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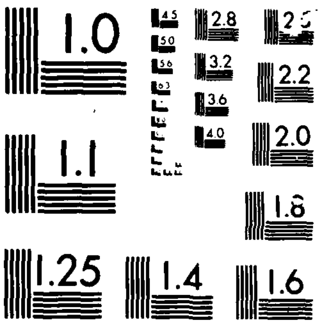

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HYDROLOGICAL MODELLING IN UNGAUGED WATERSHEDS

Final Technical Report

by

M.G.Anderson and S.Howes

February 1986

European Research Office
United States Army
London England

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Dr. M.G. Anderson

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Abstract (overleaf)

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20. Abstract

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It is shown that in these, and previous applications, MILHY2 provides improved estimations of both time to peak discharge and peak discharge, compared with MILHY.

The Fortran code for MILHY2 is presented in the report.

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A version of MILHY in which the Curve Number procedure for runoff generation is replaced by a finite difference infiltration scheme is presented. The revised model (MILHY2) is applied in an ungauged context to five catchments in the United States.

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The Fortran code for MILHY2 is presented in the report.

Keywords: Stream flow forecasting.

ACKNOWLEDGEMENTS

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CONTENTS

1.

Introduction

1.1 Background

This study relates to the further development of MILHY. Two previous reports are relevant to the research reported here. In the first of these two reports (1), a review of available hydrological models was undertaken, and a case was made for the further development of MILHY as an operational model for ungauged catchment flood forecasting. The subsequent report (2) detailed two applications of a revised MILHY scheme (referred to here as MILHY2), in which the curve number scheme for the estimation of runoff was replaced by a finite difference scheme. The advantage of such a replacement was seen to be the improved time resolution of runoff prediction and the improved accommodation of anticedent conditions whilst retaining the same data input requirements as MILHY. The results of the two applications undertaken were sufficiently encouraging for the model development work to be continued, and it is this work that is the subject of the current report.

1.2 Objectives and Scope

The two principal objectives of the research work reported here were:

(i) The application of MILHY2 to further watersheds.
(ii) The presentation of the Fortran program for MILHY2

Figure 1 illustrates how these objectives fit into the author's view of the conceptual and operational developments of MILHY2, as outlined at the MILHY Workshop st W.E.S. on the 12 January 1985. In that outline, the work reported here, and the objectives above, relate to the increase in validation (operational) and to the development of the Fortran version of MILHY2 (conceptual) under 1985.

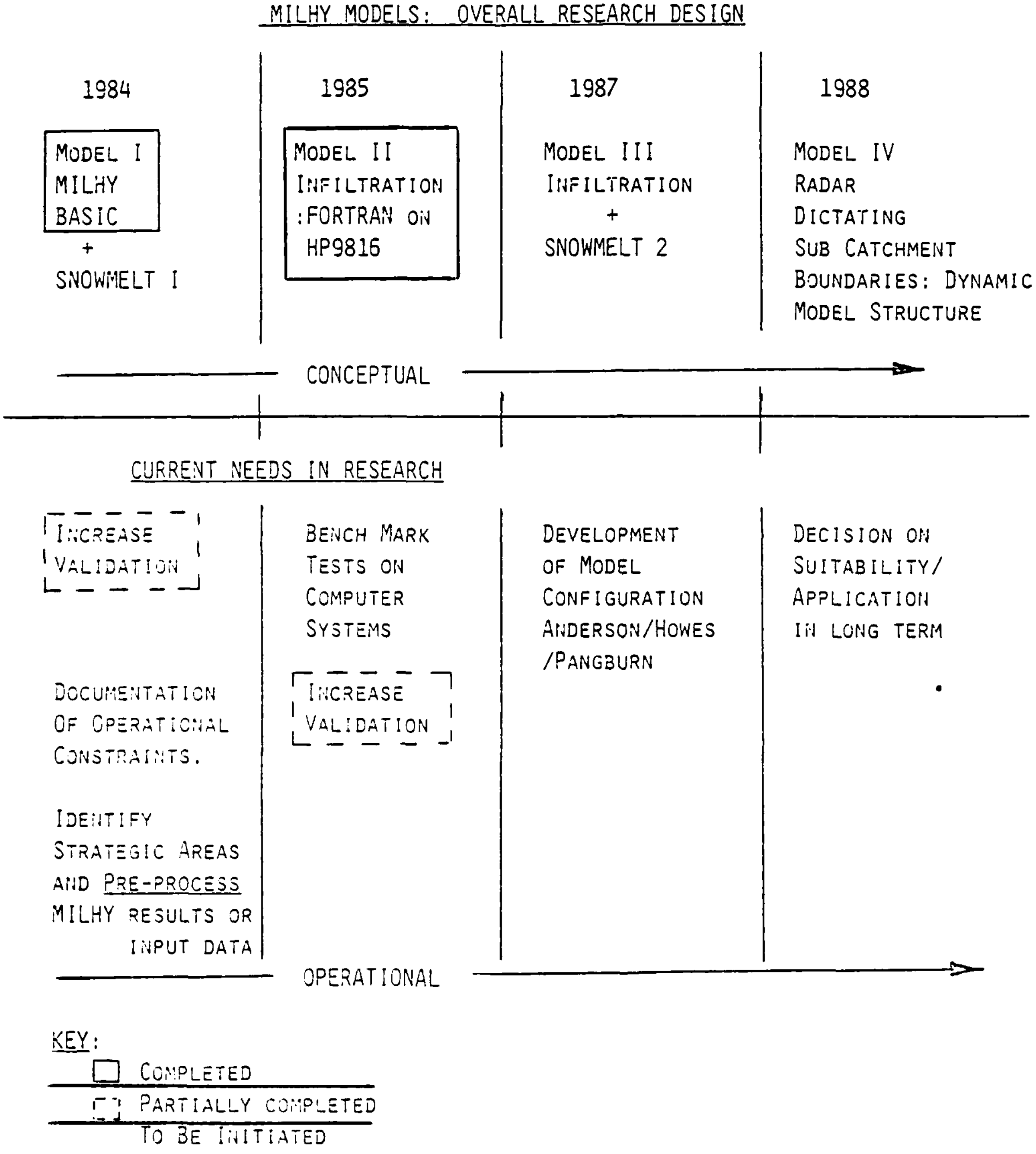


Figure 1 : Conceptual and operational developments of MILHY research

2.

Further Application of MILHY2

2.1 Introduction

Certain results of the application of MILHY2 to the North Creek catchment, Texas and the Sixmile Creek catchment, Arkansas, have been presented in DAJA37-81-C-0221 in the context of operational validation. Application to these catchments was used firstly to illustrate the suitability of the Brakensiek and Rawls empirical information for the derivation of the soils data necessary to operate the model quite successfully for the ungauged catchment, secondly to illustrate a favourable comparison of calculated to measured hydrographs for certain experimental frames. The deterministic version of MILHY2 is thus considered to be operationally valid for the variety of conditions which have been considered so far. However, it is important to extend this range of application and consequently, the details of the application of MILHY2 to a further five catchments in Vermont and Iowa, United States of America are provided in this report together with program code. In addition, these applications will provide information for discussion of the following points:

1 Is MILHY2 of a form which is suitable for application to the ungauged catchment?

  The runoff procedure which has been introduced in DAJA37-81-C-0221 is not a simple calibrated procedure, but is physically based. Much of the original, and so far undeveloped, model however, does remain calibrated and the issue of the validity of extrapolation of results which have been produced by calibration to other gauged catchments must be raised.

2 Can MILHY2 meet an operational requirement?

Operational requirements were discussed in (2). It has already been established that MILHY2 can be ported onto a microcomputer system. Application will reveal whether or not the model will run at acceptable speeds on this hardware configuration. In addition, the following questions must be considered:

a Are the data preparation requirements reasonable in the context of a potential nonprofessional user?

b Can sufficient guidelines be provided for the user in terms of application and interpretation of the model for a range of applications?

c Can the model be made user friendly?

d Is the software reliable for the now expanding range of applications?

3 Does MILHY2 have an appropriate structure for the ungauged and operational application?

The physically based infiltration model which has been developed, although simple, does attempt to attain a balance between a methodology which is scientifically acceptable, and one which remains operationally feasible. The suitability of this choice will be revealed with the application of MILHY2.

In any application, there will be interest in the accuracy of the hydrograph predictions which the model supplies. However, it has been stressed throughout the discussion on model evaluation, that there are other important questions which must also be specifically investigated in order to provide an unskilled user with sufficient information to guide the intelligent use of the model. In addition to a comparison of calculated and measured hydrographs, the following questions must also be addressed during application of MILHY2:

1 What is involved in the data acquisition and preparation stage? A user needs to know the nature of the decisions which must be taken in order to derive the necessary model parameters. It is also important

to assess the likely time period which will be required for data preparation.

2 Is the infiltration behaviour predicted by the physically based infiltration model reasonable for a range of catchment situations? Infiltration behaviour has been examined for a range of hypothetical conditions. It is important to examine its behaviour for more complex soil and precipitation conditions.

3 Is the explicit finite difference method accurate for these more complex soil profile and variable storm conditions?

These issues are now considered specifically for catchment situations. These three issues: data preparation, infiltration behaviour, and the stability of the numerical solution, have not been discussed in the context of the application to the North Creek and Sixmile Creek catchments. The information derived from these two catchments will therefore be included in those relevant sections.

This report will therefore be divided into six sections. Firstly, the five catchments which are to be used in this chapter will be introduced (2.2). Secondly, the data collection and preparation which are necessary for the application of MILHY2 to the catchments will be described (2.3). In addition, some more general points about this critical stage in model application will be made. Thirdly, a series of comparisons of calculated and measured hydrographs for a range of storms, applied to the five catchments in Vermont and Iowa, will be presented (2.4). This comparison will follow the two stage procedure in figure 2. Fourthly, the infiltration behaviour which is predicted by the model for the layered soil profiles and more erratic rainfall conditions, experienced by the catchments and the numerical errors incurred in the solution of the Richards equation by the explicit finite difference method will be examined (section 3). Finally, an attempt will be made to summarize the information derived from all experimental frames which have been used, in order to define those conditions for which the model is, and those for which it is not, appropriate (section

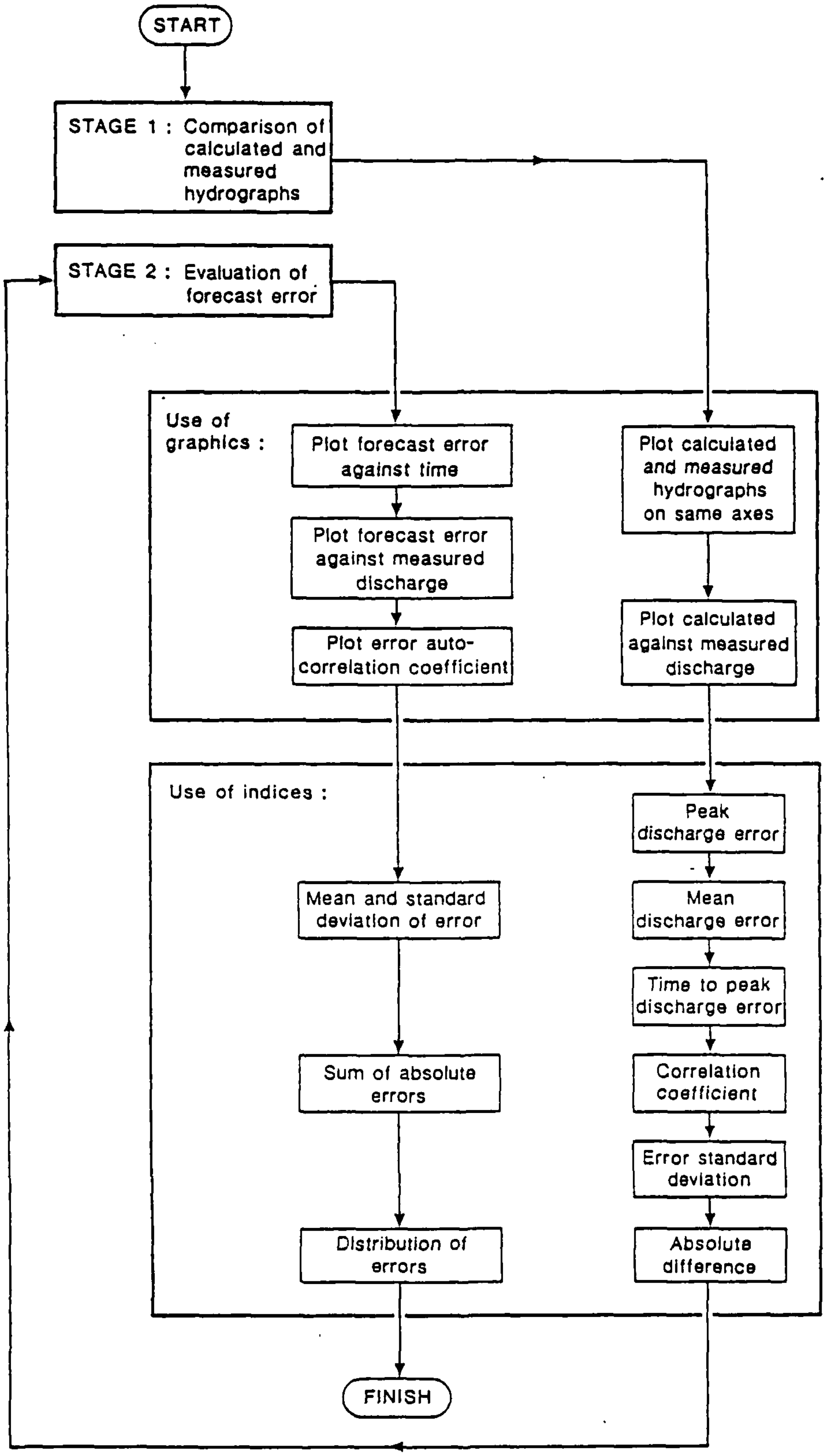


Figure 2 : Two stage procedure for hydrograph comparison

4).

2.2 Catchment location details

The five catchments documented in this chapter, and which have been used to evaluate the operation of MILHY2 are the following:

1 An unnamed triburary of the Sleepers River catchment, Connecticut River basin, watershed 2 (W-2) in North Danville, Vermont, United States of America.

2 Watershed 1 (W-1), Silver Creek, West Nishnabotna River, Missouri River basin, Treynor, Iowa, United States of America.

3 Watershed 2 (W-2), Keg Creek, Missouri River basin, Treynor, Iowa, United States of America.

4 Watershed 3 (W-3), Silver Creek, West Nishnabotna River, Missouri River basin, Treynor, Iowa, United States of America.

5 Watershed 4 (W-4), Silver Creek, West Nishnabotna River, Missouri River basin, Treynor, Iowa, United States of America.

The location of these catchments is indicated in figure 3, and a comparison of the three physical catchment characteristics which are required by the unit hydrograph procedure, is provided by table 1. All of these catchments are small in area (less than 0.6 square km) as this enables a closer examination to be made of the modified runoff component of the model without incorporating the need for channel routing.

All of these catchments are gauged catchments and are United States Department of Agriculture (USDA) Agricultural Research Service (ARS) experimental watersheds. Hydrological data from all ARS experimental watersheds are currently stored on a data base in the United States,

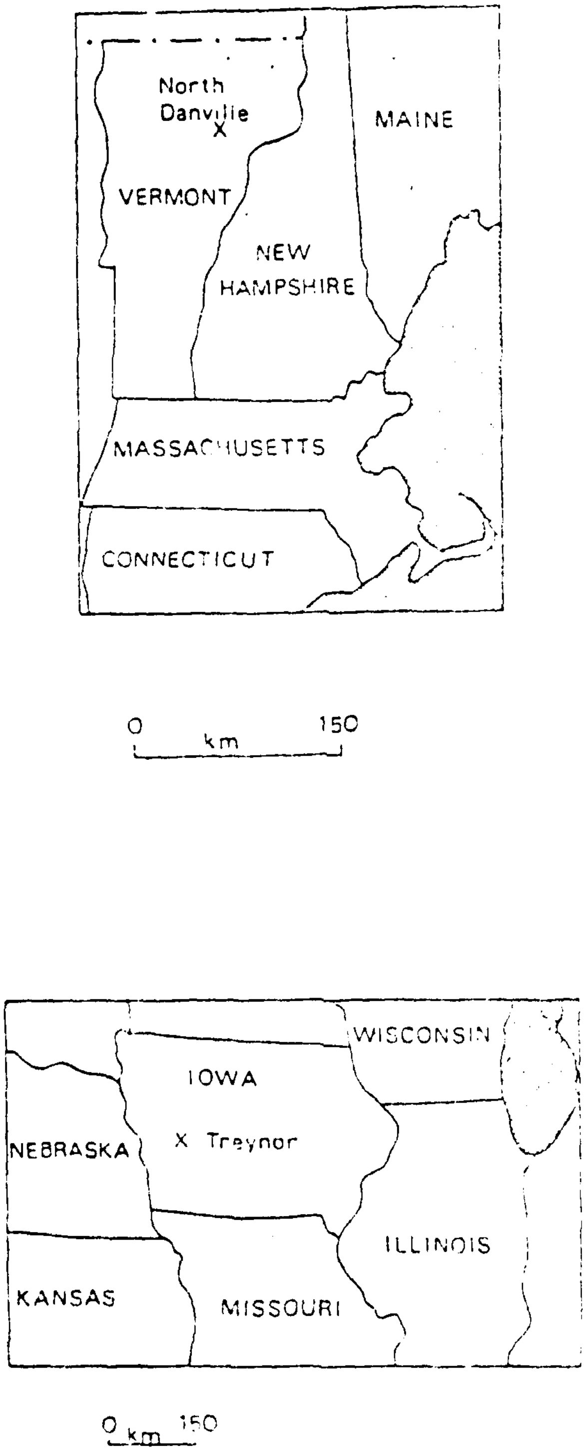


Figure 3: Location of W-2, North Danville, Vermont and W-1, 2, 3, and 4, Treynor, Iowa

Table 1 : Comparison of catchment characteristics which are required by the unit hydrograph procedure

	Area (km^2)	Difference in elevation (m)	Length of main channel (km)
W-2 North Danville Vermont	0.6	79.3	1.2
W-1 Treynor, Iowa	0.3	27.4	1.1
W-2 Treynor, Iowa	0.3	21.3	0.9
W-3 Treynor, Iowa	0.4	27.4	0.9
W-4 Treynor, Iowa	0.6	30.5	0.6

which is accessible by use of REPHLEX (REtrieval Procedures for HydroLogic data from ARS EXperimental watersheds) which has been developed by the Water Data Laboratory and documented by Thurman et al (3). This data base provides information for 305 watersheds which range from 0.2 ha to 536 square km in area. Precipitation and runoff data for individual storm events and for daily, monthly, or annual accumulations, and which range in length of record from 1 to 45 years are available. Information may be derived from the system in tabular or graphical form. An inventory of the ARS experimental watersheds (4) is published which documents the types of data (precipitation, runoff, pan evaporation, soil moisture, land use, soil survey, for example) which are available for each catchment.

The Sleepers River catchment, Connecticut River basin, Vermont, is located 8.05 km north west of St. Johnsbury. This catchment has been the location of many field studies including Dunne and Black (5,6) and it is considered to represent a typical glaciated upland catchment of New England. The location and physical characteristics of the unnamed tributary W-2, are indicated in figure 4. It is described by the USDA as comprising sloping to steep land at higher elevations. It has a covering of glacial till which exhibits good surface drainage and which overlies Devonian schist interbedded with limestone. The land use within the watershed W-2 is divided between permanant hay (37%), pasture (38%), and maple and beech trees (25%).

The four catchments near Treynor, Iowa contain soils which have developed from the deep mantle of Wisconsin loess (3.05 to 27.72 metres) which overlies Kansan glacial till which in turn overlies the bedrock of interbedded calcareous shales and limestones. The watershed topography has developed totally by erosion of loess and the deeper gullies have incised slightly into the till. The loess is considered to have a moderate rate of percolation. In all four watersheds channel flow is permanent and fed by a zone of saturation and seepage which occurs at the loess and till interface. Topographic maps of the four catchments are provided in figures 5 - 8. W-1 is located 9.65 km south west of Treynor. The catchment is laid to contour corn and exhibits high levels

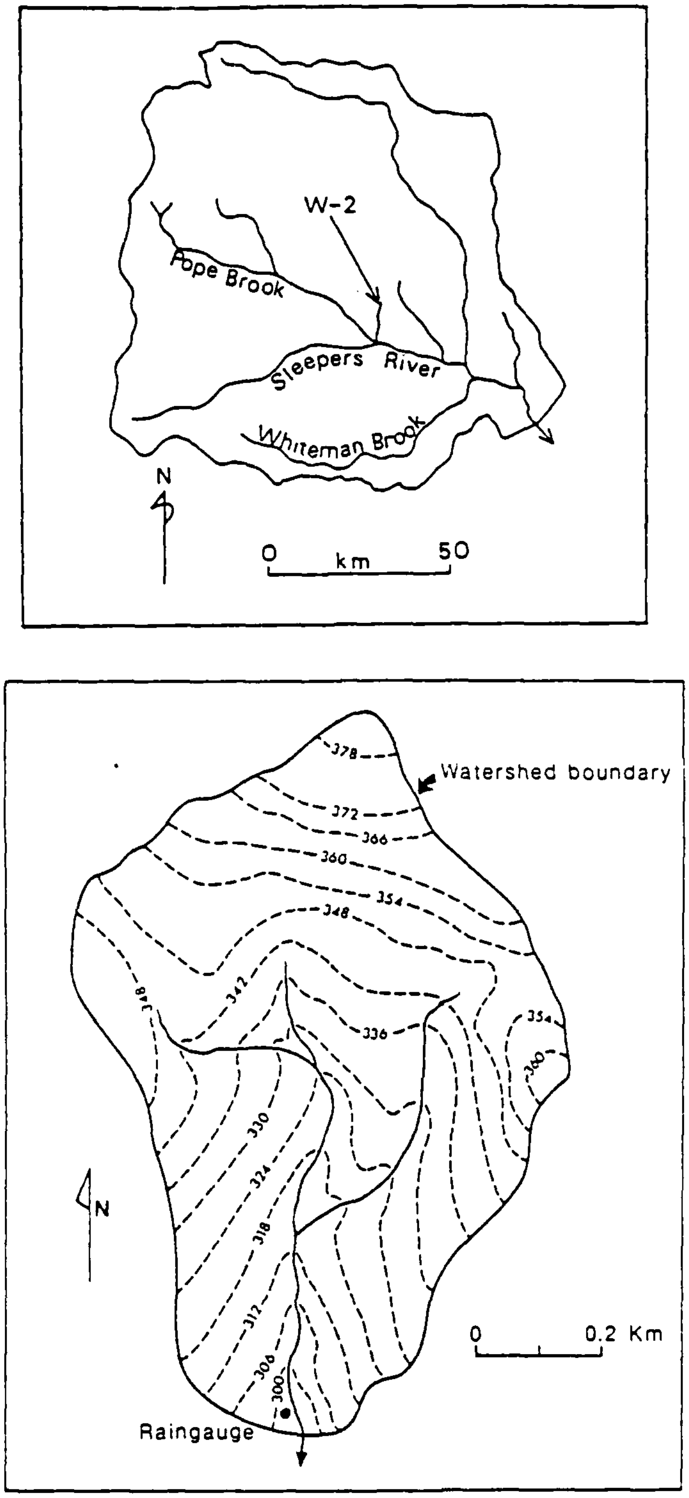


Figure 4: Watershed 2, unamed tributary of Sleepers River catchment, Connecticut River Basin, North Danville, Vermont

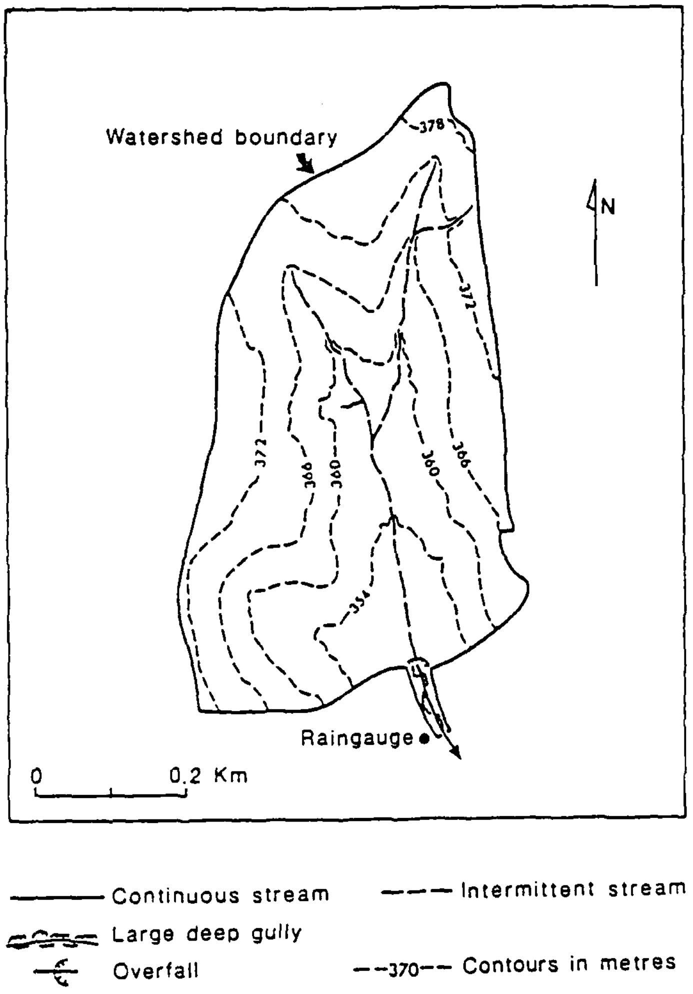


Figure 5: Watershed 1, Silver Creek, West Nishnabotna River, Missouri River Basin, Treynor, Iowa

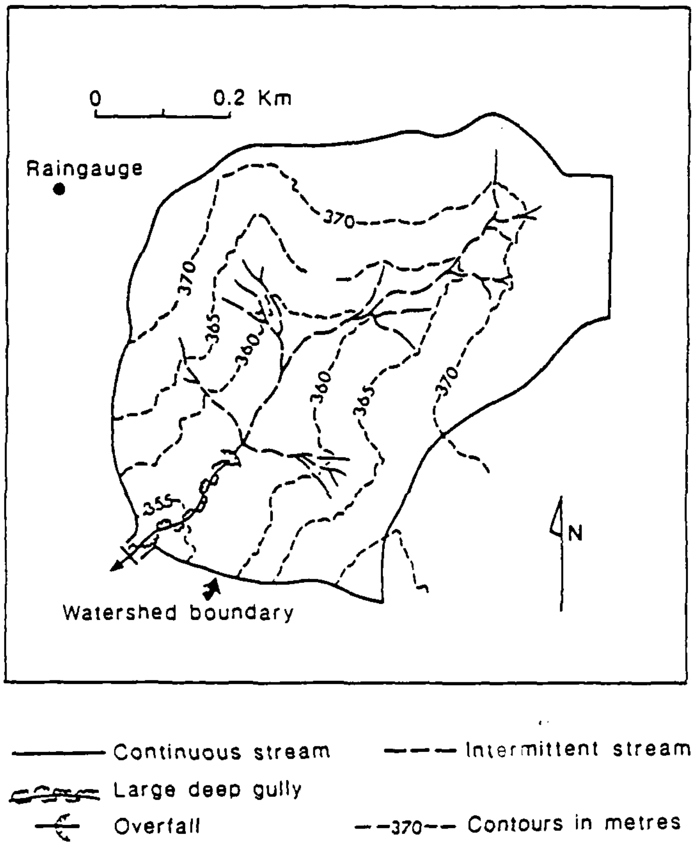


Figure 6: Watershed 2, Keg Creek, Missouri River Basin, Treynor, Iowa

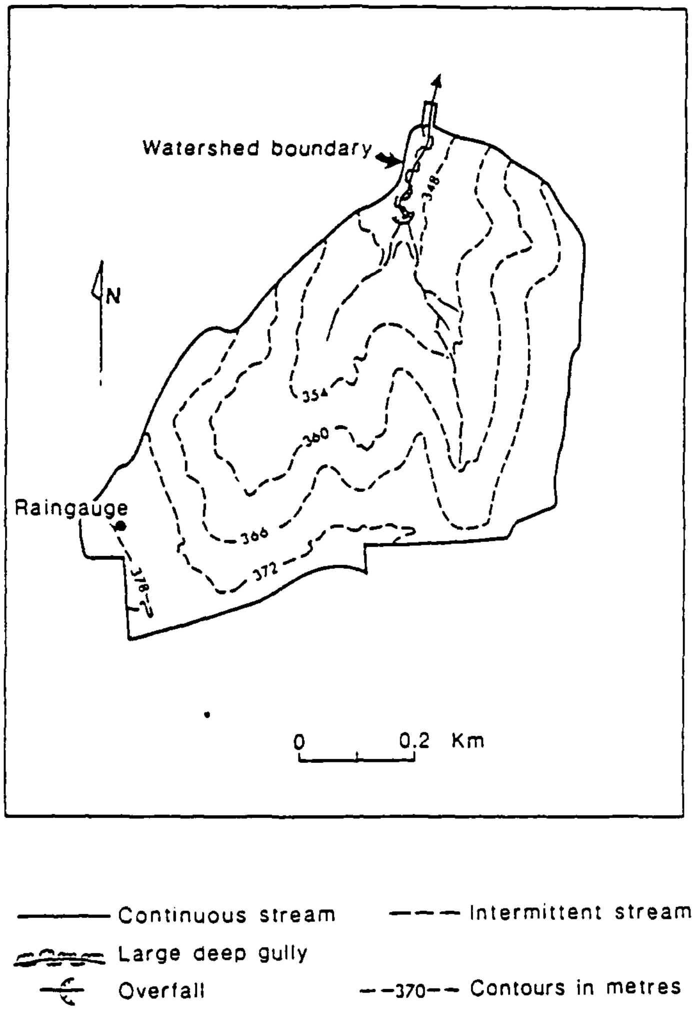


Figure 7: Watershed 3, Silver Creek, West Nishnabotna River, Missouri River Basin, Treynor, Iowa

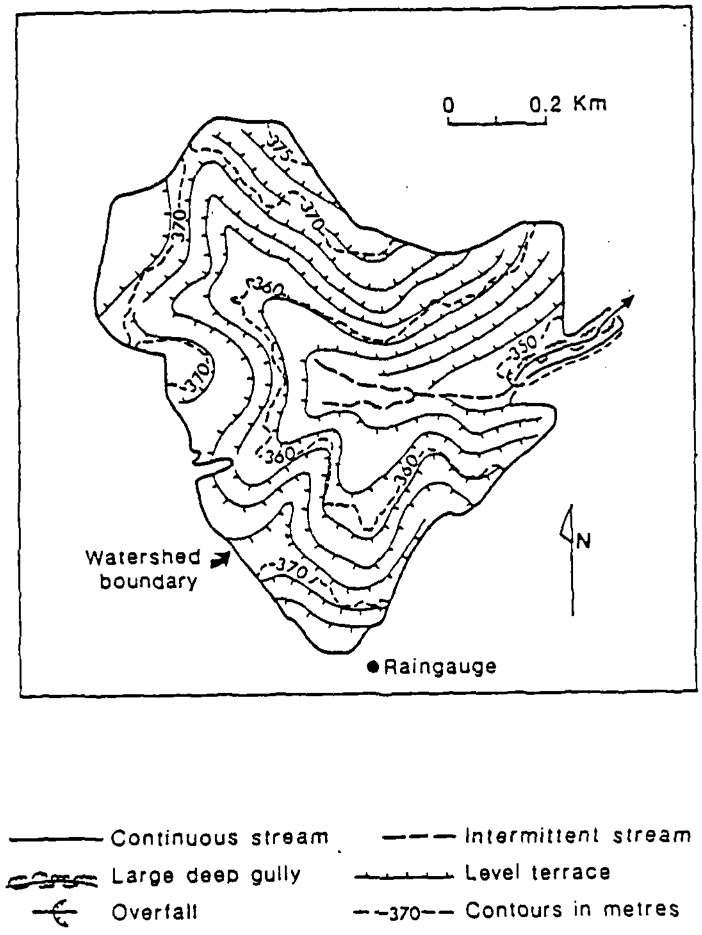


Figure 8: Watershed 4, Silver Creek, West Nishnabotna River, Missouri River Basin, Treynor, Iowa

of fertility and good farming practices. W-2, also 9.65 km south west of Trynor, has similar characteristics to W-1 but is a tributary of another stream, the Keg Creek. W-3 is located 4.83 km south west of Treynor and contains pasture with controlled grazing. Finally, W-4, located 4.83 km south west of Treynor, contains contour corn on grassed backed slope terraces. All terraces in W-4 are as recommended by the ARS.

The five catchments which have been introduced here are all below 0.6 square km. Although these may be considered to be small, certain limitations are imposed upon the catchment scale by the nature of a three year research programme. Within a three year period, it is considered that three potential research strategies are feasible within a geographical hydrological modelling exercise.

Firstly, at one extreme, it would be possible to develop and implement an entirely new mathematical hydrological model. This would demand such an investment of time that evaluation and testing could only be undertaken for one catchment. Secondly, it would be possible to provide a modification to one component of a currently utilized hydrological model, thus allowing sufficient time for a more detailed evaluation of the modified model on a series of catchments exhibiting different characteristics. Thirdly, and at the other extreme, it would be possible to apply a currently used model to a very large number of catchments, but to provide no model development. In this third strategy, a broader and more comprehensive model evaluation could be accomplished.

The first strategy has been a very popular choice. Fenves et al (7) stressed that emphasis has been placed upon model development whilst support, documentation, and evaluation have been neglected. This has led to a multiplicity of mostly underutilized models with no clear recommendations for future requirements and research. Certainly during a three year research period, insufficient time would remain after model design and implementation fully to evaluate the model and to examine its full potential.

The third strategy has, in comparison, not commonly been undertaken. It has been stressed that model evaluation has not been a popular occupation in mathematical hydrological modelling. However, although providing an opportunity for a comprehensive model evaluation and examination of operational applications, the third strategy would not allow for an investigation of ungauged catchment applications as no suitable model could be identified. It would also not allow for the examination of the potential of a physically based, rather than an empirical model for application purposes.

These issues were considered to be of importance and therefore the second strategy was adopted in this analysis. A modification to the infiltration component of HYMO was undertaken, and the period of model modification and implementation has necessarily limited the available time for catchment selection, data collection, and preparation. Thus seven small catchments were chosen. This provides a good compromise between the time limitations of a three year research programme and the need to evaluate the model over a range of catchment conditions.

The small size of catchments is not a disadvantage because the emphasis in this investigation of HYMO and MILHY2 has concentrated upon the hydrograph computation procedure. It has not been designed to examine the characteristics of the Variable Storage Coefficient channel routing technique. The selection of smaller catchments which can in the context of the application of MILHY2 be treated as single subcatchments, has allowed the hydrograph computation to be investigated without the complications of the incorporation of the routing procedure.

2.3 Parameter estimation procedure for MILHY2

The five catchments which have now been introduced in section 2.2 are all less than 0.6 square km (table 1). No subdivision of catchments has been necessary, and consequently no channel cross section information is required for channel routing operations. The catchment characteristics: area, elevation difference, and main stream length (table 1), have been derived for all five catchments from maps of the scale and detail illustrated in figures 4 to 8. The determination of the soils data will now be discussed for each catchment.

There are five major soil types in the Watershed W-2, North Danville, Vermont. These include sandy loams, silt loams, and loams, and are namely, Colrain, Peacham, Calais, Cabot, and Woodstock. The details concerning soil horizon depths and soil textural characteristics of each layer were available from the USDA ARS descriptions of the catchment (table 2). The division of each soil horizon into cells was accomplished according to the general rule that cells in the top layer must not be greater than 0.1 metres and in the lower two layers, not greater than 0.15 metres. From the soil texture information, the Brakensiek and Rawls charts were used to define the soil hydrological characteristics. For all soil textures, the centroid position on the Bakensiek and Rawls charts was used. Detention capacity was assumed to be zero and a uniform initial relative saturation of 80% was assumed.

The four catchments near Treynor all contain the same four soil types, but each soil occupies different proportions of the total catchment area. The four soil types are Monona, Marshall, Napier, and Ida, and comprise silt loams and silty clay loams. Very little information was available on the layering characteristics of these soils and therefore, no layering of the representive soil columns was incorporated. The hydrological characteristics of each soil texture group were derived from the centroid position of the Brakensiek and Rawls charts. The soil column which is defined by the depth of the soil is divided into equal sized cells of 0.05 metres for Napier (the deepest soil) and 0.025

metres for the other three soils. The details of the soils in all four of these catchments are provided by table 2. The detention capacity of catchment W-4 was set at 0.01 metres. This value is estimated according to the terracing. No detention capacity was assumed for the other three catchments. Initial relative saturation was, in the absence of soil moisture information and based on previous experience, assumed to be 80% at the surface, and to increase uniformly with depth.

The precipitation data for all storms applied to these five catchments were converted into cumulative totals at equal time intervals, the form which is required by MILHY2. The measured hydrograph for each storm event was also input to MILHY2 for comparison. The storms which were used and the runoff which they produced are indicated in table 3.

Experience of application of the model to these five catchments, and those of Texas and Arkansas, has illustrated that in order to provide the data for model application, the user is involved in four stages. Figure 9 illustrates these stages, which include data collection, data preparation, data entry and data checking.

Data collection

This involves securing three sources of information: a topography map of the catchment, a soils map and accompanying description, and precipitation data. Depending upon the level of information which is available, the precipitation data might be in the form of recording rain gauge data, storm totals or predicted rainfall data. The distribution of precipitation, where only storm totals are available, may be provided by application of one of the standard Soil Conservation Service rainfall distribution models.

Data preparation

This involves the user in a number of decisions as to the manner in which the catchment should be characterized, the use of the Brakensiek and Rawls tables and charts to derive soil hydrological properties, and a series of manual calculations to convert precipitation data into the form required by MILHY2. All of these actions could potentially

Table 2 : Soils information for application of the infiltration model to the five catchments in Vermont and Iowa

Soil type	USDA soil texture	Average depth of soil (metres)	Catchment area (%)			
W-2 North Danville, Vermont						
Colrain	sandy loam	0.84	41			
Peacham	silt loam	0.31	5			
Calais	loam	0.69	9			
Cabot	silt loam	0.46	13			
Woodstock	sandy loam	0.61	32			
Treynor, Iowa						
			W-1	W-2	W-3	W-4
Monona	silt loam	0.15	38	24	50	48
Marshall	silty clay loam	0.254	35	36	22	23
Napier	silt loam	0.762	16	17	22	23
Ida	silt loam	0.076	11	23	6	6

Table 3 : Storm characteristics for the five catchments in Vermont and Iowa.

