requested by the CWPU to provide a comparison with their considerable work on semi-logarithmic regression models. These models are used to extend flow data records and in studies of available water resources.*

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## INTRODUCTION

This report presents the results of an attempt to develop a lumped conceptual model on a daily time interval to predict river flows from historic data. The development work was carried out on two catchments with very different flow hydrographs: the 18.6 $km^2$ Ray catchment above *Grendon Underwood on the Oxford clays and the 197 $km^2$ Cam catchment* above Dernford Mill which contains a chalk aquifer partly overlain by Boulder Clay.

The basic model structure used was that of the Institute of Hydrology conceptual model, details of the philosophy and computing techniques of which are given in Douglas (1974). Previous applications of the Institute model using different concepts to describe the inter-store fluxes have been made on the Cam by Dickinson and Douglas (1972) and on the Ray by Mandeville *et al* (1970). These models used six- and three-hourly intervals respectively, and the latter divided the soil store into layers which were successively depleted by evapotranspiration. In the model development described here the objective was to determine the extent to which acceptable accuracy of prediction of successive pentad and longer interval flows could be achieved from daily inputs, the minimum data interval normally available in historic data. Precision of prediction of the fine structure of the hydrograph comparable to the earlier models was not possible using the longer interval but modification of the functions representing the interstore fluxes resulted in reasonable precision in prediction of pentad and monthly flows from the long runs of data used to test the model.

## INSTRUMENT NETWORKS AND DATA

The instrument networks in the Cam and Ray catchments consist of an outflow gauging station, a meteorological station equipped to provide data for an estimate of Penman potential evaporation, and a network of recording or daily storage raingauges. The recording gauges are used to distribute the daily catch in hourly intervals as part of the data processing. The location of instruments in the Cam is described and shown in the report by Dickinson and Douglas (1972) and in a paper by Edwards and Rodda (1970) for the Ray.

The processing procedure used for data from these networks is described by Roberts (in preparation). The processed data are stored in magnetic tape *in six monthly sequential* batches of rainfall, streamflow and evaporation. A crude quality control has been applied to the raw data, but this will only detect the more obvious data irregularities which may, or may not, be due to equipment malfunctioning. Other

# THE CONCEPTUAL MODEL

The model has three stores: an interception and surface detention store, a soil moisture store, and a groundwater store. The surface runoff is assumed to be a function of the soil deficit and rainfall intensity, and then routed through a non-linear reservoir.

Evapotranspiration from the surface store when it contains water is estimated by using Penman potential evaporation, EO, and optimising a factor, FS, for this term:

ES = FS * EO

Any excess rainfall from this store is divided between surface runoff and the soil moisture store. The surface runoff is made exponentially dependent on the soil deficit, DC, and on the effect of rainfall intensity, which is very crudely estimated by using the amount of 'effective' rainfall, ERAIN, as follows:

ROP = RC *(EXP(-RS*DC) + EXP(RR*ERAIN)-1)

where the factors RC, RS and RR are parameters to be optimised. ROP is then used as a proportioning factor giving the volume surface runoff from

ROFF = ROP * ERAIN

the residual rainfall with ROFF deducted representing the infiltration to the soil moisture store.

The volume of surface runoff, ROFF, is routed through a non-linear reservoir RSTORE as follows:

RSTORE = RSTORE + ROFF

RO = RK * RSTORE**RX

This expression gives the unit time interval contributions, RO, to total flow, each contribution being subject to a delay RDEL. The parameters RK, RX and RDEL are optimised or estimated from field data.

The rainfall passing into the soil moisture store contributed to the total evaporation in a similar fashion to the interception store, but a seasonal dependence is introduced by making the Penman factor, ECP, a function of the store deficit, DC, as follows:

ECP = (DCT - DC)/(DCT - DCS)

EECP = ECP * FC

The limit DCS is fixed so that evaporation is at a constant rate at deficits below this value, and no evaporation takes place at a higher interval. Subsequently optimisation was carried out on the time distribution parameters using a daily time interval. Inevitably a subjective element exists in this fitting process. It governs the limits set on the range within which each parameter is allowed to float and the sequence in which the parameters were optimised.

These problems often lead to the reaching of a local optimum when it becomes impossible to reduce the value of the objective function by means of the optimisation process. Global optima can then only be reached by holding certain parameters fixed at physically realistic values estimated subjectively and re-optimising the rest.

The introduction of these subjective elements is justifiable if the fit of the models in prediction mode in the split record test is successful. The main test of different combinations of parameter values giving comparable values of the objective function over the calibration period is their success in predicting flows in the remaining period.

## STATISTICS USED TO ASSESS MODEL PERFORMANCE

The basis of the statistical analysis of the model performance is the objective function which is minimised to obtain the optimum values of the model parameters. This is given in Nash and Sutcliffe (1970), as the sum of squares of the differences between computed (Q') and observed (Q) runoff for the model frequency interval:

$$F = \Sigma(Q-Q')**2$$

The efficiency of fit of the model (RE) is then estimated by an expression which is equivalent to the regression coefficient of determination.

$$RE = (FO-F)/FO$$

where

$$FO = \Sigma(Q-\bar{Q})**2$$

The square root of RE has been used as the correlation coefficient. The equivalent of the coefficient of variation has been taken to be:

$$PE = (SQRT(F/N))/\bar{Q}$$

where N is the number of model time-intervals used.

The standard error of estimate is calculated from the approximate expression:

$$SEE = (F/N**2)**\tfrac{1}{2}$$

TABLE I. MODEL PARAMETERS AND CATCHMENT OPTIMISED VALUES

| PARAMETERS AND STORES | RAY | CAM |
|---|---|---|
| Interception and surface detention store | | |
| SS - Size of interception store (mm) | 3.1417 | 1.8594 |
| FS - Factor to estimate evapotranspiration from potential evaporation | 1.6831 | 0.9259 |
| CS - Initial contents of interception store (mm) | 0.0961 | 0.0000 |
| Surface runoff | | |
| RC - Rainfall/direct runoff constant | 0.9100 | 0.2202 |
| RS - Rainfall/runoff exponential decay constant for soil moisture deficit | 0.0338 | 0.0395 |
| RR - Rainfall/runoff intensity exponential constant | 0.0019 | 0.0046 |
| RK - Runoff routing factor | 0.5548 | 0.3901 |
| RX - Runoff routing index | 1.2107 | 1.0009 |
| RDEL - Surface runoff delay factor in days | 0.6060 | 0.7733 |
| Soil moisture store | | |
| FC - Factor to estimate soil store evapotranspiration loss from potential evaporation | 0.5509 | 0.7874 |
| DCS - Deficit below which FC factor is constant (mm) | 0.2401 | 49.9962 |
| DCT - Deficit above which there are no evaporation losses from the soil store (mm) | 340.9254 | 145.5970 |
| A - Soil store percolation factor for groundwater recharge | 0.1936 | 0.2957 |
| DC - Initial moisture deficit of soil store (mm) | 22.4418 | 20.0398 |
| Groundwater store | | |
| GSU - Groundwater outflow denominator | 75.7573 | 555.5879 |
| GSP - Groundwater outflow index | 1.0004 | 5.0473 |
| GDEL - Groundwater outflow delay factor in days | 5.0019 | 5.0011 |

All figures above are given to four decimal places, but these are not significant for size and contents of stores.

TABLE III. MODEL CALIBRATION AND PREDICTION RESULTS FOR THE RAY CATCHMENT

| | Calibration period 1.64-12.67 | Prediction period 1.68-12.75 | Total period 1.64-12.75 |
|---|---|---|---|
| Daily correlation coefficient | 0.86888 | 0.82099 | 0.83635 |
| Standard error of estimate as percentage of mean flow | 3.32% | 3.15% | 2.34% |
| Pentad correlation coefficient | 0.93137 | 0.90337 | 0.91262 |
| Standard error of estimate as percentage of mean flow | 3.95% | 3.72% | 2.77% |
| Monthly correlation coefficient | 0.96197 | 0.95949 | 0.96041 |
| Standard error of estimate as percentage of mean flow | 4.93% | 3.68% | 2.95% |
| Daily efficiency | 0.755 | 0.674 | 0.699 |
| Coefficient of variation | 1.268 | 1.699 | 1.551 |
| Initial variance, FO | 2492.90 | 5461.30 | 7954.19 |
| Final variance, F | 610.87 | 1779.45 | 2390.32 |
| Monthly efficiency | 0.925 | 0.921 | 0.922 |
| Coefficient of variation | 0.342 | 0.361 | 0.353 |
| Initial variance, FO | 18036.43 | 30793.17 | 48829.60 |
| Final variance, F | 1352.09 | 2437.78 | 3789.87 |
| Predicted flow (mm) | 711.1 | 1408.4 | 2119.5 |
| Observed flow (mm) | 745.8 | 1341.4 | 2087.2 |
| Error in flow | – 4.653% | 4.998% | 1.550% |
| Durbin-Watson statistic : | | | |
| Daily | 1.852 | 1.704 | 1.743 |
| Pentad | 1.738 | 1.953 | 1.898 |
| Monthly | 1.778 | 1.947 | 1.931 |

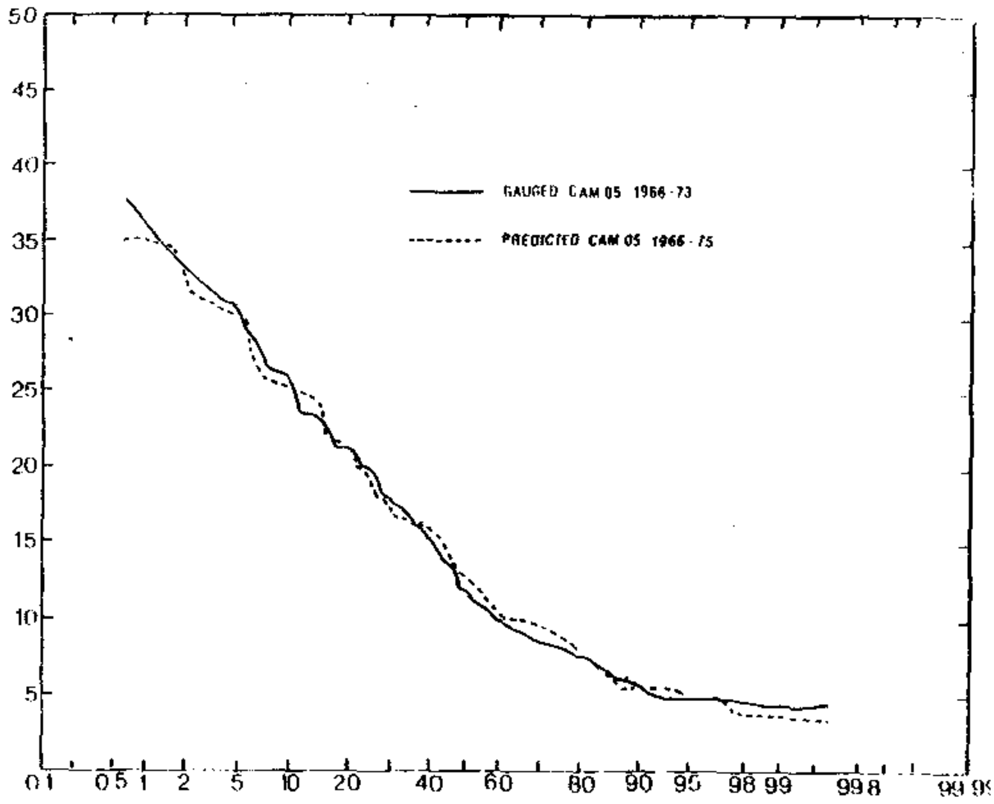

FIGURE 2 Cam flow duration curve of monthly predicted and observed flows for the period 1.66 to 12.75

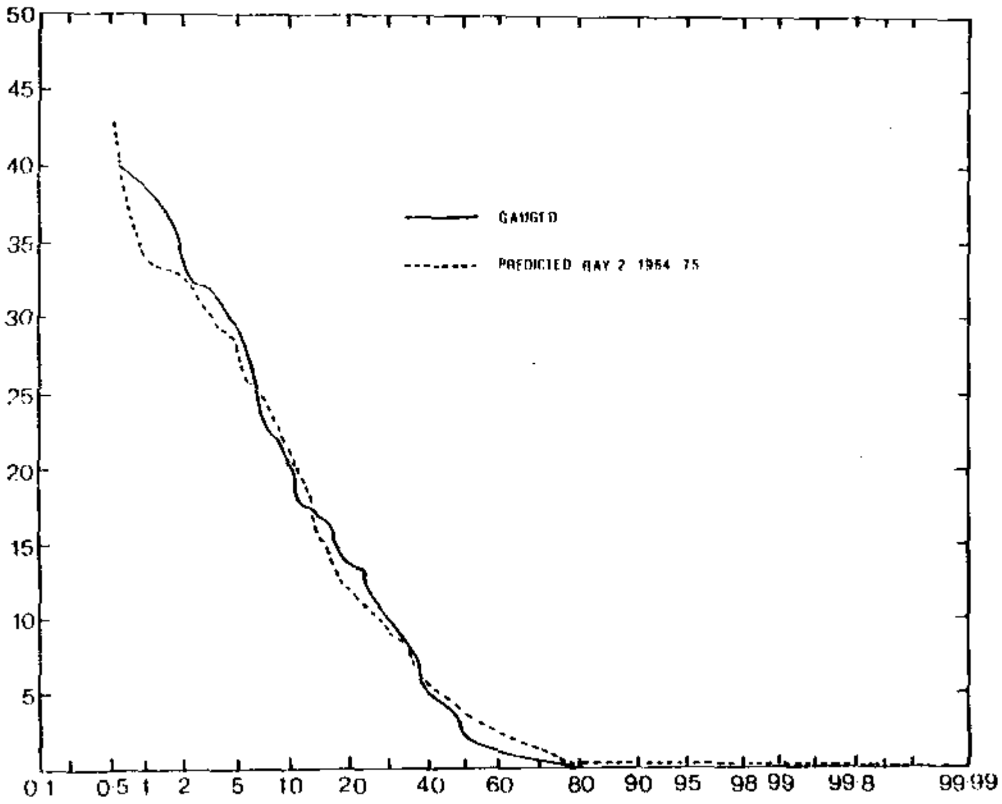

FIGURE 3 Ray flow duration curve of monthly predicted and observed flows for the period 1.64 to 12.75

would allow rainfall intensity either to be estimated more precisely or neglected, depending on the use of a shorter or longer interval. This is particularly relevant to clay catchments such as the Ray, where the greater part of the flow comprises rapid response 'surface' runoff. The problems in using the daily time interval are clearly shown by the daily plots of rainfall, observed and predicted flow at the end of this report. For each catchment the first graph demonstrates the daily departures in one year of the calibration period, the second has the worst annual correlation coefficient in the prediction period, and the last has the best coefficient.

An improved model could take into account areas of different vegetation and variations in surface zone storage during the year. The use of a direct infiltration function rather than the implicit function based on surface runoff could give an improved estimate of soil moisture storage. With the clay 'capping' of the high ground in the Cam there is the possibility of groundwater storage redistribution having a long term effect during 'dry' years followed by recharge. A secondary groundwater store of variable riverine area could improve the model in this respect.

The main cost of developing a model is in computing time taken up by the optimisation of model parameters, whilst the cost of a prediction run over a long period of data is very much lower. The optimisation computing time has been kept to a minimum by working on parameter subsets in relation to fixed parameters, and then optimising the latter.

Despite the imperfections and limitation discussed above the results demonstrate that estimation of historic flows with a reasonable in dry periods, the irregular pumping of water into the catchment from an adjacent clay pit and katabatic drainage at the climatological site.

None of these local factors could account completely for the seasonal imbalance, but a possible explanation emerges from the approach given in Thom and Oliver (1977). Their work shows the necessity of modifying the Penman equation by a generalised ventilation term, and the application of this equation to the catchment data would provide a much improved estimate of seasonal evapotranspiration. In the current models the seasonal discrepancy has been dealt with very crudely by reducing the evapotranspiration factor in phase with the soil moisture deficit and allowing the 'interception' loss rate, FS, the dominant winter evaporation process, to assume values in excess of the Penman potential rate.

The inclusion of a model section for snowfall would improve the Cam model particularly, but a satisfactory routine which would work from the current data is not available. Direct measurements are required of snowfall and snow pack in the catchments. The inclusion of data on actual groundwater abstractions and return of effluent during the calibration period in particular would enable greater precision to be achieved on this catchment.

A model based on a different time interval to the daily basis adopted here would allow rainfall intensity either to be estimated more precisely or neglected, depending on the use of a shorter or longer interval. This is particularly relevant to clay catchments such as the Ray, where the greater part of the flow comprises rapid response 'surface' runoff. The problems in using the daily time interval are clearly shown by the daily plots of rainfall, observed and predicted flow at the end of this report. For each catchment the first graph demonstrates the daily departures in one year of the calibration period, the second has the worst annual correlation coefficient in the prediction period, and the last has the best coefficient.