Storm number	Date of storm start (d.m.yr)	Time of storm start (hrs)	Time increment of rainfall (hrs)	Storm duration (hrs)	Total precip- itation (mm)	Total runoff (mm)
W-2, North Danville, Vermont						
1	11.9.1968	06:00	1.0	16.0	38.1	0.36
2	21.7.1969	15.30	0.25	3.25	24.1	0.31
3	28.8.1970	14:45	0.25	6.5	37.3	0.54
4	16.7.1967	04:30	0.5	9.0	43.9	4.67
5	30.7.1960	12:00	1.0	11.0	43.9	2.72
6	2.6.1961	02:00	0.25	6.0	21.1	4.39
W-1, Treynor, Iowa						
1	2.8.1970	21:40	0.1	1.8	67.1	22.96
2	26.6.1966	02:32	0.1	1.0	22.9	9.27
3	14.6.1967	05:10	0.1	1.7	19.6	12.34
4	20.6.1967	20:56	0.05	2.9	156.0	107.30
5	7.6.1967	17:05	0.1	1.4	41.9	31.3
W-2, Treynor, Iowa						
1	2.8.1970	21:37	0.1	1.8	41.9	17.96
2	26.6.1966	02:26	0.1	1.2	22.9	10.19
3	14.6.1967	05:13	0.1	1.7	19.8	10.97
4	20.6.1967	20:56	0.05	2.75	143.0	96.16
5	7.6.1967	17:10	0.1	1.0	43.2	25.62
W-3, Treynor, Iowa						
1	2.8.1970	21:33	0.1	1.7	41.7	1.52
2	25.6.1966	23:05	0.1	1.3	28.7	4.14
3	14.6.1967	05:10	0.1	1.8	21.1	2.99
4	20.6.1967	20:52	0.1	2.8	98.6	33.75
5	7.6.1967	17:10	0.1	1.3	23.9	4.17
W-4, Treynor, Iowa						
1	2.8.1970	21:33	0.1	1.7	41.7	0.15
2	26.6.1966	23:05	0.1	1.3	28.7	1.27
3	14.6.1967	05:10	0.1	1.8	21.1	1.21
4	20.6.1967	20:52	0.1	2.8	98.6	9.53
5	7.6.1967	17:10	0.1	1.3	23.9	1.44

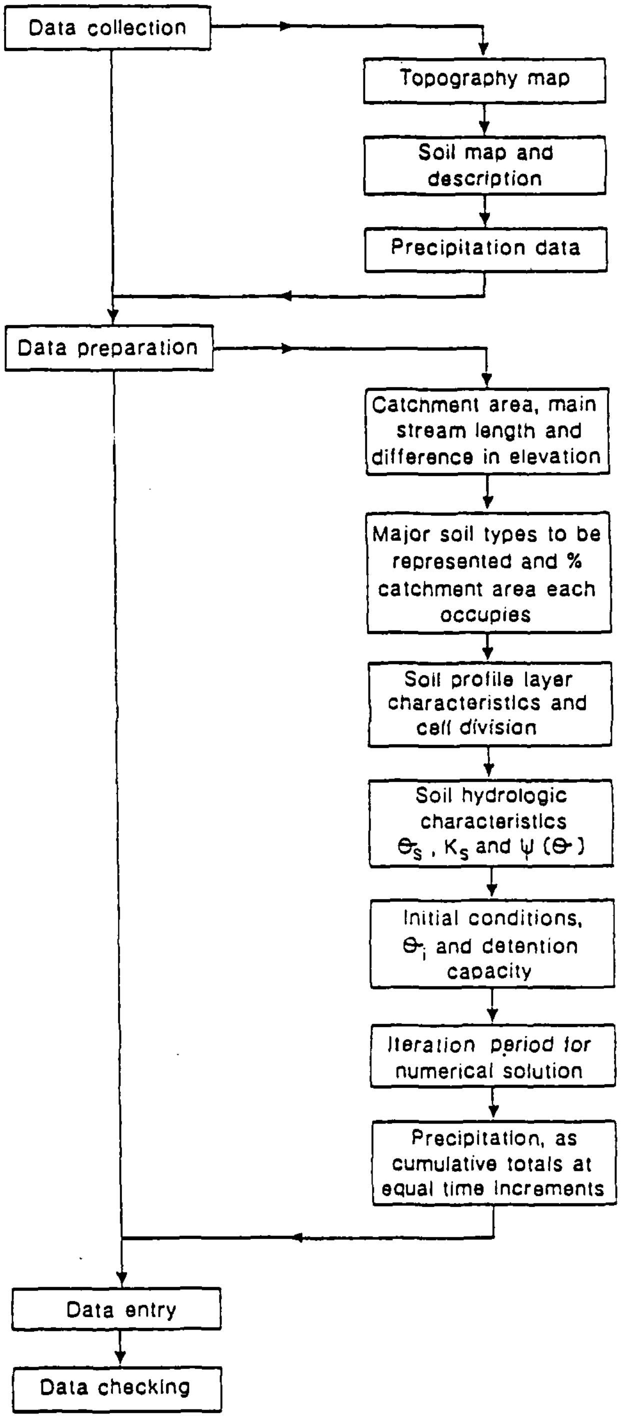


Figure 9: The four stages in data generation

introduce error into the predictions. To reduce this source of error, and to operationalize the model as fully as possible for the nonprofessional hydrologist, it is important that an attempt should be made to computerize certain procedures in this data preparation stage. It is necessary that the catchment characteristics required by the unit hydrograph method: catchment area, main stream length, and difference in elevation, be determined by the user. This is a straightforward, but tedious procedure, which does not require specialized skills. The determination of area could only be computerized should a digitizing facility be available on the computer system. Access to this cannot be assumed for the microcomputer system user. However, it is important to stress to the user the importance of accuracy in the specification of these three catchment characteristics. Figure 10 provides a summary of certain results of the application of a deterministic sensitivity analysis to the unit hydrograph method which is used by MILHY2. The sensitivity of the peak unit discharge to the three catchment characteristics is illustrated. For a constant elevation difference of 15.24 metres, figure 10(A) illustrates that as the area of the catchment increases, i.e. topography becomes less steep, the sensitivity of unit peak to length of main channel increases. For any given area and height combination, the sensitivity to length of main channel is greatest when the channel is shorter. Figure 10(B) illustrates that the unit peak is sensitive to catchment area. This sensitivity is greatest for smaller catchment areas and varies quite significantly according to the height to length ratio. As this ratio decreases and topography becomes less steep, then sensitivity to area increases. Figure 10(C) illustrates that the sensitivity of the model to elevation difference decreases as the height difference increases. The magnitude of this sensitivity is related to the catchment shape, being less for narrower and elongated catchments. It is important therefore, that these three catchment characteristics are specified as accurately as possible.

The selection of the major soil types is another choice for which very little direct help can be provided specifically for the catchment of interest to the user. Examination of the soils map is necessary to identify the major soil types, and to determine the percentage of the

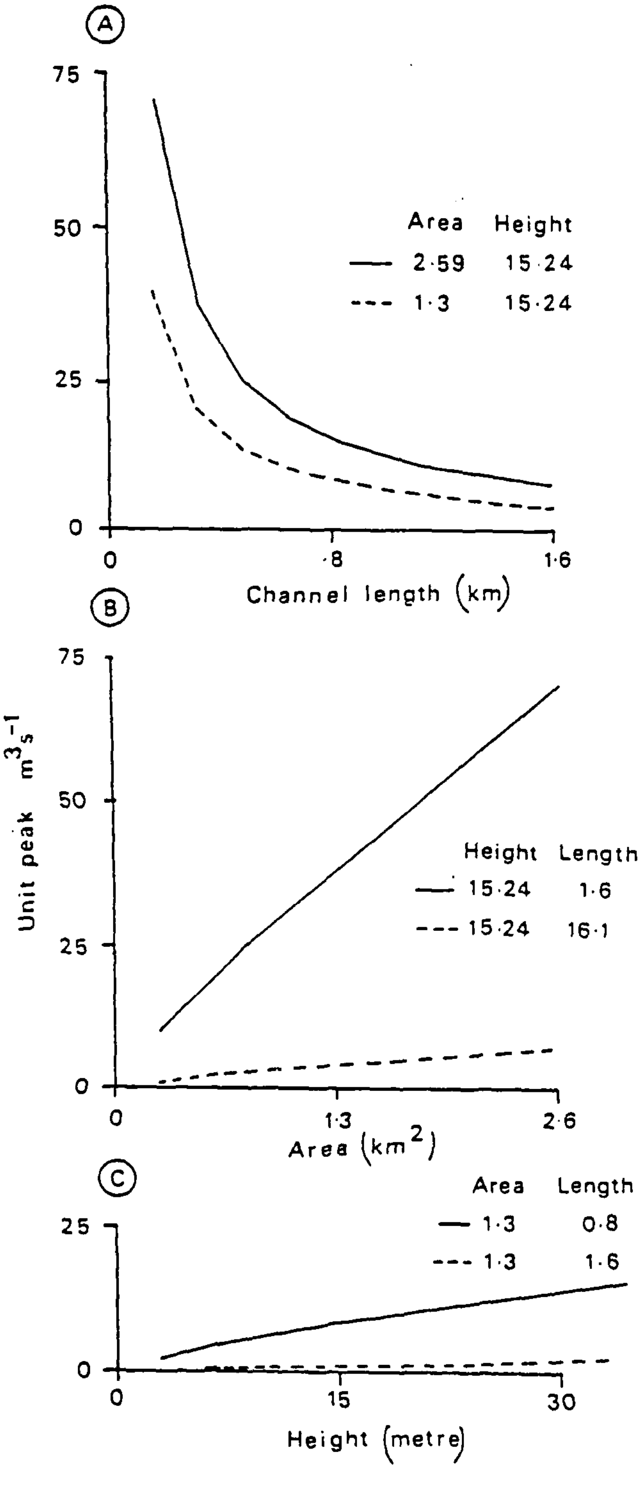


Figure 10: Sensitivity of the unit hydrograph procedure to (A) channel length (B) catchment area (C) elevation difference

catchment area which each occupies.

It is intended that the experience of a series of applications of MILHY2, which are documented in this report, will be useful in defining a very general series of guidelines to which the user may refer when selecting the appropriate number of soil columns to represent the catchment area, the layering characteristics of each soil column, and the dimensions of the cells in the soil column.

The number of soil columns will reflect a trade-off between a possible increase in prediction accuracy and the increased computer and data preparation costs which are associated with the application of a large number of soil columns. If sufficient detail is available in the soil map descriptions to define the soil texture characteristic of up to three layers in the soil, then this information can be used. Should this degree of data not be available, the user must have access to advice or a standard procedure which can be applied. Choice of the size and hence the number of cells in the soil column should also be based on the past experience of application of the model.

If a general series of rules based upon the results of gauged applications on the model can indeed be established, then it is important that a user does have access to this information. There are two forms in which this information may be stored. Firstly, it can be provided in a manual which accompanies the computer program, or secondly, it can be provided on-line. The information can be held in the computer program and provided to the user on request, in an interactive form, as the user enters the data for model application. For example, where the user is required to specify the number of soil columns for the catchment area, if insufficient information is available, or if the user is unfamiliar with the model, then the user may interrogate the system for advice. Based on past application, the number of soil columns can be related to catchment size, precipitation characteristics, the size of the computer system, and to any constraints which the user might be placing on response time. The user will then be in a position to operate the model to a greater advantage and based upon the past experience of the model application, rather than on past personal experience. With time, the information which is held by the system can be increased.

The use of the Brakensiek and Rawls (see pages 32, 33 in (2)) charts to provide the soil hydrological characteristics, saturated hydraulic conductivity, saturated moisture content, and soil moisture characteristic curve, is one very obvious area where operator error may be reduced. The look-up procedure which uses the tables could be replaced by a series of expressions which are more easily computerized. It is only necessary for the user to define the soil texture class, sand or loam for example, for each soil type, and each layer where appropriate. This information is then entered into a program which will firstly convert the soil texture category to a percentage clay and percentage sand figure, secondly, it will determine the corresponding numerical values for these three soil hydrological parameters. The values are then automatically stored in the form required by the infiltration program thus reducing the amount of data entry required of the user. The program to generate the values of saturated hydraulic conductivity and saturated soil moisture content has been developed by the SCS at Beltsville, Maryland. To derive the saturated hydraulic conductivity for example, in inches per hour, the following expression is used:

$$K = e^{\begin{array}{l}[-8.9685-0.0282(cl)+19.5235(POR)+0.0001(sd)^2-0.0094(cl)^2 \\ -8.3952(POR)^2+0.0777(sd)(POR)-0.0029(sd)^2(POR)^2 \\ -0.0195(cl)^2(POR)^2-0.00002(sd)^2(cl)-0.0273(cl)^2(POR) \\ -0.0014(sd)^2(POR)-0.000003(cl)^2(sd)]\end{array}} \qquad (1)$$

Where:

cl - percentage clay
sd - percentage sand
POR - porosity

The initial moisture content, detention capacity and iteration period must be specified by the user. Again, from repeated application of the model, a series of general rules will be derived and then rather than specifying the exact numerical figures for these parameters, the user could, by supplying a more general level of information, rely on the data preparation routines in the model to derive the data which, on the basis of past experience, are considered to be most appropriate.

Similarly, the precipitation data can be converted to the format which is required by MILHY2, from the form in which they are available.

Data entry

Under the proposed scheme, the amount of data entry required by the user is reduced. All numerical values which are generated by the data preparation procedures are automatically produced in the form required by the model.

Data checking

It is necessary to check the data before model execution is initiated. A certain degree of data checking can also be incorporated into the program, and checks on units, and on missing or incorrectly typed data will certainly be very effective.

Figure 11 illustrates the nature of the program which is suggested here. This figure illustrates the information which is required to operate the hydrograph computation. It will be recalled that this hydrological procedure comprises three sections: the derivation of the unit hydrograph, the derivation of incremental runoff, and the convolution of these two series to produce the catchment outflow hydrograph. Figure 11 indicates the information which must be supplied by the user and the two stages of data preparation and checking which could be undertaken by the computer program, before model execution begins. Certainly as further enhancements to the program are developed, a hierarchy of paths through the data preparation, entry and checking stages could be provided depending upon the nature of the catchment data available, and the status of the operator. Further refinement could involve the incorporation of editing facilities, and the capability to view and to

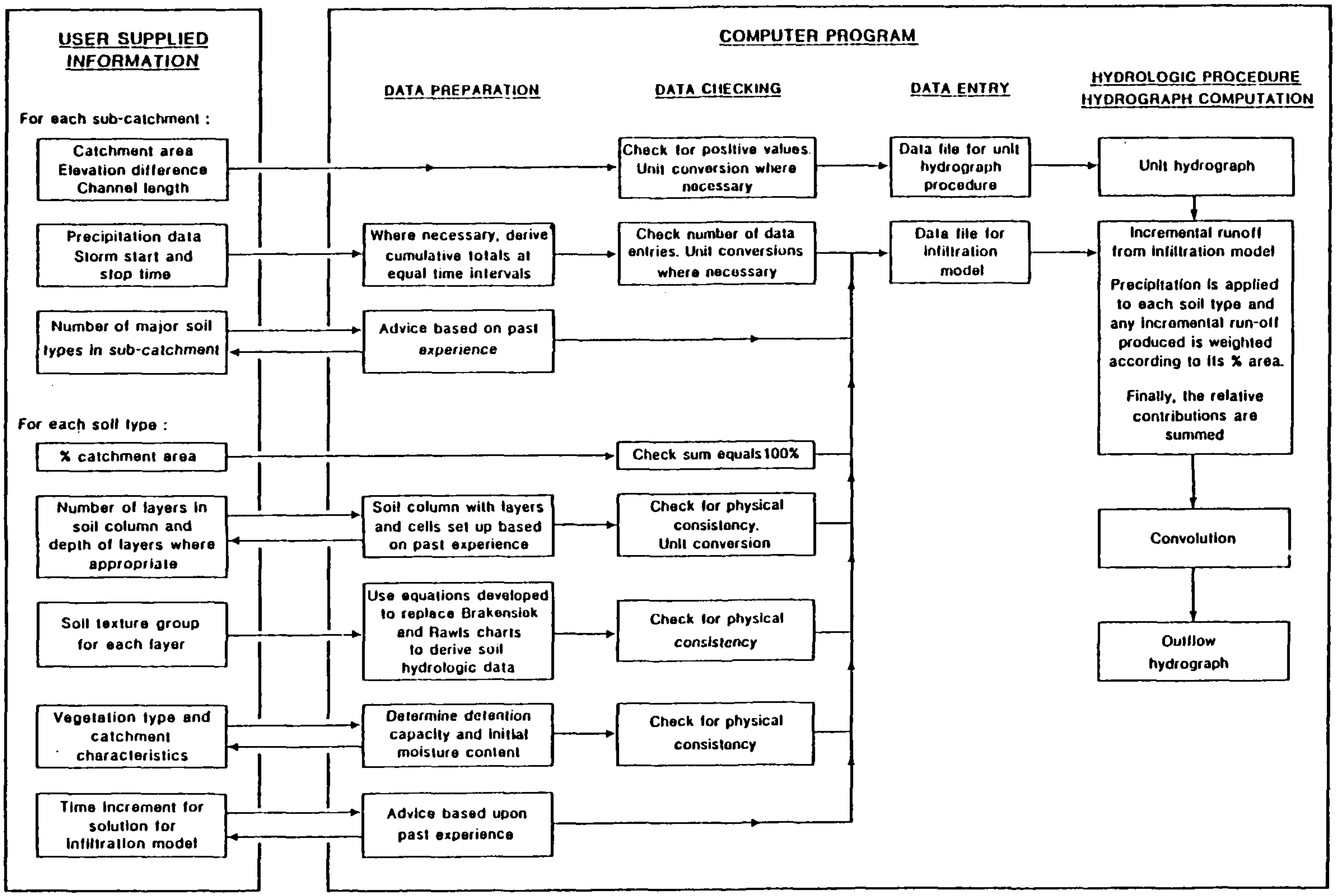


Figure 11: Proposed operational version of the hydrograph computation MILHY2.

check data both in graphical and tabular form.

2.4 Comparison of calculated and measured hydrographs

In this series of applications of MILHY2 to catchments in Vermont and Iowa, it is not proposed that any fine tuning of the model parameters be undertaken to assure the closest fit to the measured hydrograph which is possible. Rather, the catchment data which have been derived are to be used in one application to each storm. Hence, the catchment is treated as if it were ungauged.

To assess the accuracy of the model predictions for this wide range of experimental frames, the same two stage procedure of evaluation will be followed (figure 2).

In total, 26 experimental frames (six storms applied to W-2, North Danville, Vermont and five storms to each of the four catchments in Treynor, Iowa) have been described here. Not all of these will be reported in detail during the following discussion. A number of selected examples will serve to illustrate the major points which can be made. To identify each experimental frame, the catchment name and the storm number, indicated in table 3, will be provided.

The two stage procedure which compares the calculated and measured hydrographs (figure 2) will be followed in the same order as in the comparison of the predicted hydrograhs for the North Creek and Sixmile Creek.

Stage 1: Comparison of calculated and predicted hydrograph

A comparison of calculated and measured hydrographs for a selection of experimental frames is provided by figures 12 to 16. The change in scales between the North Danville and four Treynor catchments should be noted. The predictions provided by MILHY2 for W-2, North Danville do not approximate the measured to any great degree, although the large vertical scale for these time series should be appreciated. The three storm events illustrated in figure 12 represent the range of inaccurate

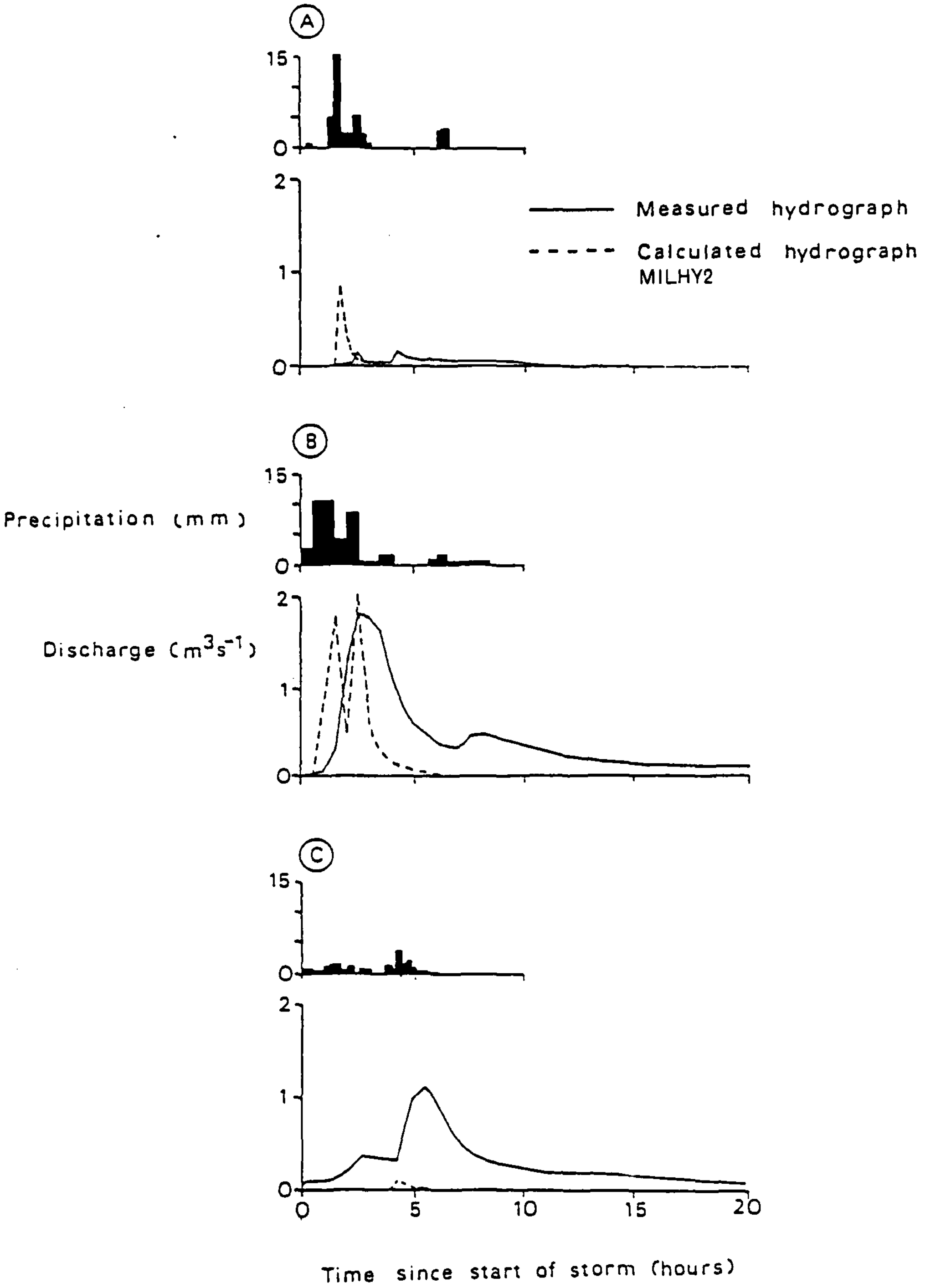
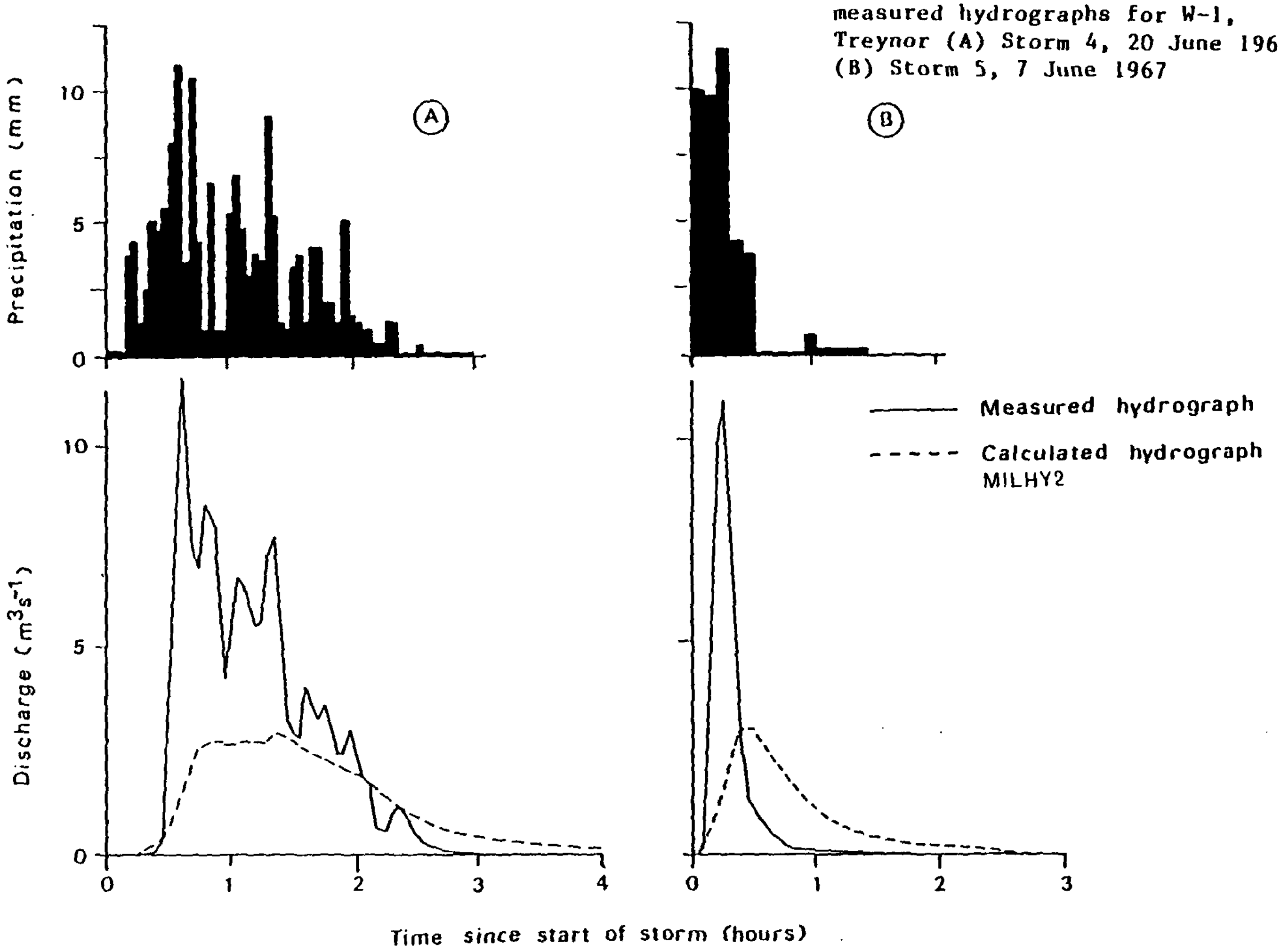


Figure 12: Comparison of calculated and measured hydrographs for W-2, North Danville, Vermont (A) Storm 3, 28 August 1970 (B) Storm 4, 16 July 1967 (C) Storm 6, 2 June 1961

Figure 13: Comparsion of calculated and measured hydrographs for W-1, Treynor (A) Storm 4, 20 June 1967 (B) Storm 5, 7 June 1967



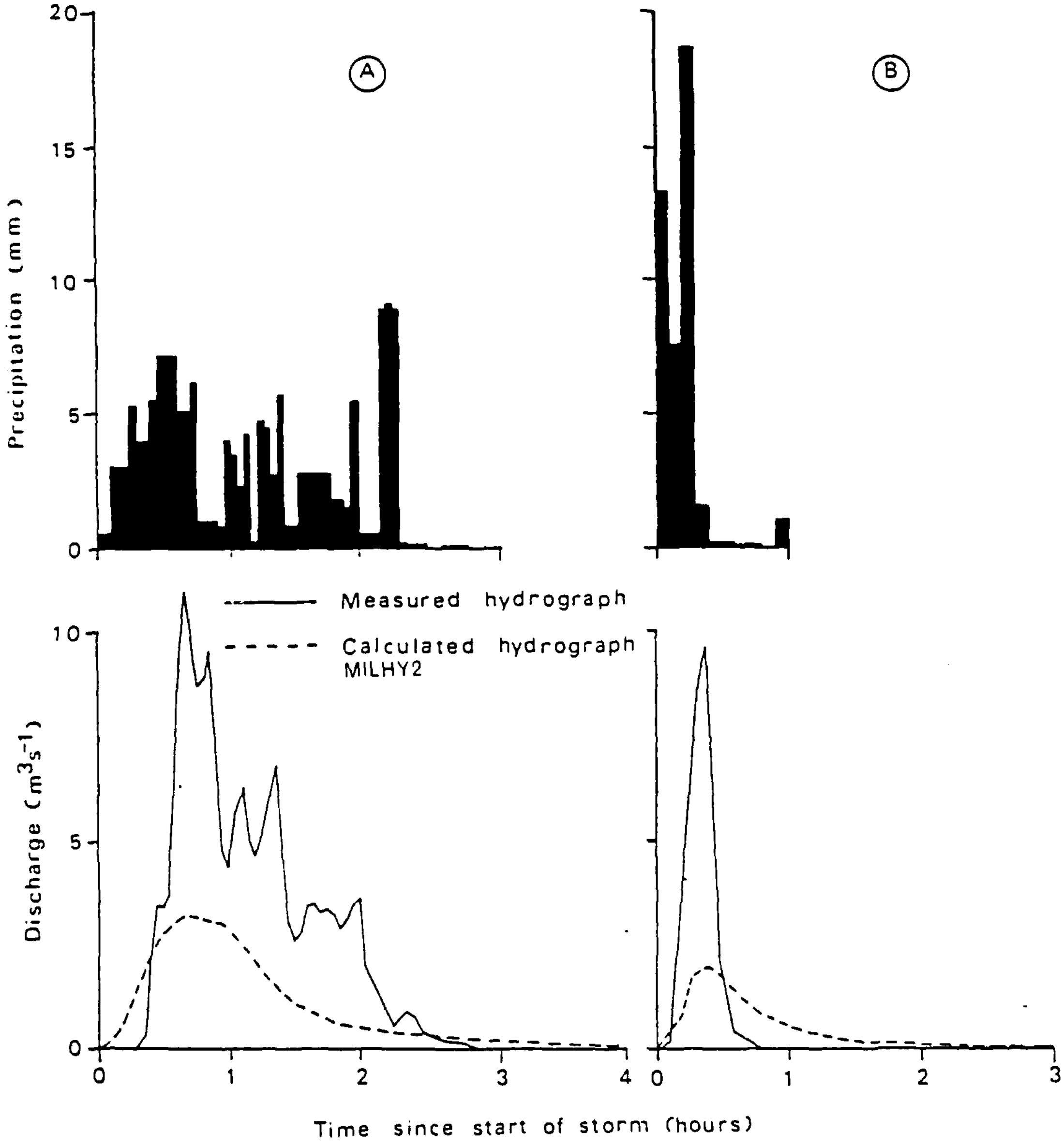


Figure 14: Comparison of calculated and measured hydrographs for W-2, Treynor, Iowa (A) Storm 4, 20 June 1967 (B) Storm 5, 7 June 1967

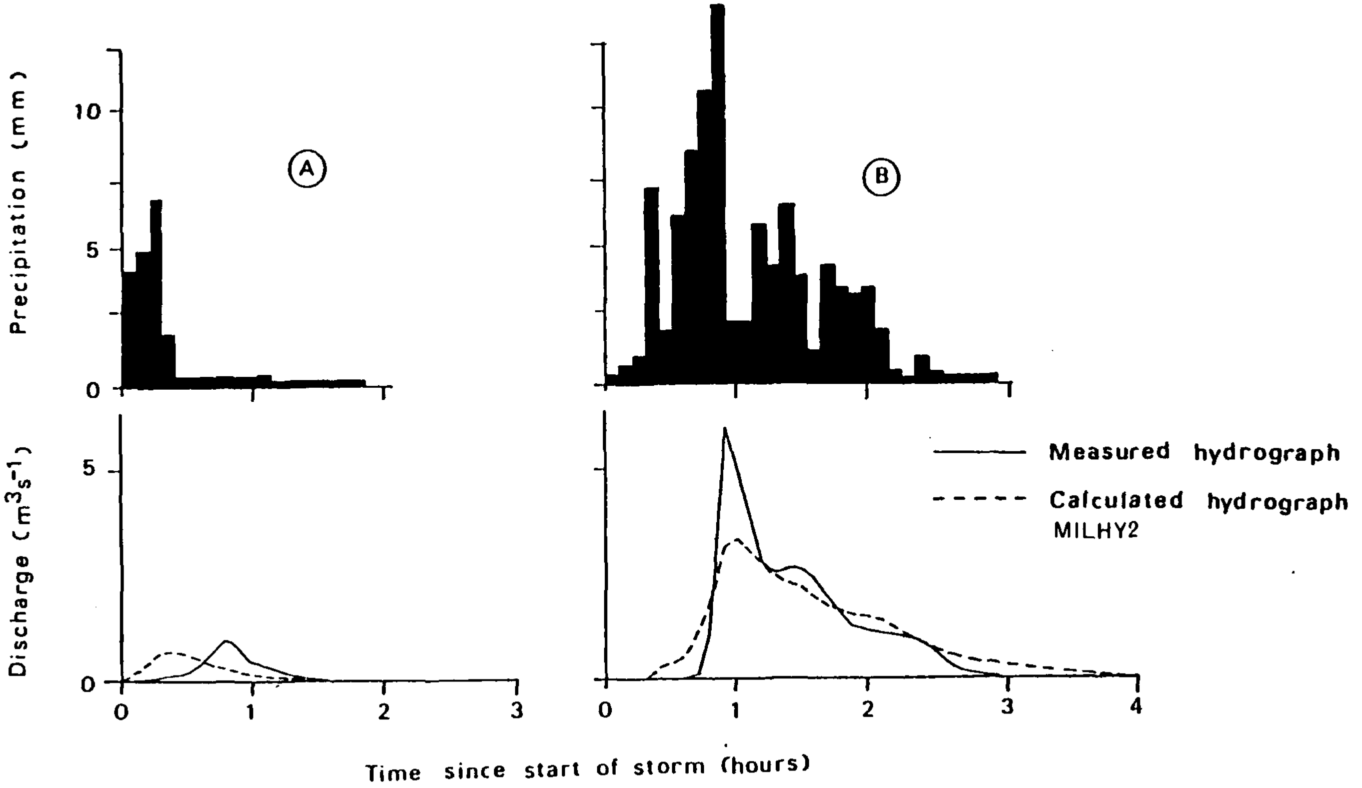


Figure 15: Comparison of calculated and measured hydrographs for W-3, Treynor, Iowa (A) Storm 4, 20 June 1967 (B) Storm 5, 7 June 1967

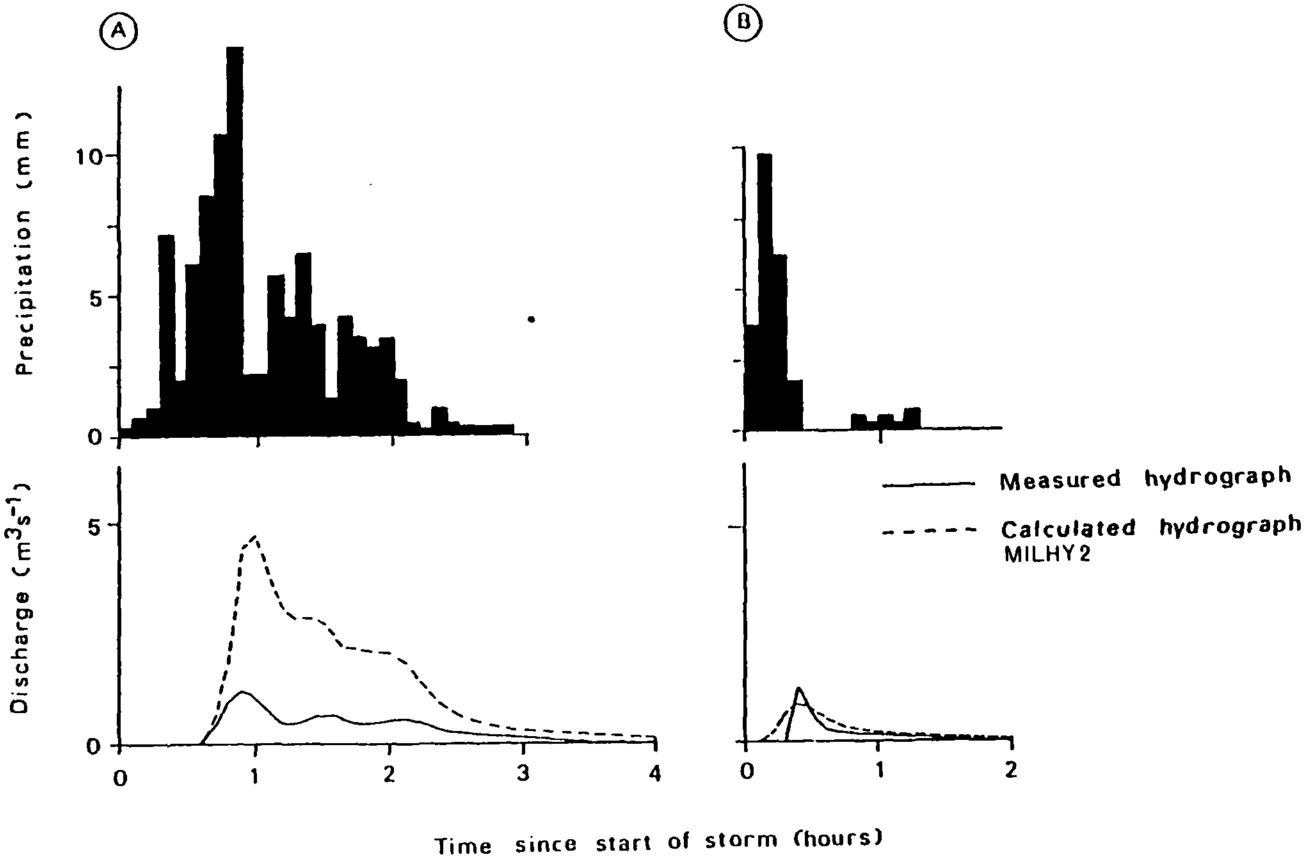


Figure 16: Comparison of calculated and measured hydrographs for W-4, Treynor, Iowa (A) Storm 4, 20 June 1967 (B) Storm 5, 7 June 1967

and inconsistent results which are obtained for this catchment. For storm 3, (figure 12(A)) the predicted hydrograph bears no similarity in form or timing to the measured. Peak discharge is also highly overestimated. The measured hydrograph for storm 4 (figure 12(B)) displays a double peak. The calculated hydrograph also has a double peak but neither the timing nor the relative magnitudes of the two peaks are correct. For storm 6 (figure 12(C)), the model predicts a much lower runoff than was experienced in the catchment.

MILHY2 provides underpredictions of peak discharge for all 10 storms applied to W-1 and W-2, Treynor, and figures 13 and 14 provide four examples of this. The relationship of calculated and measured hydrographs in these figures is very similar in form for those derived for the North Creek and Sixmile Creek (DAJA37-81-C-0221). MILHY2 has a tendency to overpredict discharge during the very early stages of the hydrograph rise, then to underpredict discharge during the peak and finally to overpredict discharge during the latter phases of recession. With the exception of storm 5 applied to W-1 however (figure 13(B)), the timing of the predicted hydrograph quite closely approximates the measured.

Figure 15 provides the calculated and measued hydrographs for storm numbers 3 and 4 applied to W-3 Treynor, Iowa. The response to storm 3 (figure 15(A)) is typical also of storms 1, 2 and 5 applied to this catchment. The measured hydrograph response is delayed and the model does not predict this. The overall hydrograph form and runoff volume are similar, but the timing is poor. The prediction for storm 4 (figure 15(B)) however is encouraging. The runoff volume and timing are very well predicted, but as noted above, the peaked form of the measured hydrograph is not predicted by MILHY2. Figure 16 illustrates the overprediction made by MILHY2 for storm 4 on W-4 Treynor, Iowa (figure 16(A)). The predicted response to storm 5 (figure 16(B)) again has a similar relationship to the measured as has been noted for the North Creek and Sixmile Creek.

A series of plots of calculated against measured discharge are provided by figures 17 and 18. The dashed line indicates the position of perfect prediction and the arrows indicate the order of occurrence of errors from t=0 and at successive time intervals through the storm event. Figure 17 illustrates quite clearly the range of overprediction (storm 3, figure 17(A))) to underprediction (storm 6, figure 17(B)) derived for this catchment. There is no systematic relationship between measured and calculated discharge for this catchment. The patterns of hydrograph prediction illustrated in figure 18(A) for storm 5, W-1 and in figure 18(B) for storm 5, W-2, Treynor, Iowa are typical of the response to the other storms applied to these catchments, and are also similar in form to those produced for North Creek and Sixmile Creek (figure 19). A systematic source of error appears to occur over a range of catchments which causes the hydrograph rising limb, peak discharge, and beginning of recession to be underpredicted, but for the discharges occurring during the latter stages of recession to be overpredicted.

A different form of hydrograph predictions is illustrated for storm 3 applied to W-3 Treynor, Iowa in figure 18(C). Here, the pattern is reversed, overpredictions of the rising limb and underpredictions of the falling limb occur. The predicted hydrograph is also illustrated to be out of phase with the calculated; two points in the curve, in the north and east corners, are observed rather than the more usual one, in the north east position. Finally, storm 5 applied to W-4 (figure 18(D)) displays a similar pattern to the Sixmile Creek and North Creek where overprediction of the rising and falling limb and underprediction of the peak discharge have produced a hydrograph which is very similar in terms of runoff volume, but not as peaked as the measured.

A comparison of percentage time to peak discharge error, percentage peak discharge error, and percentage mean discharge error for all 26 experimental frames is provided in figure 20. Percentage time to peak discharge error ranges much less widely than the other two indicies. For W-2, North Danville, time to peak discharge is predicted exactly for storm 4 and underpredicted for the other five storms by between 9% and 30%. For both W-1 and W-2, Treynor, the exact time to peak discharge is predicted for storms 2, 3, and 4. Storms 1 and 5 are overpredicted for

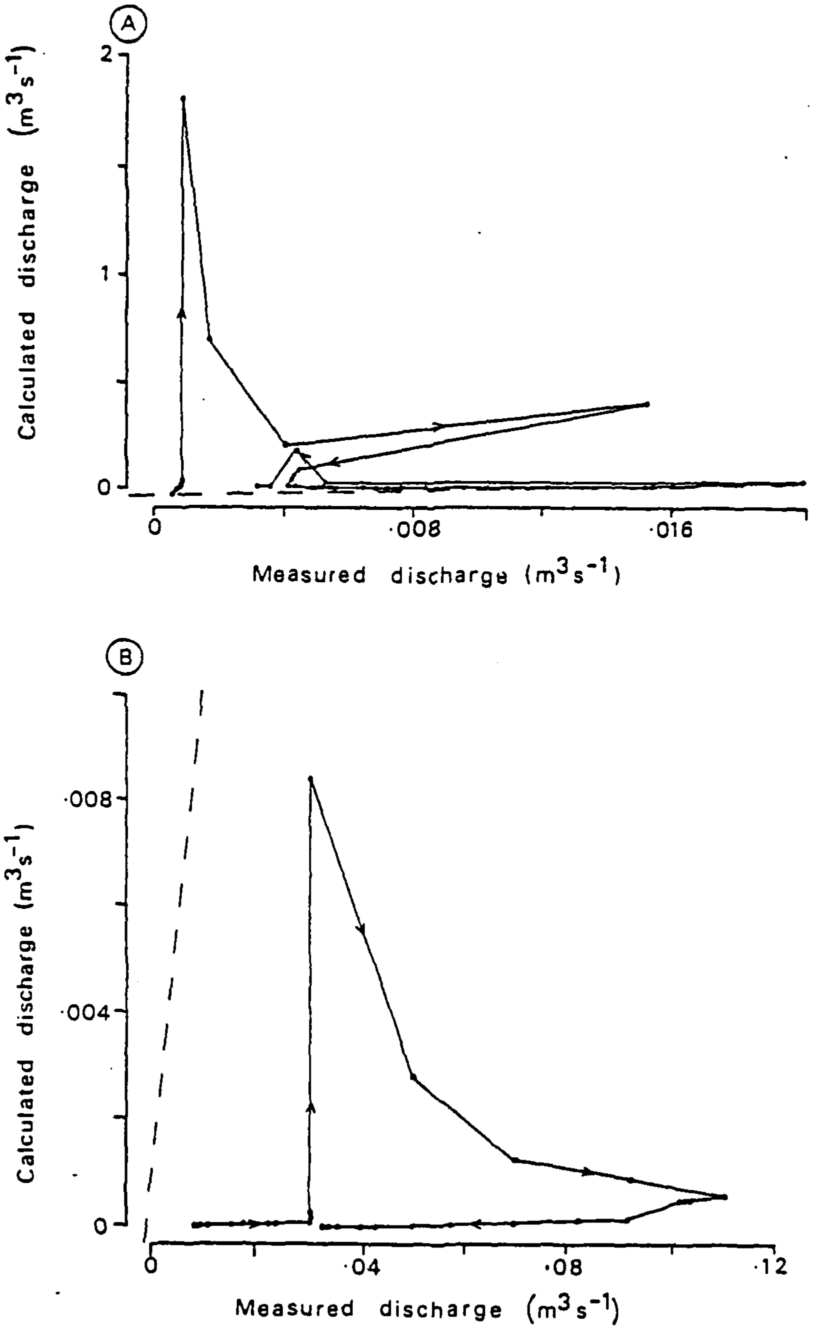


Figure 17: Relationship between discharge predicted by HYMO2 and measured discharge for W-2, North Danville, Vermont (A) Storm 3, 28 August 1970 (B) Storm 6, 2 June 1961

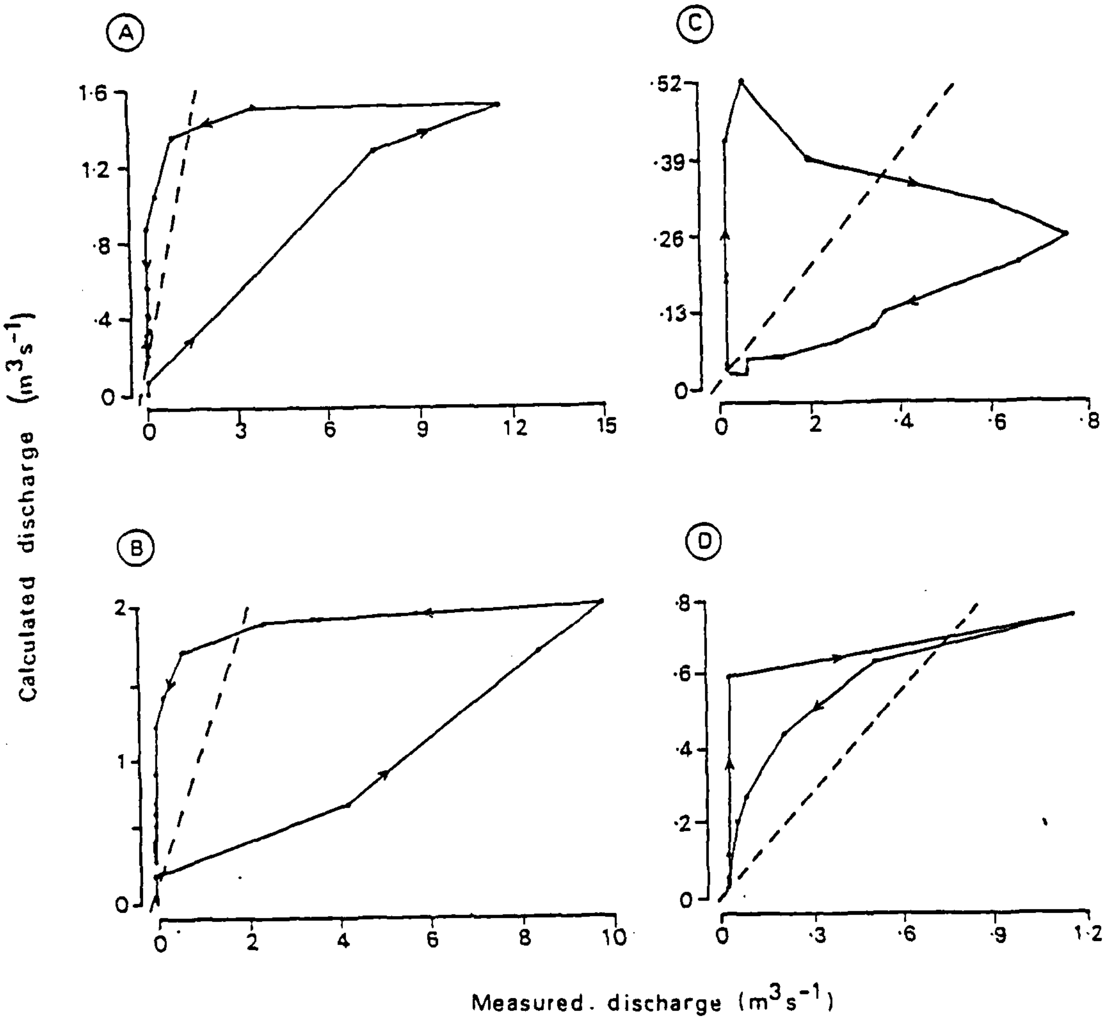
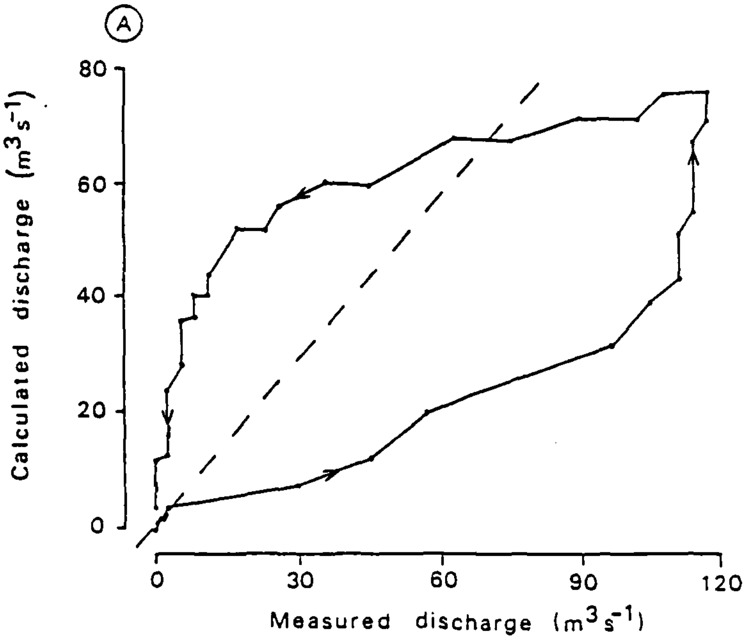


Figure 18: Relationship between discharge predicted by HYMO2 and measured discharge (A) Storm 5, 7 June 1967, W-1, Treynor, (B) Storm 5, 7 June 1967, W-2, Treynor (C) Storm 3, 14 June 1967, W-3, Treynor (D) Storm 5, 7 June 1967, W-4, Treynor



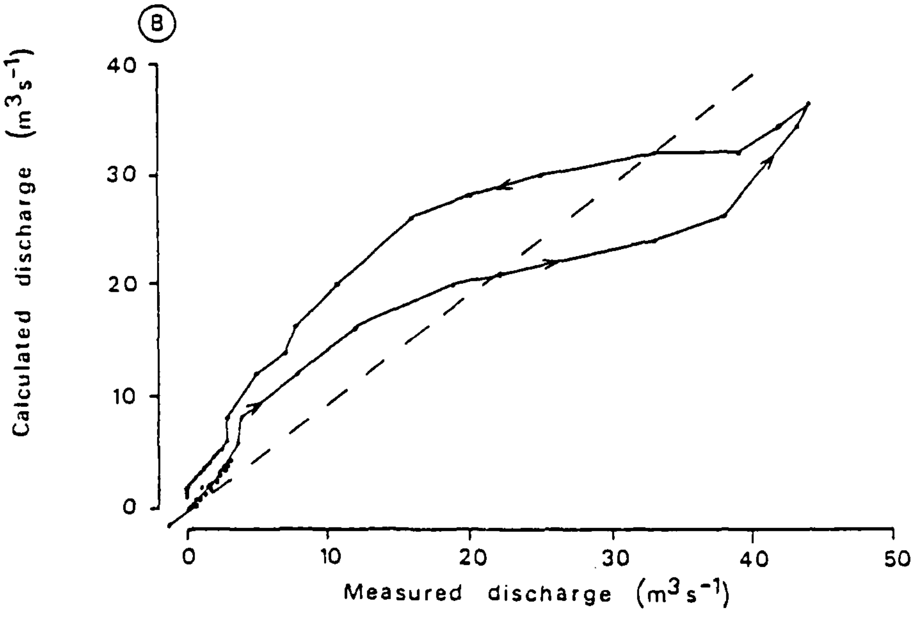


Figure 19: Relationship between discharge predicted by HYMO2 and the measured discharge for (A) Storm 1, 9 October 1962, North Creek (B) Storm 6, 4 May 1961, Sixmile Creek

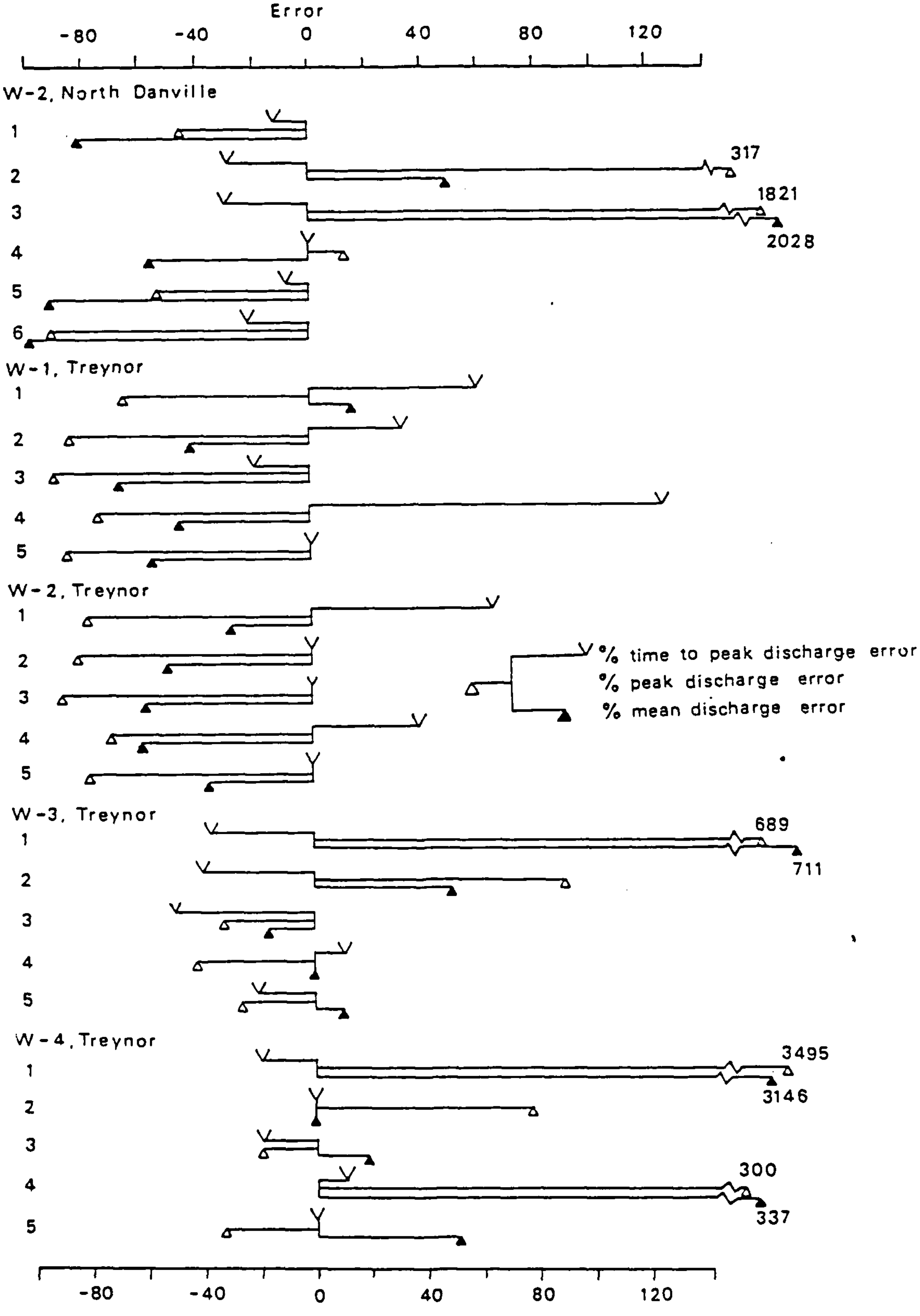


Figure 20: Percentage peak discharge error, percentage mean discharge error, and percentage time to peak discharge error for all 26 experimental frames

both catchments by between 9% and 125%. For W-3 and W-4, percentage time to peak discharge error ranges from -50% to +11% and -43% to +11% respectively. Over all 26 experimental frames, the time to peak discharge of 13 storms are predicted to within plus or minus 10% (including 9 exactly) and only in 4 cases of the 26, is the prediction of this hydrograph characteristic in error by greater than 50%. Error associated with peak discharge is greater than that for time to peak discharge. For W-2, North Danville, the error ranges from -82% to +1882% and is for only one storm within 20% of the measured. For W-1 and W-2, Treynor, peak discharge is underestimated without exception by between 91% and 67%. For W-3, error ranges from -43% to +689%. However, the greatest range of error, -33% to +3498%, is experienced by W-4. Over all 26 experimental frames, there are no events where peak discharge is predicted to within 10%. In fact, in 19 of the 26 cases, errors of greater than 50% occur.

The error associated with the prediction of mean discharge is for most storm events slightly less than that associated with peak discharge. Very wide ranges are displayed for predictions made for W-2, North Danville, and W-3 and W-4, Treynor. Over all 26 experimental frames, the mean discharge of three storm events are predicted to within 10% (including two exactly) and 14 events are associated with error of greater than 50%.

The correlation coefficients and error standard deviations calculated for these 26 experimental frames are illustrated in figure 21. The correlation coefficients are very low and indicate very little association between the calculated and measured hydrographs. For 8 of the 26 cases, a correlation coefficient of between 0.5 and -0.2 exists, and 5 of these 8 occur for W-2, North Danville. Overall, for no storm is a correlation coefficient of greater than 0.9 found. The error standard deviation values indicate a misleading picture of better predictions for the W-2 catchment, North Danville. The calculations of this statistic are affected by the absolute magnitude of the discharges involved, and which for this catchment are indeed very small. For the Treynor catchments however the error standard deviations are still low

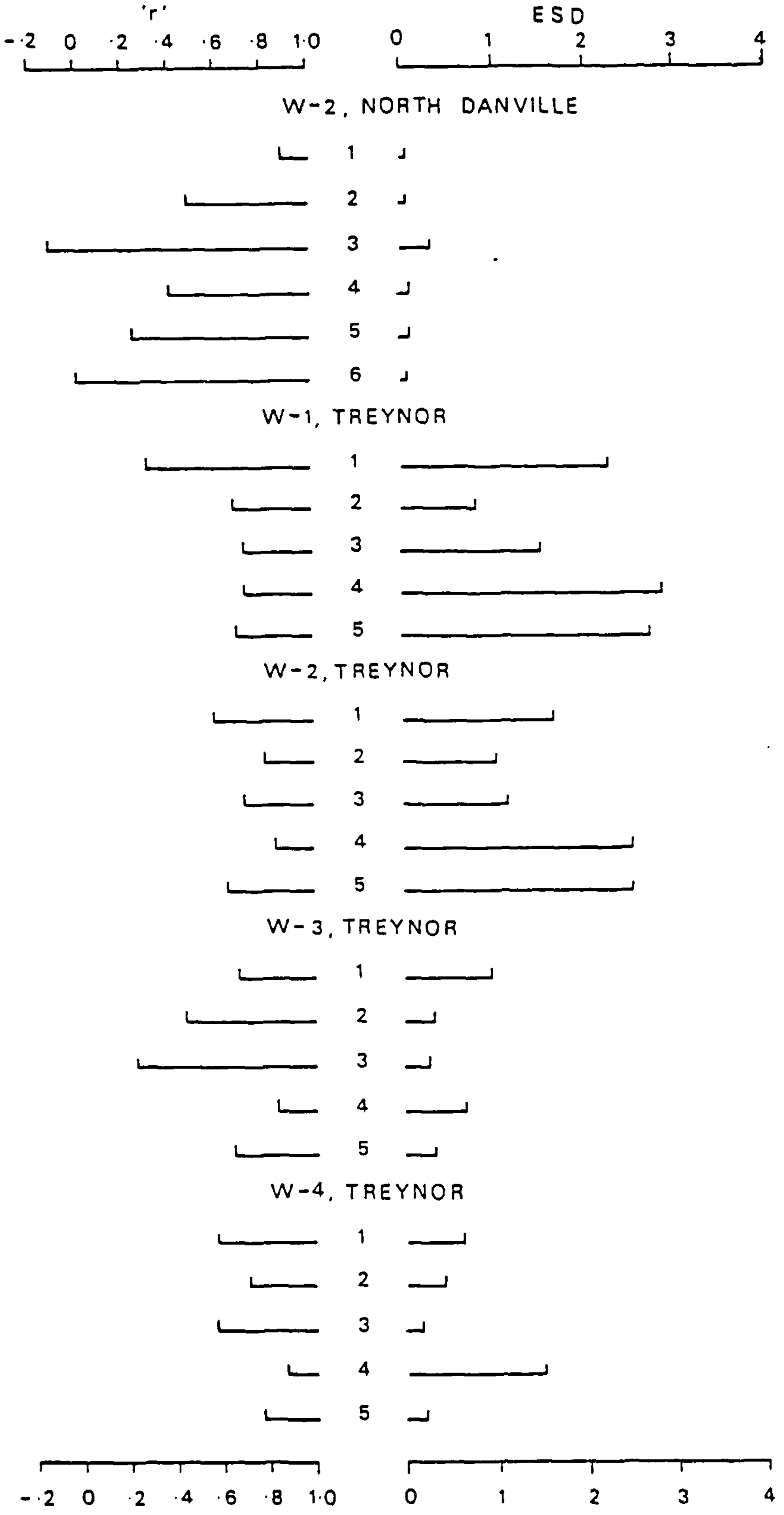


Figure 21: Correlation coefficient (r) and error standard deviation (ESD) for all 26 experimental frames

in comparison to the North Creek and Sixmile Creek, a maximum of 2.7 being displayed.

Stage 2: Evaluation of errors

Time series plots of model forecast error (measured discharge minus calculated for each time interval) for a selected number of storms are provided in figures 22 and 23, for each catchment. The differences in the scales of the vertical axes between W-2, North Danville, and the Treynor catchments should be noted. Much less error is associated with the prediction of the small discharges measured for the W-2, North Danville catchment.

All figures confirm the tendency (although there are one or two exceptions) towards overprediction (negative error) during the early stages of the storm, then a swing upwards to underprediction (positive error) during the period of peak discharge and a tendency back to overprediction during the latter stages of recession. A similar pattern in errors was exhibited for the North Creek (figure 24) and Sixmile Creek (figure 25) catchments.

A plot of error versus the measured discharge for a variety of experimental frames is provided in figure 26 for W-2, North Danville and in figure 27 for the four Treynor catchments. Figure 26 illustrates clearly the overprediction for storm 3 (figure 26(A)) and underprediction for storm 6 (figure 26(B)). In addition, for storm 6 there appears to be an almost linear relationship between error and measured discharge. Indeed these two series have a correlation coefficient of 0.99. This is statistically significant at the 95% significance level.

In figure 27, all four plots show similar systematic forms of error to the North Creek and Sixmile Creek. Storm 5 applied to W-1 (figure 27(A)) and W-2 (figure 27(B)).

The autocorrelation functions for a selection of representative storms

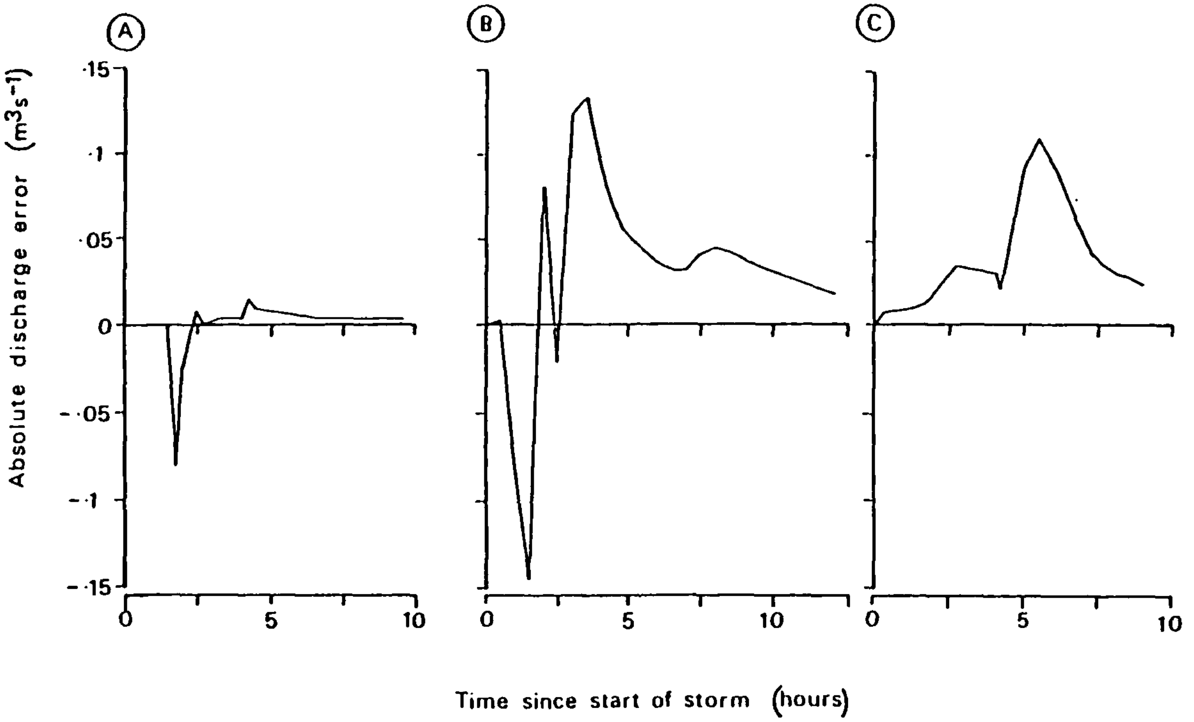


Figure 22: Absolute discharge error for W-2, North Danville (A) Storm 3, 28 August 1970 (B) Storm 4, 16 June 1967 (C) Storm 6, 2 June 1961

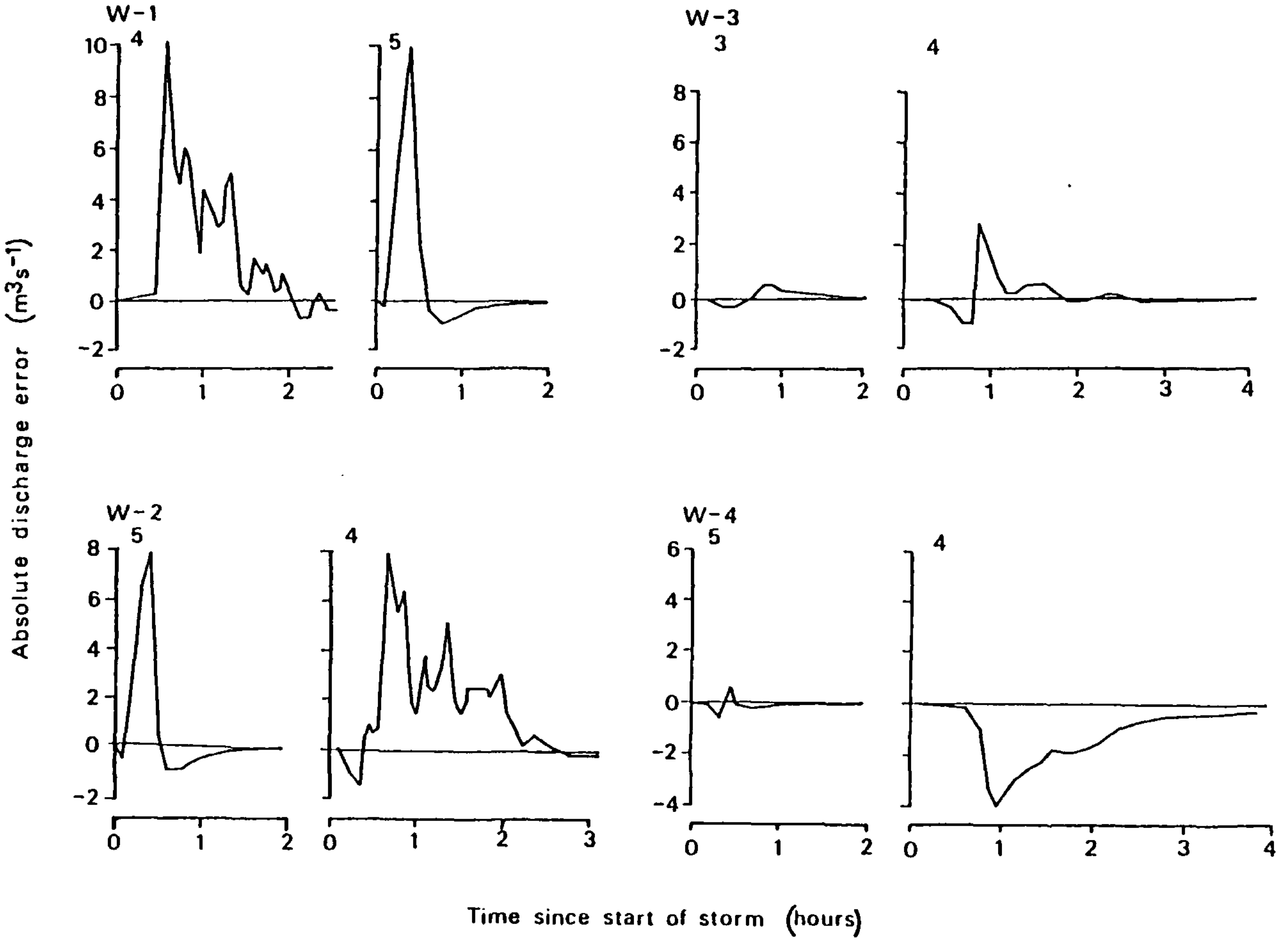


Figure 23: Absolute discharge error for a range of storms applied to the four watersheds near Treynor, Iowa (Each specific experimental frame is labelled on the figure)

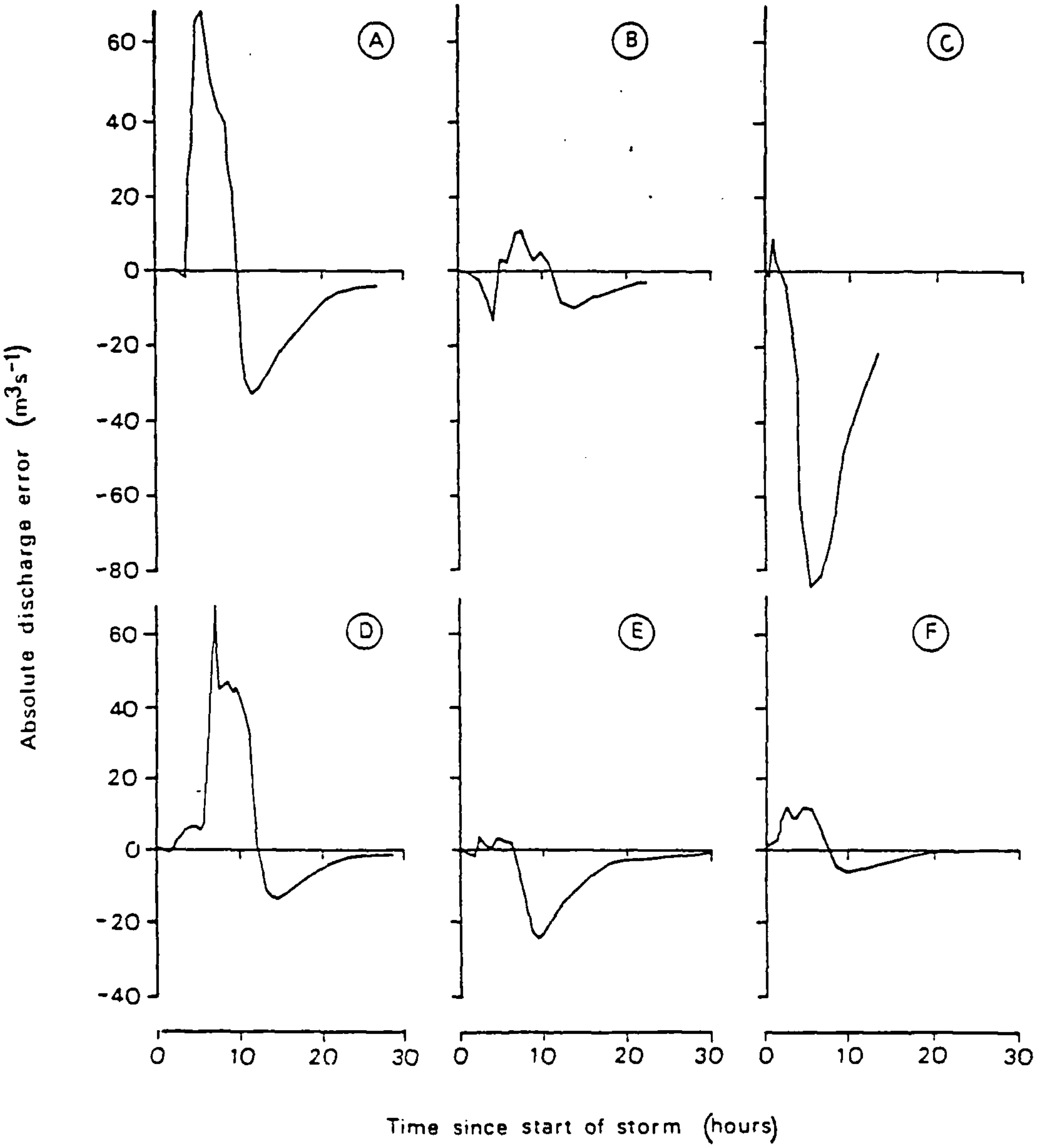


Figure 24: Absolute discharge error for North Creek (A) Storm 1, 9 October 1962 (B) Storm 2, 27 July 1962 (C) Storm 3, 18 September 1965 (D) Storm 4, 22 April 1966 (E) Storm 5, 4 May 1969 (F) Storm 6, 6 May 1969