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# APPENDIX I

## CAM DATA SUMMARIES AND MODEL FIT STATISTICS

**TABLE 1** Cam monthly rainfall and streamflow with means and standard deviations from 01.66 to 12.75

CATCHMENT 5 MONTHLY RAINFALL AND STREAMFLOW

| YEAR | | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL | RDAYS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1966 | R | 25.9 | 67.0 | 8.6 | 55.2 | 47.0 | 63.7 | 78.0 | 70.2 | 23.7 | 80.8 | 37.9 | 76.4 | 634.5 | 255 |
| | Q | 13.1 | 25.8 | 16.0 | 19.9 | 13.5 | 9.7 | 8.7 | 8.2 | 7.6 | 9.6 | 10.5 | 21.1 | 168.9 | |
| 1967 | R | 27.4 | 43.5 | 19.8 | 58.2 | 92.1 | 32.4 | 52.7 | 47.2 | 44.2 | 95.6 | 48.7 | 54.2 | 616.2 | 237 |
| | Q | 17.7 | 17.5 | 16.3 | 15.3 | 16.8 | 10.9 | 8.7 | 6.8 | 6.7 | 8.4 | 15.2 | 18.2 | 156.6 | |
| 1968 | R | 40.4 | 22.4 | 24.3 | 42.6 | 33.1 | 88.8 | 108.9 | 133.9 | 119.7 | 39.0 | 28.3 | 49.0 | 697.5 | 239 |
| | Q | 22.9 | 17.6 | 13.8 | 11.8 | 11.3 | 9.3 | 10.9 | 19.7 | 26.1 | 21.0 | 17.1 | 23.5 | 204.8 | |
| 1969 | R | 63.5 | 40.5 | 44.2 | 29.3 | 75.7 | 41.0 | 62.1 | 76.4 | 4.9 | 5.4 | 67.3 | 60.8 | 571.9 | 208 |
| | Q | 31.0 | 23.6 | 31.7 | 19.7 | 19.9 | 13.7 | 11.2 | 12.2 | 9.0 | 8.2 | 8.9 | 16.1 | 205.2 | |
| 1970 | R | 66.2 | 54.9 | 43.7 | 78.7 | 10.9 | 26.2 | 39.0 | 52.1 | 55.6 | 17.5 | 142.5 | 44.7 | 631.6 | 235 |
| | Q | 23.4 | 25.2 | 28.1 | 26.4 | 18.1 | 11.9 | 9.8 | 9.4 | 8.4 | 8.3 | 17.5 | 20.8 | 207.2 | |
| 1971 | R | 75.6 | 13.0 | 40.4 | 29.5 | 48.5 | 78.0 | 48.4 | 66.1 | 20.3 | 72.5 | 65.5 | 17.9 | 577.9 | 188 |
| | Q | 32.5 | 22.0 | 23.3 | 17.3 | 15.8 | 16.3 | 10.7 | 10.3 | 7.7 | 10.6 | 13.3 | 9.7 | 189.7 | |
| 1972 | R | 56.7 | 47.3 | 42.9 | 44.0 | 33.1 | 24.2 | 50.5 | 25.5 | 29.2 | 3.5 | 50.7 | 61.8 | 469.0 | 231 |
| | Q | 20.3 | 21.3 | 20.2 | 13.2 | 11.9 | 8.9 | 6.7 | 6.2 | 5.2 | 4.9 | 5.5 | 9.1 | 135.7 | |
| 1973 | R | 13.7 | 14.5 | 8.7 | 44.7 | 61.0 | 63.3 | 69.2 | 25.9 | 71.7 | 20.9 | 26.5 | 30.0 | 450.4 | 205 |
| | Q | 5.1 | 4.8 | 8.3 | 6.0 | 6.4 | 4.9 | 6.0 | 4.4 | 4.4 | 4.9 | 5.0 | 4.8 | 66.1 | |
| 1974 | R | 57.4 | 49.7 | 23.8 | 11.8 | 24.4 | 60.1 | 29.6 | 88.1 | 99.8 | 106.6 | 98.4 | 22.5 | 672.1 | 249 |
| | Q | 7.5 | 13.3 | 11.1 | 8.9 | 7.5 | 5.8 | 4.9 | 5.0 | 8.4 | 22.6 | 37.5 | 21.1 | 155.6 | |
| 1975 | R | 72.1 | 20.4 | 82.2 | 66.5 | 60.0 | 26.0 | 30.9 | 9.9 | 95.3 | 11.3 | 46.5 | 28.5 | 548.9 | 228 |
| | Q | 23.7 | 19.2 | 34.1 | 30.4 | 25.8 | 14.7 | 10.3 | 7.4 | 7.8 | 7.6 | 7.9 | 8.2 | 202.3 | |
| MEAN | R | 49.9 | 37.3 | 33.9 | 46.1 | 48.5 | 50.4 | 56.9 | 56.3 | 56.4 | 45.5 | 61.3 | 44.5 | 537.0 | 227 |
| | Q | 21.1 | 19.1 | 20.3 | 17.1 | 14.7 | 11.6 | 8.8 | 9.0 | 9.1 | 11.7 | 13.6 | 15.3 | 169.4 | |
| S.D. | R | 21.5 | 13.5 | 21.9 | 19.6 | 24.6 | 23.5 | 24.0 | 29.7 | 38.8 | 39.8 | 35.5 | 19.3 | 80.7 | 21 |
| | Q | 5.7 | 6.3 | 8.8 | 7.5 | 5.8 | 3.7 | 2.2 | 4.5 | 6.1 | 6.2 | 9.4 | 6.7 | 44.2 | |

TABLE 3 Cam distributions of daily rainfall, streamflow and Penman EO for the period 01.01.66 to 31.12.75

CATCHMENT 5

DISTRIBUTIONS OF DAILY R,Q,E

| | RAIN | | | | FLOW | | | | EVAP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.76MM | | | | .17MM | | | | .291MM | | | |
| INTERVAL | MM | % | DAYS | % | MM | % | DAYS | % | MM | % | DAYS | % |
| 1 | 1095.2 | 18.66 | 1611 | 70.84 | 42.9 | 2.53 | 289 | 7.91 | 49.3 | .79 | 764 | 20.92 |
| 2 | 1309.7 | 22.31 | 340 | 14.95 | 364.4 | 21.51 | 1414 | 38.72 | 131.9 | 2.11 | 372 | 10.19 |
| 3 | 1134.5 | 19.32 | 172 | 7.56 | 322.3 | 19.02 | 765 | 20.95 | 157.4 | 2.52 | 266 | 7.28 |
| 4 | 526.8 | 8.97 | 57 | 2.51 | 351.3 | 20.73 | 601 | 16.46 | 179.5 | 2.88 | 212 | 5.81 |
| 5 | 503.7 | 8.58 | 42 | 1.85 | 223.5 | 13.19 | 298 | 8.16 | 205.1 | 3.29 | 191 | 5.23 |
| 6 | 293.2 | 5.00 | 20 | .88 | 95.7 | 5.65 | 103 | 2.82 | 178.9 | 2.87 | 135 | 3.70 |
| 7 | 280.5 | 4.78 | 16 | .70 | 49.2 | 2.91 | 45 | 1.23 | 212.3 | 3.40 | 136 | 3.72 |
| 8 | 203.9 | 3.47 | 10 | .44 | 56.2 | 3.32 | 46 | 1.26 | 260.1 | 4.17 | 145 | 3.97 |
| 9 | 91.0 | 1.55 | 4 | .18 | 28.8 | 1.70 | 20 | .55 | 304.9 | 4.88 | 148 | 4.05 |
| 10 | 26.4 | .45 | 1 | .04 | 35.8 | 2.11 | 22 | .60 | 301.3 | 4.83 | 132 | 3.61 |
| 11 | 113.7 | 1.94 | 4 | .18 | 23.0 | 1.36 | 13 | .36 | 329.5 | 5.28 | 130 | 3.56 |
| 12 | 61.6 | 1.05 | 2 | .09 | 15.7 | .93 | 8 | .22 | 416.1 | 6.65 | 150 | 4.11 |
| 13 | 34.5 | .59 | 1 | .04 | 10.5 | .62 | 5 | .14 | 367.0 | 5.88 | 122 | 3.34 |
| 14 | 35.6 | .61 | 1 | .04 | 13.8 | .81 | 6 | .16 | 365.5 | 5.85 | 105 | 2.88 |
| 15 | 38.5 | .66 | 1 | .04 | 5.0 | .30 | 2 | .05 | 320.6 | 5.13 | 92 | 2.52 |
| 16 | 41.4 | .71 | 1 | .04 | 13.2 | .78 | 5 | .14 | 411.1 | 6.58 | 110 | 3.01 |
| 17 | .0 | .00 | 0 | .00 | 2.9 | .17 | 1 | .03 | 386.2 | 6.19 | 97 | 2.66 |
| 18 | .0 | .00 | 0 | .00 | 5.8 | .34 | 2 | .05 | 295.5 | 4.73 | 70 | 1.92 |
| 19 | .0 | .00 | 0 | .00 | 6.3 | .37 | 2 | .05 | 310.4 | 4.97 | 69 | 1.89 |
| 20 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 205.4 | 3.29 | 44 | 1.20 |
| 21 | .0 | .00 | 0 | .00 | 3.6 | .21 | 1 | .03 | 197.1 | 3.16 | 40 | 1.10 |
| 22 | .0 | .00 | 0 | .00 | 3.6 | .21 | 1 | .03 | 165.2 | 2.65 | 32 | .88 |
| 23 | .0 | .00 | 0 | .00 | 7.6 | .45 | 2 | .05 | 178.5 | 2.86 | 35 | .96 |
| 24 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 118.4 | 1.90 | 21 | .58 |
| 25 | .0 | .00 | 0 | .00 | 8.4 | .50 | 2 | .05 | 71.0 | 1.14 | 12 | .33 |
| 26 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 60.3 | .97 | 10 | .27 |
| 27 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 31.6 | .51 | 5 | .14 |
| 28 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 26.3 | .42 | 4 | .11 |
| 29 | 78.2 | 1.33 | 1 | .04 | 4.9 | .29 | 1 | .03 | 34.0 | .54 | 5 | .14 |
| 30 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 |
| TOTALS | 5869.7 | | 2274 | | 1694.3 | | 3652 | | 6243.6 | | 3652 | |

**TABLE 5** Cam distributions of daily rainfall, streamflow and Penman EO for the calibration period 01.01.66 to 31.12.69

CATCHMENT 5

DISTRIBUTIONS OF DAILY R.Q.E

| | RAIN | | | | FLOW | | | | EVAP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.70MM | | | | .17MM | | | | .241MM | | | |
| INTERVAL | MM | % | DAYS | % | MM | % | DAYS | % | MM | % | DAYS | % |
| 1 | 480.6 | 19.07 | 649 | 69.26 | .0 | .00 | 0 | .00 | 19.2 | .77 | 324 | 22.18 |
| 2 | 534.0 | 21.19 | 139 | 14.83 | 126.9 | 17.20 | 461 | 31.55 | 50.6 | 2.03 | 146 | 9.99 |
| 3 | 558.5 | 22.16 | 85 | 9.07 | 197.1 | 26.72 | 469 | 32.10 | 53.3 | 2.14 | 92 | 6.30 |
| 4 | 253.0 | 10.04 | 27 | 2.88 | 169.2 | 22.94 | 291 | 19.92 | 62.3 | 2.50 | 74 | 5.07 |
| 5 | 169.7 | 6.73 | 14 | 1.49 | 94.4 | 12.80 | 125 | 8.56 | 83.9 | 3.37 | 77 | 5.27 |
| 6 | 88.7 | 3.52 | 6 | .64 | 47.1 | 6.39 | 51 | 3.49 | 65.8 | 2.64 | 50 | 3.42 |
| 7 | 88.3 | 3.50 | 5 | .53 | 14.2 | 1.93 | 13 | .89 | 82.7 | 3.32 | 53 | 3.63 |
| 8 | 100.5 | 3.99 | 5 | .53 | 27.0 | 3.66 | 21 | 1.44 | 115.8 | 4.65 | 59 | 4.04 |
| 9 | 45.9 | 1.82 | 2 | .21 | 7.1 | .96 | 5 | .34 | 148.2 | 5.95 | 72 | 4.93 |
| 10 | .0 | .00 | 0 | .00 | 11.4 | 1.55 | 7 | .48 | 130.2 | 5.23 | 57 | 3.90 |
| 11 | 58.1 | 2.31 | 2 | .21 | 12.2 | 1.65 | 7 | .48 | 129.2 | 5.19 | 51 | 3.49 |
| 12 | 30.0 | 1.19 | 1 | .11 | 4.0 | .54 | 2 | .14 | 183.5 | 7.37 | 66 | 4.52 |
| 13 | 34.5 | 1.37 | 1 | .11 | 2.1 | .29 | 1 | .07 | 138.1 | 5.55 | 46 | 3.15 |
| 14 | .0 | .00 | 0 | .00 | 6.9 | .93 | 3 | .21 | 145.9 | 5.86 | 45 | 3.08 |
| 15 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 135.8 | 5.45 | 37 | 2.53 |
| 16 | .0 | .00 | 0 | .00 | 2.6 | .36 | 1 | .07 | 127.2 | 5.11 | 34 | 2.33 |
| 17 | .0 | .00 | 0 | .00 | 2.9 | .39 | 1 | .07 | 155.1 | 6.23 | 39 | 2.67 |
| 18 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 114.0 | 4.58 | 27 | 1.85 |
| 19 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 111.6 | 4.48 | 25 | 1.71 |
| 20 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 84.0 | 3.37 | 18 | 1.23 |
| 21 | .0 | .00 | 0 | .00 | 3.6 | .49 | 1 | .07 | 73.9 | 2.97 | 15 | 1.03 |
| 22 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 88.0 | 3.53 | 17 | 1.16 |
| 23 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 59.4 | 2.39 | 11 | .75 |
| 24 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 50.6 | 2.03 | 9 | .62 |
| 25 | .0 | .00 | 0 | .00 | 4.1 | .56 | 1 | .07 | 29.3 | 1.18 | 5 | .34 |
| 26 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 36.6 | 1.47 | 6 | .41 |
| 27 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 |
| 28 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 6.7 | .27 | 1 | .07 |
| 29 | 78.2 | 3.10 | 1 | .11 | 4.9 | .66 | 1 | .07 | 20.6 | .83 | 3 | .21 |
| 30 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 |
| TOTALS | 2520.0 | | 937 | | 737.6 | | 1461 | | 2489.7 | | 1461 | |

TABLE 7 Cam distributions of daily rainfall, streamflow and Penman EO for the prediction period 01.01.70 to 31.12.75

CATCHMENT 5

DISTRIBUTIONS OF DAILY R,Q,E

| | RAIN | | | | FLOW | | | | EVAP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.70MM | | | | .17MM | | | | .281MM | | | |
| INTERVAL | MM | % | DAYS | % | MM | % | DAYS | % | MM | % | DAYS | % |
| 1 | 615.6 | 18.38 | 952 | 71.20 | 42.9 | 4.48 | 289 | 13.19 | 30.1 | .80 | 440 | 20.08 |
| 2 | 775.6 | 23.15 | 201 | 15.03 | 237.6 | 24.83 | 953 | 43.50 | 81.1 | 2.16 | 226 | 10.31 |
| 3 | 575.7 | 17.19 | 87 | 6.51 | 125.1 | 13.08 | 296 | 13.51 | 104.1 | 2.77 | 174 | 7.94 |
| 4 | 273.9 | 8.18 | 30 | 2.24 | 182.1 | 19.04 | 310 | 14.15 | 117.2 | 3.12 | 138 | 6.30 |
| 5 | 334.0 | 9.97 | 28 | 2.09 | 129.1 | 13.49 | 173 | 7.90 | 122.2 | 3.26 | 114 | 5.20 |
| 6 | 204.5 | 6.11 | 14 | 1.05 | 48.5 | 5.07 | 52 | 2.37 | 113.1 | 3.01 | 85 | 3.88 |
| 7 | 192.2 | 5.74 | 11 | .82 | 35.0 | 3.66 | 32 | 1.46 | 129.6 | 3.45 | 83 | 3.79 |
| 8 | 103.4 | 3.09 | 5 | .37 | 29.2 | 3.05 | 23 | 1.05 | 154.4 | 4.11 | 86 | 3.93 |
| 9 | 45.2 | 1.35 | 2 | .15 | 21.6 | 2.26 | 15 | .68 | 156.8 | 4.18 | 76 | 3.47 |
| 10 | 26.4 | .79 | 1 | .07 | 24.4 | 2.55 | 15 | .68 | 171.2 | 4.56 | 75 | 3.42 |
| 11 | 55.9 | 1.67 | 2 | .15 | 10.8 | 1.12 | 6 | .27 | 200.3 | 5.34 | 79 | 3.61 |
| 12 | 31.6 | .94 | 1 | .07 | 11.8 | 1.23 | 6 | .27 | 232.7 | 6.20 | 87 | 3.97 |
| 13 | .0 | .00 | 0 | .00 | 8.4 | .87 | 4 | .18 | 228.9 | 6.10 | 76 | 3.47 |
| 14 | 35.6 | 1.05 | 1 | .07 | 6.9 | .73 | 3 | .14 | 194.7 | 5.19 | 60 | 2.74 |
| 15 | 38.5 | 1.15 | 1 | .07 | 5.0 | .53 | 2 | .09 | 184.7 | 4.92 | 53 | 2.42 |
| 16 | 41.4 | 1.24 | 1 | .07 | 10.6 | 1.11 | 4 | .18 | 283.9 | 7.56 | 76 | 3.47 |
| 17 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 231.1 | 6.16 | 58 | 2.65 |
| 18 | .0 | .00 | 0 | .00 | 5.8 | .61 | 2 | .09 | 181.5 | 4.84 | 43 | 1.96 |
| 19 | .0 | .00 | 0 | .00 | 6.3 | .66 | 2 | .09 | 195.8 | 5.22 | 44 | 2.01 |
| 20 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 121.4 | 3.23 | 26 | 1.19 |
| 21 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 123.2 | 3.28 | 25 | 1.14 |
| 22 | .0 | .00 | 0 | .00 | 3.6 | .38 | 1 | .05 | 77.2 | 2.06 | 13 | .59 |
| 23 | .0 | .00 | 0 | .00 | 7.6 | .79 | 2 | .09 | 118.9 | 3.17 | 22 | 1.00 |
| 24 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 67.9 | 1.81 | 12 | .55 |
| 25 | .0 | .00 | 0 | .00 | 4.2 | .44 | 1 | .05 | 41.7 | 1.11 | 7 | .32 |
| 26 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 24.3 | .65 | 4 | .18 |
| 27 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 31.6 | .84 | 5 | .23 |
| 28 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 19.7 | .52 | 3 | .14 |
| 29 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 13.8 | .37 | 2 | .09 |
| 30 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | .3 | .01 | 0 | .00 |
| TOTALS | 3349.7 | | 1337 | | 956.7 | | 2191 | | 3753.1 | | 2191 | |