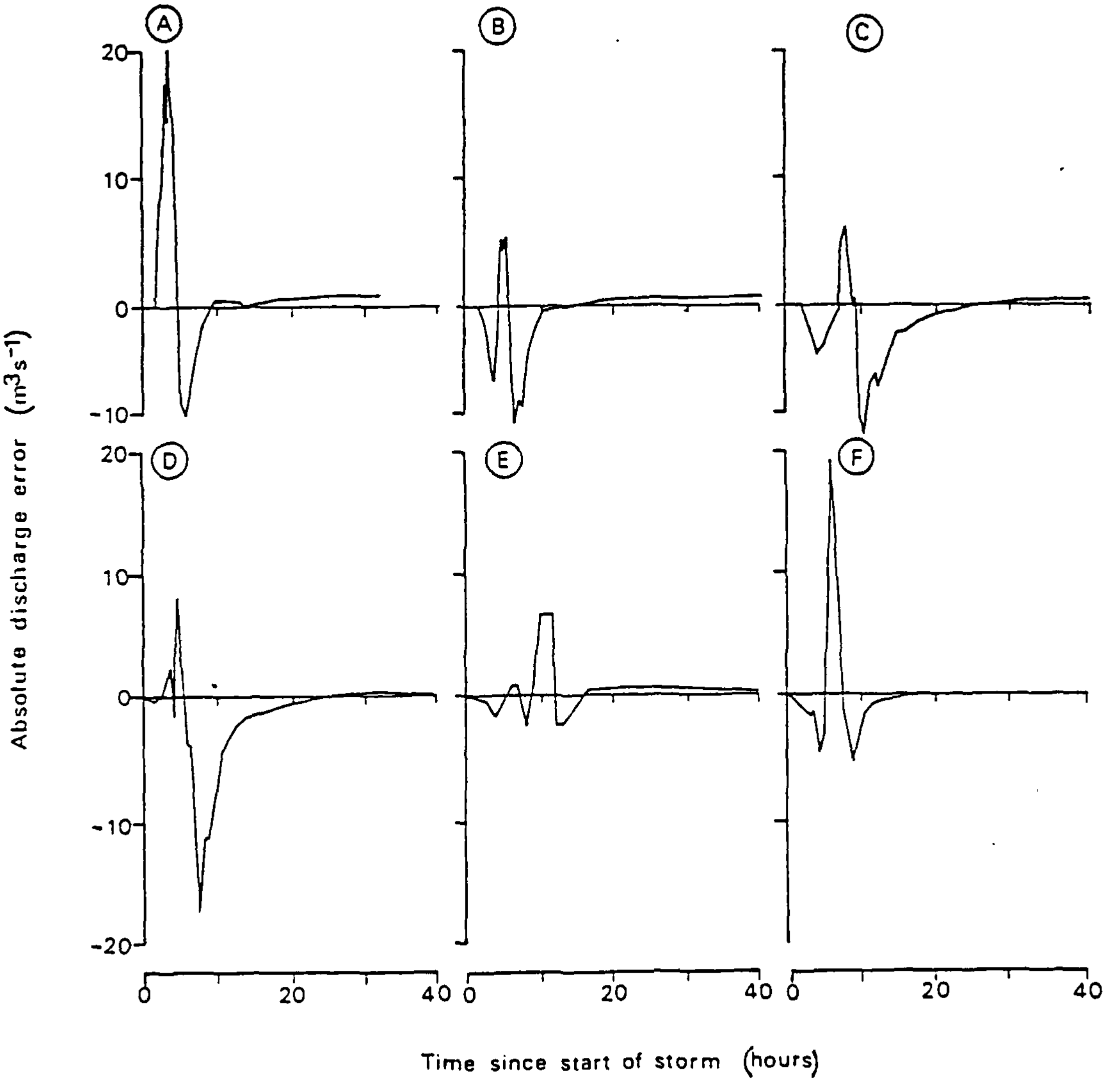


Figure 25: Absolute discharge error for Sixmile Creek (A) Storm 1, 20 March 1955 (B) Storm 2, 17 November 1957 (C) Storm 3, 25 June 1958 (D) Storm 4, 3 November 1959 (E) Storm 5, 10 December 1960 (F) Storm 6, 4 May 1961

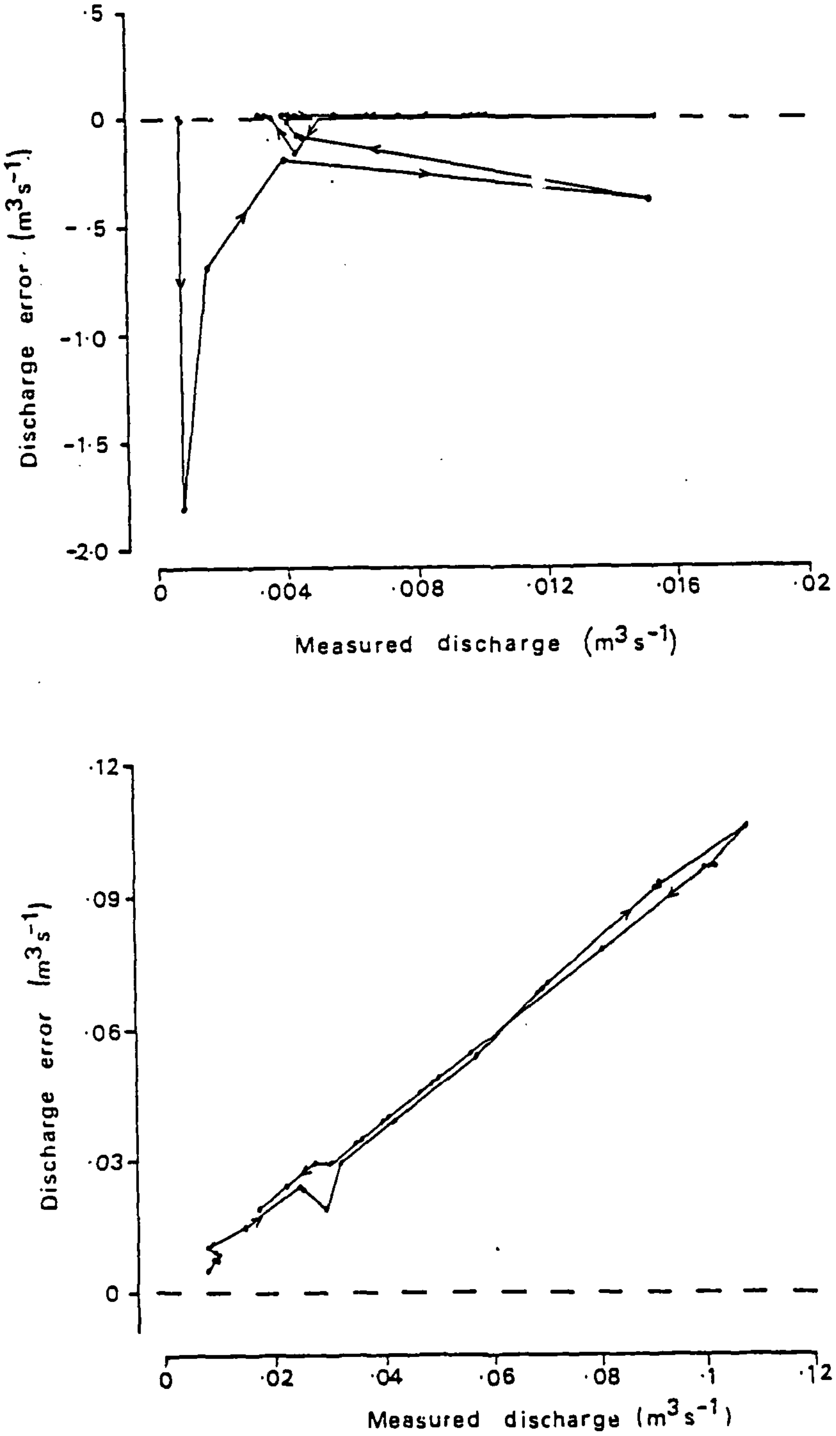


Figure 26: Relationship between discharge error provided by HYMO2 and measured discharge for W-2, North Danville (A) Storm 3, 28 August 1970 (B) Storm 6, 2 June 1961

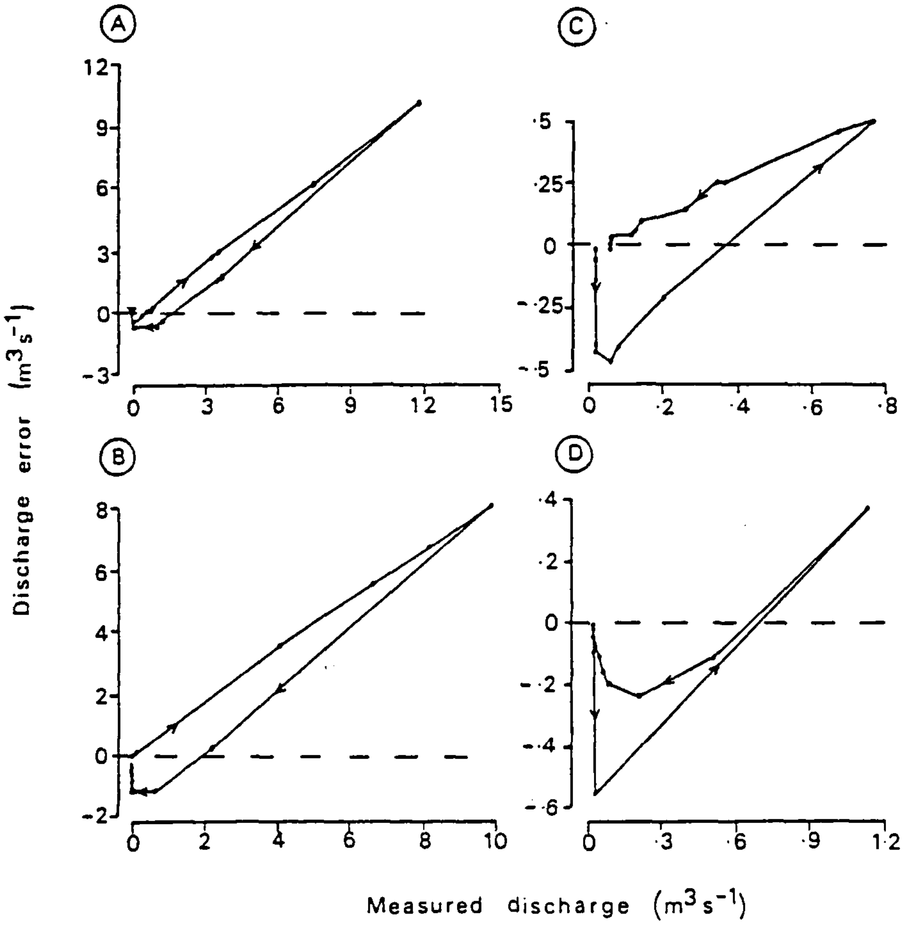


Figure 27: Relationship between discharge error provided by HYMO2 and measured discharge (A) Storm 5, 7 June 1967, W-1, Treynor (B) Storm 5, 7 June 1967, W-2, Treynor (C) Storm 3, 14 June 1967, W-3, Treynor (D) Storm 5, 20 June 1967, W-4, Treynor

for each catchment are indicated in figure 28. All of these functions indicate a much lower degree of autocorrelation of error than was the case for the North Creek and Sixmile Creek. Many autocorrelation coefficients approach zero by lag 8. However, the systematic source of error in model prediction is still significant.

The mean and standard deviation of errors is provided in figure 29. Noticeably, a mean very close to zero and a small standard deviation are exhibited by North Danville, due mostly to the nature of the small discharges which are involved. The standard deviation of error is greatest for W-1 and W-2, where one standard deviation ranges from 2.66 to 0.8 $m^3 s^{-1}$. For W-3 and W-4, on the whole, the standard deviations are much lower (0.9 to 1.1 $m^3 s^{-1}$). Over all 26 experimental frames, 17 mean errors are positive and range from 0.1 to 1.44 $m^3 s^{-1}$ indicating underprediction by the model (meausured greater than calculated). The negative errors range from -0.1 to -1.08 $m^3 s^{-1}$.

The correlation coefficients in table 4 indicate that for none of the storms documented here are the errors normally distributed.

To conclude this section which compared the predicted and measured hydrographs for a variety of storms and for 5 catchments in Vermont and Iowa, the following two points can be made:

1 MILHY2 does not appear to provide very satisfactory predictions for W-2, an unnamed tributary of the Sleepers River catchment, near North Danville, Vermont, when this catchment is treated as an ungauged catchment. It is possible that improved predictions for each storm could be derived if a degree of fine tuning of the model parameters of MILHY2 were to be undertaken. This however, is not the point of this particular exercise. It is important to establish the degree of accuracy which can be obtained from model predictions for the ungauged catchment. Error in the hydrograph predictions was for the North Creek and Sixmile Creek, attributed to model and data error. The likely sources of model error in the context of the application to W-2, North Danville will now be examined.

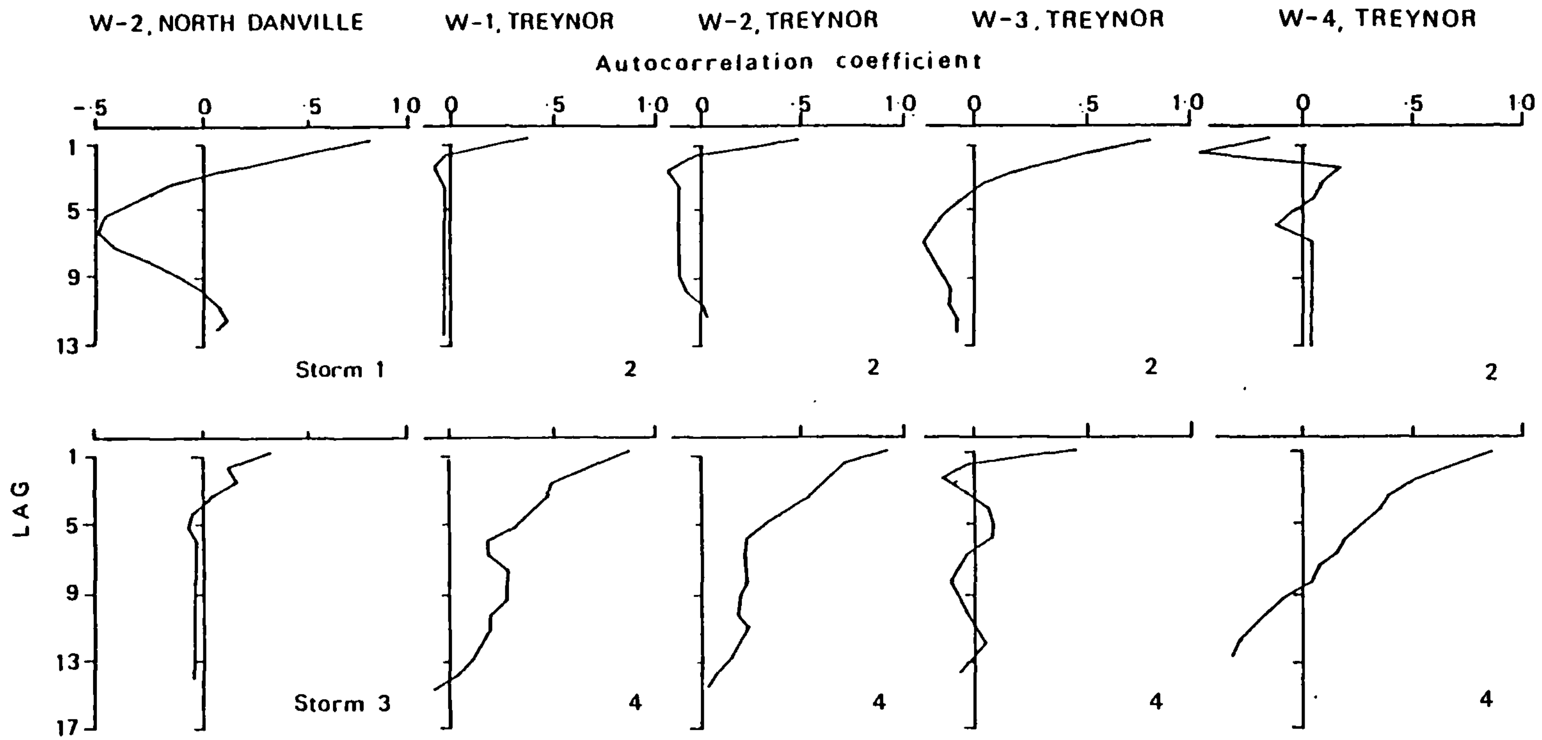


Figure 28: Autocorrelation coefficients for discharge error provided by HYMO2 for a range of catchments and storms

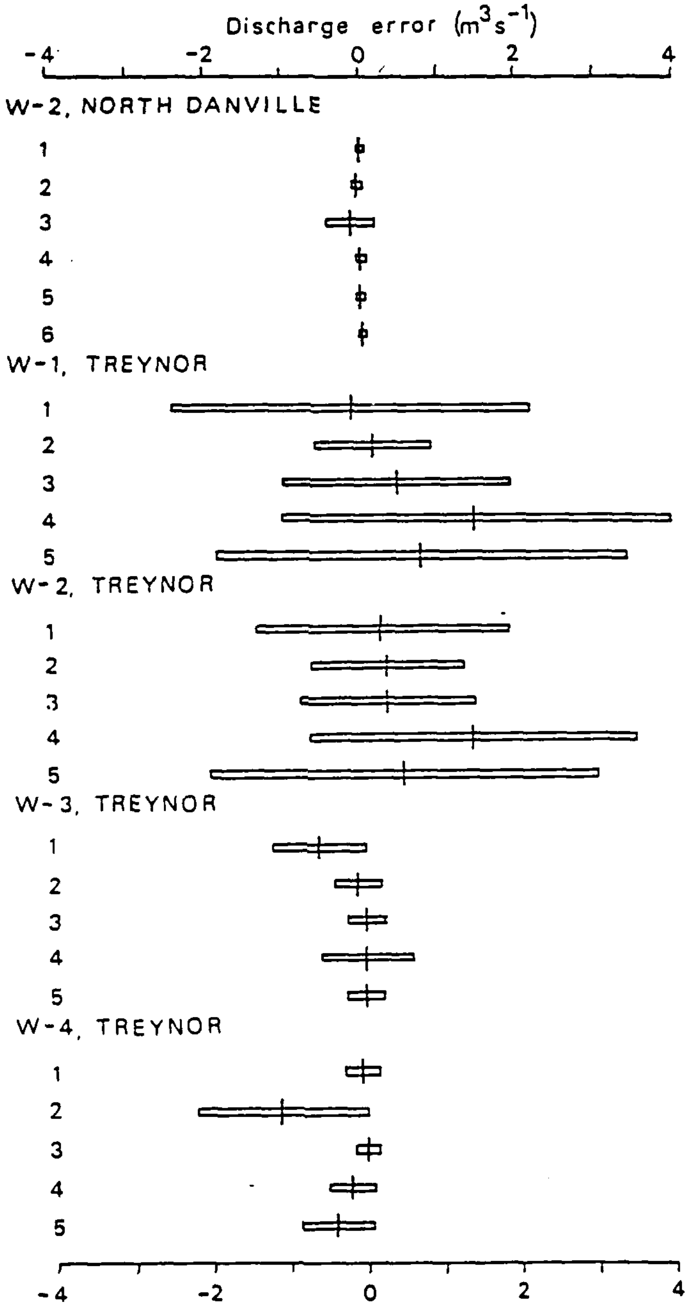


Figure 29: The mean (vertical line) and one standard deviation (horizontal bar) of discharge error, for 26 experimental frames

Table 4 : Correlation coefficients for normal probability plot of error for all experimental frames, for all catchments in Vermont and Iowa

Catchment	Correlation coefficients					
	Storm numbers					
	1	2	3	4	5	6
W-2, North Danville Vermont	0.917	0.693	0.567	0.915	0.942	0.938
W-1, Treynor, Iowa	0.750	0.618	0.658	0.899	0.734	
W-2, Treynor, Iowa	0.670	0.763	0.640	0.915	0.767	
W-3, Treynor, Iowa	0.901	0.840	0.980	0.781	0.906	
W-4, Treynor, Iowa	0.889	0.852	0.908	0.928	0.889	

No coefficient in this table is statistically significant at the 95% significance level

There is a large probability that MILHY2 is inappropriate for application to this particular catchment. Dunne and Black (1970a, 1970b) document observations and measurements of the runoff producing mechanisms which occur in a small area of the Sleepers River catchment and they suggest that there is limited evidence to suggest that these general conclusions may be extrapolated for most of the watershed. The major runoff producing mechanism is overland flow from small and variable contributing areas located adjacent to the stream, in poorly drained positions where the water table is near to the surface. Runoff from these areas reaches the channel very quickly. MILHY2 is not designed to model these particular hydrological processes in terms of the methods used to generate runoff and the use of unit hydrograph procedures to route this runoff through the catchment area. Hortonian overland flow occuring over large areas has not been observed on this catchment and indeed, the infiltration capacity of the soils exceeds most measured rainfall intensities.

There is not such a high probability that data errors will be large for this catchment. As an ARS experimental watershed, it is likely that precipitation and measured hydrograph information will be as reliable as possible. It is possible however, that the soils data which are derived from the Brakensiek and Rawls charts are not accurate for simulation in this small catchment.

2 For the four catchments located near to Treynor, Iowa, again when they are treated as ungauged catchments, a wide range of predictions is derived. Overall, very similar patterns (but not magnitude) of discharge prediction error are obtained as were derived from application to the North Creek and Sixmile Creek. The timing of the predicted hydrographs is good, but peak discharge is commonly underpredicted and a systematic source of error is identified, where mean errors differ from zero, are not normally distributed, and exhibit autocorrelation.

Again, improvements to the unit hydrograph, the most likely source of such systematic error, can be suggested. Certainly, the dimensionless unit hydrograph method which is used by MILHY2 has not been calibrated for catchments containing contour corn, located in Iowa, whereas it has been for Texas and Arkansas. This feature may also be connected with the scale of the catchments. It is possible that better predictions will be derived for larger catchments than the small ones.

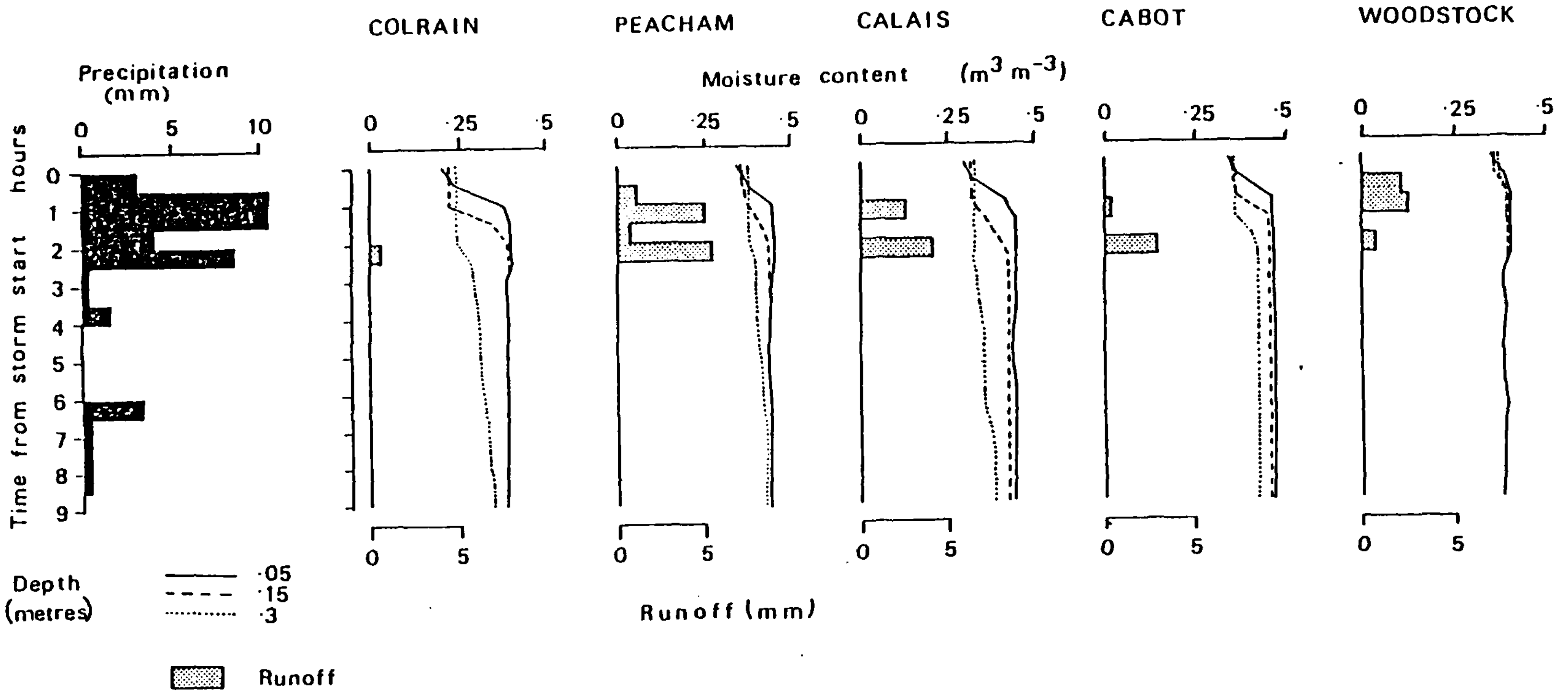


Figure 30: The runoff behaviour and change in soil moisture conditions at 3 depths which is predicted by the infiltration model for all 5 soil types in W-2, North Danville, for storm 4, 16 July 1967

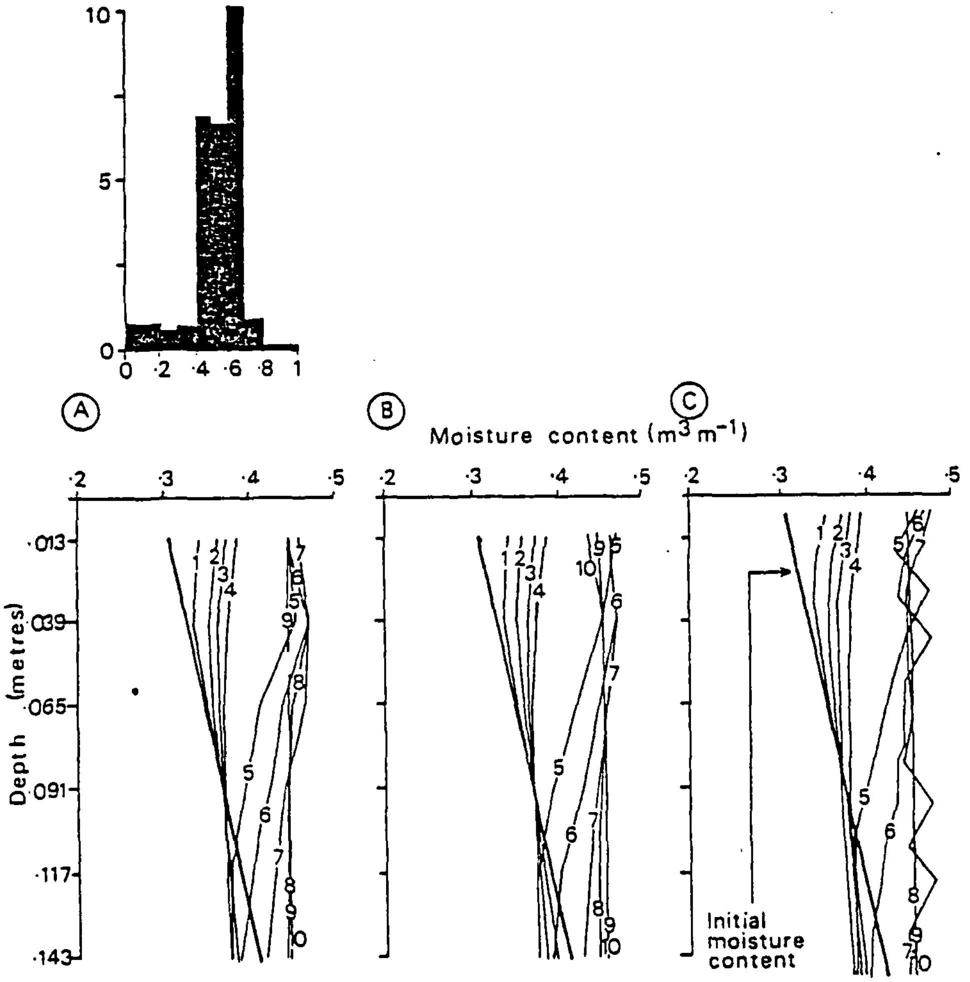


Figure 31: A comparison of the change in moisture context at 6 minute intervals which are predicted by the infiltration model for the Ida silt loam, and associated with the application of a storm of 22 June 1964 (total precipitation 27.94 mm) for (A) a 30 second iteration period (B) a 10 second iteration period (C) a 10 second iteration period and halved cell dimensions

3.

Infiltration Behaviour and Finite Difference Methods

Few cases of physically unrealistic infiltration behaviour were experienced in any application of MILHY2 which has been considered in this report. Unrealistic behaviour can be demonstrated to occur in association with a combination of very small cell size in the soil column, small time increments, and high precipitation intensity.

Figure 30 illustrates the precipitation and resulting infiltration and runoff behaviour for all five soil types in the W-2, North Daville, Vermont for storm number 4. Infiltration is represented by the changing moisture content of the five soil columns at three depths, 0.05 metres, 0.15 metres and 0.3 metres every 30 minutes from 04:30 hours (the start of the storm), for 9 hours (storm duration). For each soil type, the most rapid and greatest increase in soil moisture content is experienced at the shallowest depth indicated. The increase in soil moisture content further down the soil column is not as great, and occurs more gradually. Runoff occurs in association with saturated surface conditions and higher rainfall intensities. Where a greater amount of precipitation is required to saturate the soil (Colrain compared to Peacham, for example), less runoff results.

Figure 31 illustrates the effect which the choice of the cell size and iteration period has upon infiltration behaviour, again as represented by changes in soil moisture content. These results were derived from application of a storm of 22 June, 1964 (which has not previously been used in this thesis) which has a total of 27.94 mm precipitation to the soil column Ida (a silt loam) which occurs in the watersheds near Treynor, Iowa. This soil, in the absence of more detailed data, is assumed not to be layered and is represented by a soil column comprising

6 cells. The hydrological characteristics have been derived from the centroid position on the Brakensiek and Rawls charts. Figures 31(A), 31(B), and 31(C) all illustrate the initial moisture content and the moisture content at successive 6 minute intervals for each cell. Figure 31(A) illustrates the response when a 30 second iteration period is assumed; figure 31(B) if a 10 second period is assumed; and figure 31(C) where both a 10 second iteration period and twice as many cells, with halved cell dimension are used. There is very little difference between the soil moisture content profiles which develop during the storm when the 6 cells are utilized, and iterations of 30 or 10 seconds are used. Halving the cell size, however, has no effect during the first 4 time intervals, but during the next 3 time intervals, a form of physical instability occurs and moisture content oscillates through a range of 0.2 $m^3 m^{-3}$. This instability corresponds to periods where large amounts of precipitation occur. When the precipitation amount drops again, for intervals 8 to 10, the profile resumes a physically realistic form and one which is similar to those attained in figures 31(A) and 31(B). It is interesting to note that associated with these conditions is a value of (BAL) (equation 2), a measure of the mean numerical error, of 0.015 for condition ´C´ compared with a value of 0.010 for condition ´A´. No benefit is seen to be derived from the adoption of smaller cell sizes and shorter time increments.

$$BAL = 0_{end} - 0_{init} - ci + ce + cd \qquad (2)$$

Where:

BAL - numerical error ($m^3 m^{-3}$)
0_{end} - total water content of soil profile ($m^3 m^{-3}$) at end of
0_{init} - initial total water content of entire profile ($m^3 m^{-3}$)

ci - cumulative infiltration ($m\ s^{-1}$)
ce - cumulative evaporation ($m\ s^{-1}$)
cd - cumulative drainage ($m\ s^{-1}$)

Slightly higher errors are exhibited for more complex soil and precipitation conditions. Table 5 provides the details of the value of (BAL) (a measure of the magnitude of numerical errors incurred by the solution of the Richards equation using an explicit finite difference method) for each soil type on all seven catchments located in Texas, Arkansas, Vermont and Iowa for all storms which have now been documented. For many cases, the value of (BAL) can be related to soil depth, soil type, and precipitation intensity. For example, the results presented in table 5 for North Creek, Texas illustrate that greater errors occur for the soil column representative of the Gowen-Pulexas soil groups. This soil column is deeper than those representing the Bonti-Cona-Truce and Thurber-Hasse soil groups, and consequently has a greater number of cells for which a solution must be provided. The Gowen-Pulexas also has a higher conductivity than the other two soils, which both have clay in layers 2 and 3 (tables 6, 7, and 8). The lowest error for the Gowen-Pulexas soil occurs for storm 3. This storm has the shortest duration (1.3 hours) and the most precipitation (107 mm). In contrast, the greatest error for this soil type occurs for storm 1 which is 8.25 hours long and throughout is very erratic; periods of high precipitation intensity alternate with periods of very little rain. Such rapid fluctations in rainfall intensity in successive time intervals appear to be associated with greater errors in the solution of the Richards equation.

Very similar relationships between soil characteristics and the value of (BAL) are exhibited by the information provided for the storms applied to the Sixmile Creek. Larger errors are associated with the deeper soil, Leadvale. However, for this suite of storms, there is no clear relationship between (BAL) and storm characteristics.

For W-2, North Danville, the magnitude of error is very much less than has been noted for the previous two catchments. This may be related to the shallow soil columns which were used to represent the soils of this catchment. The greater amount of numerical error is not consistently associated with the same soil column. The Cabot soil type exhibits the greatest error for storms 1, 4, and 5, and the Woodstock soil type for

Table 5: Numerical error (BAL) derived for all experimental frames and all catchments

Storm number	BAL* ($\times 10^{-2}$ $m^3 m^{-3}$)				
	Soil types				
North Creek, Texas					
	Gowen-Pulexas	Bonti-Cona-Truce	Thurber-Hasse		
1	-9.3	-4.4	-2.0		
2	-8.8	-5.1	-1.8		
3	-6.0	-2.6	-0.9		
4	-8.2	-3.8	-0.2		
5	-8.8	-4.1	-1.2		
6	-9.0	-2.5	-1.3		
Sixmile Creek, Arkansas					
	Leadvale	Enders	Mountainburg		
1	-0.6	-0.2	-0.2		
2	-0.7	-0.2	-0.2		
3	-3.6	-0.4	-1.0		
4	-4.3	-0.2	-0.1		
5	-1.1	-0.6	-0.5		
6	-0.6	-0.1	-0.8		
W-2; North Danville, Vermont					
	Colrain	Peacham	Calais	Cabot	Woodstock
1	0.0	-0.1	0.0	-1.1	-0.5
2	0.0	0.0	0.0	0.0	-0.4
3	0.0	0.0	0.0	-0.3	-0.5
4	-0.2	0.0	0.0	-1.3	-1.2
5	0.0	-0.3	-0.1	-1.6	0.0
6	0.0	0.0	0.0	0.0	-0.2
	Mona	Marshall	Napier	Ida	
W-1, Treynor, Iowa					
1	-0.4	0.0	0.0	-3.9	
2	-0.1	0.0	0.0	-1.1	
3	0.0	0.0	0.0	-0.7	
4	-3.2	0.0	0.0	-12.6	
5	-0.4	0.0	0.0	-2.2	

Continued on following page ...

Table 5 ... continued from previous page

Storm number	BAL* ($\times 10^{-2}$ $m^3 m^{-3}$)			
	Soil types			
	Mona	Marshall	Napier	Ida
W-2, Treynor, Iowa				
1	-0.3	0.0	0.0	-2.3
2	-0.1	0.0	0.0	-0.9
3	0.0	0.0	0.0	-0.8
4	-3.3	0.0	0.0	-11.9
5	-0.3	0.0	0.0	-3.0
W-3, Treynor, Iowa				
1	-0.3	0.0	0.0	-2.8
2	0.0	0.0	0.0	-1.4
3	0.0	0.0	0.0	-0.9
4	-2.0	0.0	0.0	-9.2
5	-0.1	0.0	0.0	-0.8
W-4, Treynor, Iowa				
1	-2.7	0.0	0.0	-2.8
2	0.0	0.0	0.0	-0.9
3	0.0	0.0	0.0	-0.9
4	-2.0	0.0	0.0	-9.2
5	-0.1	0.0	0.0	-0.8

* BAL is defined in equation (2) in the text

the remaining three storms. These two soils do not have any particular characteristics in common, and the deepest soil for this catchment with the greatest number of cells is Colrain.

For all 4 catchments near Treynor, the soil column representing the Ida soil type exhibits the greatest error. This soil column is the shallowest, but the cell dimensions are the smallest. For all four catchments, the greatest error is experienced for storm 4. This storm has the highest precipitation total, but also, as noted for Texas, the most rapidly alternating successions of high and low intensity rainfall. The lowest error for W-1 and W-2 is associated with storm 3 which has the lowest total precipitation. The lowest error for W-3 and W-4 is associated with storm 5 which has the second lowest pecipitation total, but the shortest duration.

The relationship of error to precipitation is demonstrated in figure 32. The information for this figure is taken from storm 4 applied to W-1, Treynor. Cumulative precipitation is compared to cumulative (BAL) for the two soil columns which, as indicated in table 5, exhibit errors in solution. A steeper gradient on the cumulative precipitation curve appears to be related to a steeper rise in the value of cumulative BAL for each soil type. Indeed, the correlation coefficient between cumulative precipitation and the cumulative (BAL) for Monona soil type is 0.964 and for the Ida soil, is 0.997. Both of these correlation coefficients are signficant at the 95% confidence level.

Over all experimental frames, it is not considered that numerical errors are large enough to justify an examination of alternative numerical techniques.

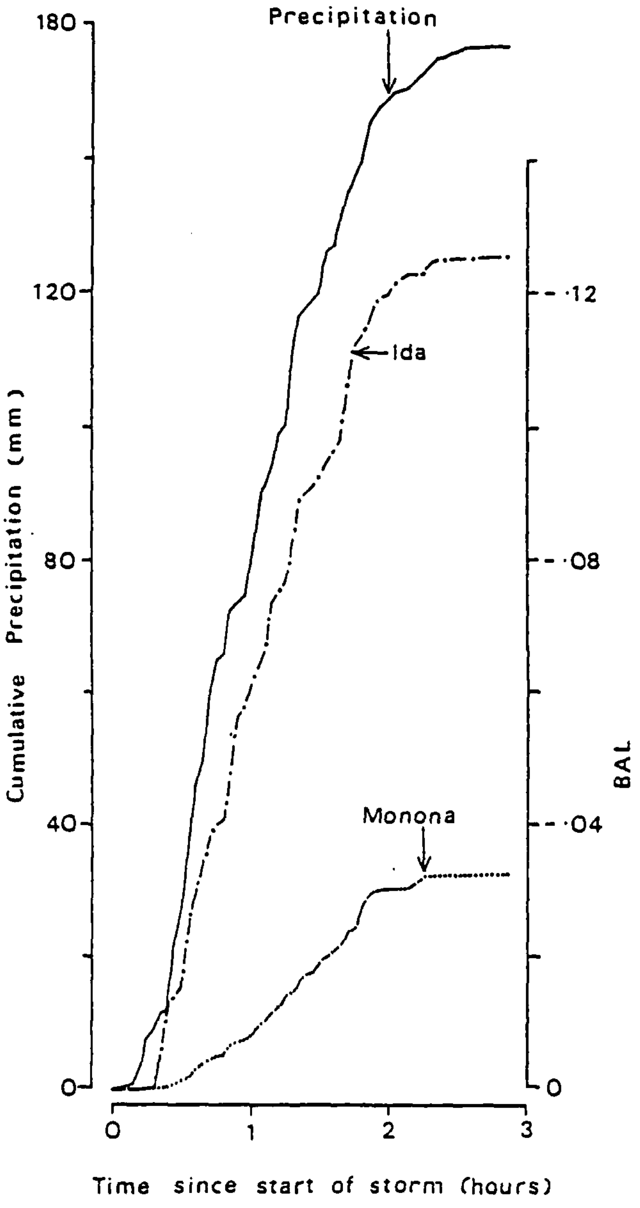


Figure 32: Relationship of numerical error (BAL) to precipitation for the Monona and Ida soil types for storm 4, 16 July 1967, applied to W-1, Treynor

4.