TABLE 9   Statistics of model performance on a daily time interval for the Cam

```
**********************************************************************
**********************************************************************
***                 INSTITUTE OF HYDROLOGY                         ***
***               CONCEPTUAL MODELLING PACKAGE                     ***
***                                                                ***
***             MODEL BEING USED: 3 STORE, INTENSITY, ROUTING      ***
***           LOCATION/CATCHMENT: ****** CAM 05 ******             ***
***             DURATION OF DATE: *** 0166 - 1275 ***              ***
***               DATA FREQUENCY:  DAILY                           ***
**********************************************************************
**********************************************************************


YEAR  COEFF  CORLL  CUMUL  CUMUL   YEAR   CUMUL   YEAR   CUMUL   MEAN   CUMUL  MEAN   CUMUL  RUNOFF   PRED   ERROR  %ERROR
        DET  COEFF    DET  CORLL    SEE     SEE  D-STAT  D-STAT  FLOW   MN.FL  PR.FL  PR.FL

1966   .815   .903   .815   .913   .006   .006  1.138   1.138   .463   .463   .472   .472  168.9   172.4     3.5    2.1
1967   .783   .886   .805   .907   .005   .004   .843   1.018   .435   .449   .455   .463  158.6   165.1     7.5    4.7
1968   .797   .893   .816   .895   .009   .004  1.617   1.354   .560   .486   .529   .485  204.8   193.5   -11.4   -5.6
1969   .824   .897   .817   .877   .008   .004  1.915   1.373   .562   .505   .583   .510  205.2   212.9     7.7    3.8
1970   .530   .751   .751   .867   .013   .004   .729   1.100   .568   .517   .575   .523  207.2   209.7     2.5    1.2
1971   .826   .909   .763   .874   .007   .004  1.001   1.089   .520   .518   .506   .523  189.7   184.5    -5.2   -2.7
1972   .372   .934   .779   .883   .005   .003   .925   1.081   .371   .497   .415   .503  135.7   148.1    12.4    9.1
1973   .179  -.422   .797   .893   .003   .003   .833   1.066   .181   .457   .164   .461   66.1    59.8    -6.3   -9.5
1974   .839   .921   .808   .899   .011   .003  1.039   1.062   .427   .454   .416   .456  155.8   151.6    -4.0   -2.5
1975   .790   .889   .805   .898   .011   .003  1.301   1.102   .554   .464   .616   .472  202.3   224.8    22.5   11.1

@XQT TCE.STATS
```

TABLE 11 Statistics of model performance on a monthly time interval for the Cam

```
*******************************************************************
*******************************************************************
***               INSTITUTE OF HYDROLOGY                        ***
***             CONCEPTUAL MODELLING PACKAGE                    ***
***                                                             ***
***          MODEL BEING USED: 3 STORE, INTENSITY, ROUTING      ***
***        LOCATION/CATCHMENT: ****** CAM US ******             ***
***          DURATION OF DATA: *** 0166 - 1275 ***              ***
***            DATA FREQUENCY:  MONTHLY                         ***
*******************************************************************
*******************************************************************
```

```
YEAR  COEFF  CORLL  CUMUL  CUMUL  YEAR   CUMUL  YEAR    CUMUL   MEAN   CUMUL_  MEAN   CUMUL  RUNOFF  PRED   ERROR  %ERROR
       DET   COEFF   DET   CORLL   SEE    SEE  D-STAT  D-STAT  FLOW   MN.FL  PR.FL  PR.FL

1966  .931   .955   .934   .956   .466   .466  1.655   1.655  14.07  14.07  14.37  14.37  168.9  172.8    3.5    2.1
1967  .959   .979   .944   .971   .279   .259   .985   1.687  13.22  13.65  13.44  14.13  158.6  165.1    7.5    4.7
1968  .993   .983   .938   .956   .544   .241  1.163   1.573  17.07  14.79  16.12  14.78  204.8  193.5  -11.4   -5.6
1969  .958   .984   .949   .979   .446   .207  2.384   1.796  17.10  15.37  17.75  15.52  205.2  212.9    7.7    3.8
1970  .937   .933   .935   .957   .757   .217  1.289   1.589  17.27  15.75  17.48  15.91  207.2  209.7    2.5    1.2
1971  .945   .972   .937   .959   .511   .197  1.189   1.677  15.81  15.76  15.38  15.82  199.7  184.5   -5.2   -2.7
1972  .931   .970   .941   .971   .473   .179   .351   1.519  11.31  15.12  12.34  15.32  135.7  148.1   12.4    9.1
1973  .233  -.483   .950   .975   .373   .163  1.862   1.545   5.56  13.92   4.98  14.77   66.1   59.9   -6.3   -9.5
1974  .909   .953   .943   .971   .883   .170   .999   1.475  12.98  13.81  12.65  13.86  155.8  151.8   -4.0   -2.5
1975  .932   .965   .942   .973   .811   .170   .313   1.313  16.86  14.12  18.73  14.35  202.3  224.8   22.5   11.1
```

# APPENDIX II

# RAY DATA SUMMARIES AND MODEL FIT STATISTICS

TABLE 1 Ray monthly rainfall and streamflow with means and standard deviations from 01.64 to 12.75

CATCHMENT 2 MONTHLY RAINFALL AND STREAMFLOW

| YEAR | | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL | RDAYS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | R | 16.0 | 23.3 | 96.3 | 58.4 | 42.1 | 74.4 | 91.6 | 18.2 | 14.5 | 20.7 | 21.3 | 42.1 | 510.5 | 207 |
| | Q | 9.5 | 8.9 | 62.4 | 18.8 | 2.2 | 3.4 | 11.0 | .1 | .0 | .6 | .1 | .3 | 116.7 | |
| 1965 | R | 56.2 | 11.5 | 48.1 | 50.5 | 55.7 | 63.9 | 105.4 | 54.5 | 83.6 | 12.7 | 52.2 | 103.6 | 677.9 | 248 |
| | Q | 5.2 | .9 | 16.1 | 3.9 | 4.6 | .7 | 9.0 | 1.5 | 12.1 | 3.0 | 14.9 | 75.4 | 148.3 | |
| 1966 | R | 29.5 | 77.6 | 15.3 | 84.4 | 66.2 | 65.7 | 64.6 | 132.0 | 45.7 | 118.1 | 41.5 | 76.1 | 736.5 | 242 |
| | Q | 27.0 | 59.4 | 4.3 | 45.6 | 22.1 | 1.1 | .3 | 7.2 | 1.0 | 63.9 | 15.2 | 54.0 | 301.0 | |
| 1967 | R | 33.3 | 53.1 | 30.3 | 43.6 | 104.7 | 32.5 | 88.2 | 37.3 | 51.2 | 116.1 | 34.3 | 59.0 | 688.6 | 242 |
| | Q | 23.9 | 34.3 | 18.5 | 5.6 | 22.5 | 1.2 | 1.9 | .2 | .2 | 18.4 | 19.8 | 33.2 | 179.7 | |
| 1968 | R | 54.7 | 16.8 | 25.7 | 50.8 | 64.1 | 65.5 | 121.6 | 72.7 | 114.2 | 54.0 | 57.6 | 64.1 | 761.6 | 246 |
| | Q | 47.1 | 9.4 | 2.0 | 3.3 | 14.5 | 1.2 | 44.7 | 3.0 | 32.7 | 22.7 | 35.3 | 44.2 | 261.9 | |
| 1969 | R | 70.8 | 36.9 | 49.9 | 32.7 | 104.5 | 24.8 | 43.8 | 69.7 | 12.3 | 3.5 | 52.2 | 60.7 | 560.7 | 222 |
| | Q | 53.1 | 32.1 | 33.0 | 4.3 | 26.2 | 2.3 | .3 | 2.3 | .1 | .1 | .4 | 7.6 | 173.5 | |
| 1970 | R | 61.1 | 51.3 | 43.1 | 81.0 | 19.3 | 32.7 | 50.8 | 66.8 | 31.8 | 19.7 | 142.7 | 37.4 | 638.3 | 247 |
| | Q | 28.3 | 34.6 | 28.0 | 40.3 | 1.7 | .1 | .1 | .3 | .1 | .1 | 17.1 | 19.0 | 169.9 | |
| 1971 | R | 95.9 | 16.9 | 42.9 | 41.1 | 28.5 | 97.8 | 43.4 | 98.1 | 16.9 | 75.5 | 76.2 | 22.9 | 656.2 | 197 |
| | Q | 67.2 | 17.0 | 21.0 | 8.6 | .5 | 9.5 | .4 | 3.3 | .2 | 8.5 | 30.6 | 10.8 | 177.1 | |
| 1972 | R | 62.8 | 47.5 | 54.0 | 42.2 | 53.3 | 36.9 | 69.9 | 26.3 | 51.4 | 19.3 | 63.5 | 67.3 | 576.5 | 225 |
| | Q | 25.7 | 34.8 | 24.3 | 8.5 | 4.4 | .4 | .4 | 1.2 | .1 | .1 | 2.2 | 27.5 | 130.6 | |
| 1973 | R | 24.2 | 13.3 | 13.2 | 43.6 | 51.8 | 70.7 | 73.1 | 35.3 | 33.2 | 24.7 | 36.5 | 40.5 | 464.7 | 195 |
| | Q | 3.2 | 5.9 | 2.2 | 1.3 | 3.4 | 1.5 | 3.9 | .3 | .0 | .1 | .2 | 2.9 | 30.0 | |
| 1974 | R | 64.4 | 83.1 | 36.5 | 7.0 | 31.5 | 89.8 | 42.9 | 96.5 | 114.3 | 76.9 | 114.2 | 39.6 | 794.6 | 247 |
| | Q | 27.4 | 41.7 | 22.0 | .4 | .2 | 1.2 | .4 | .6 | 17.9 | 38.9 | 79.8 | 13.5 | 246.2 | |
| 1975 | R | 68.1 | 33.2 | 97.5 | 46.0 | 40.1 | 10.2 | 58.2 | 25.7 | 78.9 | 31.3 | 38.4 | 23.3 | 517.9 | 223 |
| | Q | 44.2 | 23.0 | 58.0 | 21.2 | 4.0 | .1 | .5 | .0 | .3 | .0 | .2 | .5 | 152.1 | |
| MEAN | R | 53.1 | 39.7 | 44.3 | 48.5 | 55.2 | 55.4 | 71.1 | 58.5 | 52.7 | 46.0 | 60.7 | 52.9 | 637.3 | 228 |
| | Q | 32.0 | 25.2 | 24.3 | 13.5 | 8.9 | 1.8 | 6.1 | 1.7 | 5.4 | 13.0 | 18.0 | 24.1 | 173.9 | |
| S.D. | R | 23.0 | 24.2 | 23.7 | 20.4 | 27.1 | 27.3 | 25.9 | 30.2 | 36.5 | 41.1 | 35.2 | 28.1 | 111.1 | 20 |
| | Q | 20.4 | 17.3 | 17.5 | 15.2 | 9.7 | 2.4 | 12.7 | 2.1 | 16.4 | 26.3 | 23.0 | 23.7 | 71.5 | |

TABLE 3 Ray distributions of daily rainfall, streamflow and Penman EO for the period 01.01.64 to 31.12.75

CATCHMENT 2

DISTRIBUTIONS OF DAILY R.O.F

| | RAIN | | | | FLOW | | | | EVAP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.43MM | | | | .73MM | | | | .209MM | | | |
| INTERVAL | MM | % | DAYS | % | MM | % | DAYS | % | MM | % | DAYS | % |
| 1 | 1007.2 | 13.14 | 1801 | 65.61 | 407.9 | 19.54 | 3754 | 85.65 | 69.7 | .91 | 856 | 19.53 |
| 2 | 1552.4 | 20.44 | 451 | 16.43 | 287.6 | 13.78 | 280 | 6.39 | 181.7 | 2.36 | 492 | 11.27 |
| 3 | 1183.6 | 15.43 | 199 | 7.25 | 190.1 | 9.11 | 105 | 2.40 | 212.1 | 2.76 | 345 | 7.87 |
| 4 | 1105.3 | 14.47 | 131 | 4.77 | 139.5 | 6.69 | 55 | 1.25 | 217.7 | 2.83 | 251 | 5.73 |
| 5 | 561.2 | 7.34 | 53 | 1.93 | 179.4 | 8.60 | 55 | 1.25 | 228.7 | 2.97 | 205 | 4.68 |
| 6 | 423.2 | 5.54 | 32 | 1.17 | 123.5 | 5.92 | 31 | .71 | 295.7 | 3.84 | 217 | 4.95 |
| 7 | 348.5 | 4.55 | 22 | .80 | 156.6 | 7.51 | 33 | .75 | 294.8 | 3.83 | 182 | 4.15 |
| 8 | 235.6 | 3.09 | 13 | .47 | 99.4 | 4.76 | 18 | .41 | 333.0 | 4.33 | 178 | 4.06 |
| 9 | 248.3 | 3.25 | 12 | .44 | 42.6 | 2.04 | 7 | .16 | 350.4 | 4.55 | 166 | 3.79 |
| 10 | 230.3 | 3.01 | 10 | .36 | 70.0 | 3.35 | 10 | .23 | 374.5 | 4.86 | 159 | 3.63 |
| 11 | 153.3 | 2.01 | 6 | .22 | 30.6 | 1.46 | 4 | .09 | 315.5 | 4.10 | 121 | 2.76 |
| 12 | 111.4 | 1.46 | 4 | .15 | 41.5 | 1.99 | 5 | .11 | 444.9 | 5.78 | 156 | 3.56 |
| 13 | 122.4 | 1.60 | 4 | .15 | 27.9 | 1.34 | 3 | .07 | 471.9 | 6.13 | 152 | 3.47 |
| 14 | 33.5 | .44 | 1 | .04 | 29.9 | 1.43 | 3 | .07 | 476.3 | 6.19 | 142 | 3.24 |
| 15 | .0 | .00 | 0 | .00 | 31.7 | 1.52 | 3 | .07 | 506.1 | 6.57 | 140 | 3.19 |
| 16 | 75.9 | .99 | 2 | .07 | 44.9 | 2.15 | 4 | .09 | 394.4 | 5.12 | 102 | 2.33 |
| 17 | .0 | .00 | 0 | .00 | 35.9 | 1.72 | 3 | .07 | 387.4 | 5.03 | 94 | 2.14 |
| 18 | .0 | .00 | 0 | .00 | 50.5 | 2.43 | 4 | .09 | 362.3 | 4.71 | 83 | 1.89 |
| 19 | .0 | .00 | 0 | .00 | 26.7 | 1.28 | 2 | .05 | 341.7 | 4.43 | 74 | 1.69 |
| 20 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 389.1 | 5.05 | 80 | 1.83 |
| 21 | .0 | .00 | 0 | .00 | 15.3 | .73 | 1 | .02 | 250.8 | 3.26 | 49 | 1.12 |
| 22 | 53.3 | .70 | 1 | .04 | 15.5 | .75 | 1 | .02 | 256.5 | 3.33 | 48 | 1.10 |
| 23 | 54.0 | .71 | 1 | .04 | .0 | .00 | 0 | .00 | 167.9 | 2.18 | 30 | .68 |
| 24 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 110.6 | 1.44 | 19 | .43 |
| 25 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 116.3 | 1.51 | 19 | .43 |
| 26 | 53.5 | .82 | 1 | .04 | 18.5 | .89 | 1 | .02 | 88.5 | 1.15 | 14 | .32 |
| 27 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 26.3 | .34 | 4 | .09 |
| 28 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 6.8 | .09 | 1 | .02 |
| 29 | 70.4 | .92 | 1 | .04 | 21.1 | 1.01 | 1 | .02 | 14.7 | .19 | 2 | .05 |
| 30 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 14.5 | .19 | 2 | .05 |
| TOTALS | 7644.0 | | 2745 | | 2087.2 | | 4383 | | 7699.7 | | 4383 | |

**TABLE 5** Ray distribution of daily rainfall, streamflow and Penman EO for the calibration period 01.01.64 to 31.12.67

```
                                              CATCHMENT  2

                                      DISTRIBUTIONS OF DAILY R.Q.E

                      RAIN                                     FLOW                                        EVAP

                     2.43MM                                    .73MM                                      .289MM

INTERVAL     MM       %       DAYS     %          MM        %       DAYS      %           MM        %        DAYS      %


    1       361.7   13.48     606    64.33       136.8    18.35     1228    84.05         22.5     .86        299    20.47
    2       539.7   20.11     157    16.67       104.0    13.95      102     6.98         55.6    2.12        149    10.20
    3       448.0   16.69      77     8.17        73.6     9.87       41     2.81         65.3    2.49        107     7.32
    4       435.9   16.24      52     5.52        38.2     5.12       15     1.03         86.2    3.29         99     6.78
    5       157.4    5.87      15     1.59        72.0     9.65       22     1.51         67.9    2.59         61     4.18
    6       155.5    5.83      12     1.27        51.9     6.96       13      .89         80.6    3.08         59     4.04
    7        97.5    3.63       6      .64        71.0     9.52       15     1.03        103.3    3.94         64     4.38
    8        73.5    2.74       4      .42        39.0     5.23        7      .48         91.3    3.49         49     3.35
    9        62.9    2.34       3      .32         5.9      .80        1      .07        123.5    4.72         59     4.04
   10        67.9    2.53       3      .32        35.1     4.70        5      .34         93.8    3.58         40     2.74
   11        49.7    1.85       2      .21         7.8     1.05        1      .07        107.2    4.09         41     2.81
   12          .0     .00       0      .00        33.2     4.45        4      .27        168.5    6.43         59     4.04
   13        61.6    2.30       2      .21        18.4     2.47        2      .14        155.5    5.94         50     3.42
   14          .0     .00       0      .00        10.0     1.34        1      .07        177.9    6.79         53     3.63
   15          .0     .00       0      .00        10.9     1.46        1      .07        170.5    6.51         47     3.22
   16          .0     .00       0      .00          .0      .00        0      .00        162.6    6.21         42     2.87
   17          .0     .00       0      .00        12.2     1.63        1      .07        123.5    4.72         30     2.05
   18          .0     .00       0      .00        12.4     1.67        1      .07        134.6    5.14         31     2.12
   19          .0     .00       0      .00        13.3     1.78        1      .07        133.5    5.10         29     1.98
   20          .0     .00       0      .00          .0      .00        0      .00        165.5    6.32         34     2.33
   21          .0     .00       0      .00          .0      .00        0      .00         92.4    3.53         18     1.23
   22        53.3    1.98       1      .11          .0      .00        0      .00         80.3    3.06         15     1.03
   23        54.1    2.01       1      .11          .0      .00        0      .00         45.0    1.72          8      .55
   24          .0     .00       0      .00          .0      .00        0      .00         17.5     .67          3      .21
   25          .0     .00       0      .00          .0      .00        0      .00         36.7    1.40          6      .41
   26        63.0    2.35       1      .11          .0      .00        0      .00         43.0    1.64          7      .48
   27          .0     .00       0      .00          .0      .00        0      .00          6.5     .25          1      .07
   28          .0     .00       0      .00          .0      .00        0      .00           .0     .00          0      .00
   29          .0     .00       0      .00          .0      .00        0      .00          7.2     .27          1      .07
   30          .0     .00       0      .00          .0      .00        0      .00           .0     .00          0      .00

TOTALS     2683.5             942                745.8              1461                2619.7               1461
```

TABLE 7 Ray distribution of daily rainfall, streamflow and Penman EO for the prediction period 01.01.68 to 31.12.75

CATCHMENT 2 - MEAN MONTHLY RAINFALL AND STREAMFLOW

| | | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL | RDAYS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | R | 62.7 | 37.3 | 44.0 | 43.1 | 49.1 | 53.6 | 63.0 | 61.3 | 54.1 | 35.6 | 72.7 | 43.6 | 620.1 | 225 |
| | Q | 39.7 | 24.8 | 23.8 | 11.0 | 7.0 | 2.0 | 6.3 | 1.4 | 6.4 | 8.8 | 20.7 | 15.8 | 167.7 | |
| S.D. | R | 19.8 | 22.0 | 21.9 | 20.4 | 28.8 | 31.9 | 26.5 | 29.3 | 42.2 | 29.0 | 37.5 | 18.6 | 112.6 | 21 |
| | Q | 20.2 | 13.1 | 17.8 | 13.5 | 9.2 | 2.9 | 15.5 | 1.3 | 12.3 | 14.6 | 27.8 | 14.4 | 71.5 | |

MEAN MONTHLY PENMAN EO

| | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | 6.6 | 10.5 | 33.1 | 61.8 | 100.0 | 124.0 | 116.5 | 88.9 | 52.6 | 24.5 | 10.0 | 6.5 | 635.0 |
| S.D. | 2.1 | 2.5 | 7.4 | 4.7 | 8.6 | 20.8 | 16.1 | 15.6 | 3.8 | 2.9 | 2.6 | 2.7 | 39.1 |

TABLE 9 Statistics of model perormance on a daily time interval for the Ray

```
*************************************************************************
*************************************************************************
***                   INSTITUTE OF HYDROLOGY                          ***
***               CONCEPTUAL MODELLING PACKAGE                        ***
***                                                                   ***
***          MODEL BEING USED: 3 STORE, INTENSITY, ROUTING            ***
***        LOCATION/CATCHMENT: ****** RAY U2 ******                   ***
***          DURATION OF DATA: *** 0164 - 1275 ***                    ***
***            DATA FREQUENCY:  DAILY                                 ***
*************************************************************************
*************************************************************************
```

```
YEAR  COEFF  CORLL  CUMUL  CUMUL   YEAR   CUMUL   YEAR   CUMUL   MEAN   CUMUL   MEAN   CUMUL  RUNOFF   PRED   ERROR  %ERROR
        DET  COEFF    DET  CORLL    SEE     SEE D-STAT  D-STAT   FLOW   MN.FL  PR.FL   PR.FL

1964   .734   .857   .734   .857   .033    .033  2.289   2.289   .319    .319   .318   .318   116.7   115.6    -1.1     -.9
1965   .755   .875   .747   .854   .026    .021  1.619   2.036   .406    .363   .321   .321   148.3   117.3   -31.0   -20.9
1966   .776   .881   .758   .876   .042    .020  1.727   1.886   .825    .517   .770   .475   301.0   281.1   -19.9    -6.6
1967   .699   .935   .755   .859   .033    .017  1.744   1.852   .492    .511   .537   .487   179.7   196.1    16.4     9.2
1968   .588   .767   .693   .832   .069    .019  1.352   1.601   .716    .552   .759   .541   261.9   277.5    15.6     6.0
1969   .527   .772   .684   .827   .041    .017  1.764   1.626   .475    .534   .438   .524   173.5   160.0   -13.5    -7.8
1970   .550   .745   .672   .823   .041    .016  1.323   1.586   .466    .525   .392   .525   169.9   143.2   -26.7   -15.7
1971   .517   .905   .676   .819   .041    .015  2.394   1.679   .485    .523   .571   .513   177.1   208.8    31.7    17.7
1972   .470   .685   .661   .813   .034    .014  1.238   1.644   .357    .505   .437   .554   130.6   157.4    26.8    20.5
1973   .235  -.395   .662   .814   .013    .012  1.051   1.640   .062    .462   .125   .466    30.0    45.6    15.6    51.7
1974   .817   .904   .637   .833   .041    .012  2.514   1.707   .675    .482   .725   .492   246.2   265.1    18.9     7.7
1975   .327   .913   .679   .836   .028    .011  2.573   1.745   .417    .476   .414   .484   152.3   151.7     -.6     -.5

@XQT PCE.STATS
```

TABLE 11 Statistics of model performance on a monthly time interval for the Ray

```
*******************************************************************
*******************************************************************
***                 INSTITUTE OF HYDROLOGY                      ***
***              CONCEPTUAL MODELLING PACKAGE                   ***
***                                                             ***
***          MODEL BEING USED: 3 STORE, INTENSITY, ROUTING      ***
***         LOCATION/CATCHMENT: ****** RAY C2 ******            ***
***          DURATION OF DATA: *** 1964 - 1975 ***              ***
***            DATA FREQUENCY:  MONTHLY                         ***
*******************************************************************
*******************************************************************


YEAR  COEFF  CORLL  CUMUL  CUMUL   YEAR  CUMUL   YEAR   CUMUL   MEAN   CUMU_   MEAN   CUMUL  RUNOFF   PRED   ERROR  %ERROR
        DET  COEFF    DET  CORLL    SEE    SEE  F-STAT  D-STAT  FLOW   MN.FL   PR.FL  PR.FL

1964   .943   .973   .946   .973  1.223  1.223  1.918   1.918   9.73    9.73    9.71   9.71  116.7   116.6     -.2     -.1
1965   .950   .975   .939   .978  1.384   .980  1.185   1.507  12.36   11.04    9.78   9.74  148.3   117.3   -31.0   -20.9
1966   .993   .945   .932   .955  2.421   .953  3.719   1.661  25.69   15.93   23.43  14.31  301.0   281.1   -19.9    -6.6
1967   .865   .933   .925   .962  1.412   .783  2.381   1.778  14.97   15.69   16.39  14.82  179.7   195.1    16.5     9.2
1968   .311   .956   .917   .952  2.447   .771  2.311   2.043  21.83   16.84   23.13  16.48  261.9   277.5    15.6     6.0
1969   .953   .981   .916   .957  1.181   .666  1.833   2.155  14.46   16.41   13.34  15.95  173.5   160.0   -13.5    -7.8
1970   .331   .739   .913   .956  1.626   .609   .590   1.970  14.16   16.09   11.93  15.38  169.9   143.2   -26.7   -15.7
1971   .964   .982   .919   .959  1.090   .587   .793   1.923  14.76   15.97   17.36  15.63  177.1   208.4    31.3    17.7
1972   .553   .911   .906   .952  2.343   .541  1.322   1.943  10.88   15.36   13.12  15.35  130.6   157.4    26.8    20.5
1973   .177   .484   .939   .953   .692   .491  1.199   1.947   2.50   14.37    3.79  14.19   30.0    45.5    15.5    51.7
1974   .954   .932   .918   .958  1.391   .461   .931   1.963  20.52   14.66   22.09  14.91  246.2   265.1    18.9     7.7
1975   .957   .983   .922   .950  1.101   .431  2.611   1.931  12.67   14.49   12.61  14.72  152.1   151.3     -.8     -.5

@XQT 3CE.PFMT
```

# APPENDIX III

## COMPUTER GRAPH OUTPUT

## APPENDIX III

## COMPUTER GRAPH OUTPUT

| *Figure* | *Year* | *Interval* | *Correlation* coefficient | *PE* | *DWS* | Mean flow |
|---|---|---|---|---|---|---|
| CAM | | | | | | |
| 1a,b,c | 0166-1275 | Monthly | 0.970 | 0.131 | 1.310 | 14.119 |
| 2 | 1966 | Daily | 0.903 | 0.265 | 1.138 | 0.465 |
| 3 | 1970 | Daily | 0.761 | 0.436 | 0.729 | 0.568 |
| 4 | 1972 | Daily | 0.934 | 0.258 | 0.925 | 0.371 |
| RAY | | | | | | |
| 1a,b,c | 0164-1275 | Monthly | 0.960 | 1.953 | 1.931 | 14.494 |
| 2 | 1966 | Daily | 0.881 | 0.961 | 1.727 | 0.825 |
| 3 | 1973 | Daily | -0.486 | 2.467 | 1.051 | 0.082 |
| 4 | 1975 | Daily | 0.910 | 1.261 | 2.573 | 0.417 |

KEY

RAINFALL ——— (bar chart)

OBS. RUNOFF ———

PRED. RUNOFF - - - -

FIGURE 1a: Plot of monthly totals of rainfall, observed and predicted flow, 01.66 to 12.69

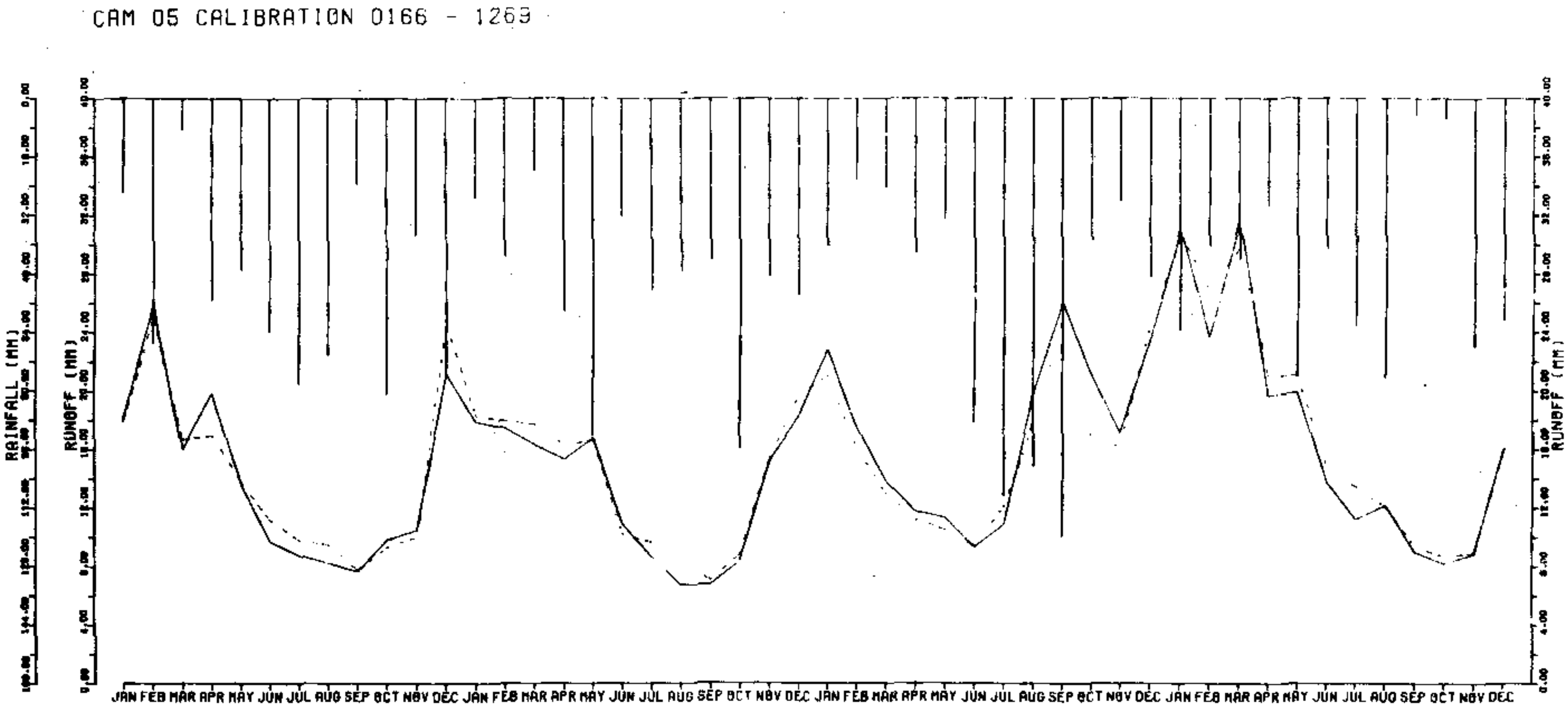

FIGURE 1c: Plot of monthly totals of rainfall, observed and predicted flow, 01.74 to 12.75