Summary Of Applications

4.1 Introduction

To summarize the results of the application of MILHY2 to 38 storms, and for a range of seven catchments in Texas, Arkansas (2), Vermont, Iowa, figures 33, 34, and 35 have been produced. Figure 33 attempts to assess the accuracy of MILHY2 for the prediction of peak discharge; figure 34, the accuracy of the time to peak discharge predictions and figure 35, the closeness of the overall hydrograph form. From these figures, the following comments may be derived:

4.2 Prediction of peak discharge

Figure 33(A) provides a plot of calculated versus measured peak discharges for all 38 experimental frames. A correlation coefficient of 0.911 between these two series has been calculated. This is not statistically significant, and the trend towards underprediction of peak discharge, which has been noted previously, is seen clearly. This type of plot, although often produced in modelling studies, is slightly misleading in that the very small deviations from the dashed line (indicating perfect prediction) in the lower peak discharge range can be, in relative terms, a good deal more significant than the apparently larger deviations which occur at higher discharges. This point is illustrated by figure 33(B), where percentage peak discharge error plotted against measured discharge is given by:

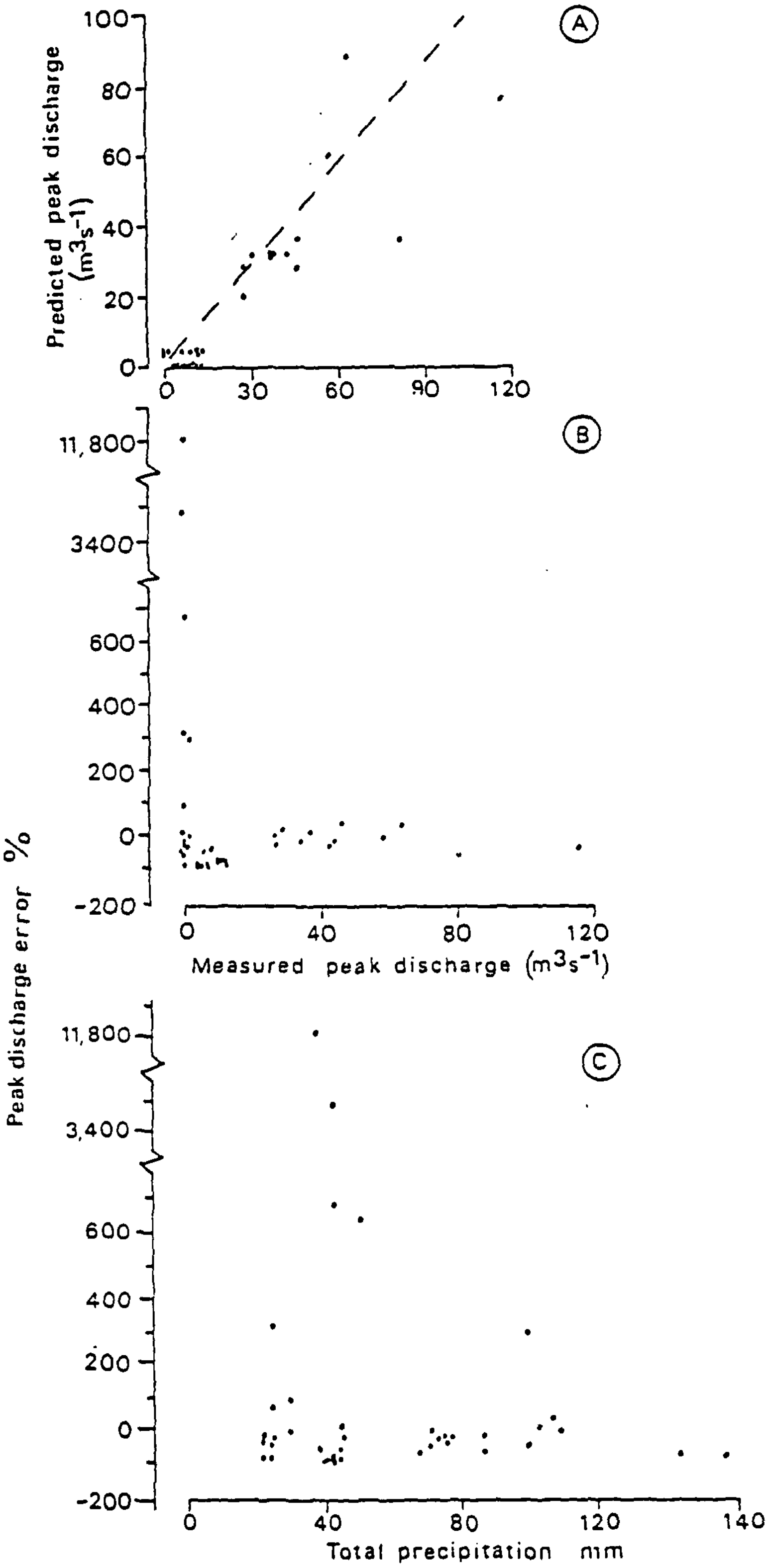


Figure 33: A summary of the accuracy of HYMO2 for the prediction of peak discharge over all 38 experimental frames (A) the relationship of calculated and measured peak discharge (B) the relationship of percentage peak error and measured peak discharge (C) the relationship of percentage peak discharge error and total precipitation

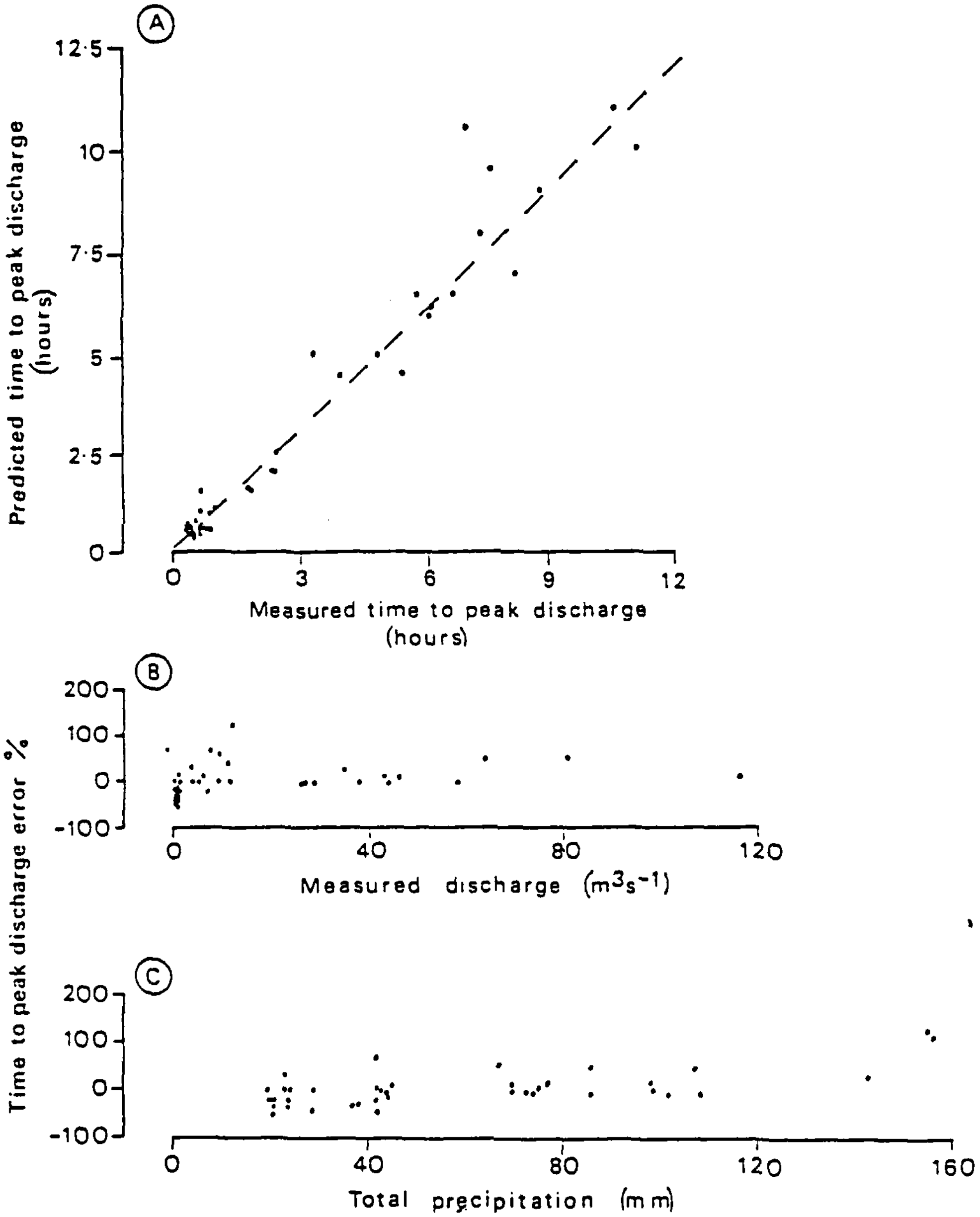


Figure 34: A summary of the accuracy of HYMO2 for the prediction of the time to peak discharge over all 38 experimental frames (A) the relationship of calculated and measured time to peak discharge (B) the relationship of percentage time to peak discharge error and measured peak discharge (C) the relationship of percentage time to peak discharge error and total precipitation

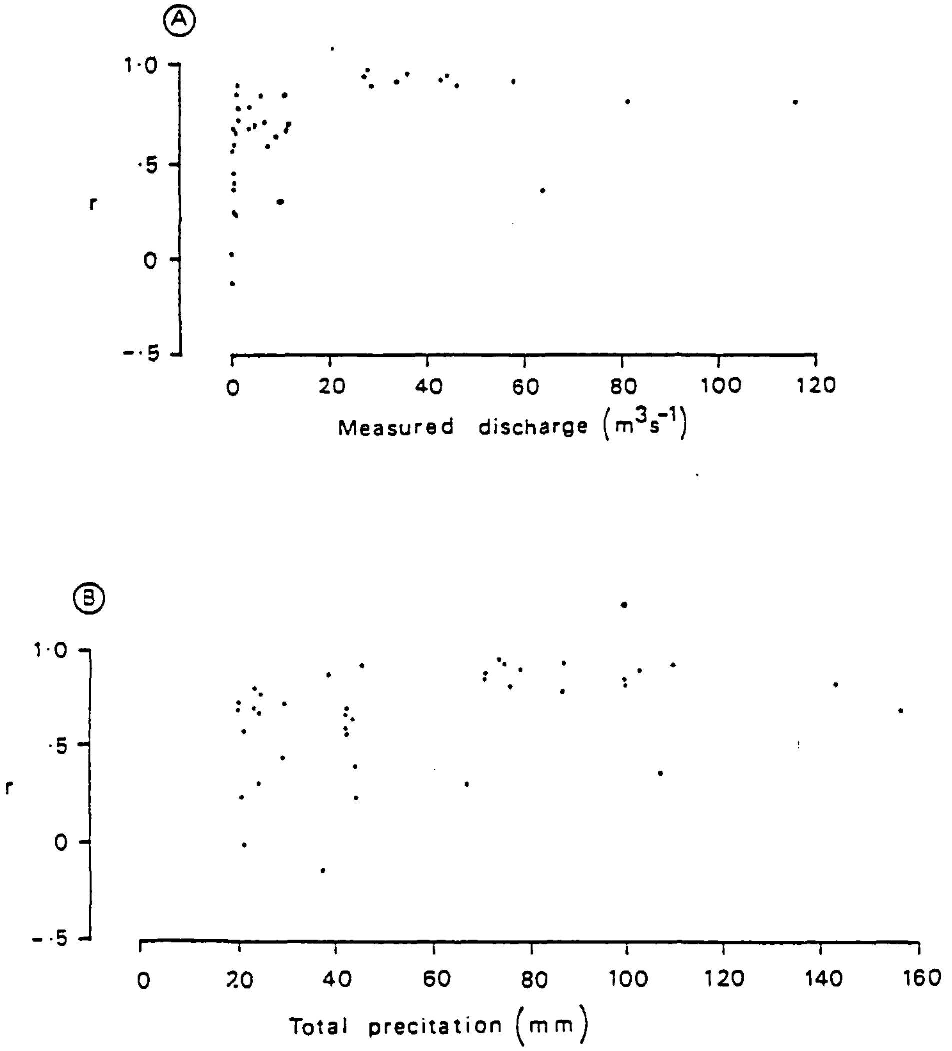


Figure 35: A summary of the accuracy of HYMO2 for the prediction of the overall form of the discharge hydrograph for 38 experimental frames (A) the relationship of the correlation coefficient (r) the measured peak discharge (B) the relationship of the correlation coefficient and total precipitation

$$PDE = \frac{q_p m - q_p c}{q_p m} \times 100\% \qquad (3)$$

Where:

$q_p m$ - measured peak discharge ($ft^3 s^{-1}$)
$q_p c$ - calculated peak discharge ($ft^3 s^{-1}$)

Much greater error is seen to be associated with the prediction of lower peak discharge than with higher. Indeed, this figure suggests that the closest estimate of peak discharge, provided by MILHY2, will be derived for peak discharges between the range 20 to 65 $m^3 s^{-1}$. There is a greater tendency towards overestimation within the lower discharges, and underestimation at higher.

Figure 33(C) provides a plot of percentage peak discharge error versus total precipitation. From this range of experimental frames, there does not appear to be a clear relationship between these two series. However, it could be suggested that in general, greater accuracy is provided by MILHY2 for the prediction of the peak discharge for larger storms.

4.3 Predictions of time to peak discharge

MILHY2 predicts the time to peak discharge much more accurately than any other hydrograph characteristic. The correlation between calculated and measured time to peak discharge, indicated in figure 34(A), is 0.974. This is higher than that calculated for the association between calculated and measured peak discharge. Figure 34(B) indicates that over the total range of measured peak discharges which are considered in this study, a much lower percentage error for time to peak discharge is derived, than for peak discharge. There are just one or two outliers, for example at 12 $m^3 s^{-1}$. This can be identified as the error associated with the prediction of time to peak discharge for storm 4, W-1, Treynor. As the other errors for this hydrograph characteristic are much lower, this outlier might possibly be associated with error in the precipitation or measured hydrograph data which were utilized for this particular storm event. Figure 34(C) also indicates very little clear relationship of percentage time to peak discharge error to precipitation totals.

4.4 Predictions of the overall form of the discharge hydrograph

The closeness of form of the calculated to measured hydrograph is, for the purposes of this comparison, indicated by the value of the correlation coefficient. Figure 35(A) provides the distribution of the correlation coefficient according to measured peak discharge. On the whole, a closer association is derived for hydrograph events where peak discharge ranges between 20 and 60 $m^3 s^{-1}$. Below and above these values, the correlation coefficient between the calculated to measured increases in range. Figure 35(B) indicates no clear relationship between the correlation coefficient and total storm precipitation, although very generally, the closeness of fit does have a tendency to improve as the total precipitation increases.

MILHY2 does also appear to provide more accurate predictions for some catchments than others. To assess the overall goodness of fit of the calculated hydrographs for the range of storms applied to each catchment, a multiple index (I_x) was derived from the percentage peak discharge error (PDE), percentage time to peak error (TPE), and the correlation coefficient (r) according to the following expression:

$$I_x = |\,PDE\,| + |\,TPE\,| + 100(1-r) \qquad (4)$$

This index was evaluated for each experimental frame, and the mean value was derived for each catchment. The results of this are presented in table 9. For the range of storms which have been considered in this analysis, the best predictions are derived for the Sixmile Creek, Arkansas, and then for the North Creek, Texas. The model does not

Table 9: Multiple index (I_x^*) of overall hydrograph fit for all experimental frames, and for all catchments

Catchment	Value of I_x for each storm						Mean value of I_x
	1	2	3	4	5	6	
North Creek, Texas	62	45	150	104	9	42	69
Sixmile Creek, Arkansas	62	18	7	24	27	23	27
W-2, North Danville, Vermont	69	402	11961	71	139	211	2142
W-1, Treynor, Iowa	196	149	139	229	117		166
W-2, Treynor, Iowa	188	104	117	125	116		130
W-3, Treynor, Iowa	758	185	159	69	47		244
W-4, Treynor, Iowa	3557	28	80	322	55		808

* I_x is defined in equation (4), in the text

appear to provide suitable predictions for the unnamed tributary, W-2, of the Sleepers River catchment. In comparison to this catchment, it was more successful for the four catchments near Treynor, Iowa. In this context, it should be recalled that the unit hydrograph procedure has been calibrated for 34 catchments located in Texas, Oklahoma, Arkansas, Louisiana, Mississippi, and Tennessee.

5.

Discussion

Application of MILHY2 has provided a range of results from catchments in Texas and Arkansas (see (2)), and Vermont and Iowa (this report). The following points are worthy of note:

i) the correlation between predicted and measured peak discharge using MILHY2 is high (r = 0.91)

ii) the time to peak dsicharge estimation is particularly good using MILHY2 (correlation between predicted and measured = 0.97)

iii) the prediction for w-2 (Sleepes River Catchment) is poor (see figure 12)

iv) comparison of MILHY2 and MILHY (HYMO) for 32 experimental frames shows strong evidence of the overall improvements achieved by MILHY2 (figures 36 and 37), especially in time to peak discharge

It is recommended that further field trials of MILHY2 are undertaken (this work is currently taking place under DAJA45-85-C-0022) and that the computing needs of MILHY2 are explored with respect to run-time performance.

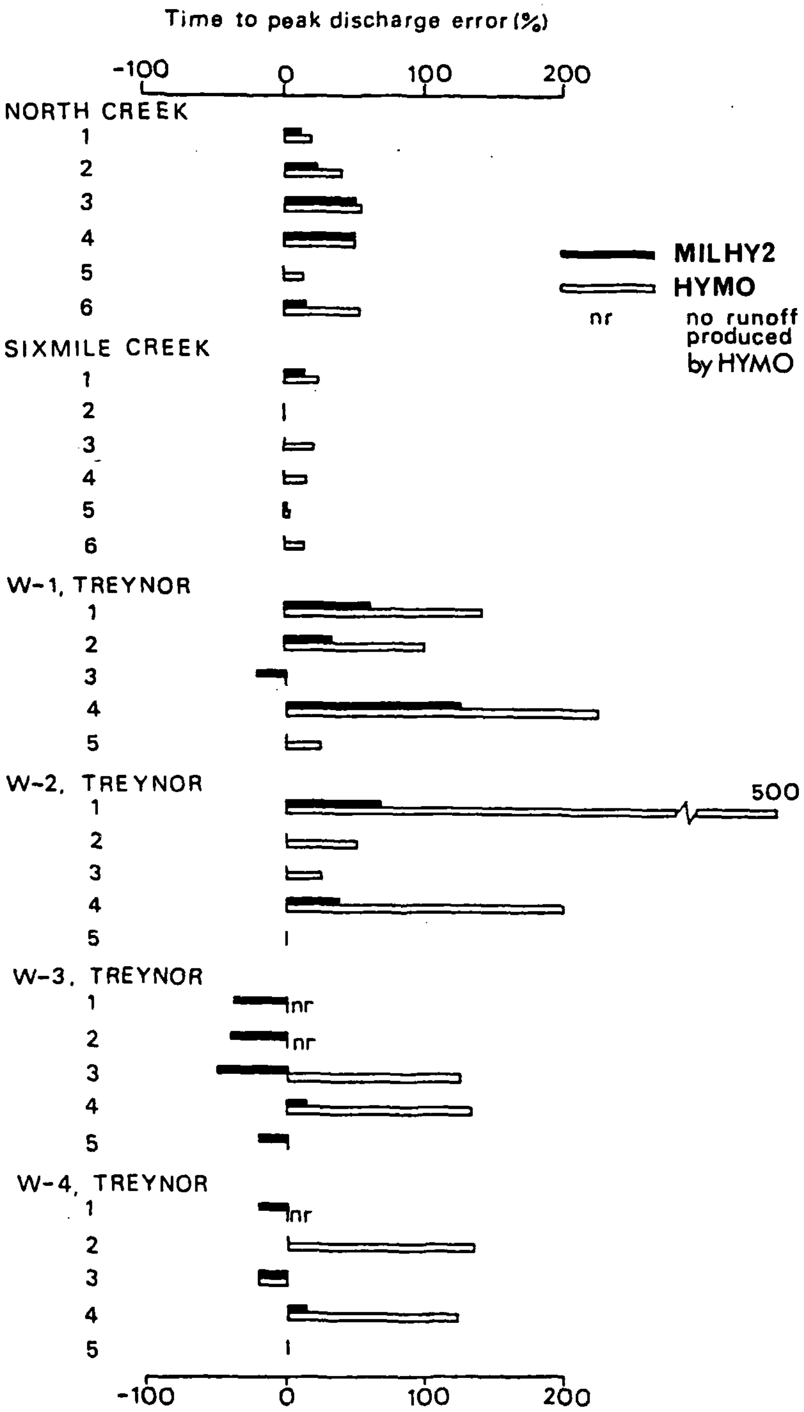


Figure 36: Comparison of the percentage time to peak discharge error of MILHY2 and HYMO, for 32 experimental frames

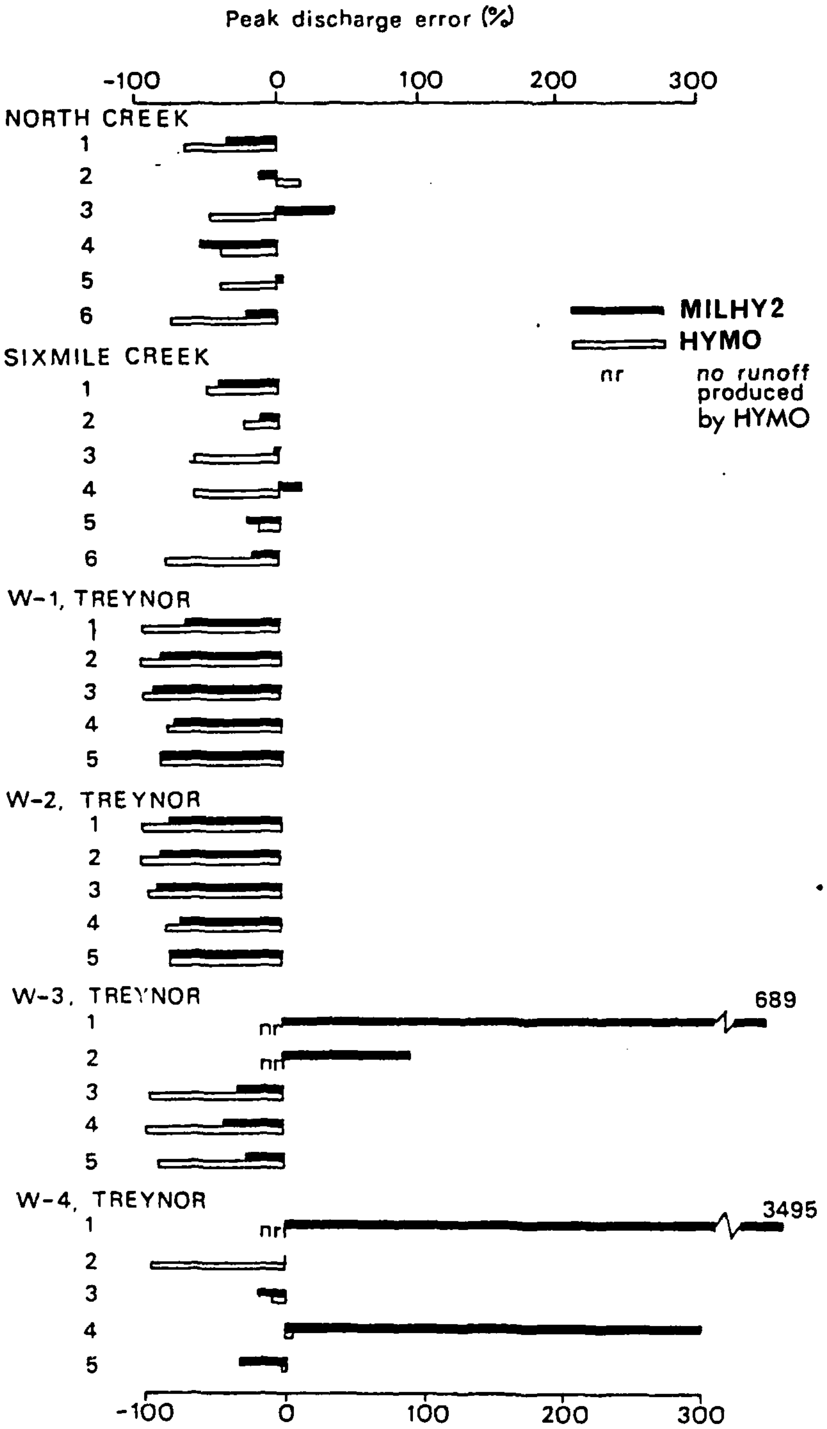


Figure 37: Comparison of the percentage peak discharge error of MILHY2 and HYMO, for 32 experimental frames

6

Fortran Code for MILHY2

```
C -----------------------------------------------------------------------

C Program:      MILHY2
C               HYMO including a physically based infiltration algorithmn
C               which replaces the Soil Conservation Service curve number
C               model

C Coded by:     S Howes
C               University of Bristol

C Notes:        Much of the code remains unaltered but a number of
C               subroutines and functions have been added.
C               All additional code is written in FORTRAN77

C               Modifications occur in following subroutines:
C                      CMHYD
C                      ERROR

C               Additional subroutines:
C                      SOILM
C                      HYDCON
C                      TWO
C                      GRAD
C                      SMCURV
C                      BLOCK DATA

C               Additional functions:
C                      RMAX
C                      RMIN


C -----------------------------------------------------------------------


      OPEN (1,STATUS="OLD",FORM="FORMATTED",FILE="data1",MODE="IN")
      OPEN(25,FORM="FORMATTED",FILE="data2",MODE="IN",STATUS="OLD")
      OPEN(6,FORM="FORMATTED",STATUS="NEW",MODE="OUT",FILE="results")

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE

C Definition of variables in common

C OCFS    Hydrograph discharge
C DATA    Data associated with each command
C CFS     Unit hydrograph discharge
C CTBLE   Command table
C RAIN    Cumulative precipitation values
C ROIN    Runoff volume of discharge hydrograph
C A       End area
C Q       Flow rate for rating curve
C DEEP    Elevation of water surface (for rating curve)
C ITBLE   Integer table
C DP      Flow depth for previously computed travel time flow relationship
```

```
C SCFS    Discharge for previously computed travel time flow relationship
C C       Travel time coefficient for previously computed travel time
C         flow relationship
C ZALFA   Alphnumeric code table
C IEND    Number of points in the hydrograph
C DA      Drainage area
C DIST    Segment boundary point for each segment of a cross section
C SEGN    Mannings ´n´ for each segment of a cross section
C DT      Time increment for rainfall or discharge
C PEAK    Peak discharge for hydrograph
C ISG
C NPU     Punch code
C NHD     Hydrograph identification number
C NER     Error number
C MAXNO   Maximum number of data entires to be expected for any command
C NCOMM   Number of commands
C ICC     Continuation line
C NCODE   Number of command
C TIME    Start time of simulation
C KCODE   Measurement unit of input
C                0 - imperial
C            not 0 - metric
C ICODE   Measurement unit of output
C                0 - imperial
C            not 0 - metric

      NCODE=0
      NPU=0
      ICC=0
1     NER=0
      CALL HONDO
      IF (NER) 2,2,19
2     GO TO (3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19), NCODE
3     TIME=DATA(1)
      NPU=DATA(2)
      KCODE=DATA(3)
      ICODE=DATA(4)
      GO TO 1
4     CALL STHYD
      GO TO 1
5     CALL RECHD
      GO TO 1
6     CALL CMPHYD
      GO TO 1
7     CALL PRTHYD
      GO TO 1
8     CALL PUHYD
      GO TO 1
9     CALL HPLOT
      GO TO 1
10    CALL ADHYD
      GO TO 1
11    CALL SRC
      GO TO 1
12    CALL CMPRC
      GO TO 1
13    CALL STT
```

```
      GO TO 1
14    CALL CMPTT
      GO TO 1
15    CALL ROUTE
      GO TO 1
16    CALL RESVO
      GO TO 1
17    CALL ERROR
      GO TO 1
18    CALL SEDT
      GO TO 1
19    STOP
      END


      SUBROUTINE HONDO

C This subroutine reads in the data from 'datal', searches an alphanumeric
C code table to determine the NCODE of the required operation, and collects
C variables from the freefloating data field.

C The command table (CTBLE), integer table (ITBLE), number of commands
C (NCOMM) and alphanumeric array (ZALFA) are initialized in BLOCK DATA
C located at the end of this listing.


      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE

      DIMENSION CHAR(60), ALPHA(11),AUXA(10),AUXB(10)

      IF (ICC) 1,1,3
C     READ IN DATA CARD
1     READ (1,42) (ALPHA(I),I=1,11),(CHAR(I),I=1,60)
C     IF FIRST CHARACTER IS BLANK THE CARD IS A CONTINUATION OF
C     PREVIOUS CARD.
      IF (ALPHA(1)-ZALFA(11)) 2,9,2
2     IF (ICC) 3,3,40
C     ASTERISK IN COL. 80 MEANS SKIP TO NEW PAGE BEFORE PRINTING CARD
3     IF (CHAR(60)-ZALFA(11)) 4,5,4
4     WRITE (6,43)
5     WRITE (6,44) (ALPHA(I),I=1,11),(CHAR(I),I=1,60)
C     IF FIRST CHARACTER IS A *  THE PREVIOUS CARD WAS A COMMENT CARD
      IF (ALPHA(1)-ZALFA(12)) 10,6,10
C     IF PUNCH CODE POSITIVE, COMMENT CARDS ARE PUNCHED.
6     IF (NPU) 8,8,7
7     WRITE (7,45) (ALPHA(I),I=1,11),(CHAR(I),I=1,60)
8     ICC=0
      GO TO 1
9     WRITE (6,44) (ALPHA(I),I=1,11),(CHAR(I),I=1,60)
      GO TO 24
C     SEARCH FIRST TWO ALPHAMERIC CHARACTERS TO SEE IF THEY ARE NUMBERS
10    ICC=1
```

```
      DO 12 I=1,10
      IF (ALPHA(1)-ZALFA(I)) 11,15,11
11    IF (ALPHA(2)-ZALFA(I)) 12,15,12
12    CONTINUE
C     STATEMENT NUMBER 7 IS BRANCHED TO IF NUMBERS ARE PRESENT
C     IF NOT NUMBER SEARCH COMMAND TABLE FOR MATCH
C     CALL FIRST 10 VALUES FROM PERMANENT DATA STORAGE
      DO 14 I=1,NCOMM
      DO 13 J=1,11
      IF (CTBLE(I,J)-ALPHA(J)) 14,13,14
C     SN 10=PART MATCH
13    CONTINUE
C     IF THIS LOOP IS COMPLETED WE HAVE COMPLETE MATCH- CALL NCODE
C     AND MAX NUMBER AND EXIT LOOP
      NCODE=ITBLE(I,1)
      MAXNO=ITBLE(I,2)
      GO TO 21
14    CONTINUE
C     IF MAJOR LOOPS FINISHED WITHOUT A MATCH WRITE ERROR MESSAGE
C     AND SET NER  = 1
      NER=1
      WRITE (6,46)
      RETURN
C     CONVERT DIGIT INPUT CODE FROM ALPHAMERIC TO INTEGER FORM
15    NCODE=GIT(ALPHA,1,2,1.)+0.5
C     FIND MAX NUMBER OF DATA ITEMS FOR THIS NCODE
      DO 17 I=1,NCOMM
      IF (ITBLE(I,1)-NCODE) 17,16,17
16    MAXNO=ITBLE(I,2)
      GO TO 21
17    CONTINUE
C     SEARCH DATA ROUTINE
C     SEE IF ANY DATA FOR THIS CARD
      DO 19 I=1,NCOMM
      IF (ITBLE(I,1)-NCODE) 19,18,19
18    MAXNO=ITBLE(I,2)
      GO TO 20
19    CONTINUE
20    CONTINUE
21    IF (MAXNO) 23,22,23
22    RETURN
C      ZERO ARRAYS AND COUNTERS
23    DO 47 I=1,310
47    DATA (I)=0.
      NDATA=1
24    NCHAR=0
25    DO 26 I=1,10
      AUXA(I)=0.
26    AUXB(I)=0.
      IT1=1
      IT2=1
      SIGN=1.
      LDGIT=0
      KDGIT=0
C     CARRY OUT DIGIT BY DIGIT SEARCH AND ACCUMULATION
27    NCHAR=NCHAR+1
C     HAVE WE CONSIDERED ALL CHARACTERS - RETURN IF SO
```

```
      IF (NCHAR-60) 28,32,1
28    DO 29 I=1,15
      IF (CHAR(NCHAR)-ZALFA(I)) 29,30,29
29    CONTINUE
      GO TO 32
30    GO TO (33,33,33,33,33,33,33,33,33,33,32,27,36,32,31,27), I
C     SN 39  HANDLES SIGN CONTROL ON 1130 VERSION
31    SIGN=-1.0
      GO TO 27
C     CHARACTER IS BLANK OR COMMA - DOES IT FOLLOW A DIGIT
32    GO TO (27,48), IT1
C     CHARACTER IS A DIGIT - HAS A DECIMAL BEEN ENCOUNTERED
33    GO TO (34,35), IT2
34    LDGIT=LDGIT+1
      IT1=2
      AUXA(LDGIT)=CHAR(NCHAR)
      GO TO 27
35    KDGIT=KDGIT+1
      AUXB(KDGIT)=CHAR(NCHAR)
      GO TO 27
C     CHARACTER IS A DECIMAL - DOES IT FOLLOW A DIGIT
36    GO TO (37,38), IT1
37    IT1=2
      LDGIT=1
38    IT2=2
      GO TO 27
C     ROUTINE TO CONVERT ALPHABETIC ARRAY TO FLOATING POINT NUMBER
48    DATA (NDATA)=GIT(AUXA,1,LDGIT,1.)+GIT(AUXB,1,10,0.)
      DATA (NDATA)=DATA(NDATA)*SIGN
C     IS ALL DATA FURNISHED  YES-RETURN  NO INCREASE N DATA KEEP ON
      IF (NDATA-MAXNO) 41,39,39
39    ICC=0
40    RETURN
41    NDATA=NDATA+1
      GO TO 25
C
42    FORMAT (2A1,9A2,60A1)
43    FORMAT (1H1)
44    FORMAT (5X,2A1,9A2,60A1)
45    FORMAT (2A1,9A2,60A1)
46    FORMAT (10X,20HCOMMAND NOT IN TABLE)
      END


      FUNCTION GIT (TCARD,J,JLAST,SHIFT)

C Converts alphabetic array to floating point numbet


      DIMENSION TCARD(10), A(10)
      DATA A(1)/1H1/,A(2)/1H2/,A(3)/1H3/,A(4)/1H4/,A(5)/1H5/,A(6)/1H6/
      DATA A(7)/1H7/,A(8)/1H8/,A(9)/1H9/,A(10)/1H0/

      GIT=0.
      TEN=10.
      SUM=0.
```

```
      DO 3 JNOW=J,JLAST
      TTEST=TCARD(JNOW)
C     CHECK FOR LAST ENTRY
      IF (TTEST.EQ.0.) GO TO 4
C     FIND NUMBER AND COMPUTE VALUE
      DO 2 NUMB=1,10
      IF (TTEST-A(NUMB)) 2,1,2
1     ZTEST=NUMB
      IF (ZTEST.EQ.10.) ZTEST=0.
      SUM=SUM*TEN+ZTEST
      GO TO 3
2     CONTINUE
3     CONTINUE
4     IF (SHIFT) 6,5,6
5     FI=JNOW-1
      SUM=SUM*(0.1**FI)
6     GIT=SUM
      RETURN
      END



      SUBROUTINE STHYD

C     THIS SUBROUTINE STORES THE COORDINATES OF HYDROGRAPHS.

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE

      DIMENSION DUMMY(300)

      ID=DATA(1)
      NHD=DATA(2)
      DT(ID)=DATA(3)
      IF(KCODE.EQ.0)GO TO 10
      DATA(4)=DATA(4)/2.590
      DO 11 J=5,305
      DATA(J)=DATA(J)/.02832
11    CONTINUE
10    DA(ID)=DATA(4)
      J=5
C     REMAINING DATA ARE FLOW RATES
      OCFS(1,ID)=DATA(J)
      PEAK(ID) = 1.
      RO = DATA(J)
      DO 4 I=2,300
      J=J+1
      OCFS(I,ID)=DATA(J)
      RO = RO + OCFS(I,ID)
C     IS FLOW RECEDING
      IF (OCFS(I,ID)-OCFS(I-1,ID)) 1,2,2
C     HAS FLOW RECEDED TO CUTOFF RATE
1     IF (OCFS(I,ID)) 5,5,4
C     DETERMINE PEAK FLOW
```

```
2     IF(OCFS(I,ID) - PEAK(ID)) 4,4,3
3     PEAK(ID) = OCFS(I,ID)
4     CONTINUE
5     IEND(ID)=I-1
      M=IEND(ID)
      ROIN(ID) = (RO*DT(ID))/(DA(ID)*645.333)
      IF(NPU.LE.0)GO TO 7
      IF(ICODE.EQ.0)GO TO 6
      ROIN1=ROIN(ID)*25.4
      DA1=DA(ID)*2.590
      PEAK1=PEAK(ID)*.02832
      DO 13 J=1,M
      DUMMY(J)=OCFS(J,ID)*0.02832
13    CONTINUE
      WRITE(7,14)ID,NHD,DT(ID),DA1,PEAK1,ROIN1,IEND(ID),ICODE
      WRITE(7,15)(DUMMY(I),I=1,M)
      RETURN
C     PUNCH CODE
6     WRITE(7,8)ID,NHD,DT(ID),DA(ID),PEAK(ID),ROIN(ID),IEND(ID),ICODE
      WRITE (7,9) (OCFS(J,ID),J=1,M)
7     RETURN
C
8     FORMAT(   ´RECALL HYD´,T21,´ID=´,I1,T29,´HYD NO=´,I3,T42,´DT=´,F9.
     &6,´ HRS´,T61,´DA=´,F8.3,´ SQ MI´/T21,´PEAK=´,F7.0,´CFS´,T40,´RO=´,
     &F6.3," INCHES ",T59,"NO PTS =",I3/T21,"CODE=",I1/T21,
     &"FLOW RATES")
9     FORMAT (T21,7F8.0)
14    FORMAT("RECALL HYD",T21,"ID=",I1,T29,"HYD NO =",I3,T42,
     &"DT=",F9.6,"HRS",T61,"DA=",F8.3,"SQ KM"/T21,"PEAK",F7.2,
     &"CMS",T40,"RO=",F6.0," MM ",T59,"NO PTS=",I3/T21,"CODE=",
     &I1/T21,"FLOW RATES")
15    FORMAT (T21,7F8.2)
      END


      SUBROUTINE RECHD

C     THIS SUBROUTINE RECALLS PREVIOUSLY COMPUTED AND PUNCHED
C     HYDROGRAPHS

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE

      MET1=DATA(8)
      IF(MET1.EQ.0)GO TO 2
      DATA(4)=DATA(4)/2.590
      DATA(5)=DATA(5)/.02832
      DATA(6)=DATA(6)/25.4
      M=DATA(7)
      DO 3 I=9,M+9
      DATA(I)=DATA(I)/0.02832
3     CONTINUE
2     ID=DATA(1)
      NHD=DATA(2)
```

```
      DT(ID)=DATA(3)
      DA(ID)=DATA(4)
      PEAK(ID)=DATA(5)
      ROIN(ID)=DATA(6)
      IEND(ID)=DATA(7)
      M=IEND(ID)
      J = 9
C     REMAINING DATA ARE FLOW RATES
      DO 1 I=1,M
      OCFS(I,ID)=DATA(J)
1     J=J+1
      RETURN
      END


      SUBROUTINE CMPHYD

C This subroutine develops a unit hydrograph, converts rainfall data
C into runoff by calling the soil moisture finite difference model,
C and sums these two to produce the storm runoff hydrograph.


      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE


      DIMENSION DUMMY(300)
      TEMP=0.


C Input data read into subroutine


      ID=DATA(1)
      NHD=DATA(2)
      DT(ID)=DATA(3)

      IF(KCODE.NE.0)THEN
C           Convert metric to imperial
            DATA(4)=DATA(4)/2.590
            IF(DATA(6).LT.0)GO TO 40
            DATA(6)=DATA(6)/0.3048
            DATA(7)=DATA(7)/1.6
      ENDIF

40    DA(ID)=DATA(4)
C


C Data items 6 and 7 normally hold watershed height and length and
C from these the constants XK(recession constant) and Tp(time to peak)
C can be calculated.
C If XK and Tp are known however, they can be entered instead
```

```
C and a negative sign is put before their values.

      IF (DATA(6).LT.0.)THEN
         XK=-DATA(6)
         TP=-DATA(7)
      ELSE
         HT=DATA(6)
         XL=DATA(7)
         SLOPE=HT/XL
         XLDW=(XL**2.)/DA(ID)
         XK=27.0*(DA(ID)**.231)*(SLOPE**(-.777))*(XLDW**.124)
         TP=4.63*(DA(ID)**.422)*(SLOPE**(-.46))*(XLDW**.133)
      ENDIF




C The storm runoff array is intialised to 0, and peak of hydrograph to 1

        DO 4 I=1,300
4       OCFS(I,ID)=0.
        PEAK(ID)=1.

C Compute ´N´ by iteration
      XN=5.0
      XKTP=XK/TP
        DO 6 I=1,50
        TINF=1.+SQRT(1./(XN-1.))
        XN1=.05/(XKTP*(ALOG(TINF/(TINF+.05))+.05))+1.
        DIFF=ABS(XN1-XN)
        IF (DIFF-.001) 7,7,5
5       XN=XN1
6       CONTINUE
      WRITE (6,29)
29    FORMAT(´ N DID NOT CONVERGE AFTER 50 ITERATIONS.´)
      GO TO 28

C Compute ´C1´
7     DELT=TINF/100.
      TC1=0.
      XN1P=XN-1.
      XN1M=1.-XN
        DO 8 I=2,101
        TC1=TC1+DELT
8       CFS(I)=(TC1**XN1P)*EXP(XN1M*(TC1-1.))
      SUM=CFS(101)/2.
        DO 9 I=2,100
9       SUM=SUM+CFS(I)
      C1=SUM*DELT
C
C Compute ´B´
      CFSII=CFS(101)
      TTINF=TINF*TP
      TREC1=TTINF+2.*XK
      EEE=EXP((TTINF-TREC1)/XK)
      XK1=3.*XK
      B=645.333/(C1+CFSII*(XKTP*(1.-EEE)+EEE*(XK1/TP)))
```

```
C
C Compute 'QP' and 'CFSI'
C
      QP=(B*DA(ID))/TP
      CFSI=QP*CFS(101)
      CFSR1=CFSI*EEE
      IF(ICODE.EQ.0)GO TO 45
      QP1=QP*.02832
      WRITE(6,38)XN,QP1
38    FORMAT(' Shape constant, N = ',F6.3/' Unit peak = ',F10.1,1X
     &,'cms'/)
      GO TO 44
45    WRITE (6,30) XN,QP
30    FORMAT(' Shape constant, N = ',F6.3/' Unit peak = ',F10.1,1X
     *,'cms'/)
C
44    CONTINUE
C
C Determine the incremental runoff
C
      IF(KCODE.NE.0)THEN
          IF(DATA(8).LT.0)GO TO 13
C             Convert rainfall data from mm to inches.
           DO 34 K=8,308
             DATA(K)=DATA(K)/25.4
34           CONTINUE
      ENDIF
C
35    J=8
      IF (DATA(J)) 13,10,10
10    RAIN(1)=DATA(J)
        DO 11 I=2,300
        J=J+1
        RAIN(I)=DATA(J)
        IF (RAIN(I)-RAIN(I-1)) 12,11,11
11      CONTINUE
12    NUMB=I-1
13    CONTINUE
      DO 5555 I=1,300
5555  DATA(I)=0.
C
C
      TEMP=DT(ID)
C
      CALL SOILM(TEMP,NUMB,RAIN,DATA)

C Subroutine returns a vector of runoff values from the soil moisture model
C If no runoff has been generated by the soil water model, then the simulation
C stops.

      DO 100 I=1,NUMB
      IF(DATA(I).EQ.0.)GOTO 100
      GOTO 200
100   CONTINUE
      WRITE(6,300)
300   FORMAT(' Soil water model generated no runoff'/
     &' Simulation terminates')
```

```
      STOP
200   CONTINUE

Compute unit hydrograph

      T2=0.
      CFS(1)=0.
        DO 20 I=2,300
        T2=T2+DT(ID)
        IF (T2-TTINF) 16,16,17
16      CFS(I)=QP*((T2/TP)**XN1P)*EXP(XN1M*(T2/TP-1.))
        GO TO 20
17      IF (T2-TREC1) 18,18,19
18      CFS(I)=CFSI*EXP((TTINF-T2)/XK)
        GO TO 20
19      CFS(I)=CFSR1*EXP((TREC1-T2)/XK1)
        IF (CFS(I)-1.) 21,21,20
20      CONTINUE
      I=300
21    ICND=I
C
C
C Compute the storm runoff hydrograph by summing the unit hydrograph and
C the runoff from the soil moisture model.
C
C
        DO 24 J=2,NUMB
        N=J+ICND-2
        IF (N-300) 23,23,22
22      N=300
23      I = 2
          DO 24 K= J,N
          OCFS(K,ID)=OCFS(K,ID)+DATA(J)*CFS(I)
          I=I+1
24        CONTINUE
C
C Compute the runoff volume and determine the peak.
C
C
      RO = 0.
        DO 26 I = 2,N
        RO = RO + OCFS(I,ID)
        IF (OCFS(I,ID)-PEAK(ID))26,26,25
25      PEAK(ID)= OCFS(I,ID)
26      CONTINUE
      IEND (ID) = N
      ROIN(ID)=(RO*DT(ID))/(DA(ID) * 645.333)
C
C     PUNCH CODE
      IF (NPU) 28,28,27
27    IF(ICODE.EQ.0)GO TO 39
      ROIN1=ROIN(ID)*25.4
      DA1=DA(ID)*2.590
      PEAK1=PEAK(ID)*.02832
        DO 41 J=1,N
      DUMMY(J)=OCFS(I,ID)*0.02832
41    CONTINUE
```

```
      WRITE(7,37)ID,NHD,DT(ID),DA1,PEAK1,ROIN1,IEND(ID),ICODE
      WRITE(7,42)(DUMMY(I),I=1,N)
      RETURN
39    WRITE(7,31)ID,NHD,DT(ID),DA(ID),PEAK(ID),ROIN(ID),IEND(ID),ICODE
      WRITE (7,32) (OCFS(I,ID),I=1,N)
28    RETURN
C
31     FORMAT(   'RECALL HYD',T21,'ID=',I1,T29,'HYD NO=',I3,T42,'DT=',F9.
     &6,' HRS',T61,'DA=',F8.3,' SQ MI'/T21,'PEAK=',F7.0,'CFS',T40,'RO=',
     &F6.3,' INCHES',T59,'NO PTS=',I3/T21,"CODE=",I1/T21,'FLOW RATES')
37     FORMAT(   'RECALL HYD',T21,'ID=',I1,T29,'HYD NO=',I3,T42,'DT=',F9.
     &6,' HRS',T61,'DA=',F8.3,' SQ KM'/T21,'PEAK=',F7.2,'CMS',T40,'RO=',
     &F6.0,' MM  ',T59,'NO PTS=',I3/T21,"CODE=",I1/T21,'FLOW RATES')
42     FORMAT (T21,7F8.2)
32     FORMAT (T21,7F8.0)
      END


      SUBROUTINE SOILM(DT,IR,CUMRAIN,DATA)

C A physically based parameter infiltration model which simulates near surfac
C soil water movement, and hence runoff.

C Variables used in this subroutine

C     TIME          Time when simulation begins (hours).
C     SR1           Soil water content at saturation  layer 1.
C     SR2                                  (m3/m3)  layer 2.
C     SR3                                           layer 3.
C     NLA           Number of cells in layer 1.
C     NLB           Number of cells in layer 2.
C     NL            Total number of cells in column
C     SATCON        Saturated permeability (ms-1)  layer 1.
C     SATCON2                                      layer 2.
C     SATCON3                                      layer 3.
C     EMAX          Maximum evaporation during the day (ms-1).
C     SIMDUR        Simulation duration (hours).
C     DETCAP        Surface detention capacity (m).
C     AF            Simulation iteration period (secs).
C     WT            Write-out time period (hrs).
C     THETA         Initial soil water content for each cell (m3/m3).
C     TCOM          Thickness of each cell.
C     ALR           Rain start time (hours).
C     AMR           Rain stop time.
C     NQ            Number of observations on suction moisture curve.
C     X             Moisture values....layer 1 (m3/m3).
C     Y             Suction values.....layer 1 (bars).
C     X2                               layer 2.
C     Y2                               layer 2.
C     X3                               layer 3.
C     Y3                               layer 3.
C     IR             Number of rainfall observations.
C     DT             Rainfall data time increments (hours).
C     CUMRAIN        Cumulative rainfall data at DT time increments (inches).
C     NSCOL          Number of soil columns.
C     IPCAREA        Percent area of soil column.
```

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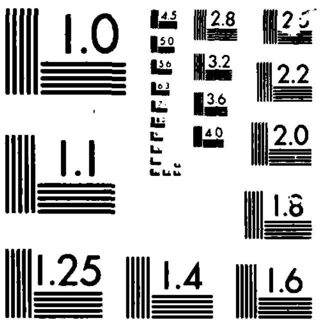

MICROCOP CHART

```
C     IOUT           Determines amount of output.
C                        1 - total output
C                        0 - shorter

C  Note:
C     If SR1, SR2, SR3, SATCON, SATCON2, SATCON3, DETCAP, THETA, X, X2, or X3
C     are proceeded by an ´A´, then the variable type is double precision
C     rather than real.  If SR1, SR2, SR3, SATCON, SATCON2, SATCON2, DETCAP,
C     OR THETA are preceeded by an ´S´,then the variable represents the
C     standard deviation of that particular soil hydrological characteristic.

C     SCURV1         Standard deviation of soil moisture curve for layer 1
C     SCURV2                                                       layer 2
C     SCURV3                                                       layer 3




C                  ---------------
C                  INITIAL SECTION
C                  ---------------
C
C
C
      DIMENSION FLUX(20),TCOM(20),SWP(20),THETA(20),COND(20)
      DIMENSION VOL(20),ANFLUX(20),AVCOND(20),DEPTH(20),DIST(20)
      DIMENSION X(20),Y(20),G(20),GZ(20),FSWP(20),CNT(20)
      DIMENSION CUMRAIN(251),Z(20),PPT(250),XP(20),FS(20)
      DIMENSION DATA(300),WDATA(300,10),HPOT(20)
      DIMENSION G2(20),Y2(20),X2(20),GZ2(20),Z2(20)
      DIMENSION G3(20),Y3(20),X3(20),GZ3(20),Z3(20)
      DIMENSION RSAT(20)
      DIMENSION AX(20),AX2(20),AX3(20),ATHETA(20)
      DIMENSION XNEW(20),YNEW(20),X2NEW(20),Y2NEW(20),
     &          X3NEW(20),Y3NEW(20)

      DOUBLE PRECISION G05DDF
      DOUBLE PRECISION DLOG10
      DOUBLE PRECISION ATHETA,AX,AX2,AX3,ADETCAP,ASR1,ASR2,ASR3,
     *   ASATCON,ASATCON2,ASATCON3,BSATCON,BSATCON2,BSATCON3,
     *   SDETCAP,SSR1,SSR2,SSR3,STHETA,SSATCON,SSATCON2,SSATCON3,
     *   SCURV1,SCURV2,SCURV3
C
C
C
C             READ IN DATA
C             ------------
C
C
C
      READ(25,1000)TIME,ALR,AMR,SIMDUR
      READ(25,1000)IOUT
      READ(25,1000)AF,WT
      READ(25,1000)NSCOL
```

```
C The array RAIN which is passed to the subroutine as a cumulative
C rainfall total is in inches.This has to be transfered to array
C PPT which is in m and represents the total for each time increment.
      IRR=IR-1
      DO 100 I=1,IRR
100   PPT(I)=(CUMRAIN(I+1)-CUMRAIN(I))*.0254


      DO 34543 W=1,NSCOL
C     For each soil column in turn, read in data and proceed through
C     simulation to determine runoff

      READ(25,1000)IPCAREA
      READ(25,1000)NL,NLA,NLB
      READ(25,1000)(TCOM(I),I=1,NL)
      READ(25,1000)EMAX,ADETCAP,SDETCAP
      READ(25,1000)ASR1,SSR1,ASR2,SSR2,ASR3,SSR3
      READ(25,1000)ASATCON,SSATCON,ASATCON2,SSATCON2,ASATCON3,SSATCON3
      READ(25,1000)(ATHETA(I),I=1,NL)
      READ(25,1000)STHETA
      READ(25,1000)NQ
      READ(25,1000)(AX(I),I=1,NQ)
      READ(25,1000)(Y(I),I=1,NQ)
      READ(25,1000)SCURV1
      READ(25,1000)(AX2(I),I=1,NQ)
      READ(25,1000)(Y2(I),I=1,NQ)
      READ(25,1000)SCURV2
      READ(25,1000)(AX3(I),I=1,NQ)
      READ(25,1000)(Y3(I),I=1,NQ)
      READ(25,1000)SCURV3
1000  FORMAT(V)
      NQJ=NQ
      NLL=NL+1

      IF(AMR.LT.ALR)THEN
          AMR=AMR+24.0
      ENDIF

C
C
C                 CHECK DATA INPUTS
C                 -----------------
C
      NERROR=0

C Check number of cells in soil column
      IF(NLA+NLB.GE.NL)THEN
         WRITE(6,1015)
1015     FORMAT(' Error-NLA,NLB,NL')
         NERROR=NERROR+1
      ENDIF
C
C Check dimensions of input vectors
      IF(NQ.GT.20.OR.NL.GT.20.OR.IR.GT.250)THEN
         WRITE(6,1020)
1020     FORMAT(' Error-limit exceeded,NQ,NL,IR')
         NERROR=NERROR+1
```

```
      ENDIF
C
C Check rainfall passed from CMPHYD
      KN=IR-1
      DO 50 I=1,KN
         IF(CUMRAIN(I+1).LT.CUMRAIN(I))THEN
            WRITE(6,1030)
1030        FORMAT(' Error-not cumulative rainfall totals')
            NERROR=NERROR+1
         ENDIF
50     CONTINUE
C
C Check that initial moisture content of each cell lies within the range of
C the suction moisture curve and does not exceed stated saturated moisture
C content.
      DO 51 I=1,NLA
         IF(ATHETA(I).GT.ASR1)THEN
            WRITE(6,1050)
1050        FORMAT(' Error-THETA larger then sat moisture content(1)')
            NERROR=NERROR+1
         ENDIF
         IF (ATHETA(I).GT.AX(NQ).OR.ATHETA(I).LT.AX(1))THEN
             WRITE(6,1055)
1055         FORMAT(' Error-THETA outside range of curves-(1)')
         ENDIF
51    CONTINUE
      NLAA=NLA+1
      NLH=NLA+NLB
      DO 52 I=NLAA,NLH
         IF(ATHETA(I).GT.ASR2)THEN
            WRITE(6,1060)
1060        FORMAT(' Error-THETA larger than sat moisture content(2)')
            NERROR=NERROR+1
         ENDIF
      IF(ATHETA(I).GT.AX2(NQ).OR.ATHETA(I).LT.AX2(1))THEN
         WRITE(6,1065)
1065     FORMAT(' Error-THETA outside range of curve-(2)')
         NERROR=NERROR+1
      ENDIF
52    CONTINUE
      NLBB=NLB+NLA+1
      DO 53 I=NLBB,NL
         IF(ATHETA(I).GT.ASR3)THEN
            WRITE(6,1070)
1070        FORMAT(' Error-THETA larger than sat moisture content(3)')
            STOP
         ENDIF
         IF(ATHETA(I).GT.AX3(NQ).OR.ATHETA(I).LT.AX3(1))THEN
            WRITE(6,1075)
1075        FORMAT(' Error-THETA outside range of curve -(2)')
```

```
             NERROR=NERROR+1
          ENDIF
53     CONTINUE
C
       IF (NERROR.NE.0)THEN
           WRITE(6,1076)NERROR
1076       FORMAT(' SOILM:   number of input data errors  ',I2,
     &'Simulation terminates')
           STOP
       ENDIF
C
C
C
C
C         DEPTH CALCULATION
C         -----------------
C
C
C
C The variable DEPTH is calculated. This refers to the distance from
C ground level to any cell midpoint.
C DIST refers to the distance between any two adjacent cell midpoints.
C
       DIST(1)=TCOM(1)/2.
       DEPTH(1)=DIST(1)
       DO 110 I=2,NL
       DEPTH(I)=DEPTH(I-1)+0.5*(TCOM(I-1)+TCOM(I))
110    DIST(I)=0.5*(TCOM(I-1)+TCOM(I))
C
C
C
C
C           PARAMETER VARIABILITY
C           ---------------------
C
C  Five input variables, detention capacity, soil water content at
C saturation, soil moisture content at given tensions, saturated conductivity
C and initial moisture content are varied stochastically.
C NAG functions are called which return a 'psuedo random' value from a
C distribution with a given standard deviation and mean.
C All are assumed to have a normal distribution except the saturated
C conductivity which takes on a lognormal.
C
C
C
C Generate only one set of stochastic variables to run in HYMO.
C
C
C              RANDOM PARAMETER VALUE
C              ----------------------
```

```
C
      WRITE(6,1079)
1079    FORMAT(' INCREMENTAL RUNOFF-Parameter variability included'//)
C
C     Detention capacity.
          DETCAP=G05DDF(ADETCAP,SDETCAP)
          IF(DETCAP.LT.0.)DETCAP=0.0
          SD=SDETCAP
          WRITE(6,1180)SD
1180      FORMAT(' SD of detcap ',F5.3)
C
C     Soil water content at saturation
          SR1=G05DDF(ASR1,SSR1)
          SR2=G05DDF(ASR2,SSR2)
          SR3=G05DDF(ASR3,SSR3)
          SD1=SSR1
          SD2=SSR2
          SD3=SSR3
          WRITE(6,1181)SD1,SD2,SD3
1181      FORMAT(' SD of saturated soil content',F5.3,' layer 1'/
     &      '                             ',F5.3,' layer 2'/
     &      '                             ',F5.3,' layer 3')
C
C     Soil moisture content at given tensions
C     Layer 1
        CALL SMCURV(SR1,NQ,AX,Y,XNEW,YNEW,SCURV1)
        DO 120 I=1,20
          X(I)=XNEW(I)
120       Y(I)=YNEW(I)
C     Layer 2
        CALL SMCURV(SR2,NQ,AX2,Y2,X2NEW,Y2NEW,SCURV2)
        DO 130 I=1,20
          X2(I)=X2NEW(I)
130       Y2(I)=Y2NEW(I)
C     Layer 3
        CALL SMCURV(SR3,NQ,AX3,Y3,X3NEW,Y3NEW,SCURV3)
        DO 140 I=1,20
          X3(I)=X3NEW(I)
140       Y3(I)=Y3NEW(I)
        SD1=SCURV1
        SD2=SCURV2
        SD3=SCURV3
        WRITE(6,1182)SD1,SD2,SD3
1182    FORMAT(' SD of suction moisture curve', F5.3,' layer 1'/
     &     '                              ', F5.3,' layer 2'/
     &     '                              ',F5.3,' layer 3')
C
C Saturated conductivity for each layer
          BSATCON=DLOG10(ASATCON)
          SATCON=G05DDF(BSATCON,SSATCON)
```

```
          SATCON=10**SATCON
          BSATCON2=DLOG10(ASATCON2)
          SATCON2=G05DDF(BSATCON2,SSATCON2)
          SATCON2=10**SATCON2
          BSATCON3=DLOG10(ASATCON3)
          SATCON3=G05DDF(BSATCON3,SSATCON3)
          SATCON3=10**SATCON3
          SD1=SSATCON
          SD2=SSATCON2
          SD3=SSATCON3
          WRITE(6,1183)SD1,SD2,SD3
1183      FORMAT(' SD of sat conductivity',F5.3,' layer 1'/
     &          '                     ',F5.3,' layer 2'/
     &          '                     ',F5.3,' layer 3')
C
C Initial moisture content
          DO 150 I=1,NL
150          THETA(I)=G05DDF(ATHETA(I),STHETA)
C         Check on initial soil moisture values
          DO 160 I=1,NLA
             IF(THETA(I).GE.X(20))THETA(I)=X(20)-0.001
160          IF(THETA(I).LE.X(1))THETA(I)=X(1)+0.001
          DO 170 I=NLAA,NLH
             IF(THETA(I).GE.X2(20))THETA(I)=X2(20)-0.001
170          IF(THETA(I).LE.X2(1))THETA(I)=X2(1)+0.001
          DO 180 I=NLBB,NL
             IF(THETA(I).GE.X3(20))THETA(I)=X3(20)-0.001
180          IF(THETA(I).LE.X3(1))THETA(I)=X3(1)+0.001
        SD=STHETA
         WRITE(6,1184)SD
1184     FORMAT(' SD of initial water content',F5.3)
C
C
C
C         HYDRAULIC CONDUCTIVITY CALCULATION
C         ----------------------------------
C
C
C
C The hydraulic conductivity is calculated from suction moisture
C data  for each layer.
      NQJ=NQ
      CALL HYDCON(X,SATCON,SR1,Z,Y)
      CALL HYDCON(X2,SATCON2,SR2,Z2,Y2)
      CALL HYDCON(X3,SATCON3,SR3,Z3,Y3)
C
C
C
C
C          WRITE-OUT INITIAL CONDITIONS
```

```
C          ----------------------------
C
C
C
C Write-out.suction moisture curve and generated K-values.
C
      WRITE(6,1080)
1080  FORMAT('OGENERATED K-MOISTURE CURVE'/
     &' Millington-Quirk Method'/
     &' Layer 1',26X,'Layer 2',26X,'Layer 3'/
     &3(' Moisture Suction     Unsat K    '))
      DO 175 I=1,20
175   WRITE(6,1090)X(I),Y(I),Z(I),X2(I),Y2(I),Z2(I),X3(I),Y3(I),Z3(I)
1090  FORMAT(1H ,3(F6.3,2X,F8.3,F15.12,2X))
C Write-out start conditions.
C
      WRITE(6,1100)
1100  FORMAT('OSTART CONDITIONS '/)
      WRITE(6,1110)TIME
1110  FORMAT(' Simulation start time',F4.1,'hrs')
      WRITE(6,1130)ALR,AMR
1130  FORMAT(' Precipitation begins at ',F4.1,2X,'and ends at ',F4.1)
      WRITE(6,1140)DT
1140  FORMAT(' Rainfall data time increment = ',F6.4,2X,'hrs')
      WRITE(6,1120)AF
1120  FORMAT(' Time increment for iteration period = ',F6.1,
     &2X,'secs'/)
      WRITE(6,1150)EMAX,DETCAP
1150  FORMAT(' Maximum evaporation during the day = ',F10.8,2X,'ms-1'/
     &' Surface detention capacity = ',F6.4,2X,'m'//)
C
C Calculate initial relative saturation of each cell in soil column
      DO 1151 I=1,NL
         IF(I.LE.NLA)RSAT(I)=THETA(I)/SR1
         IF(I.GT.NLA.AND.I.LT.NLBB)RSAT(I)=THETA(I)/SR2
         IF(I.GE.NLBB)RSAT(I)=THETA(I)/SR3
1151  CONTINUE

      WRITE(6,1152)
1152  FORMAT(' INITIAL SOIL COLUMN CONDITIONS'//)
      WRITE(6,1153)
1153  FORMAT(11X,'SAT',8X,'SAT HYD',6X,'CELL',1X,'DEPTH',
     &2X,'INITAL',2X,'REL'/
     &1H ,10X,'THETA',7X,'COND',9X,'NO',10X,'THETA',2X,'SAT'/
     &1H ,10X,'m3/m3',7X,'ms-1',14X,'m',5X,'m3/m3'/)
      WRITE(6,1154)SR1,SATCON,DEPTH(1),THETA(1),RSAT(1)
1154  FORMAT(' Layer 1  ',F7.4,1X,F15.12,3X,'1',2X,F6.4,1X,F7.4,1X,F5.3)
      IF(NLA.GT.1)THEN
          DO 1155 I=2,NLA
```

```
                WRITE(6,1156)I,DEPTH(I),THETA(I),RSAT(I)
1156            FORMAT(1H ,34X,I2,2X,F6.4,1X,F7.4,1X,F5.3)
1155        CONTINUE
      ENDIF
      WRITE(6,1157)SR2,SATCON2,NLAA,DEPTH(NLAA),THETA(NLAA),RSAT(NLAA)
1157  FORMAT(' Layer 2  ',F7.4,1X,F15.12,2X,I2,2X,F6.4,1X,F7.4,1X,F5.3)
      IF(NLB.GT.1)THEN
          DO 1158 I=NLA+2,NLH
              WRITE(6,1159)I,DEPTH(I),THETA(I),RSAT(I)
1159          FORMAT(1H ,34X,I2,2X,F6.4,1X,F7.4,1X,F5.3)
1158      CONTINUE
      ENDIF
      WRITE(6,1160)SR3,SATCON3,NLH+1,DEPTH(NLH+1),THETA(NLH+1),
     &RSAT(NLH+1)
1160  FORMAT(' Layer 3  ',F7.4,1X,F15.12,2X,I2,2X,F6.4,1X,F7.4,1X,F5.3)
      IF((NL-NLH).GT.1)THEN
          DO 1161 I=NLH+2,NL
              WRITE(6,1162)I,DEPTH(I),THETA(I),RSAT(I)
1162          FORMAT(1H ,34X,I2,2X,F6.4,1X,F7.4,1X,F5.3)
1161      CONTINUE
      ENDIF
C
C
C
C       INITIALISATION OF VARIABLES
C       ---------------------------
C
C
C
        DO 184 I=1,300
184     WDATA(I,W)=0.0
      WATI=0.0
      MMM=2
        DO 185 I=2,NL
185     ANFLUX(I)=0.0
      CTIME=TIME*3600
      SRAIN1=0.0
      CUMDRN=0.
      CINFIL=0.
      SUMD=0.
      ICOUNT =0
      BR=AMR-ALR
      EVAPI=0.0
      SOG=THETA(1)/SR1
      RTOT=0.0
      ANFILT=0.0
      PPTT=0.0
      TG=0.0
C
C
```

```
C
C          BALANCE CHECK
C          -------------
C
C
C
C A calculation for the water balance check.
C The initial soil water content of the soil column.
C
      DO 190 I=1,NL
190   WATI=TCOM(I)*THETA(I)+WATI
C
C
C
C            CURVE GRADIENTS
C            ---------------
C
C
C
C Calculations of the gradients of the suction-moisture curve and the
C K-moisture curve for each layer.
C
      CALL GRAD(G,GZ,Y,X,Z)
      CALL GRAD(G2,GZ2,Y2,X2,Z2)
      CALL GRAD(G3,GZ3,Y3,X3,Z3)
C
C
C
C                  ----------------------------
C                  DYNAMIC SECTION - SIMULATION
C                  ----------------------------
C
C
C This loop is completed for each time increment until end of simulation.
C
      ITMAX=SIMDUR*3600/AF
        DO 9995 II=1,ITMAX
      ICOUNT=ICOUNT+AF
      TG=TG+AF
      T=II
C
C
C       CALCULATE WATER VOLUME OF EACH CELL
C       -----------------------------------
C
C
      DO 200 I=1,NL
200   VOL(I)=TCOM(I)*THETA(I)
C
C
```

```
C
C
C                  24-HOUR CLOCK
C                  -------------
C
C
C
C Calculate REAL TIME for current iteration period using the 24-hour clock
C
      CTIME=CTIME+AF
      IF (CTIME.GE.86400)THEN
         CTIME=CTIME-86400
      ENDIF
C
C
C       SWP,HPOT,COND CALCULATIONS
C       --------------------------
C
C
C
C Calculate the soil water pressure, hydraulic potential and conductivity
C for each cell as conditions change during the simulation.
C
      CALL TWO(1,NLA,THETA,X,SWP,Y,G,HPOT,DEPTH,GZ,COND,Z)
      CALL TWO(NLAA,NLH,THETA,X2,SWP,Y2,G2,HPOT,DEPTH,GZ2,COND,Z2)
      CALL TWO(NLBB,NL,THETA,X3,SWP,Y3,G3,HPOT,DEPTH,GZ3,COND,Z3)
C
C
C
C          DETERMINE RAINFALL
C          ------------------
C
C
C
C Determine rainfall per second at end of the current iteration
C period.
C T1 is the time in hours when the current iteration period ends.
C Check that T1 is between the rain start and stop.
C If it is, decide which element of PPT array the data is to be taken from
C and make SRAIN equal to that precipitation per second.
C If it is not within the storm period, set SRAIN to 0.
C
C
      T1=T*AF/3600.0
      IF(T1.LE.(ALR-TIME).OR.T1.GT.(AMR-TIME))THEN
       SRAIN=0.0
      ELSE
       T2=T1-(AF/3600.)
       IELEM=((T2-(ALR-TIME))/DT)+1
       SRAIN=PPT(IELEM)/(DT*3600.0)
      ENDIF
```

```
c
c
C Increment precipitation total by amount of precipitation in current
C iteration period.
C
      PPTT=PPTT+(SRAIN*AF)
C
C
C
C          AVERAGE HYDRAULIC CONDUCTIVITY
C          ------------------------------
C
C
C
C Average hyraulic conductivity for flow through boundary between
C adjoining cells is weighted according to its thickness.
C
        DO 210 I=2,NL
210    AVCOND(I)=(COND(I-1)*TCOM(I-1)+COND(I)*TCOM(I))
     &/(TCOM(I-1)+TCOM(I))
C
C
C
C              BOTTOM BOUNDARY CONDITION
C              -------------------------
C
C
C Determine the bottom boundary condition under the assumption that
C water is flowing out of the soil column under gravity.
C
      FLUX(NLL)=COND(NL)
C
C
C
C             FLUX BETWEEN CELLS
C             ------------------
C
C
C
C The flux between each cell then follows Darcy´s law in discrete form.
C
      DO 220 I=2,NL
220   FLUX(I)=(HPOT(I-1)-HPOT(I))*AVCOND(I)/DIST(I)
C
C
C
C            DETERMINE TOP BOUNDARY CONDITIONS
C            ----------------------------------
C
```

```
C
C
C Calculate the infiltration capacity.
C
      BNCAP=(0.0-HPOT(1))*0.5*(SATCON+COND(1))/DIST(1)
C
C Calculate precipitation excess
C
      IF(SRAIN1.EQ.SRAIN)THEN
        SUMD=(SRAIN-ANFILT)*AF+SUMD
      ELSE
         SUMD=0.0+SUMD
      ENDIF
      SRAIN1=SRAIN
C
C Calculate amount detained on the surface.
C
      IF(SUMD.LT.0.0)THEN
         DETAIN=0.0
      ELSE
         DETAIN=SUMD
      ENDIF
C
C Calculate evaporation, the flux into cell 1 and runoff.
C
      IF(SRAIN.GT.0.0) THEN
C
       EVAP= 0.0
C
       IF(SRAIN.LT.BNCAP.AND.DETAIN.LE.0.0)THEN
          ANFILT=SRAIN
       ELSE
          ANFILT=BNCAP
       ENDIF
       FLUX(1)=ANFILT
C
       IF(DETAIN.GT.DETCAP)THEN
         SUMD=DETCAP
         DETAIN=DETCAP
         RUNOFF=0.0
         IF(SRAIN.GT.BNCAP)RUNOFF=(SRAIN-BNCAP)*AF
         RTOT=RTOT+RUNOFF
       ELSE
         RUNOFF=0.0
       ENDIF
C
      ELSE
C
       RUNOFF=0.0
C
```

```
        IF(CTIME.GT.64800.AND.CTIME.LE.21600)THEN
           EVAP=EMAX/100.
       ELSE
           EVAP=EMAX*SIN(2.*3.14159*(CTIME-21600.)/86400.)
       ENDIF
C
       IF(DETAIN.LE.0.)THEN
           ANFILT=0.0
           FLUX(1)=EVAP*(-1.)
       ELSE
           ANFILT=BNCAP
           FLUX(1)=ANFILT
             DETAIN=DETAIN-(EVAP*AF)
       ENDIF
C
      ENDIF
C
C
C          CHANGES IN SOIL MOISTURE CONTENT
C          --------------------------------
C
C
C
      SWP(NLL)=-102.0
      DO 230 I=1,NL
C     If SWP in cell is greater then 0, it is saturated and flux must
C     therefore be 0.
      IF(SWP(I+1).GE.0.0)FLUX(I+1)=0.0
C     ANFLUX represents the net change in moisture content in the cell.
      ANFLUX(I)=FLUX(I)-FLUX(I+1)
      ANFLUX(I)=ANFLUX(I)*AF
C     Recalculate theta according to the  change influx(per unit area).
      THETA(I)=(VOL(I)+ANFLUX(I))/TCOM(I)
C     Due to recalculation, theta may be greater than possible water content
C     at saturation and therefore it is necessary to reset SWP to
C     0 and theta to the water content at saturation, the value of which is
C     entered into the model.
      IF (THETA(I).GE.SR1.AND.I.LE.NLA)SWP(I)=0.0
      IF (THETA(I).GE.SR2.AND.I.GT.NLA.AND.I.LE.NLH)SWP(I)=0.0
      IF(THETA(I).GE.SR3.AND.I.GT.NLH)SWP(I)=0.0
      IF(THETA(I).GE.SR1.AND.I.LE.NLA)THETA(I)=SR1
      IF(THETA(I).GE.SR2.AND.I.GT.NLA.AND.I.LE.NLH)THETA(I)=SR2
230   IF(THETA(I).GE.SR3.AND.I.GT.NLB)THETA(I)=SR3
C
C
C
C
C      CALCULATE CUMULATIVE TOTALS
C      ---------------------------
C
```

```
C
C
C
      CUMDRN=CUMDRN+FLUX(NLL)*AF
      EVAPI=EVAP*AF+EVAPI
      CINFIL=CINFIL+ANFILT*AF
      SOG=THETA(1)/SR1
C
C
C
C
C
C
C
C                 ---------------------------
C                 TERMINAL SECTION  WRITE OUT
C                 ---------------------------
C
C
C
C
C
C To print out data for every time increment for which PPT data is
C entered, check ICOUNT to see if that period has passed by.
      IF(ICOUNT.LT.(DT*3600)) GOTO 9995
      ICOUNT=0
C
C
C                       CALCULATE TIME FROM THE START
C                       -----------------------------

      T=T*AF/3600
      WRITE(6,1170)T
1170  FORMAT(´OSOIL COLUMN CONDITIONS ´,F7.3,1X,´HRS SINCE RAIN BEGAN´/)
      IF(TG.EQ.86400.0)TG=0.0
C
C
C            WRITE-OUT CONDITIONS OF SOIL COLUMN
C            ------------------------------------
C
C
      IF(IOUT.EQ.0)GOTO 305

      WRITE(6,7780)
7780  FORMAT(´  Cell  Depth     SWP   Theta     Hyd cond     Net´,1X,
     &´flux     Rel sat´)
        DO 300 I=1,NL
        IF(I.LE.NLA)SOG=THETA(I)/SR1
        IF(I.GT.NLA.AND.I.LT.NLBB)SOG=THETA(I)/SR2
        IF(I.GE.NLBB)SOG=THETA(I)/SR3
```

```
300     WRITE(6,1190)I,DEPTH(I),SWP(I),THETA(I),COND(I),ANFLUX(I),SOG
1190   FORMAT(I6,3F8.4,2F14.9,F9.3)
C
C
C                           WATER BALANCE CHECK
C                           -------------------
C
C Philips (1964) simple water balance;
C -------
C
C
C                                        Amount  added
C     (Initial soil)-(Current soil) =      by       - Evaporation- Drainage
C     (  moisture   ) (  moisture   )  infiltration       loss          loss
C
305    WATN=0.
          DO 310 I=1,NL
310       WATN=TCOM(I)*THETA(I)+WATN
       BAL=WATN-WATI-CINFIL+EVAPI+CUMDRN
       WRITE(6,1200)BAL
1200   FORMAT('0Balance check on soil column water status =',F12.7)
       BAL=(BAL*100.)/WATN
       WRITE(6,1210)BAL
1210   FORMAT(' Balance check as  column water vol.   =',F12.7,' %'/)
C
C
        IF(IOUT.EQ.0)GOTO 306

       WRITE(6,1220)EVAPI,PPTT,CINFIL,CUMDRN
1220    FORMAT(' Cumulative evaporation    = ',F12.8/
      &' Cumulative precipitation = ',F8.4/
      &' Cumulative infiltration   = ',F10.6/
      &' Cumulative drainage       = ',F10.6/)
306     IF(DETAIN.EQ.DETCAP)THEN
           WRITE(6,1222)
1222       FORMAT(' Detention capacity exceeded')
           WRITE(6,1230)RTOT,RTOT/.0254,T
1230       FORMAT(' Runoff total in the last period',F10.7,2X,'m'/
      &    ' Runoff total in the last period',F10.7,2X,'ins',
      $       F7.3/)
        ELSE
           WRITE(6,1221)DETAIN
1221       FORMAT(' Surface water = ',F10.6)
           WRITE(6,1226)
1226       FORMAT(' No runoff')
        ENDIF
C
C
C
```

```
C                     CREATION OF ARRAY DATA
C                     ----------------------
C
C
C Runoff is recorded in array WDATA
C The runoff for each soil column is weighted according to the
C percentage area which it occupies in the catchment area
C
      WDATA(MMM,W)=(RTOT/.0254)*(IPCAREA/100.)
      RTOT=0.0
      MMM=MMM+1
9995  CONTINUE


C End of simulation of single soil column, it more than one, then return to
C to the beginning of this subroutine to repeat for next soil column

34543  CONTINUE


      DO 76567 I=1,MMM
C     Sum the weighted runoff for each soil column to derive total runoff
C     passed back to CMPHYD as DATA
         CUMDATA=0.
         DO 54345 J=1,NSCOL
              CUMDATA=WDATA(I,J)+CUMDATA
54345   CONTINUE
        DATA(I)=CUMDATA
76567 CONTINUE


      IR=MMM-1

      RETURN
      END



      SUBROUTINE HYDCON(X,SATCON,SR,Z,Y)

C This subroutine calculates hydraulic conductivity for each layer
C from the given soil moisture characteristic curve.
C Uses the Millington and Quirk method

      DIMENSION X(20),Y(20),Z(20)
      DO 845 I=1,20
      IIJ=20-I+1
      XII=X(IIJ)
      TOPS=0.
      BOTS=0.
```

```
         DO 846 J=1,20
         JF=20-J+1
         YJJ=Y(JF)
 846     BOTS=((2*J-1)*YJJ**(-2))+BOTS
      II=I
         DO 847 J=II,20
         JF=20-J+1
         YJJ=Y(JF)
  847    TOPS=((2*J+1-2*I)*YJJ**(-2))+TOPS
      JT=20-I+1
  845 Z(JT)=SATCON*(X(II)/SR)*TOPS/BOTS
      RETURN
      END


      SUBROUTINE TWO(NA,NB,THETA,X,SWP,Y,G,HPOT,DEPTH,GZ,COND,Z)

C This subroutine calculates soil water pressure, hydraulic potential
C and hydraulic conductivity for each cell as conditions change
C during simulation.

      DIMENSION THETA(20),X(20),SWP(20),Y(20),G(20),HPOT(20),
     &DEPTH(20),GZ(20),COND(20),Z(20)
      DO 15 I=NA,NB
         DO 16 J=1,19
         IF(THETA(I).GE.X(J).AND.THETA(I).LT.X(J+1))SWP(I)=Y(J)+G(J)*
     &   (THETA(I)-X(J))
 16      CONTINUE
      HPOT(I)=SWP(I)-DEPTH(I)
         DO 17 J=1,19
         IF(THETA(I).GT.X(J).AND.THETA(I).LE.X(J+1))COND(I)=Z(J)+GZ(J)*
     &   (THETA(I)-X(J))
17       CONTINUE
15    CONTINUE
        RETURN
        END


      SUBROUTINE GRAD(G,GZ,Y,X,Z)

C This subroutine calculates the gradients of the suction-moisture
C and hydraulic conductivity-moisture curves.
C
      DIMENSION G(20),GZ(20),Y(20),X(20),Z(20)
      DO 261 I=1,19
      G(I)=(Y(I+1)-Y(I))/(X(I+1)-X(I))
261   GZ(I)=(Z(I+1)-Z(I))/(X(I+1)-X(I))
      RETURN
```

```
      END


      SUBROUTINE SMCURV(SR,NQ,AX,Y,XNEW,YNEW,SCURV)

C  Generates a stochastic suction moisture curve to be fed into
C  soil moisture model
c
C
      DOUBLE PRECISION G05DDF
      DOUBLE PRECISION AX,SCURV
      DIMENSION AX(20),X(20),XNEW(20),YNEW(20),G(20),Y(20)
C
C
C  Determine the stochastic values of moisture
C
      X(1)=G05DDF(AX(1),SCURV)
      IF(X(1).LT.0.)X(1)=0.001
C
      DO 100 I=2,NQ
      X(I)=G05DDF(AX(I),SCURV)
100   IF(X(I).LE.X(I-1))X(I)=X(I-1)+0.001
      IF(X(NQ).GE.SR)SR=X(NQ)+0.001
C
C Calculate gradients of this new suction-moisture curve
c
      NNQ=NQ-1
      DO 200 I=1,NNQ
200   G(I)=(Y(I+1)-Y(I))/(X(I+1)-X(I))
C
C Calculate max and min moisture values, and determine the size of
C equal intervals.
C
      XMAX=RMAX(X,NQ)
      XMIN=RMIN(X,NQ)
      XINT=(XMAX-XMIN)/19.
C
C Determine the new values of moisture-equal intervals
C
      XNEW(1)=XMIN
      DO 300 I=2,19
300   XNEW(I)=XNEW(1)+(XINT*(I-1))
      XNEW(20)=XMAX
C
C Determine the associated new values of suction
C
      DO 350 I=1,19
        DO 400 J=1,NNQ
          IF(XNEW(I).GE.X(J).AND.XNEW(I).LT.X(J+1))
```

```
     &    YNEW(I)=Y(J)+G(J)*(XNEW(I)-X(J))
400       CONTINUE
350     CONTINUE
        YNEW(20)=Y(NQ)
C
C
C
C
        RETURN
        END


        FUNCTION RMAX (X,NQ)

C Determines the maximum real in an array

        DIMENSION X(NQ)
C
        RMAX=X(1)
        DO 10 I=2,NQ
10        IF(X(I).GT.RMAX)RMAX=X(I)
C
        RETURN
        END


        FUNCTION RMIN(X,NQ)

C Determines minimum real in an array

        DIMENSION X(NQ)
C
        RMIN=X(1)
        DO 10 I=2,NQ
10        IF(X(I).LT.RMIN)RMIN=X(I)
C
        RETURN
        END


        SUBROUTINE PRTHYD

C       THIS SUBROUTINE PRINTS THE COORDINATES OF A HYDROGRAPH.

        COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
       &RAIN(300),ROIN(6),
       &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
       &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
```

```
      &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      DIMENSION DUMMY(300)
C Input data is read into the subroutine.
      ID=DATA(1)
      NPK=DATA(2)
C     DETERMINE TYPE OF HYDROGRAPH
      IF (NHD-100) 6,6,2
1     WRITE (6,14) NHD
      GO TO 7
2     IF (NHD-300) 3,3,4
3     WRITE (6,15) NHD
      GO TO 7
4     IF (NHD-500) 1,1,5
5     WRITE (6,16) NHD
      GO TO 7
6     WRITE (6,17) NHD
C     POSITIVE NPK MEANS PRINT ONLY PEAK AND VOLUME
7     IF (NPK) 8,8,25
8     J=0
      M=IEND(ID)
      TIME1=TIME
C     BUILD TIME ARRAY IN DATA
      DO 9 I=1,M
      DATA (I)=TIME1
9     TIME1=TIME1+DT(ID)
      M4=M+4
      M5=M4/5
      DO 22 I=1,M
      DUMMY(I)=OCFS(I,ID)*0.02832
22    CONTINUE



      WRITE(6,27)
24    J=J+1
      WRITE(6,39)(DATA(I),DUMMY(I),I=J,M,M5)
      IF(J-M5)24,25,25
25    ROIN1=ROIN(ID)*25.4
      PEAK1=PEAK(ID)*0.02832
      WRITE(6,26)ROIN1,PEAK1
30    IF(NPU)13,13,12
12    WRITE (7,21) ID,NPK

13    RETURN
C
14    FORMAT (1H0,46X,21HHYDROGRAPH FROM AREA ,I3/)
```

```
15    FORMAT (1H0,41X,19HPARTIAL HYDROGRAPH ,I4/)
16    FORMAT (1H0,39X,29HOUTFLOW HYDROGRAPH RESERVOIR ,I4/)
17    FORMAT (1H0,44X,25HOUTFLOW HYDROGRAPH REACH ,I4/)
27    FORMAT(10X,"TIME",6X," FLOW",11X,"TIME",6X," FLOW",11X,"TIME",
     &6X,"FLOW",11X,"TIME",6X,"FLOW",11X,"TIME",6X,"FLOW"/11X,"HRS",
     &7X," MS",12X,"HRS",7X," MS",12X,"HRS",7X," MS",12X,"HRS",
     &7X," MS",12X,"HRS",7X," MS")
19    FORMAT (5(5X,F10.3,F10.0))
21    FORMAT(   ´PRINT HYD´,T21,´ID=´,I1,T29,´CODE=´,I1)
26    FORMAT(1H0,9X,"RUNOFF VOLUME=",F10.0," MM "/10X,"PEAK DISCHARGE
     & RATE =",F10.0,"CMS"///)
39    FORMAT (5(5X,F10.3,F10.2))
      END


      SUBROUTINE PUHYD

C     THIS SUBROUTINE PUNCHES HYDROGRAPHS IN FORM TO BE USED BY
C     SUBROUTINE RECHD

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      DIMENSION DUMMY(300)
      ID=DATA(1)
      M=IEND(ID)
      IF(ICODE.EQ.0)GO TO 3
      DA1=DA(ID)*2.590
      PEAK1=PEAK(ID)*0.02832
      ROIN1=ROIN(ID)*25.4
        DO 4 I=1,M
      DUMMY(I)=OCFS(I,ID)*0.02832
4     CONTINUE
      WRITE(7,5)ID,NHD,DT(ID),DA1,PEAK1,ROIN1,IEND(ID),ICODE
      WRITE(7,6)(DUMMY(I),I=1,M)
      RETURN
3     WRITE(7,1)ID,NHD,DT(ID),DA(ID),PEAK(ID),ROIN(ID),IEND(ID),ICODE
      WRITE (7,2) (OCFS(I,ID),I=1,M)
      RETURN
C
1     FORMAT(   ´RECALL HYD´,T21,´ID=´,I1,T29,´HYD NO=´,I3,T42,´DT=´,F9.
     &6,´ HRS´,T61,´DA=´,F8.3,´ SQ MI´/T21,´PEAK=´,F7.0,´CFS´,T40,´RO=´,