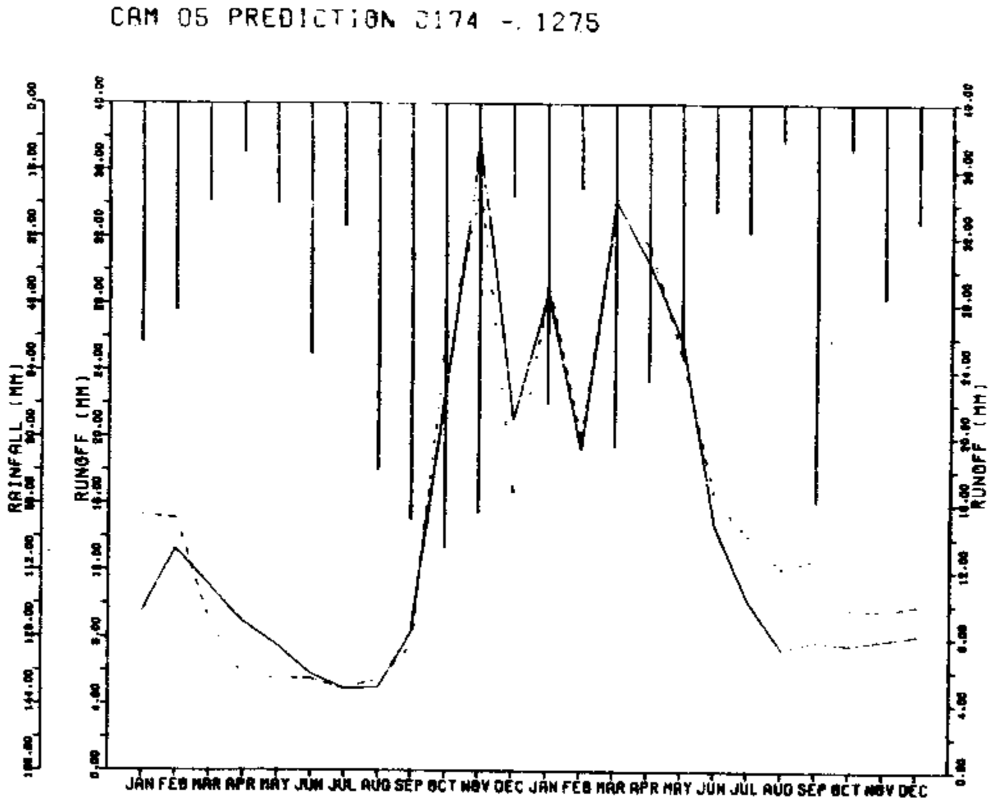

FIGURE 3:  Daily plot of worst fit year in the prediction period

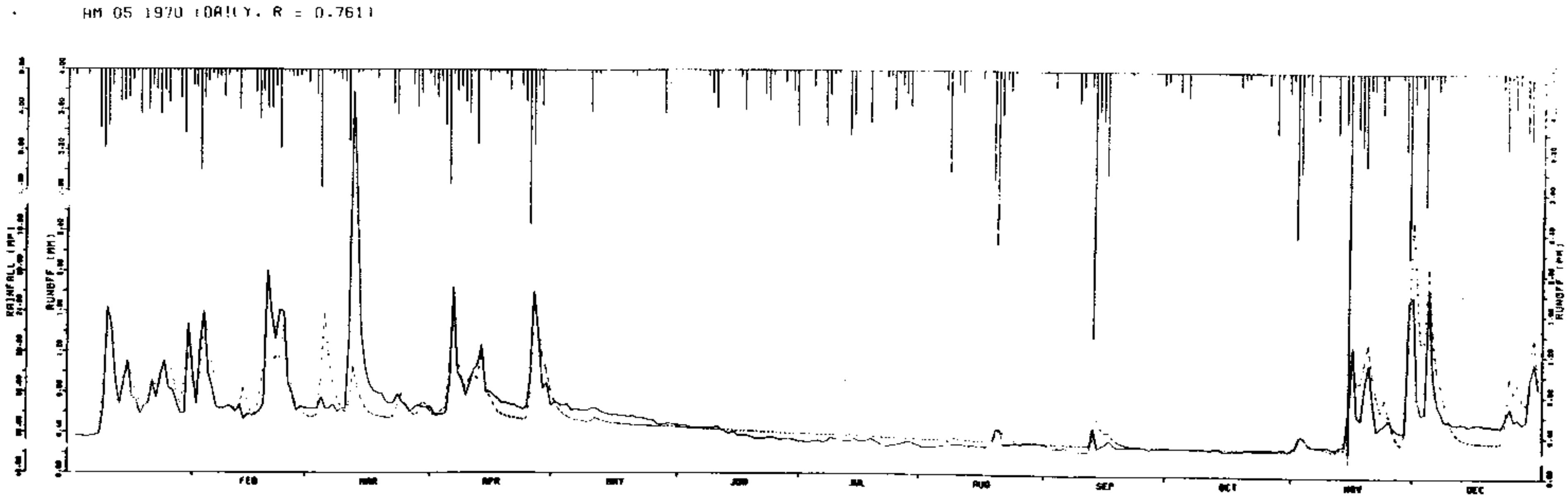

FIGURE 1a: Plot of monthly totals of rainfall, observed and predicted flow, 01.64 to 12.67

RAY 02 CALIBRATION 0164 - 1267

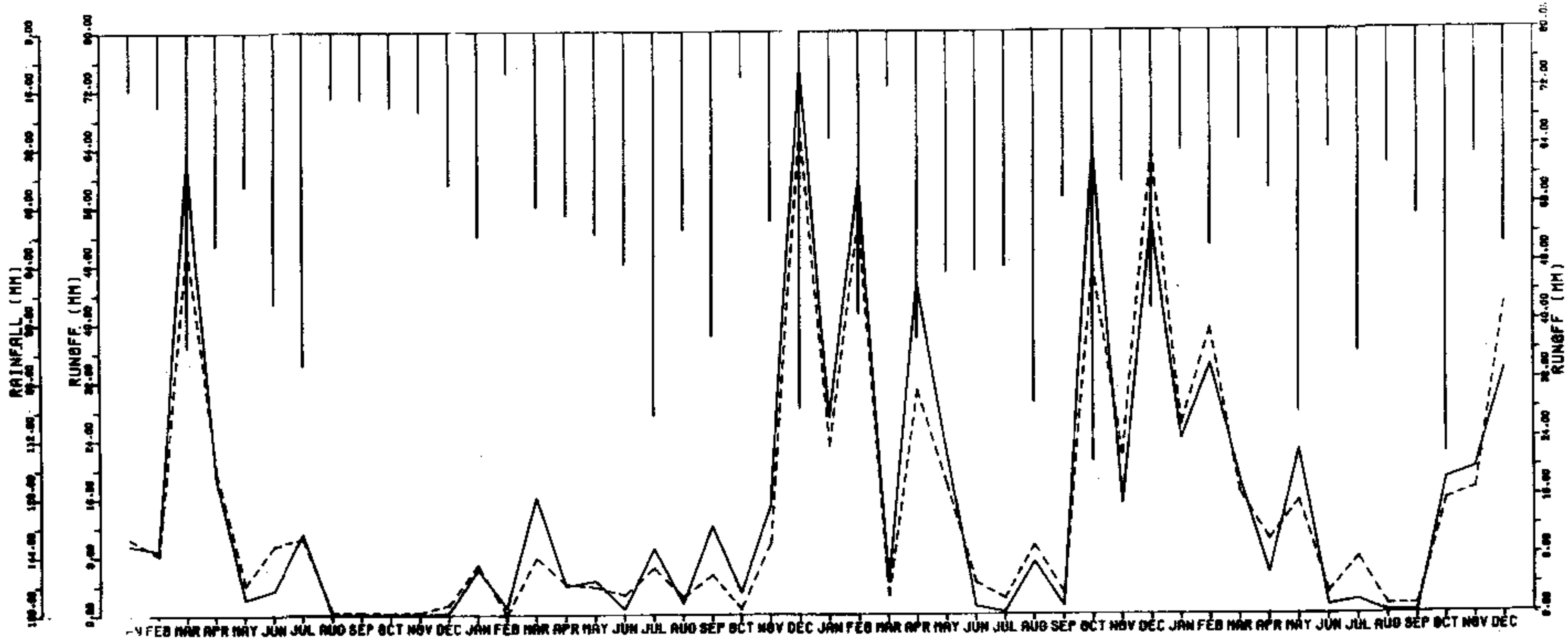

FIGURE 1c: Plot of monthly otals of rainfall, observed and predicted flow, 01.72 to 12.75

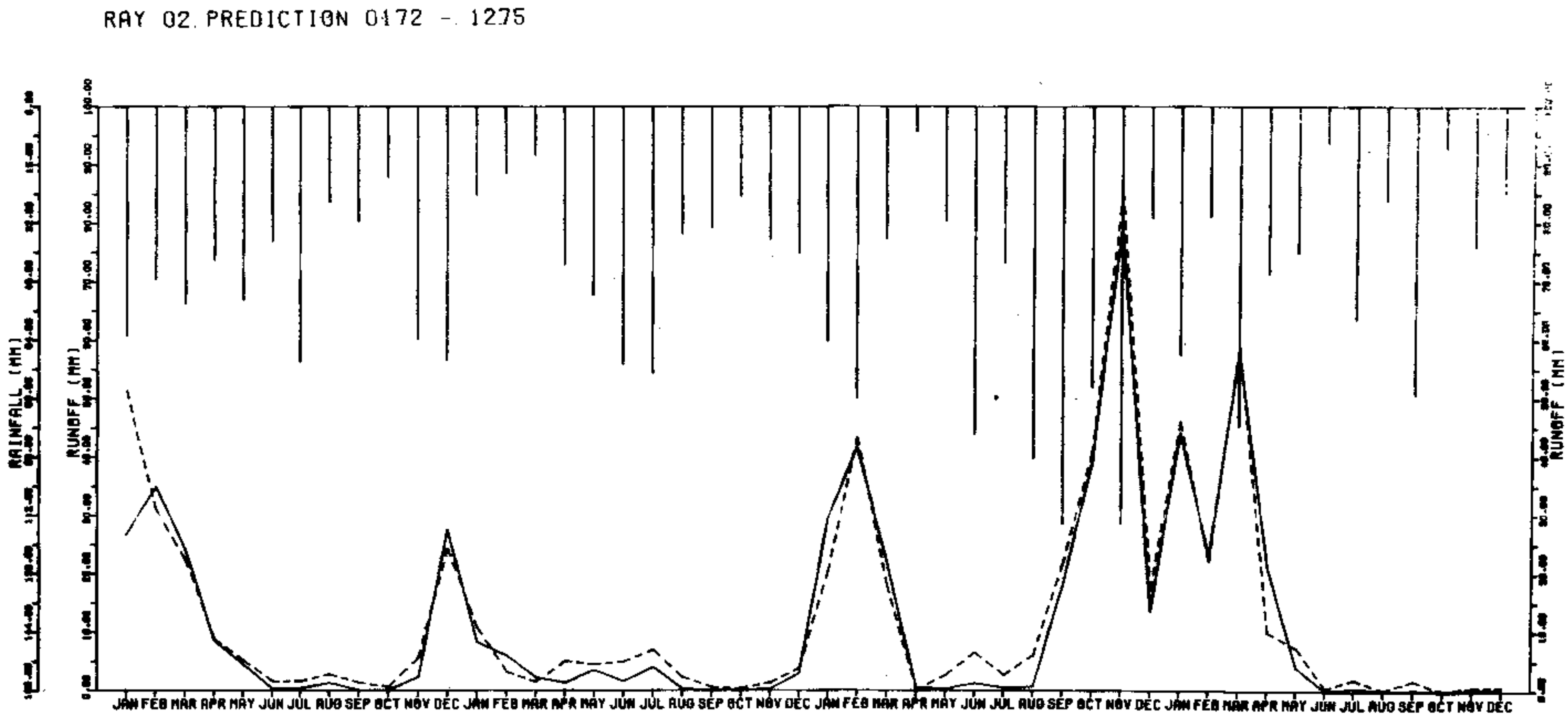

FIGURE 3: Daily plot of worst fit year in the prediction period

RAY 02 1973 (DAILY R = -0.486)

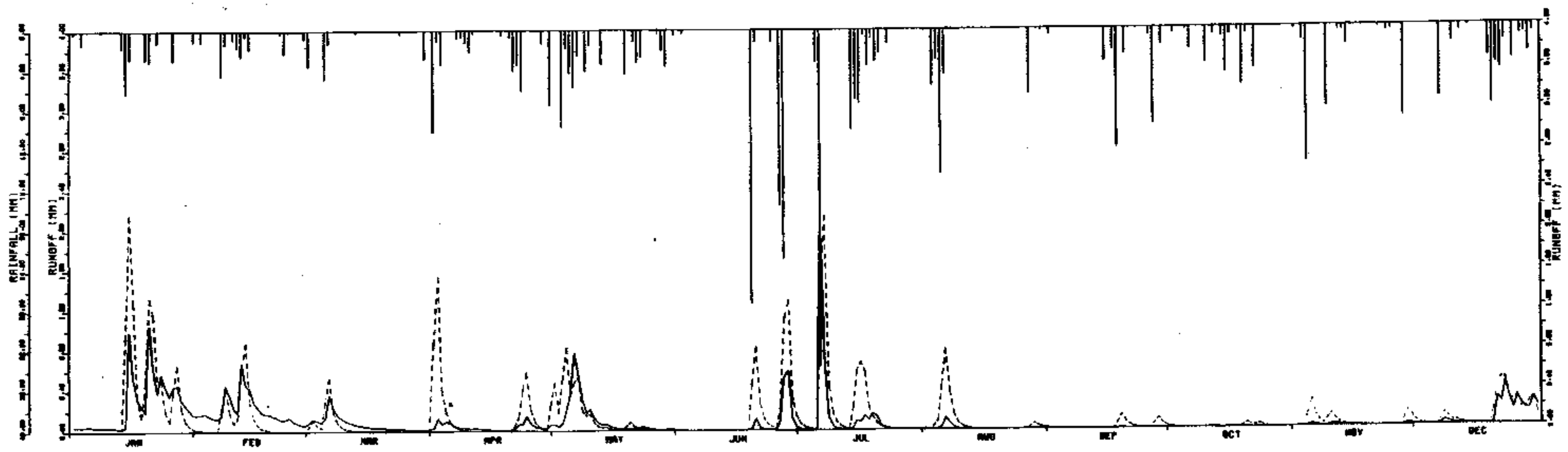

FIGURE 4: Daily plot of best fit year in the prediction period

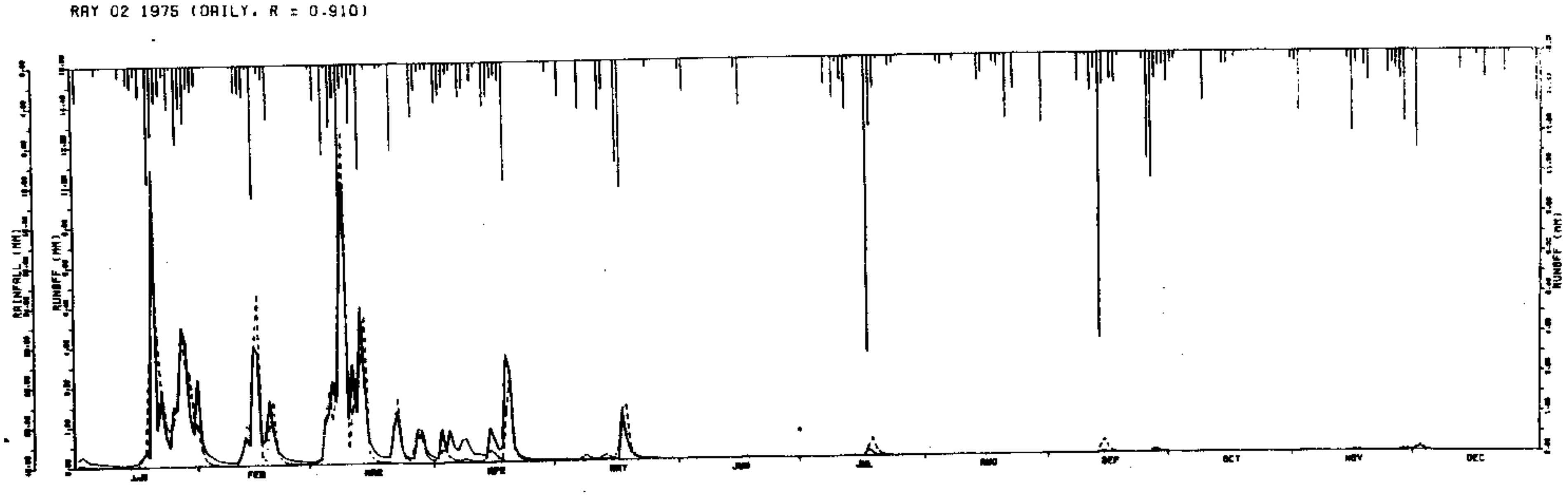

FIGURE 2: Daily plot of best fit year in the calibration period

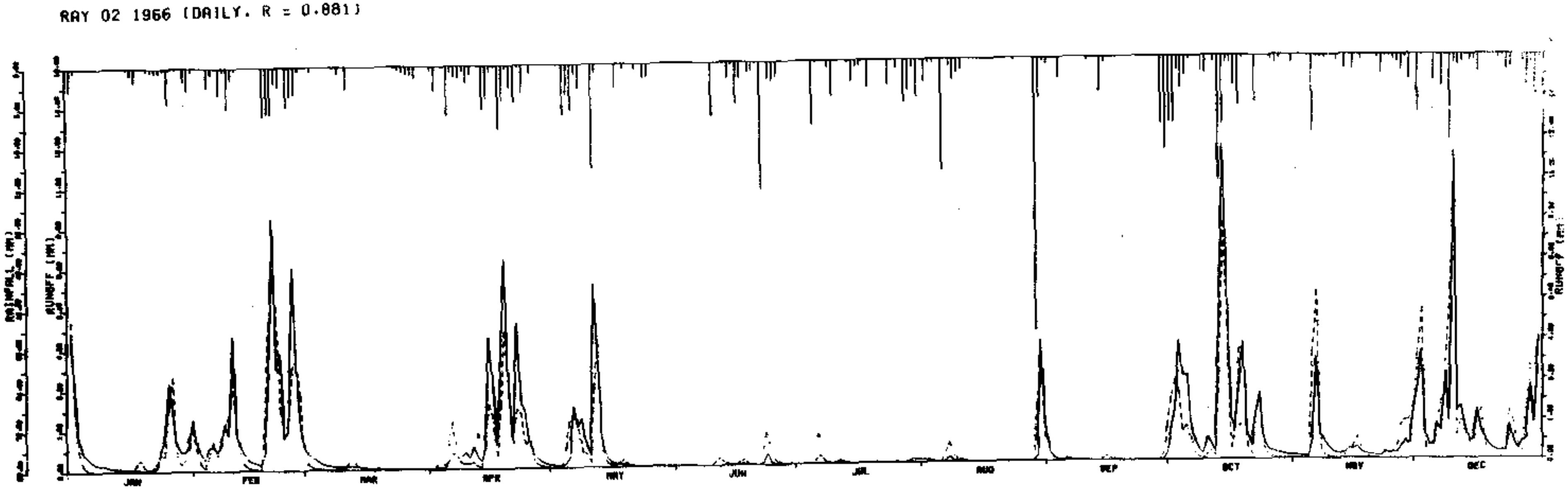

FIGURE 1b: Plot of monhtly totals of rainfall, observed and predicted flow, 01.68 to 12.71