     &F6.3," INCHES ",T59,"NO PTS=",I3/21X,"CODE=",I1/T21,
     &"FLOW RATES")
5     FORMAT(   ´RECALL HYD´,T21,´ID=´,I1,T29,´HYD NO=´,I3,T42,´DT=´,F9.
     &6,´ HRS´,T61,´DA=´,F8.3,´ SQ KM´/T21,´PEAK=´,F7.2,´CMS´,T40,´RO=´,
     &F6.0," MM     ",T59,"NO PTS=",I3/21X,"CODE=",I1/T21,
```

```
      &"FLOW RATES")
2      FORMAT (T21,7F8.0)
6      FORMAT (T21,7F8.2)
       END


       SUBROUTINE HPLOT
C      THIS SUBROUTINE PLOTS EITHER 1 OR 2 HYDROGRAPHS ON A SET OF AXIS
       COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
      &RAIN(300),ROIN(6),
      &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
      &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
      &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
       ID1=DATA(1)
       ID2=DATA(2)
       DATA ZERO, PLUS, BLANK, DASH, DOT/'0','+',' ','-','.'/
       MAX=121
       J=1
C      ARE THERE 1 OR 2 HYDROGRAPHS
       IF (ID2) 1,1,2
C      DETERMINE HIGHEST PEAK IF 2 HYDROGRAPHS
1      QMAX=PEAK(ID1)
       GO TO 14
2      IF (PEAK(ID1)-PEAK(ID2)) 3,3,4
3      QMAX=PEAK(ID2)
       GO TO 5
4      QMAX=PEAK(ID1)
C      IF 2 HYDROGRAPHS DETERMINE LARGEST DT AND INTERPOLATE OTHER
C      HYDROGRAPH IF NECESSARY
5      IF (DT(ID1)-DT(ID2)) 6,13,7
6      L=ID1
       K=ID2
       GO TO 8
7      L=ID2
       K=ID1
8      M=IEND(L)
       TID=DT(K)
       TIDH=0.
       DO 11 I=2,M
       TIDH=TIDH+DT(L)
       IF (TID-TIDH) 10,9,11
9      J=J+1
       CFS(J)=OCFS(I,L)
       TID=TID+DT(K)
       GO TO 11
```

```
10     J=J+1
       CFS(J)=OCFS(I-1,L)+((TID-TIDH+DT(L))/DT(L))*(OCFS(I,L)-OCFS(I-1,L)
      &)
       TID=TID+DT(K)
11     CONTINUE
       IEND(L)=J
       DT(L)=DT(K)
       DO 12 I=2,J
12     OCFS(I,L)=CFS(I)
13     IF (IEND(ID1)-IEND(ID2)) 14,14,15
14     M=IEND(ID1)
       GO TO 16
15     M=IEND(ID2)
16     XM = M
C      DETERMINE TIME SCALE
       XSCL = XM / 120.
       YSCL=QMAX/50.
C      PLOT HYDROGRAPHS
       DO 20 I=1,MAX
20     CFS(I)=DASH
       IF(ICODE.EQ.0)GO TO 49
       WRITE(6,50)
50     FORMAT(T2,"FLOW RATE (CMS)")
       QMAX1=QMAX*0.02832
       WRITE(6,41)QMAX1,DOT,(CFS(I),I=1,MAX),DOT
       GO TO 51
49     WRITE(6,48)
48     FORMAT(T2,'FLOW RATE (CFS)')
       WRITE(6,41)QMAX,DOT,(CFS(I),I=1,MAX),DOT
51     Q1=QMAX
       J1=10
       DO 37 J=1,50
       IF (J-J1) 23,21,23
21     DO 22 I=1,MAX
22     CFS(I)=DASH
       GO TO 25
23     DO 24 I=1,MAX
24     CFS(I)=BLANK
25     Q2=Q1-YSCL
       DO 28 I=2,M
       IF (OCFS(I,ID1)-Q1) 26,27,28
26     IF (OCFS(I,ID1)-Q2) 28,28,27
27     XI = I
       K = XI / XSCL + 1.
       CFS(K)=ZERO
28     CONTINUE
       WRITE (6,44) DOT,(CFS(I),I=1,MAX),DOT
       IF (ID2) 34,34,29
29     DO 18 I = 1, MAX
```

```
18     CFS(I) = BLANK
       DO 33 I=1,M
       IF (OCFS(I,ID2)-Q1) 30,31,33
30     IF (OCFS(I,ID2)-Q2) 33,33,31
31     XI = I
       K = XI / XSCL + 1.
       CFS(K)=PLUS
33     CONTINUE
       WRITE (6,42) (CFS(I),I=1,MAX)
34     IF (J-J1) 36,35,36
35     J1=J1+10
       IF(ICODE.EQ.0)GO TO 52
       QD=Q2*0.02832
       WRITE(6,43)QD
       GO TO 36
52     WRITE(6,43)Q2
36     Q1=Q2
37     CONTINUE
       CFS(1)=TIME
       DTT=DT(ID1)*(XM - 1.) / 12.
C      PUT TIME ARRAY IN CFS AND WRITE TIME SCALE
       DO 38 I=2,13
38     CFS(I)=CFS(I-1)+DTT
       WRITE (6,45) (CFS(I),I=1,13)
       WRITE (6,46)
       IF (NPU) 40,40,39
39     WRITE (7,47) ID1,ID2
40     RETURN
C
41     FORMAT(1X,F7.0,123A1)
42     FORMAT(1H+,8X,121A1)
43     FORMAT (1H+,F7.0)
44     FORMAT(8X,123A1)
45     FORMAT(T3,13F10.2)
46     FORMAT(49X,´TIME HOURS´///)
47     FORMAT(   ´PLOT HYD´,T21,´ID I=´,I1,T29,´ID II=´,I1)
       END



       SUBROUTINE ADHYD

C      THIS SUBROUTINE ADDS TWO HYDROGRAPHS.

       COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
      &RAIN(300),ROIN(6),
      &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
      &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
      &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
```

```
      ID=DATA(1)
      NHD=DATA(2)
      ID1=DATA(3)
      ID2=DATA(4)
      PEAK(ID) = 1.
C     MAKE TIME INCREMENTS EQUAL IF NOT EQUAL. USE SMALLER INCREMENT
      IF (DT(ID1)-DT(ID2)) 1,3,2
1     DT(ID)=DT(ID1)
      L=ID1
      K=ID2
      GO TO 6
2     DT(ID)=DT(ID2)
      L=ID2
      K=ID1
      GO TO 6
3     DT(ID)=DT(ID1)
      IF (IEND(ID1)-IEND(ID2)) 4,4,5
4     M3=IEND(ID1)
      K1=ID2
      IEND(ID)=IEND(ID2)
      GO TO 18
5     M3=IEND(ID2)
      K1=ID1
      IEND(ID)=IEND(ID1)
      GO TO 18
C     DETERMINE DURATIONS OF FLOW
6     XIEND1=IEND(ID1)-1
      XIEND2=IEND(ID2)-1
      DUR1=XIEND1*DT(ID1)
      DUR2=XIEND2*DT(ID2)
      IF (DUR1-DUR2) 7,8,8
7     IEND(ID)=DUR2/DT(ID)+1.
      M3=DUR1/DT(ID)+1.
      K1=ID2
      GO TO 9
8     IEND(ID)=DUR1/DT(ID)+1.
      M3=DUR2/DT(ID)+1.
      K1=ID1
9     IF (IEND(ID)-300) 11,11,10
10    IEND(ID)=300
11    M2=IEND(K)
      J=1
C     INTERPOLATE ONE HYDROGRAPH IF NECESSARY
      TIDH=0.
      TID=DT(ID)
      DO 15 I=2,M2
      TIDH=TIDH+DT(K)
12    IF (TIDH-TID) 15,13,14
13    J=J+1
      DATA (J)=OCFS(I,K)
```

```
      TID=TID+DT(ID)
      IF (J-300) 15,16,16
14    J=J+1
      DATA (J)=OCFS(I-1,K)+((TID-TIDH+DT(K))/DT(K))*(OCFS(I,K)-OCFS(I-1,
     &K))
      TID=TID+DT(ID)
      IF (J-300) 12,16,16
15    CONTINUE
16    IEND(K)=J
      DO 17 I=2,J
17    OCFS(I,K)=DATA(I)
18    M=IEND(ID)
      DA(ID)=DA(ID1)+DA(ID2)
      RO = 0.
C     ADD HYDROGRAPHS
      DO 20 I=1,M3
      OCFS(I,ID)=OCFS(I,ID1)+OCFS(I,ID2)
      IF (OCFS(I,ID) - PEAK(ID)) 20,20,19
19    PEAK(ID) = OCFS(I,ID)
20    RO = RO + OCFS(I,ID)
      IF (PEAK(ID) - PEAK(K1)) 21,22,22
21    PEAK(ID) = PEAK(K1)
22    IF (M-M3) 25,25,23
23    M3 = M3 + 1
      DO 24 I = M3,M
      OCFS(I,ID) = OCFS (I,K1)
24    RO = RO + OCFS(I,ID)
25    ROIN(ID) = (RO * DT(ID)) / (DA(ID) * 645.333)
      IF (NPU) 27,27,26
26    WRITE (7,28) ID,NHD,ID1,ID2
27    RETURN
C
28    FORMAT(   'ADD HYD',T21,'ID=',I1,T29,' HYD NO=',I3,T45,'ID I=',I1,
     &T60,'ID II=',I1)
      END


      SUBROUTINE SRC

C     THIS SUBROUTINE STORES AN ELEVATION - END AREA - FLOW TABLE.

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      ID=DATA(1)
      VS=DATA(2)
C     VALLEY SECTION NUMBER
C     REMAINING DATA ARE ELEVATION, AREA, AND FLOW FOR EACH POINT OF
```

```
C     THE RATING CURVE
      IF(KCODE.EQ.0)GO TO 2
      J=3
      DO 3 I=1,20
      DATA(J)=DATA(J)/0.3048
      DATA(J+1)=DATA(J+1)/0.093
      DATA(J+2)=DATA(J+2)/0.02832
      J=J+3
3     CONTINUE
2     EMIN=DATA(3)
      J=3
      DO 1 I=1,20
      DEEP(I,ID)=DATA(J)-EMIN
      A(I,ID)=DATA(J+1)
      Q(I,ID)=DATA(J+2)
      J=J+3
1     CONTINUE
      RETURN
      END


      SUBROUTINE CMPRC

C     THIS SUBROUTINE COMPUTES THE DISCHARGE END-AREA ELEVATION
C     RELATIONSHIP FOR A VALLEY SECTION.

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      ID=DATA(1)
C     STORAGE LOCATION NUMBER. (1-6)
      VS=DATA(2)
C     VALLEY SECTION IDENTIFICATION NUMBER.
      NSEG=DATA(3)
C     NUMBER OF SEGMENTS IN THE VALLEY SECTION.
      IF(KCODE.EQ.0)GO TO 26
      DATA(4)=DATA(4)/0.3048
      DATA(5)=DATA(5)/0.3048
26    ELO=DATA(4)
      EMAX=DATA(5)
C     MAXIMUM ELEVATION FOR COMPUTATIONS.
      SLOPE1=DATA(6)
C     CHANNEL SLOPE.
      SLOPE2=DATA(7)
C     FLOOD PLAIN SLOPE.
      DIF=(EMAX-ELO)/19.
```

```
      C(1)=ELO
      DO 1 I=2,20
1     C(I)=C(I-1)+DIF
C     SET AREA AND DISCHARGE ARRAYS = 0.
      DO 2 I=1,20
      A(I,ID)=0.
2     Q(I,ID)=0.
      J=8
C     READ N VALUES AND SEGMENT BORDER POINTS.
      DO 3 I=1,NSEG
      SEGN(I)=DATA(J)
      IF(KCODE.NE.0)DATA(J+1)=DATA(J+1)/0.3048
      DIST(I)=DATA(J+1)
3     J=J+2
C     REMAINING DATA ITEMS ARE DISTANCES AND ELEVATIONS.
      IF(KCODE.EQ.0)GO TO 27
      DO 28 I=J,310
      DATA(I)=DATA(I)/0.3048
28    CONTINUE
27    JJJ=J
      DO 6 I=1,NSEG
4     J=J+2
      IF (DATA(J) - DIST(I)) 4,5,5
5     ISG(I) = J + 1
6     CONTINUE
C     COMPUTE DISCHARGES AND END AREAS FOR EACH SEGMENT.
      DO 22 K=1,NSEG
      J=JJJ
      JJJ1=JJJ+1
      IF (SEGN(K)) 7,7,8
7     SLOPE=SLOPE1
      SEGN(K)=-SEGN(K)
      GO TO 9
8     SLOPE=SLOPE2
9     SLPN=1.486*SLOPE**.5
C     COMPUTE AREA AND DISCHARGE FOR SEGMENT.
      DO 21 I=2,20
      AA=0.
      P=0.
      J=JJJ-1
      DEP2=0.
10    J=J+2
      IF (J-ISG(K)) 12,12,11
11    IF (AA-.001) 21,21,20
12    IF (DATA(J)-C(I)) 13,10,10
13    DEP1=C(I)-DATA(J)
      IF (J-JJJ1) 16,16,14
14    XL=DATA(J-1)-DATA(J-3)
      DEP3=ABS(DATA(J-2)-DATA(J))
      XL=XL*DEP1/DEP3
```

```
15     AA=AA+XL*(DEP1+DEP2)/2.
       P=P+SQRT((DEP1-DEP2)**2+XL**2)
16     DEP2=DEP1
       J=J+2
       IF (J-ISG(K)) 17,17,20
17     IF (DATA(J)-C(I)) 18,18,19
18     DEP1=C(I)-DATA(J)
       XL=DATA(J-1)-DATA(J-3)
       GO TO 15
19     DEP1=0.
       XL=DATA(J-1)-DATA(J-3)
       DEP3=ABS(DATA(J-2)-DATA(J))
       XL=XL*DEP2/DEP3
       AA=AA+XL*(DEP1+DEP2)/2.
       P=P+SQRT((DEP1-DEP2)**2+XL**2)
       DEP2=0.
       GO TO 10
20     R=AA/P
       SGN=SEGN(K) - .0025*R
C      ADD DISCHARGES AND AREAS FOR ALL SEGMENTS TO OBTAIN TOTALS FOR
C      VALLEY SECTION.
       Q(I,ID)=Q(I,ID)+AA*R**.66667*SLPN/SGN
       A(I,ID)=A(I,ID)+AA
21     CONTINUE
       JJJ=J-3
22     CONTINUE
       IF(ICODE.EQ.0)GO TO 29
       WRITE(6,31)VS
       DO 30 I=1,20
       C1=C(I)*0.3048
       A1=A(I,ID)*0.093
       Q1=Q(I,ID)*0.02832
       DEEP(I,ID)=C(I)-ELO
       WRITE(6,32)C1,A1,Q1
30     CONTINUE
       RETURN
29     WRITE(6,24)VS
       DO 23 I=1,20
       DEEP(I,ID)=C(I)-ELO
       WRITE (6,25) C(I),A(I,ID),Q(I,ID)
23     CONTINUE
       RETURN
C
24     FORMAT(1H0,T42,´RATING CURVE VALLEY SECTION´,F5.1/T46,´WATER´,T56,
      &´FLOW´,T66,´FLOW´/T45,´SURFACE´,T56,´AREA´,T66,´RATE´/T46,´ELEV´,
      &T56,´SQ FT´,T66,´CFS´)
31     FORMAT(1H0,T42,´RATING CURVE VALLEY SECTION´,F5.1/T46,´WATER´,T56,
      &´FLOW´,T66,´FLOW´/T45,´SURFACE´,T56,´AREA´,T66,´RATE´/T46,´ELEV´,
      &T56,´SQ M´,T66,´CMS´)
25     FORMAT (40X,F10.2,2F10.1)
```

```
32    FORMAT (40X,3F10.2)
      END


      SUBROUTINE STT

C     THIS SUBROUTINE STORES A DEPTH - FLOW - TRAVEL TIME TABLE.

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      ID=DATA(1)
      REACH=DATA(2)
      MET1=DATA(5)
      IF(MET1.EQ.0)GO TO 2
      DATA(3)=DATA(3)/0.3048
      J=6
      DO 3 I=1,19
      DATA(J)=DATA(J)/0.3048
      DATA(J+1)=DATA(J+1)/0.02832
3     J=J+3
2     XL=DATA(3)
      SLOPE=DATA(4)
      DIST(ID)=SLOPE*XL
      J=6
      DO 1 I=1,19
      DP(I)=DATA(J)
      SCFS(I)=DATA(J+1)
      C(I)=DATA(J+2)
1     J=J+3
      RETURN
      END


      SUBROUTINE CMPTT

C     THIS SUBROUTINE COMPUTES THE TRAVEL TIME AT GIVEN
C     DISCHARGE RATES

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      ID=DATA(1)
      REACH=DATA(2)
      NOVS=DATA(3)
```

```
      IF(KCODE.NE.0)DATA(4)=DATA(4)/0.3048
      XL=DATA(4)
      SLOPE=DATA(5)
      DIST(ID)=SLOPE*XL
      XLD36 = XL / 3600.
C     ZERO ARRAYS
      DO 1 J=1,20
      DATA (J)=0.
1     CFS(J)=0.
      ID1=1
C     FIND RATING CURVE WITH SMALLEST MAXIMUM FLOW RATE
2     QMIN=Q(20,ID1)
      MIN=ID1
      GO TO 4
3     ID1=ID1+1
      IF (QMIN-Q(20,ID1)) 4,4,2
4     IF (ID1-NOVS) 3,5,5
5     I=1
C     SET SCFS ARRAY EQUAL TO Q ARRAY OF LOWEST RATING CURVE
      DO 6 J=2,20
      SCFS(I)=Q(J,MIN)
6     I=I+1
C     COMPUT END AREA AND DEPTH
      DO 9 ID1=1,NOVS
      DO 9 J=1,19
      DO 7 I=2,20
      IF (Q(I,ID1)-SCFS(J)) 7,17,8
7     CONTINUE
17    DATA (J)=A(I,ID1)+DATA(J)
      CFS(J)=DEEP(I,ID1)+CFS(J)
      GO TO 9
8     XY=(SCFS(J)-Q(I-1,ID1))/(Q(I,ID1)-Q(I-1,ID1))
      DATA (J)=A(I-1,ID1)+XY*(A(I,ID1)-A(I-1,ID1))+DATA(J)
      CFS(J)=DEEP(I-1,ID1)+XY*(DEEP(I,ID1)-DEEP(I-1,ID1))+CFS(J)
9     CONTINUE
      XNOVS=NOVS
      IF(ICODE.EQ.0)GO TO 19
      WRITE(6,20)REACH
      GO TO 21
19    WRITE(6,13)REACH
21    DO 10 I=1,19
      AVAREA = DATA (I) / XNOVS
      DP (I) = CFS(I) / XNOVS
      S = AVAREA * XLD36
      C(I) = S/SCFS(I)
      IF(ICODE.EQ.0)GO TO 24
      DP1=DP(I)*0.3048
      SCFS1=SCFS(I)*0.02832
      WRITE(6,14)DP1,SCFS1,C(I)
```

```
      GO TO 10
24    WRITE(6,14)DP(I),SCFS(I),C(I)
10    CONTINUE
C     PUNCH CODE
      IF(NPU)12,12,25
25    IF(ICODE.EQ.0)GO TO 11
      XL1=XL*0.3048
      WRITE(7,22)ID,REACH,XL1,SLOPE,ICODE
      DO 23 I=1,19
      DP1=DP(I)*0.3048
      SCFS1=SCFS(I)*0.02832
      WRITE(7,26)DP1,SCFS1,C(I)
23    CONTINUE
      RETURN
11    WRITE(7,15)ID,REACH,XL,SLOPE,ICODE
      WRITE (7,16) (DP(I),SCFS(I),C(I),I=1,19)
12    RETURN
C
13    FORMAT(1H0,T46,´TRAVEL TIME TABLE´/T54,´REACH´,F5.1//T46,´WATER´,T
     &56,´FLOW´,T65,´TRAVEL´/T46,´DEPTH´,T56,´RATE´,T66,´TIME´/T46,´FEET
     &´,T56,´CFS´,T66,´HRS´)
14    FORMAT (40X,F10.2,F10.0,F10.2)
15    FORMAT(´STORE TRAVEL TIME´,T21,´ID=´,I1,T29,´REACH NO=´,F5.1,T44,
     &´LENGTH=´,F9.0,´ FT´/T21,´SLOPE=´,F8.6,´FT/FT´,"CODE=",I1/T2
     &1,´DEPTH(FT)´,T35,´FLOW(CFS)´,T49,´TIME(HRS)´)
20    FORMAT(1H0,T46,´TRAVEL TIME TABLE´/T54,´REACH´,F5.1//T46,´WATER´,T
     &56,´FLOW´,T65,´TRAVEL´/T46,´DEPTH´,T56,´RATE´,T66,´TIME´/T46,
     &"METER",T56,´CMS´,T66,´HRS´)
22    FORMAT(´STORE TRAVEL TIME´,T21,´ID=´,I1,T29,´REACH NO=´,F5.1,T44,
     &´LENGTH=´,F9.0,´ M´/T21,´SLOPE=´,F8.6,´M/M´,"CODE=",I1/T2
     &1,´DEPTH(M)´,T35,´FLOW(CMS)´,T49,´TIME(HRS)´)
16    FORMAT (T21,F7.2,F15.2,F15.3)
26    FORMAT (T21,F7.2,2F15.3)
      END


      SUBROUTINE ROUTE

C     THIS SUBROUTINE ROUTES A HYDROGRAPH THROUGH A REACH WITH THE
C     NEW VSC METHOD OF FLOOD ROUTING. THIS METHOD ACCOUNTS FOR THE
C     VARIATION IN WATER SURFACE SLOPE.

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      ID=DATA(1)
      NHD=DATA(2)
      IDH=DATA(3)
```

```
      DT(ID)=DATA(4)
      DA(ID)=DA(IDH)
      M=IEND(IDH)
C     IF ID AND IDH ARE EQUAL, ADD 1 TO IDH
      IF (ID-IDH) 3,1,3
1     IDH=IDH+1
      DO 2 I=1,M
2     OCFS(I,IDH)=OCFS(I,IDH-1)
      DT(IDH)=DT(IDH-1)
      PEAK(IDH)=PEAK(IDH-1)
3     NERRT=0
      PEAK(ID) = 1.
      RO = 0.
      N=19
      OCFS(1,ID)=0.
      S = 0.
      T1 = C(1)
      J=1
      GUES = 1.
      CFS(1)=0.
C     IF ROUTING INTERVAL IS NOT EQUAL TO TIME INCREMENT OF INFLOW
C     HYDROGRAPH, INTERPOLATE
      IF (DT(ID)-DT(IDH)) 8,15,4
4     TID=DT(ID)
      TIDH=0.
      DO 7 I=2,M
      TIDH=TIDH+DT(IDH)
      IF (TID-TIDH) 6,5,7
5     J=J+1
      CFS(J)=OCFS(I,IDH)
      TID=TID+DT(ID)
      GO TO 7
6     J=J+1
      CFS(J)=OCFS(I-1,IDH)+((TID-TIDH+DT(IDH))/DT(IDH))*(OCFS(I,IDH)-OCF
     &S(I-1,IDH))
      TID=TID+DT(ID)
7     CONTINUE
      GO TO 13
8     TIDH=0.
      TID=DT(ID)
      DO 12 I=2,M
      TIDH=TIDH+DT(IDH)
9     IF (TIDH-TID) 12,10,11
10    J=J+1
      CFS(J)=OCFS(I,IDH)
      TID=TID+DT(ID)
      IF (J-300) 12,13,13
11    J=J+1
      CFS(J)=OCFS(I-1,IDH)+((TID-TIDH+DT(IDH))/DT(IDH))*(OCFS(I,IDH)-OCF
     &S(I-1,IDH))
```

```
      TID=TID+DT(ID)
      IF (J-300) 9,13,13
12    CONTINUE
13    IEND(IDH)=J
      DT(IDH)=DT(ID)
      M=J
      DO 14 I=2,M
14    OCFS(I,IDH)=CFS(I)
C     IF INFLOW IS ZERO, SO IS OUTFLOW
15    DO 16 L=2,M
      IF (OCFS(L,IDH)) 16,16,49
16    OCFS(L,ID)=0.
C     ROUTE
49    DATA (L-1) = 0.
      DO 42 I=L,300
      IF (I-M) 18,18,17
17    OCFS(I,IDH)=OCFS(I-1,IDH)*.9
18    AVIN=(OCFS(I,IDH)+OCFS(I-1,IDH))/2.
      SIA = AVIN + S
      J=1
C     DETERMINE DEPTH AND TRAVEL TIME OF INFLOW
      IF (OCFS(I,IDH)-SCFS(1)) 19,23,20
19    DI2 = (OCFS(I,IDH) / SCFS(1)) * DP(1)
      TI2 = C(1)
      GO TO 25
20    DO 21 J=2,N
      IF (OCFS(I,IDH)-SCFS(J)) 24,23,21
21    CONTINUE
      IF (NERRT) 22,22,36
22    WRITE (6,46)
      NERRT=1
      GO TO 36
23    DI2=DP(J)
      TI2 = C(J)
      GO TO 25
24    RATIO=(OCFS(I,IDH)-SCFS(J-1))/(SCFS(J)-SCFS(J-1))
      DI2=DP(J-1)+RATIO*(DP(J)-DP(J-1))
      TI2=C(J-1)+RATIO*(C(J)-C(J-1))
25    DO 35 IT=1,10
      J=1
C     DETERMINE DEPTH AND TRAVEL TIME OF OUTFLOW
      IF (GUES-SCFS(1)) 26,29,27
26    DO2 = (GUES / SCFS(1))* DP(1)
      TO2 = C(1)
      GO TO 31
27    DO 28 J=2,N
      IF (GUES-SCFS(J)) 30,29,28
28    CONTINUE
      J=N
29    DO2=DP(J)
```

```
      TO2=C(J)
      GO TO 31
30    RATIO=(GUES-SCFS(J-1))/(SCFS(J)-SCFS(J-1))
      DO2=DP(J-1)+RATIO*(DP(J)-DP(J-1))
      TO2=C(J-1)+RATIO*(C(J)-C(J-1))
C     FIND WATER SURFACE SLOPE
31    DDD=DIST(ID)/(DIST(ID)+DI2-DO2)
      IF (DDD-.01) 32,32,33
32    GUES=OCFS(I-1,IDH)
      GO TO 35
33    T2 = .5 * (TI2 + TO2)
      T2=T2*SQRT(DDD)
      T = T1 + T2
C     COMPUTE ROUTING COEFFICIENT
      COEF =(2. * DT(ID)) / (T+DT(ID))
      O2 = COEF * SIA
      TRY1 = GUES
      RATIO=O2/(GUES+.1E-20)
      DIFF=ABS(1.-RATIO)
C     TEST FOR CONVERGENCE
      IF (DIFF-.001) 37,37,34
34    GUES=O2
35    CONTINUE
      OCFS(I,ID)=DATA(I-1)*SIA
      DATA(I) = DATA(I-1)
      WRITE (6,47) I,OCFS(I,ID)
      GO TO 38
36    OCFS(I,ID)=DATA(I-1)*SIA
      DATA(I) = DATA(I-1)
      GO TO 38
37    OCFS(I,ID)=O2
      DATA (I) = COEF
C     COMPUTE NEW STORAGE
38    S = SIA - OCFS(I,ID)
      T1 = T2
      RO = RO + OCFS (I,ID)
      IF (OCFS(I,ID) - OCFS(I-1,ID)) 39,40,40
39    IF(OCFS(I,ID) -1.) 43,43,42
40    IF(OCFS(I,ID) - PEAK(ID)) 42,42,41
41    PEAK(ID)=OCFS (I,ID)
42    CONTINUE
      I=300
43    IEND(ID)=I
      ROIN(ID) = (RO*DT(ID))/(DA(ID)*645.333)
C     PUNCH CODE
      IF (NPU) 45,45,44
44    WRITE (7,48) ID,NHD,IDH,DT(ID)
45    RETURN
C
```

```
46     FORMAT(1H0, 'TRAVEL TIME TABLE EXCEEDED')
47     FORMAT(T10,'PROBLEM FAILED TO CONVERGE AFTER10 ITERATIONS. CONVERG
      &ENCE WAS FORCED.'/T20,'OUTFLOW NUMBER = ',I4,'RATE =',F10.2)
48     FORMAT(   'ROUTE',T21,'ID=',I1,T29,'HYD NO=',I3,T45,'INFLOW ID=',I
      &1,T65,'DT=',F8.6,'HRS')
       END


       SUBROUTINE RESVO

C      THIS SUBROUTINE ROUTES A HYDROGRAPH THROUGH A RESERVOIR WITH THE
C      STORAGE-INDICATION METHOD.

       COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
      &RAIN(300),ROIN(6),
      &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
      &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
      &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
       ID=DATA(1)
       NHD=DATA(2)
       IDH=DATA(3)
       NERES=0
       DT(ID)=DT(IDH)
       RO = 0.
       DA(ID)=DA(IDH)
       PEAK(ID) = 1.
       J=1
       I=4
C      REMAINING DATA ARE FLOW AND STORAGE VALUES
       IF(KCODE.EQ.0)GO TO 25
       DATA(I)=DATA(I)/0.02832
       DATA(I+1)=DATA(I+1)/1.21968
25     SCFS(J)=DATA(I)
       STORE1=DATA(I+1)*12.1
       STORE=STORE1
C      COMPUTE STORAGE COEFFICIENT ARRAY C
1      C(J)=(SCFS(J)/2.)+(STORE/DT(ID))
       I=I+2
       J=J+1
       IF (J-20) 2,2,3
2      IF(KCODE.EQ.0)GO TO 26
       DATA(I)=DATA(I)/0.02832
       DATA(I+1)=DATA(I+1)/1.21968
26     SCFS(J)=DATA(I)
       STORE=DATA(I+1)*12.1
       IF (SCFS(J)-.001) 3,3,1
3      N=J-1
       OCFS(1,ID)=0.
       S=STORE1/DT(ID)
```

```
C     ROUTE
      DO 15 I=2,150
      IF (I-IEND(IDH)) 5,5,4
4     OCFS(I,IDH)=0.0
5     AVIN=(OCFS(I,IDH)+OCFS(I-1,IDH))/2.
      SIA=S+AVIN
C     DETERMINE PROPER C
      DO 6 J=1,N
      IF (SIA-C(J)) 10,9,6
6     CONTINUE
      IF (NERES) 7,7,8
7     WRITE (6,19)
      NERES=1
8     RESC=SCFS(N)/C(N)
C     COMPUT OUTFLOW
      OCFS(I,ID)=RESC*SIA
      GO TO 11
9     OCFS(I,ID)=SCFS(J)
      GO TO 11
10    OCFS(I,ID)=SCFS(J-1)+((SIA-C(J-1))/(C(J)-C(J-1)))*(SCFS(J)-SCFS(J-
     &1))
C     DETERMINE NEW STORAGE
11    S=SIA-OCFS(I,ID)
      RO = RO + OCFS(I,ID)
      IF (OCFS(I,ID)-OCFS(I-1,ID)) 12,13,13
12    IF (OCFS(I,ID)-1.) 16,16,15
13    IF(OCFS(I,ID) - PEAK(ID)) 15,15,14
14    PEAK(ID) = OCFS(I,ID)
15    CONTINUE
      I=150
16    IEND(ID)=I
      ROIN(ID) = RO * DT(ID)/(DA(ID)*645.333)
C     PUNCH CODE
      IF (NPU) 18,18,17
17    II=2*N+3
      IF(ICODE.EQ.0)GO TO 22
      WRITE(7,24)ID,NHD,IDH,KCODE
      DO 23 I=5,II,2
      DATA(I)=DATA(I)*0.02832
      DATA(I+1)=DATA(I+1)*1.21968
23    CONTINUE
      WRITE(7,27)(DATA(I),I=5,II)
      RETURN
22    WRITE(7,20)ID,NHD,IDH,ICODE
      WRITE (7,21) (DATA(I),I=5,II)
18    RETURN
C
19    FORMAT (1H0,33HSTORAGE-DISCHARGE TABLE EXCEEDED.)
20    FORMAT(    ´ROUTE RESERVOIR´,T21,´ID=´,I1,T29,´HYD NO=´,I3,T42,´INF
     &LOW ID=´,I1,T60,"CODE=",I1          /T21,´OUTFLOW(CFS)´,T37,´STOR
```

```
     &AGE(AC FT)')
24    FORMAT(   'ROUTE RESERVOIR',T21,'ID=',I1,T29,'HYD NO=',I3,T42,'INF
     &LOW ID=',I1,T60,"CODE=",I1         /T21,'OUTFLOW(CMS)',T37,'STOR
     &AGE(1000CU M)')
21    FORMAT (T21,F10.1,F13.1)
27    FORMAT (T21,F10.2,F13.2)
      END


      SUBROUTINE ERROR

C This subroutine determines the error standard deviation and the peak flow
C error for 2 hydrographs (original program retained).
C Assumes that measured is ID1
C In addition, 10 other measures of goodness of fit are calculated.
C All indicies are printed out in metric units.

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE

      ID1=DATA(1)
      ID2=DATA(2)
      SSE=0.
           WRITE(6,21)
21         FORMAT(1H0,T33,'TIME',T55,'FLOW 1',T76,
     &     'FLOW 2',T95,'ERROR'/T34,
     &     'HRS',T57,'CMS',T78,'CMS',T97,'CMS')

22    J=1
C If the time increments are not equal, interpolate.

      IF (DT(ID1)-DT(ID2)) 1,8,2
1     L=ID1
      K=ID2
      GO TO 3
2     L=ID2
      K=ID1
3     M=IEND(L)
      TID=DT(K)
      TIDH=0.
      DO 6 I=2,M
      TIDH=TIDH+DT(L)
      IF (TID-TIDH) 5,4,6
4     J=J+1
      CFS(J)=OCFS(I,L)
      TID=TID+DT(K)
      GO TO 6
```

```
5     J=J+1
      CFS(J)=OCFS(I-1,L)+((TID-TIDH+DT(L))/DT(L))*(OCFS(I,L)-OCFS(I-1,L)
     &)
      TID=TID+DT(K)
6     CONTINUE
      IEND(L)=J
      DT(L)=DT(K)
      DO 7 I=2,J
7     OCFS(I,L)=CFS(I)
8     IF (IEND(ID1)-IEND(ID2)) 9,9,10
9     M=IEND(ID1)
      GO TO 11
10    M=IEND(ID2)
11    T2=TIME

      IF (KCODE.EQ.0)THEN
        DO 997 I=1,M
              OCFS(I,ID1)=OCFS(I,ID1)*.02832
997           OCFS(I,ID2)=OCFS(I,ID2)*.02832
      ENDIF

C Determine error - original method

      DO 12 I=1,M
      ERR=OCFS(I,ID1)-OCFS(I,ID2)
              WRITE(6,16)T2,OCFS(I,ID1),OCFS(I,ID2),ERR
16            FORMAT (6X,F12.3,3F12.0)
25            T2=T2+DT(ID1)

C Sum of squares of error

12    SSE=SSE+ERR*ERR
      XM=M

C Error variance

      EVAR=SSE/XM

C Error standard deviation

      ESDEV=SQRT(EVAR)

C Percent error for peak discharge

      ERPK=ABS(PEAK(ID1)-PEAK(ID2))
      PCTER=(ERPK/PEAK(ID1))*100.

C Other goodness of fit calculations...

      SUM01=0.
```

```
      SUM0=0.
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      SUM5=0.
      SUM6=0.
      SUM7=0.
      SUM8=0.
      SUM9=0.
      SUM10=0.
      SUM11=0.
      SUM12=0.

      DO 77 I=1,M
        ERR=OCFS(I,ID1)-OCFS(I,ID2)
        IF(OCFS(I,ID1).EQ.0.0.AND.OCFS(I,ID2).NE.0.0)THEN
            LOGERR=ALOG(OCFS(I,ID2))
        ELSE IF(OCFS(I,ID1).NE.0.0.AND.OCFS(I,ID2).EQ.0.0)THEN
            LOGERR=ALOG(OCFS(I,ID1))
        ELSE IF(OCFS(I,ID1).EQ.0.0.AND.OCFS(I,ID2).EQ.0.0)THEN
           LOGERR=0.
        ELSE
           LOGERR=ALOG(OCFS(I,ID1))-ALOG(OCFS(I,ID2))
        ENDIF
        SUM0=OCFS(I,ID1)+SUM0
        SUM01=OCFS(I,ID2)+SUM01
        SUM1=ERR+SUM1
        SUM2=ERR**2+SUM2
        SUM3=LOGERR**2+SUM3
        IF(OCFS(I,ID1).EQ.0.)OCFS(I,ID1)=1.
        SUM4=((ERR/OCFS(I,ID1))**2)+SUM4
77      CONTINUE

      DO 13 I=2,M
        DIFF1=OCFS(I,ID1)-OCFS(I-1,ID1)
        DIFF2=OCFS(I,ID2)-OCFS(I-1,ID2)
        SUM5=((DIFF1-DIFF2)**2)+SUM5
        SUM7=DIFF1+SUM7
        IF(DIFF1.EQ.0.)DIFF1=1.
        SUM6=(((DIFF1-DIFF2)/DIFF1)**2)+SUM6
13      CONTINUE


      SIMMEAN=SUM01/M
      OBSMEAN=SUM0/M
      DIFFM1=SUM7/M

      DO 14 I=2,M
        SUM8=(((OCFS(I,ID1)-OCFS(I-1,ID1))-DIFFM1)**2)+SUM8
```

```
        SUM9=((((OCFS(I,ID1)-OCFS(I-1,ID1))/DIFFM1)-1)**2)+SUM9
14      CONTINUE

      DO 73 I=1,M
        SUM10=((OCFS(I,ID1)-OBSMEAN)**2)+SUM10
        SUM11=(((OCFS(I,ID1)/OBSMEAN)-I)**2)+SUM11
        SUM12=((OCFS(I,ID2)-SIMMEAN)**2)+SUM12
73      CONTINUE

      SDM=SQRT(SUM10/(M-1))
      SDS=SQRT(SUM12/(M-1))

      DO 115 I=1,M
115       SUM13=((OCFS(I,ID1)-OBSMEAN)/SDM)*((OCFS(I,ID2)-
     &    SIMMEAN)/SDS)+SUM13


      OF1=SUM1
      OF2=SUM2
      OF3=SUM3
      OF4=SUM4
      OF5=SUM5
      OF6=SUM6
      OF7=SUM2/SUM10
      OF8=SUM4/SUM11
      OF9=SUM5/SUM8
      OF10=SUM6/SUM9
      AM=M
      OF11=(1./AM)*SUM13

      WRITE(6,95)
95    FORMAT(1H0,10X,´------------------------------------------´)
      WRITE(6,50)
50    FORMAT(15X,´ MEASURES OF FIT ´//)
      WRITE(6,91)
91    FORMAT(10X,´------------------------------------------´)
      WRITE(6,51)OF1
51    FORMAT(10X,´SUM OF ERRORS          ´,F20.5)
      WRITE(6,52)OF2
52    FORMAT(10X,´OLSQ                   ´,F20.5)
      WRITE(6,53)OF3
53    FORMAT(10X,´LOG LSQ                ´,F20.5)
      WRITE(6,54)OF4
54    FORMAT(10X,´RELATIVE ERROR         ´,F20.5)
      WRITE(6,55)OF5
55    FORMAT(10X,´ABS ERROR - DIFF       ´,F20.5)
      WRITE(6,56)OF6
56    FORMAT(10X,´REL ERROR - DIFF       ´,F20.5)
      WRITE(6,57)OF7
57    FORMAT(10X,´ABS ERROR/VAR         ´,F20.5)
```

```
      WRITE(6,58)OF8
58    FORMAT(10X,'REL ERROR/VAR          ',F20.5)
      WRITE(6,59)OF9
59    FORMAT(10X,'ABS ERROR(diff)/VAR    ',F20.5)
      WRITE(6,60)OF10
60    FORMAT(10X,'REL ERROR(diff)/VAR    ',F20.5)
      WRITE(6,61)OF11
61    FORMAT(10X,'PEARSONS r             ',F20.5)
      WRITE(6,92)ESDEV
92    FORMAT(10X,'ERR STANDARD DEV       ',F20.5)
      WRITE(6,93)PCTER
93    FORMAT(10X,'PEAK Q ERROR           ',F20.5)
      WRITE(6,96)
96    FORMAT(10X,'------------------------------------------')

      WRITE (6,98)
98    FORMAT (//10X,'NOTE:  All indicies are in metric units')

      IF (KCODE.EQ.0)THEN
        DO 9969 I=1,M
              OCFS(I,ID1)=OCFS(I,ID1)/.02832
9969          OCFS(I,ID2)=OCFS(I,ID2)/.02832
      ENDIF

      RETURN
C
      END



      SUBROUTINE SEDT

C     THIS SUBROUTINE COMPUTES THE SEDIMENT YIELD FOR A FLOOD

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALFA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE
      ID=DATA(1)
      SOIL=DATA(2)
      CROP=DATA(3)
      CP=DATA(4)
      SL=DATA(5)
C     COMPUTE SEDIMENT YIELD
      X=ROIN(ID)*DA(ID)*53.333*PEAK(ID)
      SED=95.*X**.56*SOIL*CROP*CP*SL
      IF(ICODE.EQ.0)GO TO 5
      SED1=SED*0.9072
      WRITE(6,6)SED1
```

```
      GO TO 7
5     WRITE (6,3) SED
C     PUNCH CODE
7     IF(NPU)2,2,1
1     WRITE (7,4) ID,SOIL,CROP,CP,SL
2     RETURN
3     FORMAT (10X, ´SEDIMENT YIELD = ´, F10.1, ´ TONS´)
4     FORMAT(   ´SEDIMENT YIELD´,T21,´ID=´,I1,T29,´SOIL=´,F5.3,T42,´CROP
     &=´,F5.3,T57,´CP=´,F5.3,T70,´LS=´,F5.3)
6     FORMAT(10X,"SEDIMENT YIELD=",F10.1,"METRIC TON")
      END


      BLOCK DATA

C     BLOCK DATA SUBPROGRAM UZED TO INITIALIZE ZALFA,CTBLE,ITBLE
C     AND NCOMM.

      COMMON/BLOCK1/ OCFS(300,6),DATA(310),CFS(300),CTBLE(50,11),
     &RAIN(300),ROIN(6),
     &A(20,6),Q(20,6),DEEP(20,6),ITBLE(50,2),DP(20),SCFS(20),C(20),
     &ZALPHA(20),IEND(6),DA(6),DIST(6),SEGN(6),DT(6),PEAK(6),ISG(6),
     &NPU,NHD,NER,MAXNO,NCOMM,ICC,NCODE,TIME,KCODE,ICODE

      DATA ZALPHA/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1H0,1H ,
     &1H*,1H.,1H,,1H-,1H ,1H ,1H ,1H ,1H /

      DATA NCOMM/17/

      DATA CTBLE/1HS,1HS,1HR,1HC,1HP,1HP,1HP,1HA,1HS,1HC,1HS,1HC,1HR,
     &1HR,1HE,1HS,1HF,33*1H ,
     &1HT,1HT,1HE,1HO,1HR,1HU,1HL,1HD,1HT,1HO,1HT,1HO,1HO,1HO,1HR,
     &1HE,1HI,33*1H ,
     &2HAR,2HOR,2HCA,2HMP,2HIN,2HNC,2HOT,2HD ,2HOR,2HMP,2HOR,2HMP,
     &2HUT,2HUT,2HRO,2HDI,2HNI,33*2H  ,
     &2HT ,2HE ,2HLL,2HUT,2HT ,2HH ,2H H,2HHY,2HE ,2HUT,2HE ,2HUT,
     &2HE ,2HE ,2HR ,2HME,2HSH,33*2H  ,
     &2H  ,2HHY,2H H,2HE ,2HHY,2HHY,2HYD,2HD ,2HRA,2HE ,2HTR,2HE ,
     &2H  ,2HRE,2HAN,2HNT,2H  ,33*2H  ,
     &2H  ,2HD ,2HYD,2HHY,2HD ,2HD ,2H  ,2H  ,2HTI,2HRA,2HAV,2HTR,
     &2H  ,2HSE,2HAL,2H Y,2H  ,33*2H  ,
     &2H  ,2H  ,2H  ,2HD ,2H  ,2H  ,2H  ,2H  ,2HNG,2HTI,2HEL,2HAV,
     &2H  ,2HRV,2HYS,2HIE,2H  ,33*2H  ,
     &8*2H  ,2H C,2HNG,2H T,2HEL,2H  ,2HOI,2HIS,2HLD,34*2H  ,
     &8*2H  ,2HUR,2H C,2HIM,2H T,2H  ,2HR ,36*2H  ,
     &8*2H  ,2HVE,2HUR,2HE ,2HIM,38*2H  ,
     &9*2H  ,2HVE,2H  ,2HE ,38*2H´ /

      DATA ITBLE/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,33*1H ,
     &2,310,310,310,2,1,2,4,100,310,100,5,4,100,2,5,0,33*1H /
      END
```