RAY 02 PREDICTION 0168 - 1271

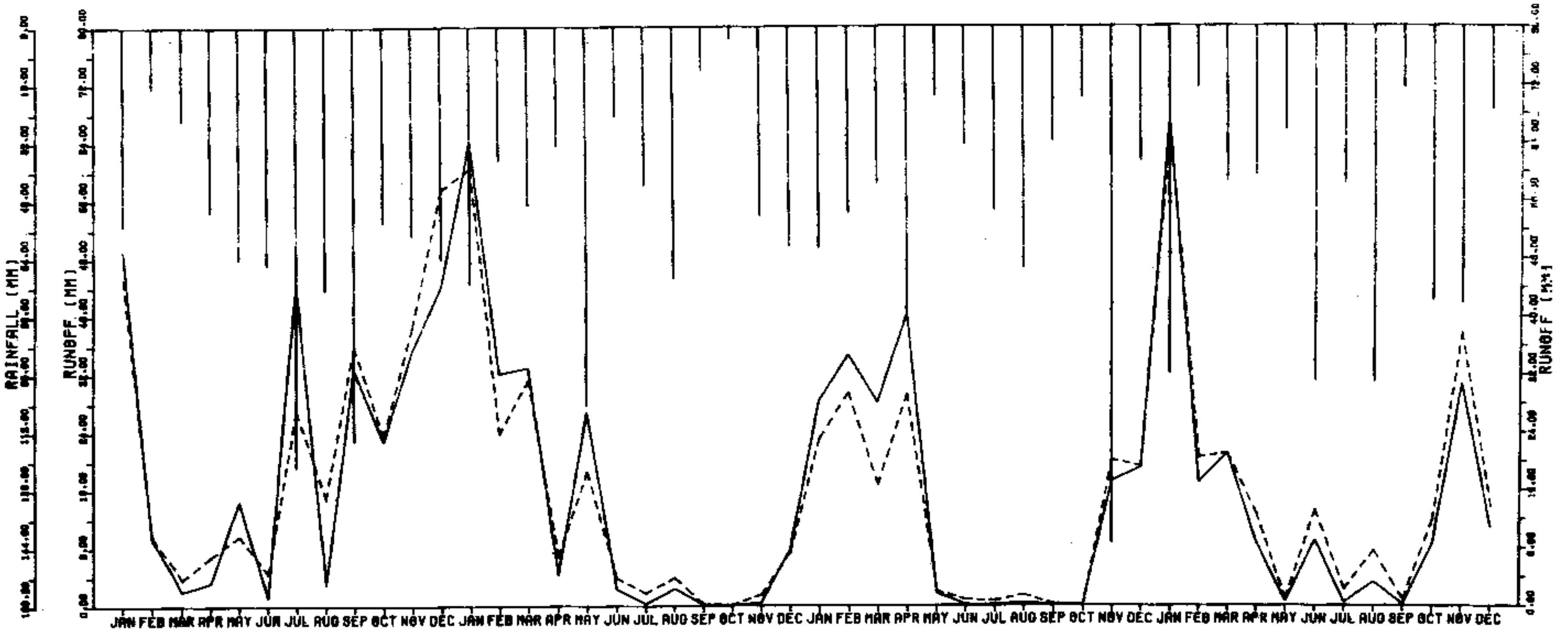

FIGURE 4: Daily plot of best fit year in the prediction period

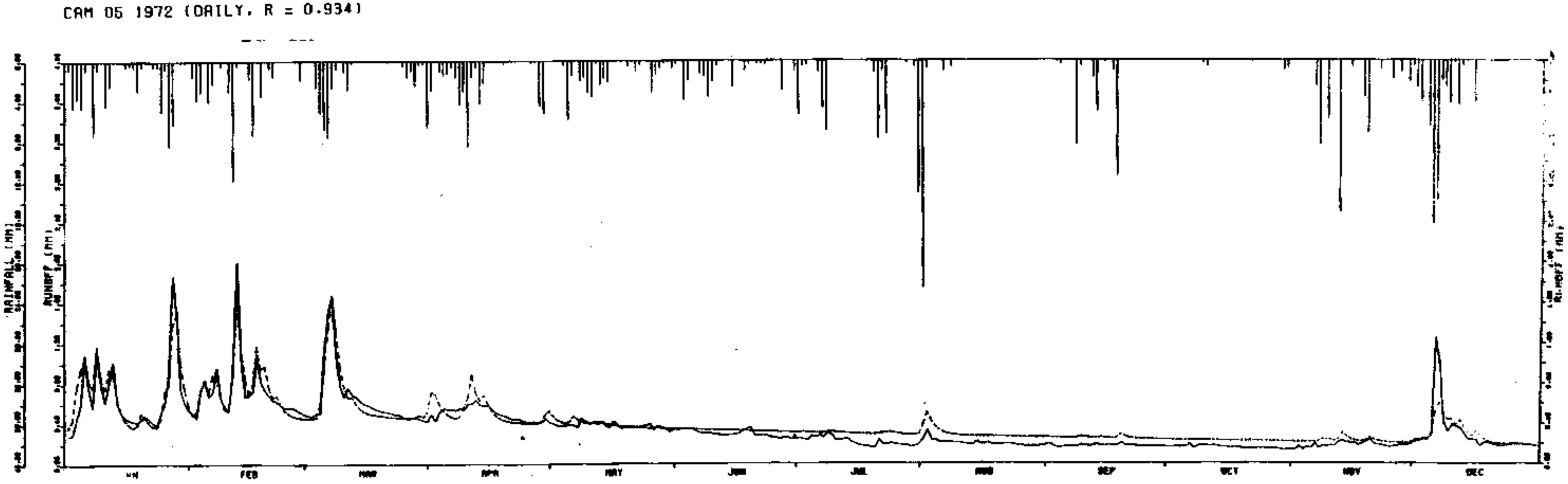

FIGURE 2: Daily plot of best fit year in the calibration period

CAM 05 1966 (DAILY. R = 0.903)

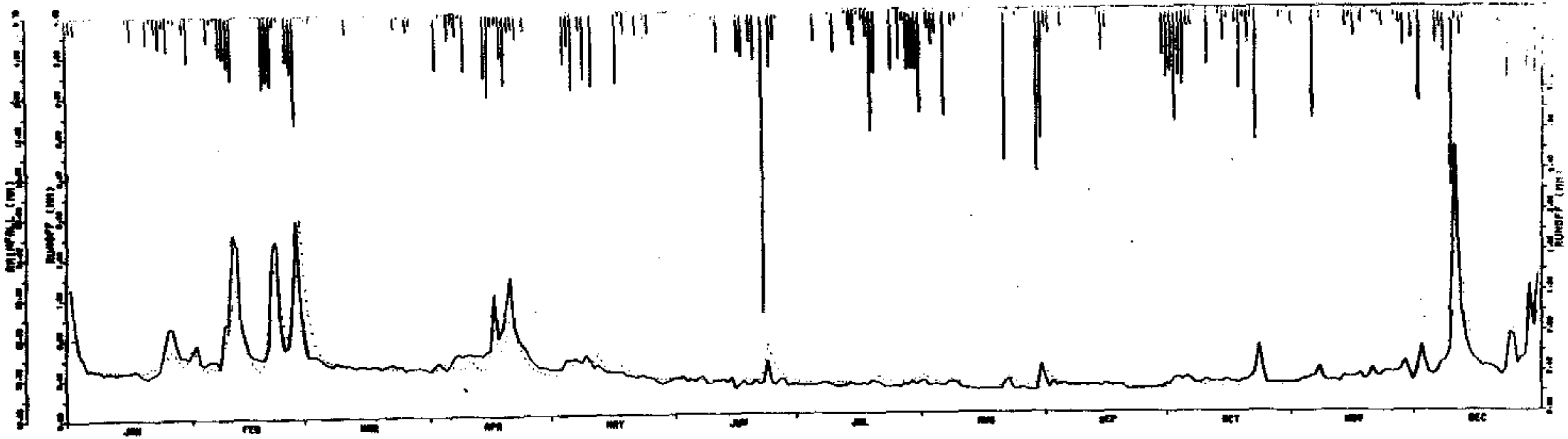

FIGURE 1b: Plot of monthly totals of rainfall, observed and predicted flow, 01.70 to 12.73

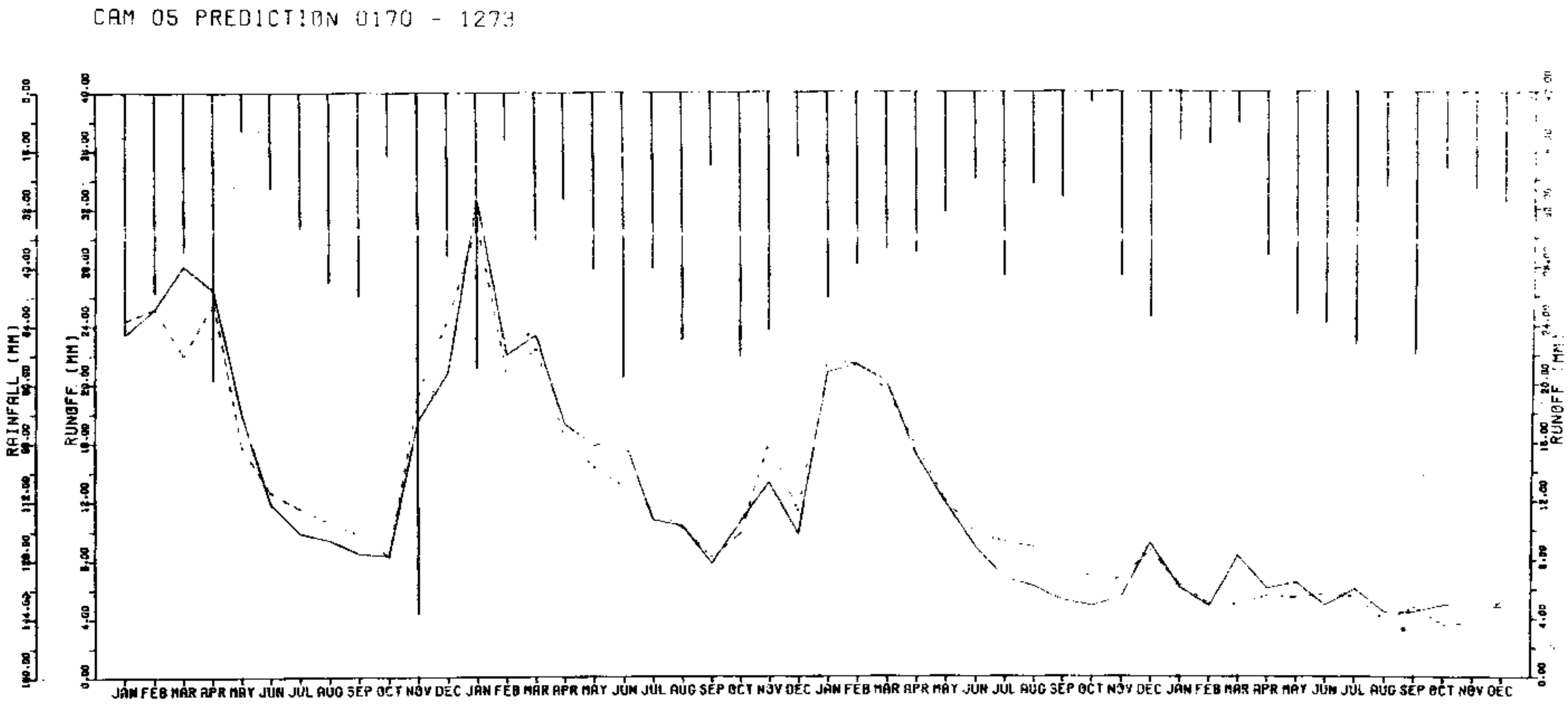

TABLE 10 Statistics of model performance on a pentad time interval for the Ray

```
*****************************************************************
*****************************************************************
***                 INSTITUTE OF HYDROLOGY                    ***
***              CONCEPTUAL MODELLING PACKAGE                 ***
***                                                           ***
***         MODEL BEING USED: 3 STORE, INTENSITY, ROUTING     ***
***       LOCATION/CATCHMENT: ****** RAY L2 ******            ***
***         DURATION OF DATA: *** 0164 - 1275 ***             ***
***           DATA FREQUENCY:   PENTAD                        ***
*****************************************************************
*****************************************************************



YEAR  COEFF  CORLL  CUMUL  CUMUL   YEAR  CUMUL   YEAR   CUMUL  MEAN   CUMUL  MEAN   CUMUL  RUNOFF   PRED   ERROR  PERROR
        DET  COEFF    DET  CORLL    SEE    SEE D-STAT  D-STAT  FLOW   MN.FL  PR.FL  PR.FL

1964   .906   .952   .906   .952   .161   .161  1.901   1.901  1.60   1.62   1.57   1.57  116.7   114.8    -.1     -.1
1965   .855   .925   .886   .941   .167   .115  1.182   1.529  2.03   1.82   1.62   1.61  148.3   118.3  -31.0   -20.9
1966   .851   .922   .879   .935   .274   .119  1.677   1.619  4.12   2.56   3.83   2.34  301.0   279.6  -19.7    -6.6
1967   .835   .914   .867   .931   .191   .111  2.120   1.738  2.46   2.55   2.70   2.43  179.7   197.3   16.5     9.2
1968   .651   .807   .797   .893   .468   .122  2.207   2.095  3.57   2.76   3.77   2.73  260.4   275.9   17.2     6.6
1969   .885   .941   .810   .900   .189   .106  1.753   2.079  2.38   2.69   2.16   2.61  173.5   158.0  -15.5    -7.8
1970   .587   .766   .792   .890   .285   .100  1.780   2.130  2.33   2.64   1.99   2.52  169.9   144.3  -26.7   -15.7
1971   .905   .952   .804   .897   .166   .090  2.171   2.038  2.43   2.61   2.75   2.55  177.1   201.1   31.3    17.7
1972   .639   .799   .775   .882   .241   .084  1.136   1.949  1.74   2.52   2.15   2.50  129.3   155.8   27.1    20.9
1973   .029   .170   .798   .893   .077   .076  1.412   1.944   .81   2.31    .63   2.32   30.0    45.5   15.5    51.7
1974   .935   .967   .823   .907   .241   .071  1.953   1.936  3.37   2.81   3.62   2.49  286.2   269.5   19.7     7.7
1975   .951   .975   .833   .913   .122   .066  1.252   1.923  2.18   2.34   2.19   2.41  152.1   151.3    -.8     -.5

3FIN
```

## TABLE 8 Ray model variance table and correlation matrix for the period 01.64 to 12.75

Variance table (4383 daily points)

| Variable | | Mean (mm) | Min (mm) | Max (mm) | Standard derivation (mm) | Variance (mm²) |
|---|---|---|---|---|---|---|
| Model input: | | | | | | |
| R | RAIN | 1.74 | 0.0 | 70.4 | 4.04 | 16.31 |
| EO | Penman EO | 1.76 | 0.0 | 7.2 | 1.61 | 2.59 |
| Model output: | | | | | | |
| PEV | Evapotranspiration | 1.28 | 0.0 | 5.1 | 1.06 | 1.12 |
| SMD | Soil moisture deficit | 44.0 | -1.1 | 152.0 | 38.6 | 1491.3 |
| GWS | Groundwater store | 1.00 | 0.0 | 17.4 | 1.82 | 3.33 |
| DIRP | Direct runoff % R | 8.04 | 0.0 | 95.3 | 20.6 | 424.3 |
| PRUN | Predicted runoff | 0.48 | 0.0 | 16.8 | 1.30 | 1.69 |
| RUN | Runoff | 0.48 | 0.0 | 21.1 | 1.35 | 1.82 |
| ERR | Error | 0.01 | 0.0 | 9.8 | 0.74 | 0.55 |

Upper triangular of the symmetric correlation matrix.

| | R | EO | PEV | SMD | GWS | DIRP | RUN | PRUN | ERR |
|---|---|---|---|---|---|---|---|---|---|
| R | 1.0 | -0.06 | 0.28 | -0.01 | -0.03 | 0.40 | 0.38 | 0.38 | -0.03 |
| EO | | 1.0 | 0.75 | 0.39 | -0.13 | -0.29 | -0.22 | -0.21 | 0.03 |
| PEV | | | 1.0 | 0.23 | -0.10 | -0.15 | -0.09 | -0.07 | 0.04 |
| SMD | | | | 1.0 | -0.33 | -0.35 | -0.31 | -0.31 | 0.03 |
| GWS | | | | | 1.0 | 0.09 | 0.09 | 0.08 | -0.03 |
| DIRP | | | | | | 1.0 | 0.51 | 0.58 | 0.08 |
| RUN | | | | | | | 1.0 | 0.84 | -0.34 |
| PRUN | | | | | | | | 1.0 | 0.22 |
| ERR | | | | | | | | | 1.00 |

TABLE 6 Ray prediction period 01.68 to 12.75 mean monthly rainfall, streamflow and Penman EO with standard deviations

CATCHMENT 2

DISTRIBUTIONS OF DAILY R.Q.E

| | RAIN | | | | FLOW | | | | EVAP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.43MM | | | | .73MM | | | | .249MM | | | |
| INTERVAL | MM | % | DAYS | % | MM | % | DAYS | % | MM | % | DAYS | % |
| 1 | 645.5 | 13.01 | 1195 | 66.28 | 271.0 | 20.21 | 2526 | 86.45 | 47.3 | .93 | 557 | 19.06 |
| 2 | 1022.7 | 20.62 | 294 | 16.31 | 183.5 | 13.69 | 178 | 6.09 | 125.6 | 2.47 | 343 | 11.74 |
| 3 | 735.6 | 14.83 | 122 | 6.77 | 116.5 | 8.68 | 64 | 2.19 | 146.9 | 2.89 | 238 | 8.15 |
| 4 | 669.5 | 13.50 | 79 | 4.38 | 101.4 | 7.56 | 40 | 1.37 | 131.5 | 2.59 | 152 | 5.20 |
| 5 | 453.7 | 9.14 | 38 | 2.11 | 111.5 | 8.31 | 33 | 1.13 | 160.9 | 3.17 | 144 | 4.93 |
| 6 | 266.7 | 5.38 | 20 | 1.11 | 71.6 | 5.34 | 18 | .62 | 214.6 | 4.23 | 158 | 5.41 |
| 7 | 265.3 | 5.35 | 16 | .89 | 85.8 | 6.40 | 18 | .62 | 191.5 | 3.77 | 118 | 4.04 |
| 8 | 162.4 | 3.27 | 9 | .50 | 60.4 | 4.51 | 11 | .38 | 241.8 | 4.76 | 129 | 4.41 |
| 9 | 185.4 | 3.74 | 9 | .50 | 36.6 | 2.73 | 6 | .21 | 226.0 | 4.45 | 107 | 3.66 |
| 10 | 162.3 | 3.27 | 7 | .39 | 34.9 | 2.60 | 5 | .17 | 280.7 | 5.53 | 119 | 4.07 |
| 11 | 103.6 | 2.09 | 4 | .22 | 22.7 | 1.69 | 3 | .10 | 208.6 | 4.11 | 80 | 2.74 |
| 12 | 111.4 | 2.25 | 4 | .22 | 8.4 | .62 | 1 | .03 | 276.4 | 5.44 | 97 | 3.32 |
| 13 | 60.8 | 1.23 | 2 | .11 | 9.4 | .70 | 1 | .03 | 316.3 | 6.23 | 102 | 3.49 |
| 14 | 33.5 | .68 | 1 | .06 | 19.9 | 1.49 | 2 | .07 | 298.4 | 5.87 | 89 | 3.05 |
| 15 | .0 | .00 | 0 | .00 | 20.8 | 1.55 | 2 | .07 | 335.5 | 6.60 | 93 | 3.18 |
| 16 | 75.9 | 1.53 | 2 | .11 | 44.9 | 3.35 | 4 | .14 | 231.9 | 4.56 | 60 | 2.05 |
| 17 | .0 | .00 | 0 | .00 | 23.8 | 1.77 | 2 | .07 | 263.9 | 5.19 | 64 | 2.19 |
| 18 | .0 | .00 | 0 | .00 | 38.2 | 2.85 | 3 | .10 | 227.7 | 4.48 | 52 | 1.78 |
| 19 | .0 | .00 | 0 | .00 | 13.4 | 1.00 | 1 | .03 | 207.6 | 4.09 | 45 | 1.54 |
| 20 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 223.6 | 4.40 | 46 | 1.57 |
| 21 | .0 | .00 | 0 | .00 | 15.3 | 1.14 | 1 | .03 | 158.4 | 3.12 | 31 | 1.06 |
| 22 | .0 | .00 | 0 | .00 | 15.6 | 1.16 | 1 | .03 | 176.3 | 3.47 | 33 | 1.13 |
| 23 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 122.9 | 2.42 | 22 | .75 |
| 24 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 93.1 | 1.83 | 16 | .55 |
| 25 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 79.5 | 1.57 | 13 | .44 |
| 26 | .0 | .00 | 0 | .00 | 18.5 | 1.38 | 1 | .03 | 44.4 | .87 | 7 | .24 |
| 27 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 19.9 | .39 | 4 | .14 |
| 28 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 6.8 | .13 | 1 | .03 |
| 29 | 70.4 | 1.42 | 1 | .06 | 21.1 | 1.58 | 1 | .03 | 7.0 | .14 | 1 | .03 |
| 30 | .0 | .00 | 0 | .00 | .0 | .00 | 0 | .00 | 14.5 | .29 | 2 | .07 |
| TOTALS | 4960.5 | | 1803 | | 1341.4 | | 2922 | | 5080.1 | | 2922 | |

TABLE 4 Ray calibration period 01.64 to 12.67 mean monthly rainfall, streamflow and Penman E0 with standard deviations

CATCHMENT 2 - MEAN MONTHLY RAINFALL AND STREAMFLOW

| | | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL | RDAYS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | R | 33.7 | 42.1 | 44.9 | 59.2 | 67.2 | 59.1 | 87.5 | 52.9 | 49.8 | 66.9 | 37.4 | 70.2 | 670.9 | 235 |
| | Q | 16.7 | 25.9 | 25.3 | 18.5 | 12.8 | 1.6 | 5.6 | 2.3 | 3.3 | 21.3 | 12.5 | 40.7 | 186.4 | |
| S.D. | R | 16.7 | 31.4 | 30.7 | 17.8 | 26.9 | 18.3 | 17.0 | 35.9 | 26.7 | 58.1 | 12.7 | 26.2 | 115.7 | 1 |
| | Q | 10.3 | 26.5 | 25.5 | 19.3 | 10.9 | 1.2 | 5.3 | 3.3 | 5.9 | 29.5 | 8.6 | 32.0 | 80.6 | |

MEAN MONTHLY PENMAN EO

| | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | 5.7 | 14.8 | 36.7 | 59.8 | 106.3 | 121.0 | 119.2 | 96.9 | 57.0 | 24.6 | 8.0 | 4.9 | 654.9 |
| S.D. | 1.1 | 3.0 | 9.8 | 4.3 | 10.1 | 7.5 | 11.8 | 2.9 | 8.8 | 3.1 | 2.3 | 1.2 | 12.2 |

TABLE 2 Ray monthly Penman EO with means and standard deviations from 01.64 to 12.75

CATCHMENT 2 MONTHLY PENMAN EO

| YEAR | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1964 | 4.6 | 10.9 | 23.6 | 65.2 | 116.9 | 110.8 | 126.8 | 101.0 | 58.1 | 22.3 | 6.7 | 6.7 | 665.4 |
| 1965 | 7.2 | 14.9 | 37.7 | 58.7 | 101.1 | 122.5 | 105.5 | 96.6 | 53.9 | 27.0 | 8.8 | 4.2 | 638.2 |
| 1966 | 5.9 | 18.1 | 38.1 | 54.8 | 112.3 | 129.4 | 113.5 | 95.8 | 58.8 | 21.9 | 9.7 | 4.6 | 662.8 |
| 1967 | 5.1 | 15.4 | 47.5 | 60.5 | 94.8 | 121.5 | 131.1 | 94.2 | 47.2 | 27.5 | 4.6 | 4.1 | 653.7 |
| 1968 | 5.4 | 8.4 | 45.7 | 67.4 | 86.5 | 109.4 | 99.2 | 68.4 | 53.4 | 26.2 | 8.4 | 3.0 | 582.2 |
| 1969 | 5.5 | 7.8 | 23.8 | 68.1 | 95.8 | 151.6 | 136.4 | 86.2 | 50.2 | 27.7 | 12.1 | 4.3 | 665.4 |
| 1970 | 5.0 | 10.6 | 33.4 | 55.3 | 110.7 | 141.9 | 113.8 | 88.7 | 56.9 | 28.5 | 10.7 | 7.0 | 662.4 |
| 1971 | 5.6 | 11.0 | 32.5 | 57.3 | 117.6 | 95.7 | 133.0 | 83.2 | 54.9 | 23.2 | 7.6 | 7.0 | 618.0 |
| 1972 | 7.1 | 7.5 | 38.9 | 63.4 | 96.5 | 103.2 | 104.7 | 81.3 | 47.9 | 25.1 | 7.8 | 7.7 | 590.9 |
| 1973 | 5.3 | 12.3 | 37.7 | 64.4 | 111.5 | 128.6 | 113.4 | 110.7 | 53.7 | 22.3 | 11.1 | 7.5 | 658.7 |
| 1974 | 7.7 | 14.5 | 27.6 | 60.6 | 118.7 | 117.3 | 114.7 | 78.8 | 47.2 | 19.7 | 14.7 | 11.5 | 612.1 |
| 1975 | 11.1 | 12.0 | 25.7 | 58.9 | 92.7 | 144.6 | 136.5 | 113.4 | 56.7 | 23.3 | 7.4 | 4.2 | 686.5 |
| MEAN | 6.3 | 11.9 | 34.3 | 61.2 | 102.1 | 123.0 | 117.4 | 91.5 | 54.1 | 24.5 | 9.3 | 6.3 | 641.6 |
| S.D. | 1.8 | 3.3 | 8.0 | 4.5 | 9.2 | 17.1 | 14.3 | 13.1 | 5.9 | 2.8 | 2.6 | 2.4 | 33.3 |

TABLE 10 Statistics of model performance on a pentad time interval for the Cam

```
************************************************************
************************************************************
***               INSTITUTE OF HYDROLOGY                 ***
***             CONCEPTUAL MODELLING PACKAGE             ***
***                                                      ***
***      MODEL STRING USED: 3 STORE, INTENSITY, ROUTING  ***
***   LOCATION/CATCHMENT: ****** CAM 05 ******           ***
***     DURATION OF DATA: *** 0166 - 1275 ***            ***
***       DATA FREQUENCY:   PENTAD                       ***
************************************************************
************************************************************


YEAR  COEFF  CORLL  CUMUL  CUMUL   YEAR  CUMUL   YEAR   CUMUL   MEAN  CUMUL  MEAN  CUMUL  RUNOFF  PRED   ERROR  %ERROR
        DET  COEFF    DET  CORLL    SEE    SEE  D-STAT  D-STAT  FLOW  MN.FL PR.FL  PR.FL

1966  .873   .943   .873   .943   .046   .046  1.003   1.003   2.31   2.31  2.36   2.36  148.9   172.2    3.5    2.1
1967  .852   .923   .875   .935   .044   .032  1.418   1.201   2.17   2.24  2.28   2.32  158.6   166.3    7.5    4.7
1968  .777   .882   .835   .914   .082   .034  1.006   1.262   2.76   2.42  2.66   2.43  201.7   194.4   -3.2   -4.1
1969  .917   .953   .856   .931   .053   .029  1.626   1.378   2.81   2.52  2.91   2.55  205.2   212.0    7.7    3.8
1970  .682   .826   .823   .935   .105   .031  1.407   1.392   2.84   2.55  2.86   2.61  207.2   209.0    2.5    1.2
1971  .331   .755   .832   .912   .059   .028   .949   1.349   2.60   2.58  2.53   2.61  189.7   184.4   -5.2   -2.7
1972  .899   .948   .844   .917   .048   .024   .758   1.327   1.85   2.48  2.02   2.52  134.8   147.1   13.3    9.9
1973  .380  -.593   .862   .928   .031   .022   .706   1.308    .90   2.28   .82   2.31   66.1    59.9   -6.3   -9.5
1974  .899   .948   .873   .932   .075   .021   .598   1.195   2.13   2.25  2.09   2.25  155.8   152.0   -4.1   -2.5
1975  .821   .933   .873   .934   .179   .020  1.310   1.212   2.77   2.32  3.06   2.36  202.3   223.4   22.5   11.1
```

## TABLE 8 Cam model variance table and correlation matrix for the period 01.66 to 12.75

Variance table (3652 daily points)

| Variable | | Mean (mm) | Min (mm) | Max (mm) | Standard derivation (mm) | Variance ($mm^2$) |
|---|---|---|---|---|---|---|
| Model input: | | | | | | |
| R | RAIN | 1.61 | 0.0 | 78.2 | 3.67 | 13.44 |
| EO | Penmen EO | 1.71 | 0.0 | 7.0 | 1.57 | 2.48 |
| Model output: | | | | | | |
| PEV | Evapotranspiration | 1.15 | 0.0 | 5.5 | 1.01 | 1.03 |
| SMD | Soil moisture deficit | 41.0 | -25.3 | 135.3 | 40.6 | 1648.7 |
| GWS | Groundwater store | 436.7 | 347.7 | 521.4 | 38.9 | 1510.2 |
| DIRP | Direct runoff % R | 3.63 | 0.0 | 37.8 | 7.76 | 60.26 |
| PRUN | Predicted runoff | 0.47 | 0.10 | 4.89 | 0.34 | 0.12 |
| RUN | Runoff | 0.46 | 0.08 | 4.85 | 0.36 | 0.13 |
| ERR | Error | 0.01 | -2.74 | 1.32 | 0.16 | 0.025 |

Upper triangular of the symmetric correlation matrix

| | R | EO | PEV | SMD | GWS | DIRP | RUN | PRUN | ERR |
|---|---|---|---|---|---|---|---|---|---|
| R | 1.0 | -0.10 | -0.01 | 0.00 | -0.03 | 0.33 | 0.15 | 0.16 | 0.01 |
| EO | | 1.0 | 0.90 | 0.57 | 0.04 | -0.37 | -0.25 | -0.24 | 0.04 |
| PEV | | | 1.0 | 0.35 | 0.08 | -0.34 | -0.16 | -0.17 | -0.01 |
| SMD | | | | 1.0 | -0.29 | -0.45 | -0.54 | -0.52 | -0.10 |
| GWS | | | | | 1.0 | 0.10 | 0.50 | 0.51 | -0.02 |
| DIRP | | | | | | 1.0 | 0.51 | 0.56 | 0.11 |
| RUN | | | | | | | 1.0 | 0.90 | -0.33 |
| PRUN | | | | | | | | 1.0 | 0.12 |
| ERR | | | | | | | | | 1.0 |

TABLE 6 Cam prediction period 01.70 to 12.75 mean monthly rainfall, streamflow and Penman EO with standard deviations

CATCHMENT 5 - MEAN MONTHLY RAINFALL AND STREAMFLOW

| | | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL | RDAYS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | R | 57.0 | 33.3 | 40.3 | 45.9 | 39.6 | 46.3 | 44.6 | 44.8 | 62.0 | 38.6 | 71.7 | 34.2 | 558.3 | 27[illegible] |
| | Q | 20.2 | 17.6 | 20.9 | 17.4 | 14.2 | 10.4 | 8.1 | 7.1 | 7.0 | 9.9 | 14.4 | 12.3 | 159.5 | |
| S.D. | R | 22.5 | 19.3 | 24.7 | 24.3 | 20.4 | 23.6 | 14.8 | 29.9 | 33.1 | 41.3 | 42.2 | 16.3 | 87.6 | 22 |
| | Q | 10.5 | 7.4 | 9.9 | 9.6 | 7.2 | 4.7 | 2.5 | 2.4 | 1.7 | 6.7 | 12.3 | 6.9 | 53.5 | |

MEAN MONTHLY PENMAN EO

| | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | 6.1 | 11.2 | 32.6 | 62.8 | 104.6 | 117.8 | 108.6 | 89.4 | 55.0 | 22.4 | 8.3 | 6.9 | 625.5 |
| S.D. | 3.5 | 3.5 | 7.3 | 5.5 | 7.1 | 17.3 | 11.5 | 11.0 | 6.4 | 4.2 | 2.4 | 3.7 | 29.2 |

**TABLE 4** Cam calibration period 01.66 to 12.69 mean monthly rainfall, streamflow and Penman EO with standard deviations

CATCHMENT 5 - MEAN MONTHLY RAINFALL AND STREAMFLOW

| | | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL | RDAYS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | R | 39.3 | 43.4 | 24.2 | 46.3 | 62.0 | 56.5 | 75.4 | 73.7 | 48.1 | 55.2 | 45.6 | 60.1 | 630.0 | 234 |
| | Q | 22.4 | 21.1 | 19.4 | 16.7 | 15.4 | 10.9 | 9.9 | 11.7 | 12.4 | 11.9 | 12.9 | 19.7 | 184.4 | |
| S.D. | R | 17.4 | 18.3 | 14.9 | 13.2 | 26.8 | 25.3 | 24.6 | 22.1 | 50.4 | 40.9 | 17.0 | 11.9 | 52.1 | 23 |
| | Q | 6.2 | 4.3 | 8.2 | 3.9 | 3.8 | 2.0 | 1.4 | 5.8 | 9.2 | 6.2 | 3.9 | 3.3 | 24.2 | |

MEAN MONTHLY PENMAN EO

| | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN | 5.4 | 9.6 | 38.0 | 65.0 | 92.1 | 121.6 | 114.4 | 86.7 | 53.8 | 25.9 | 7.0 | 3.2 | 622.7 |
| S.D. | 3.3 | 3.9 | 12.4 | 3.8 | 8.2 | 5.4 | 17.6 | 16.2 | 8.6 | 1.4 | 1.0 | 1.4 | 39.2 |

TABLE 2 Cam monthly Peman EO with means and standard deviations from 01.66 to 12.75

CATCHMENT 5 MONTHLY PENMAN EO

| YEAR | J | F | M | A | M | J | J | A | S | O | N | D | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1966 | 9.8 | 14.8 | 42.9 | 62.0 | 102.0 | 127.2 | 98.6 | 96.1 | 66.5 | 25.7 | 8.0 | 5.0 | 658.6 |
| 1967 | 1.9 | 9.6 | 45.5 | 63.5 | 91.4 | 118.5 | 138.1 | 102.3 | 47.2 | 27.8 | 5.6 | 2.7 | 654.2 |
| 1968 | 5.5 | 8.7 | 44.1 | 70.5 | 93.0 | 115.6 | 104.1 | 65.8 | 51.5 | 29.7 | 7.2 | 1.6 | 597.3 |
| 1969 | 4.3 | 5.4 | 19.5 | 63.8 | 81.9 | 125.2 | 116.9 | 82.4 | 50.0 | 20.4 | 7.1 | 3.9 | 584.5 |
| 1970 | 1.7 | 8.5 | 32.0 | 56.2 | 114.4 | 136.1 | 103.1 | 92.6 | 65.7 | 27.9 | 11.3 | 2.8 | 652.4 |
| 1971 | 2.8 | 8.9 | 35.8 | 61.0 | 108.3 | 97.4 | 126.4 | 79.4 | 56.6 | 20.4 | 5.9 | 7.0 | 609.8 |
| 1972 | 8.5 | 9.5 | 36.2 | 71.4 | 108.2 | 113.4 | 101.6 | 84.0 | 47.9 | 27.4 | 10.9 | 8.7 | 628.2 |
| 1973 | 5.9 | 17.8 | 42.0 | 66.7 | 103.3 | 120.4 | 100.6 | 86.6 | 55.3 | 18.2 | 7.8 | 3.5 | 628.7 |
| 1974 | 5.5 | 10.2 | 28.9 | 58.9 | 98.5 | 100.8 | 99.8 | 83.4 | 49.0 | 21.8 | 7.9 | 12.8 | 577.4 |
| 1975 | 11.3 | 11.9 | 20.7 | 62.9 | 95.1 | 138.5 | 120.0 | 109.9 | 55.5 | 19.0 | 5.8 | 6.3 | 656.5 |
| MEAN | 5.8 | 10.6 | 34.8 | 63.7 | 99.6 | 119.3 | 110.9 | 88.3 | 54.5 | 23.8 | 7.8 | 5.4 | 624.4 |
| S.D. | 3.3 | 3.5 | 9.4 | 4.9 | 9.6 | 13.4 | 13.6 | 12.5 | 6.9 | 3.7 | 2.0 | 3.4 | 31.5 |

precision can be made from daily rainfall records using this type of model providing some function is used to estimate Penman potential evaporation. This could be based on the nearest available site records, a probability function using the highest and lowest limits for each month, or the empirical derivation of a rainfall/EO relationship from available data for each month. The possibilities of deriving such relationships have been demonstrated by Thom and Ledger (1976).

The Durbin-Watson statistics (DWS) to estimate the significance of residual correlation is shown for daily, pentad and monthly model predictions at the end of Table II. These values are unexpectedly high as there is usually a serial correlation between model residuals. From these figures it would appear that the residuals for the Ray model are almost completely uncorrelated, but those for the Cam model are indeterminately correlated when the following approximation is considered:

$$DWS \simeq 2 \; (1 - r)$$

where r is the first serial correlation.

In Appendices I and II there are more detailed summaries of the rainfall, streamflow and Penman EO data for both catchments. The data are given as monthly totals and the frequency distribution of daily observations are also given for the total run of data, calibration and prediction periods for each catchment. These tables show the seasonal differences and extremes encountered by the model in calibration and prediction modes.

The following tables give a more detailed analysis of the model fit. The model variance and correlation matrices for the catchments show no significant correlation between prediction errors and the model components in the analysis. For the Cam there is an indication that there is a problem in the partitioning of effective rainfall between surface runoff and infiltration, but this could be expected with the use of a lumped model on a catchment almost equally divided in area between Boulder Clay and Chalk. The tables with the statistics of model fit analysed by years, show the bad correlation of the model in the dry year 1973, but this is exagerated by the low flows and the volume prediction errors are not exceptional.

## GENERAL CONCLUSIONS AND POSSIBLE FUTURE CONCEPTUAL MODEL DEVELOPMENTS

Previous examination of the Ray catchment data had established that although the Penman equation could be the basis for a reliable estimate of the annual evapotranspiration, it gave a summer over-estimate and winter under-estimate when compared with water balance measurements. Edwards and Rodda (1970) suggested that a soil heat storage term would remove this seasonal error.

However, an examination by Simmers (1977) of later catchment data which included the results from heat flux plates showed that the inclusion of this term still left a systematic seasonal imbalance. Other possible sources of error affecting the water balance components were the presence of an aquifer on the northern catchment boundary, the difficulty of estimating soil moisture in the cracking of the Oxford Clays depth of the collecting funnel which limits the amount of snow collected. The exposure will also affect the temporal distribution of the melt, which may be completely different from that of the snow cover. In terms of the model output these factors cause an under-prediction of runoff over the snow period, together with a predicted hydrograph completely at variance with the observed flows.

Snow was lying in the Cambridge area during the months 4.66, 1.68, 3.69, 3.70, 1.71, 3.71, 3.73, 3.74 and 12.74. If the under-prediction of flow from the Cam for these months is disregarded and replaced by the observed flows then the amended prediction should be 1748 mm over the ten year period. This gives an over-prediction error of 3.1%, but this is a very unreliable figure due to the lack of data on the snowfall within the catchment.

A good example of the snow problem occurs in the month of March 1970 in the Cam. The part of the month affected is clearly shown in the daily plots of rainfall, observed and predicted flow for 1970 presented in Appendix III of this report. In the period between the 3rd and 10th March, 17.4 mm of recorded 'rain' gave a predicted flow response of 2.7 mm whereas the measured increase in runoff above the base flow level amounted to 0.4 mm. Subsequent 'rain' between the 9th and 17th gave a predicted response of 1.2 mm and the observed flow increase was 7.7 mm. Examination of the meteorological data indicates that snow accumulated in the first of these periods, and in the second the rainfall resulted from the passage of a warm front through the area. The interpretation of the discrepancies between observed and predicted flow is that the recorded rain in the first period was due to the melting of that part of the snowfall collected by the raingauges, whilst the high observed flow in the second period was due to melting of the snow cover during the passage of the warm front. Comparing the changes in the model stores over the month with the observed flow there would appear to be a 12% underestimate of precipitation and, over the period when snow could have been lying in the catchment, the catch in the raingauges appears to have given too low an estimate by at least a factor of four.

A further problem in the consideration of the model prediction for the Cam is the licensed abstraction from groundwater by public services of 8.854 mgd, and by industry of 6.008 mgd giving a total possible groundwater loss of 14.862 mgd. During the summer months the observed base flow is of the order of a third of a millimetre per day (17.35 mgd) which is not very much greater than the figure for the total licensed abstraction from groundwater.

Over-prediction of the base flow during the summer months is particularly marked in 1972 and 1975 as shown on the Cam monthly graph (Appendix III). This may be due to relatively large abstractions lowering the observed flow significantly during these dry years. A full discussion of the groundwater resources and abstractions over the whole Great Ouse basin is given in Wright (1974).

Flow duration curves are shown in Figures 2 and 3 for observed and predicted flows from the Cam and Ray catchments. These curves use monthly totals for the full run of data and show the good agreement between the model predicted values and the observed streamflow.

TABLE II. MODEL CALIBRATION AND PREDICTION RESULTS FOR THE CAM CATCHMENT

| | Calibration period 1.66-12.69 | Prediction period 1.70-12.75 | Total period 1.66-12.75 |
|---|---|---|---|
| Daily correlation coefficient | 0.89851 | 0.89637 | 0.89802 |
| Standard error of estimate as percentage of mean flow | 0.75% | 0.82% | 0.57% |
| Pentad correlation coefficient | 0.94661 | 0.93561 | 0.93968 |
| Standard error of estimate as percentage of mean flow | 1.00% | 1.28% | 0.84% |
| Monthly correlation coefficient | 0.97426 | 0.96819 | 0.97037 |
| Standard error of estimate as percentage of mean flow | 1.32% | 1.86% | 1.20% |
| Daily efficiency | 0.807 | 0.803 | 0.806 |
| Coefficient of variation | 0.286 | 0.379 | 0.342 |
| Initial variance, FO | 158.02 | 317.66 | 475.67 |
| Final variance, F | 30.45 | 61.62 | 92.07 |
| Monthly efficiency | 0.949 | 0.937 | 0.942 |
| Coefficient of variation | 0.091 | 0.158 | 0.131 |
| Initial variance, FO | 1864.36 | 5172.62 | 7036.98 |
| Final variance, F | 94.73 | 316.04 | 410.77 |
| Predicted flow (mm) | 744.9 | 978.7 | 1723.6 |
| Observed flow (mm) | 737.6 | 956.7 | 1694.3 |
| Error in flow | - 0.991% | 2.302% | 1.730% |
| Durbin-Watson statistic : | | | |
| Daily | 1.373 | 0.967 | 1.102 |
| Pentad | 1.324 | 1.127 | 1.180 |
| Monthly | 1.796 | 1.161 | 1.310 |

The Durbin-Watson D statistic used to test the significance of the residual correlation is of the usual form:

$$D = \frac{\sum_{i=2}^{N} (\varepsilon_i - \varepsilon_{i-1})**2}{\sum^{N} \varepsilon_i**2}$$

Here the residuals are the difference between the observed and predicted flows

$$\varepsilon_i = Q_i - Q_i'$$

## MODEL FIT AND PERFORMANCE IN PREDICTION MODE

The model parameters optimised on the four year calibration periods for each catchment are shown in Table I. The general model applied to both catchments has fifteen active parameters, together with starting values for the contents of two stores which may have to be optimised.

Details of the model performance on both sets of data are given in Tables II and III. The monthly correlation coefficient for the Cam is 0.974 over the calibration period, and is 0.968 for the following six year prediction period. The comparable figures for the Ray are 0.962 and 0.959 for the prediction over the following eight years. The goodness of fit of the model in prediction mode is shown by these correlation figures, and is sufficient justification for any subjective bias introduced in reaching global optima for parameters during the calibration four year period. The catchments have correlation coefficients of 0.970 for the Cam and 0.960 for the Ray over their complete run of data.

In terms of flow volumes the model gives an over-prediction of 1.7% for the ten years of data from the Cam, and an over-prediction of 1.6% for the twelve years of data from the Ray. If allowances are made for snow in January 1968, March 1970, and for lost flow in January 1972, then the observed flow for the Ray over the whole period becomes 2120 mm and the predicted flow 2135 mm. This changes the prediction error to 1.1% for the twelve year period.

The only measurement made of the fall of snow in these catchments is the melt water caught in the raingauges. There are a number of factors governing both the amount collected and also when the melt occurs. The most serious factors are probably the exposure of the gauges and the deficit than DCT FC, DCS and DCT may be optimised.

A simple linear function governs percolation from the soil store to groundwater store. If there is a deficit there is no recharge but where there is a profile surplus (ie when DC is negative) then a constant proportion is drained from the soil store

$$GPR = -A*DC \qquad DC < 0$$

The runoff contribution from the groundwater store follows a non-linear flow curve with two parameters, GSU and GSP, operating on the contents of the store, GS:

$$GRO = (GS/GSU)**GSP$$

This component of runoff is then delayed in time by a factor, GDEL.

The concepts of this model do not include consideration of snowfall, and infiltration into the soil is an implicit function of the complicated runoff expression. The model structure is such that recharge to the groundwater store can occur only after the soil moisture deficit is satisfied. Where field data are available the initial deficit, DC, and hence the zero deficit level, are determined. In the absence of field data the initial value of DC is optimised.

## MODEL FITTING TECHNIQUES

The model as described above was fitted to the data by optimising the parameter values on the first four years of data from each catchment. In each case the optimised values were then used in prediction mode to determine the performance of the model on the remaining data.

Initial values of the parameters, and of the contents of each store, were determined from field measurements where possible or estimated from water balance assessments or previous experience. Starting from these values, the parameters and initial store contents were optimised using the algorithm described by Rosenbrock (1960), and discussed and recommended for use in hydrological modelling by Ibbitt and O'Donnell (1971). The objective function which is minimised during the parameter optimisation by this technique is the sum of squares of the model residuals. This technique is comprehensively discussed by Clarke (1973), and is compared with others by Pickup (1977). This choice of objective function does give a model bias towards high flows, (Fleming, 1975) but this effect can be minimised by the use of selected data runs within the model calibration period.

Stage one of this overall process was to optimise those parameters controlling the volume input/output relationship on a monthly time sources of bias will only be shown by double mass analysis or model error analysis.

The data used were continuous from January 1964 to December 1975 for the Ray, and from January 1966 to December 1975 for the Cam. In each case the first four years of data were used to optimise the model parameters, and the succeeding run of observed streamflow used to check model performance in prediction mode.

The initial prediction runs over the period 1970-75 for the Cam revealed marked discrepancies between observed and predicted flow from 1972 onwards. The nature of these discrepancies suggested that they could arise from systematic errors in the data rather than the inadequacy of the model. Detailed examination uncovered a systematic error in the radiation data from 1972 to 1975, and a processing error in the rainfall data for 1975, shown in Figure 1. Correction of these errors resulted in a considerably closer agreement between predicted and observed flows. This provides a useful demonstration of the validity of the model and the optimised parameters in a range of data input conditions outside those experienced in the calibration period.

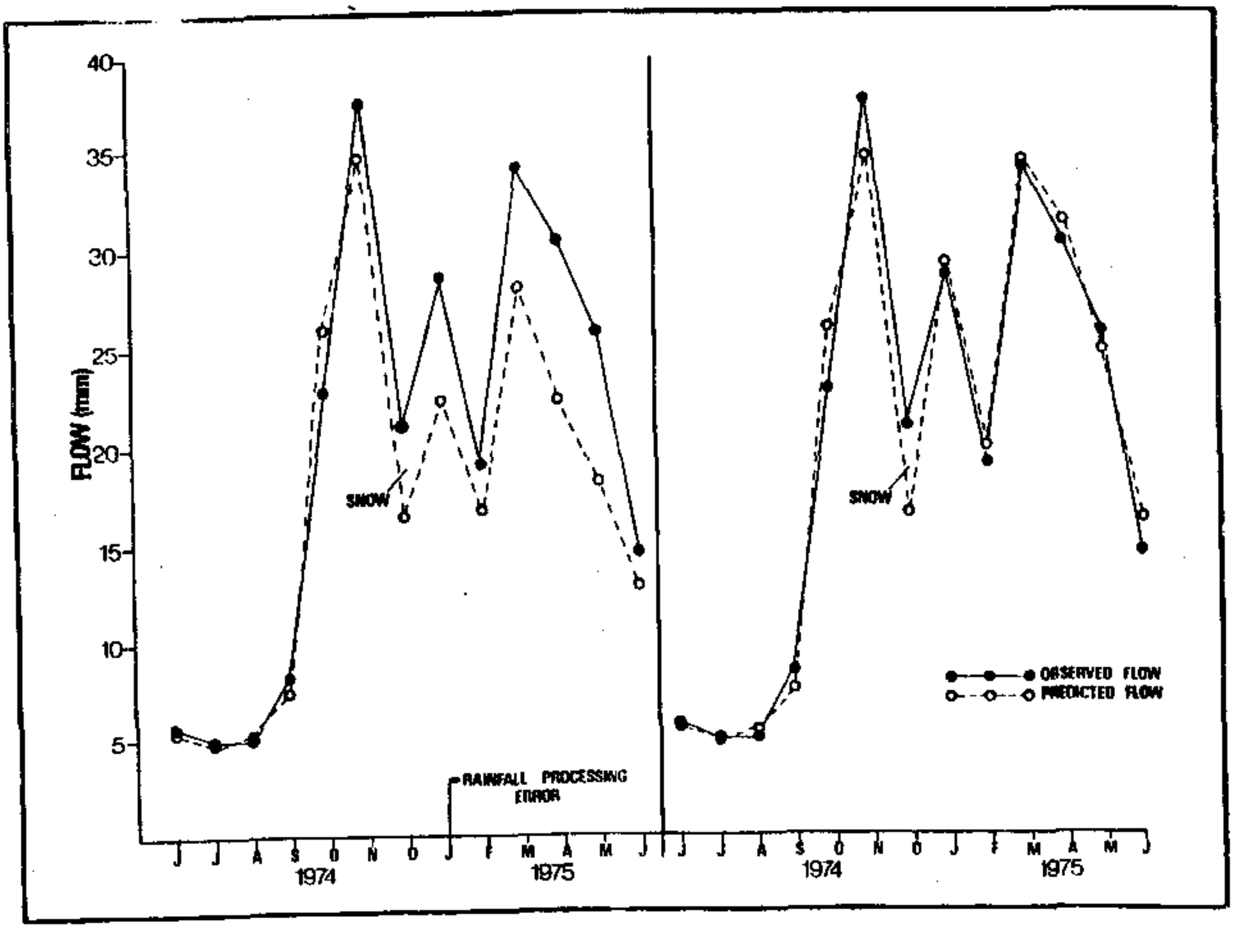

FIGURE 1 The effect of a rainfall processing error on model flow prediction from the Cam catchment