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Data files for MILHY2

```
*
*  NORTH CREEK - TEXAS
*       STORM 6
*
*
*
START                RAINFALL BEGINS AT 15.25 HRS
COMPUTE HYD          ID=1 HYDNO=354 DT=.25 DA=23.7 CN=87 HT=355 L=11.745
                     CUMULATIVE RAINFALL = .0 .0 .01 .03 .13 .16 .27 .94
                     1.11 1.15 1.19 1.2 1.22 1.46 1.48 1.5 1.53 1.54 1.55
                     1.56 1.57 1.6 1.63 1.66 1.69 1.69 1.7 1.7 1.71 1.72
                     1.73 1.74 1.75 1.76 1.77 1.78 1.78
*
*
STORE HYD            ID=2 HYD   NO=454 DT=.25 DA=23.7 FLOW RATES=
                      .0 .0 .0 .0 50. 15. 69. 122. 333. 417. 549. 680. 710.
                      740. 825. 910. 1030. 1150. 1250. 1350. 1393. 1435.
                      1478. 1520. 1490. 1460. 1430. 1400. 1320. 1240. 1160.
                      1080. 1005. 930. 855. 780. 730. 680. 630. 580. 546.
                      512. 478. 444. 419. 394. 369. 344. 324. 304. 284. 264.
                      248. 231. 215. 198. 189. 179. 170. 161. 152. 142. 137.
                      132. 127. 122. 118. 114. 110. 106. 102. 98. 96. 92. 89.
                      86. 83. 80. 78. 76. 74. 72. 70. 68. 66. 65. 63. 61. 59.
                      57. 56. 55. 54. 53. 52. 51. 50. 48. 46. 44. 43. 42. 41.
                      40. 39. 38. 37. 36. 35. 35. 35. 34. 34. 34. 34. 33. 33.
                      33. 33. 32. 32. 32. 32. 31. 31. 30. 30. 30. 29. 29. 29.
                      28.
PRINT HYD            ID=1
PRINT HYD            ID=2
PLOT HYD              ID=1 ID=2
*
FINISH
```

```
15.25 15.25 0.25 9.0
1
60. .25
3
23
10 4 2
.15 .15 .15 .15 .15 .15 .15 .15 .15 .15
0. .00D0 .0D0
.43D0 .0D0 .45D0 .0D0 .36D0 .0D0
6.94D-7 .0D0 1.5D-7 .0D0 4.44D-7 .0D0
.43D0 .43D0 .43D0 .43D0 .44D0 .44D0 .35D0 .35D0 .35D0 .35D0
.0D0
6
.2427D0 .272D0 .300D0 .335D0 .371D0 .434D0
-20. -10. -6. -3. -2. -.4
.0D0
.298D0 .326D0 .356D0 .385D0 .416D0 .450D0
-20. -10. -6. -3. -2. -.8
.0D0
.259D0 .276D0 .294D0 .310D0 .330D0 .36D0
-20. -10. -6. -3. -2. -.35
0.0D0
67
6 1 3
.15 .15 .15 .15 .15 .15
0. .00D0 .0D0
.425D0 .0D0 .48D0 .0D0 .48D0 .0D0
7.2D-6 .0D0 1.67D-8 .0D0 1.67D-8 .0D0
.42D0 .46D0 .46D0 .46D0 .46D0 .46D0
0.0D0
7
.0171D0 .109D0 .127D0 .148D0 .17D0 .210D0 .425D0
-150. -20. -10. -6. -3. -2. -.3
.0D0
.318D0 .378D0 .404D0 .429D0  .454D0 .478D0 .48D0
-150. -20. -10. -6. -3. -2. -.3
.0D0
.318D0 .378D0 .404D0 .429D0 .454D0 .478D0 .48D0
-150. -20. -10. -6. -3. -2. -.3
0.0D0
10
9 1 4
.15 .15 .15 .15 .15 .15 .15 .15 .15
0.0 0.0D0 0.0D0
.36D0 .0D0 .48D0 .0D0 .48D0 .0D0
6.39D-7 .0D0 1.67D-7 .0D0 1.67D-7 .0D0
.35D0 .47D0 .47D0 .47D0 .47D0 .47D0 .47D0 .47D0 .47D0
0.0D0
6
.261D0 .286D0 .31D0 .336D0 .35D0 .36D0
-20. -10. -6. -3. -2. -.6
.0D0
.378D0 .404D0 .429D0 .454D0 .478D0 .48D0
-20. -10. -6. -3. -2. -.86
.0D0
.378D0 .404D0 .429D0 .454D0 .478D0 .48D0
-20. -10. -6. -3. -2. -.86
0.0D0
```

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Sample output results for MILHY2

```
    *
\c
    *  NORTH CREEK - TEXAS
\c
    *       STORM 6
\c
    *
\c
    *
\c
    *
\c
    START                  RAINFALL BEGINS AT 15.25 HRS
\c
    COMPUTE HYD            ID=1 HYDNO=354 DT=.25 DA=23.7 CN=87 HT=355 L=11.745
\c
                           CUMULATIVE RAINFALL = .0 .0 .01 .03 .13 .16 .27 .94
\c
                           1.11 1.15 1.19 1.2 1.22 1.46 1.48 1.5 1.53 1.54 1.55
\c
                           1.56 1.57 1.6 1.63 1.66 1.69 1.69 1.7 1.7 1.71 1.72
\c
                           1.73 1.74 1.75 1.76 1.77 1.78 1.78
\c
Shape constant, N =  3.319
Unit peak =     1567.3 cms

INCREMENTAL RUNOFF-Parameter variability included


SD of detcap 0.000
SD of saturated soil content0.000 layer 1
                            0.000 layer 2
                            0.000 layer 3
SD of suction moisture curve0.000 layer 1
                            0.000 layer 2
                            0.000 layer 3
SD of sat conductivity0.000 layer 1
                      0.000 layer 2
                      0.000 layer 3
SD of initial water content0.000

GENERATED K-MOISTURE CURVE
Millington-Quirk Method
Layer 1                               Layer 2                               Layer 3
Moisture Suction     Unsat K      Moisture Suction       Unsat K      Moisture
Sucti
\con     Unsat K
 0.243   -20.000 0.000000000033    0.298   -20.000 0.000000000014    0.259
-20.0
```

```
\c00 0.000000000023
 0.253   -16.564 0.000000000146   0.306   -17.143 0.000000000062   0.264
-16.8
\c73 0.000000000098
 0.263   -13.127 0.000000000373   0.314   -14.286 0.000000000154   0.270
-13.7
\c46 0.000000000248
 0.273    -9.871 0.000000000789   0.322   -11.429 0.000000000311   0.275
-10.6
\c19 0.000000000515
 0.283    -8.432 0.000000001479   0.330    -9.467 0.000000000562   0.280
-9.0
\c53 0.000000000953
 0.293    -6.994 0.000000002541   0.338    -8.400 0.000000000937   0.286
-7.8
\c71 0.000000001613
 0.303    -5.733 0.000000004132   0.346    -7.333 0.000000001466   0.291
-6.6
\c90 0.000000002568
 0.313    -4.870 0.000000006446   0.354    -6.267 0.000000002195   0.296
-5.5
\c86 0.000000003931
 0.323    -4.007 0.000000009764   0.362    -5.379 0.000000003191   0.302
-4.5
\c89 0.000000005880
 0.333    -3.144 0.000000014612   0.370    -4.552 0.000000004545   0.307
-3.5
\c92 0.000000008738
 0.343    -2.767 0.000000021541   0.378    -3.724 0.000000006409   0.312
-2.8
\c92 0.000000013010
 0.353    -2.487 0.000000030938   0.386    -2.968 0.000000009050   0.317
-2.6
\c26 0.000000019126
 0.364    -2.208 0.000000043250   0.394    -2.710 0.000000012702   0.323
-2.3
\c61 0.000000027424
 0.374    -1.934 0.000000059123   0.402    -2.452 0.000000017521   0.328
-2.0
\c95 0.000000038379
 0.384    -1.679 0.000000079470   0.410    -2.194 0.000000023725   0.333
-1.8
\c12 0.000000052724
 0.394    -1.423 0.000000105690   0.418    -1.929 0.000000031631   0.339
-1.5
\c19 0.000000071686
 0.404    -1.167 0.000000140181   0.426    -1.647 0.000000041757   0.344
-1.2
\c27 0.000000097445
 0.414    -0.911 0.000000187554   0.434    -1.365 0.000000054986   0.349
-0.9
```

```
\c35 0.000000134366
 0.424    -0.656 0.000000258405   0.442    -1.082 0.000000072941   0.355
-0.6
\c42 0.000000193370
 0.434     -0.40 0.000000387204   0.450    -0.800 0.000000099113   0.360
-0.
\c35 0.000000318548

START CONDITIONS

Simulation start time15.3hrs
Precipitation begins at 15.3  and ends at 24.3
Rainfall data time increment = 0.2500  hrs
Time increment for iteration period =   60.0  secs

Maximum evaporation during the day = 0.00000000  ms-1
Surface detention capacity = 0.0000  m


INITIAL SOIL COLUMN CONDITIONS


          SAT          SAT HYD        CELL DEPTH  INITAL  REL
          THETA         COND           NO          THETA  SAT
          m3/m3         ms-1                 m    m3/m3

Layer 1   0.4350   0.000000694000    1  0.0750  0.4300 0.989
                                     2  0.2250  0.4300 0.989
                                     3  0.3750  0.4300 0.989
                                     4  0.5250  0.4300 0.989
Layer 2   0.4510   0.000000150000    5  0.6750  0.4400 0.976
                                     6  0.8250  0.4400 0.976
Layer 3   0.3610   0.000000444000    7  0.9750  0.3500 0.970
                                     8  1.1250  0.3500 0.970
                                     9  1.2750  0.3500 0.970
                                    10  1.4250  0.3500 0.970

SOIL COLUMN CONDITIONS   0.250 HRS SINCE RAIN BEGAN

 Cell  Depth     SWP    Theta      Hyd cond      Net flux      Rel sat
    1  0.0750 -0.5645  0.4273   0.000000304   -0.00003174     0.982
    2  0.2250 -0.7034  0.4216   0.000000245   -0.00006666     0.969
    3  0.3750 -2.2778  0.3610   0.000000040   0.000095139     0.830
    4  0.5250 -2.3384  0.3587   0.000000037   -0.00002351     0.825
    5  0.6750 -5.4902  0.3610   0.000000003   0.000026605     0.800
    6  0.8250 -5.4902  0.3610   0.000000003   0.000072302     0.800
    7  0.9750 -1.3438  0.3415   0.000000087   -0.00006142     0.946
    8  1.1250 -0.9503  0.3490   0.000000132   -0.00001637     0.967
    9  1.2750 -0.9044  0.3499   0.000000140   -0.00000253     0.969
   10  1.4250 -0.9003  0.3500   0.000000141   -0.00000025     0.970
```

```
Balance check on soil column water status =   -0.047726
Balance check as  column water vol.    =  -8.6438310 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0000
Cumulative infiltration  =   0.000000
Cumulative drainage       =   0.000127

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  0.250


SOIL COLUMN CONDITIONS   0.500 HRS SINCE RAIN BEGAN

 Cell  Depth     SWP    Theta      Hyd cond        Net flux        Rel sat
    1  0.0750 -0.6125  0.4255    0.000000280     -0.00001982      0.978
    2  0.2250 -0.8394  0.4164    0.000000207     -0.00004191      0.957
    3  0.3750 -2.2778  0.3610    0.000000040     0.000074599      0.830
    4  0.5250 -2.3996  0.3565    0.000000035     -0.00002046      0.819
    5  0.6750 -5.4902  0.3610    0.000000003     0.000024360      0.800
    6  0.8250 -5.4902  0.3610    0.000000003     0.000051867      0.800
    7  0.9750 -1.6053  0.3369    0.000000066     -0.00003634      0.933
    8  1.1250 -1.0445  0.3473    0.000000121     -0.00001698      0.962
    9  1.2750 -0.9266  0.3495    0.000000136     -0.00000541      0.968
   10  1.4250 -0.9043  0.3499    0.000000141     -0.00000136      0.969

Balance check on soil column water status =   -0.050252
Balance check as  column water vol.    =  -9.1409788 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0003
Cumulative infiltration  =   0.000254
Cumulative drainage       =   0.000254

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  0.500


SOIL COLUMN CONDITIONS   0.750 HRS SINCE RAIN BEGAN

 Cell  Depth     SWP    Theta      Hyd cond        Net flux        Rel sat
    1  0.0750 -0.6282  0.4250    0.000000272     -0.00000704      0.977
    2  0.2250 -0.9256  0.4131    0.000000185     -0.00002670      0.950
    3  0.3750 -2.2778  0.3610    0.000000040     0.000062898      0.830
    4  0.5250 -2.4531  0.3546    0.000000032     -0.00001791      0.815
    5  0.6750 -5.4902  0.3610    0.000000003     0.000022456      0.800
    6  0.8250 -5.4902  0.3610    0.000000003     0.000041719      0.800
    7  0.9750 -1.7741  0.3339    0.000000055     -0.00002538      0.925
    8  1.1250 -1.1332  0.3457    0.000000109     -0.00001504      0.958
```

```
    9  1.2750 -0.9603  0.3489   0.000000131    -0.00000675     0.966
   10  1.4250 -0.9152  0.3497   0.000000138    -0.00000265     0.969

Balance check on soil column water status =   -0.052308
Balance check as  column water vol.   =  -9.5440872 %

Cumulative evaporation   =   0.00000000
Cumulative precipitation =   0.0008
Cumulative infiltration  =   0.000762
Cumulative drainage      =   0.000380

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  0.750


SOIL COLUMN CONDITIONS   1.000 HRS SINCE RAIN BEGAN

 Cell  Depth    SWP    Theta    Hyd cond      Net flux      Rel sat
    1  0.0750  0.0000  0.4344   0.000000385   -0.00009129    0.999
    2  0.2250 -0.9405  0.4131   0.000000182   0.000057525    0.950
    3  0.3750 -2.2778  0.3610   0.000000040   0.000060876    0.830
    4  0.5250 -2.5000  0.3529   0.000000031   -0.00001583    0.811
    5  0.6750 -5.4902  0.3610   0.000000003   0.000020908    0.800
    6  0.8250 -5.4902  0.3610   0.000000003   0.000035737    0.800
    7  0.9750 -1.8947  0.3317   0.000000049   -0.00001974    0.919
    8  1.1250 -1.2106  0.3443   0.000000100   -0.00001302    0.954
    9  1.2750 -0.9988  0.3482   0.000000126   -0.00000716    0.964
   10  1.4250 -0.9326  0.3494   0.000000135   -0.00000371    0.968

Balance check on soil column water status =   -0.054123
Balance check as  column water vol.   =  -9.8668475 %

Cumulative evaporation   =   0.00000000
Cumulative precipitation =   0.0033
Cumulative infiltration  =   0.003165
Cumulative drainage      =   0.000503

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  1.000


SOIL COLUMN CONDITIONS   1.250 HRS SINCE RAIN BEGAN

 Cell  Depth    SWP    Theta    Hyd cond      Net flux      Rel sat
    1  0.0750  -0.430  0.4327   0.000000372   -0.00001958    0.995
    2  0.2250 -0.9091  0.4140   0.000000188   0.000001018    0.952
    3  0.3750 -2.2778  0.3610   0.000000040   0.000063627    0.830
    4  0.5250 -2.5418  0.3514   0.000000029   -0.00001420    0.808
    5  0.6750 -5.4902  0.3610   0.000000003   0.000019756    0.800
```

```
    6  0.8250 -5.4902  0.3610    0.000000003    0.000031517       0.800
    7  0.9750 -1.9899  0.3300    0.000000044    -0.00001598       0.914
    8  1.1250 -1.2781  0.3430    0.000000093    -0.00001151       0.950
    9  1.2750 -1.0384  0.3474    0.000000121    -0.00000722       0.962
   10  1.4250 -0.9552  0.3490    0.000000132    -0.00000452       0.967

Balance check on soil column water status =    -0.055876
Balance check as  column water vol.    = -10.2044863 %

Cumulative evaporation   =   0.00000000
Cumulative precipitation =   0.0041
Cumulative infiltration  =   0.004065
Cumulative drainage      =   0.000622

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  1.250


SOIL COLUMN CONDITIONS   1.500 HRS SINCE RAIN BEGAN

 Cell  Depth     SWP    Theta      Hyd cond       Net flux        Rel sat
    1  0.0750  -0.404   0.4347    0.000000385    0.000135718       0.999
    2  0.2250 -0.8589  0.4159    0.000000202    -0.00000496       0.956
    3  0.3750 -2.2778  0.3610    0.000000040    0.000069876       0.830
    4  0.5250 -2.5794  0.3501    0.000000028    -0.00001278       0.805
    5  0.6750 -5.4902  0.3610    0.000000003    0.000018742       0.800
    6  0.8250 -5.4902  0.3610    0.000000003    0.000028204       0.800
    7  0.9750 -2.0678  0.3285    0.000000040    -0.00001325       0.910
    8  1.1250 -1.3382  0.3420    0.000000088    -0.00001027       0.947
    9  1.2750 -1.0780  0.3467    0.000000116    -0.00000712       0.960
   10  1.4250 -0.9817  0.3485    0.000000128    -0.00000507       0.965

Balance check on soil column water status =    -0.057849
Balance check as  column water vol.    = -10.5678383 %

Cumulative evaporation   =   0.00000000
Cumulative precipitation =   0.0069
Cumulative infiltration  =   0.005997
Cumulative drainage      =   0.000739

Detention capacity exceeded
Runoff total in the last period 0.0003078  m
Runoff total in the last period 0.0121178  ins  1.500


SOIL COLUMN CONDITIONS   1.750 HRS SINCE RAIN BEGAN

 Cell  Depth     SWP    Theta      Hyd cond       Net flux        Rel sat
    1  0.0750  0.0000  0.4339    0.000000386    -0.00008395       0.997
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```
  2  0.2250 -0.8237  0.4176   0.000000212   0.000035491     0.960
  3  0.3750 -2.2778  0.3610   0.000000040   0.000074357     0.830
  4  0.5250 -2.6132  0.3488   0.000000027  -0.00001153      0.802
  5  0.6750 -5.4902  0.3610   0.000000003   0.000017844     0.800
  6  0.8250 -5.4902  0.3610   0.000000003   0.000025822     0.800
  7  0.9750 -2.1311  0.3273   0.000000037  -0.00001152      0.907
  8  1.1250 -1.3920  0.3410   0.000000083  -0.00000924      0.945
  9  1.2750 -1.1167  0.3460   0.000000111  -0.00000693      0.958
 10  1.4250 -1.0105  0.3480   0.000000125  -0.00000541      0.964

Balance check on soil column water status =   -0.060018
Balance check as  column water vol.   = -10.9756570 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0239
Cumulative infiltration  =   0.007703
Cumulative drainage       =   0.000853

Detention capacity exceeded
Runoff total in the last period 0.0143848  m
Runoff total in the last period 0.5663301  ins  1.750


SOIL COLUMN CONDITIONS   2.000 HRS SINCE RAIN BEGAN

 Cell  Depth    SWP    Theta     Hyd cond      Net flux      Rel sat
   1  0.0750  0.0000  0.4344   0.000000386  -0.00008278     0.999
   2  0.2250 -0.8054  0.4183   0.000000217   0.000031749    0.961
   3  0.3750 -2.2778  0.3610   0.000000040   0.000076631    0.830
   4  0.5250 -2.6438  0.3478   0.000000026  -0.00001043     0.799
   5  0.6750 -5.4902  0.3610   0.000000003   0.000017046    0.800
   6  0.8250 -5.4902  0.3610   0.000000003   0.000023964    0.800
   7  0.9750 -2.1858  0.3262   0.000000035  -0.00001029     0.904
   8  1.1250 -1.4406  0.3401   0.000000079  -0.00000842     0.942
   9  1.2750 -1.1543  0.3453   0.000000107  -0.00000671     0.957
  10  1.4250 -1.0408  0.3474   0.000000121  -0.00000559     0.962

Balance check on soil column water status =   -0.062239
Balance check as  column water vol.   = -11.3912754 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0282
Cumulative infiltration  =   0.009580
Cumulative drainage       =   0.000964

Detention capacity exceeded
Runoff total in the last period 0.0023587  m
Runoff total in the last period 0.0928615  ins  2.000


SOIL COLUMN CONDITIONS   2.250 HRS SINCE RAIN BEGAN
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Cell  Depth     SWP     Theta     Hyd cond      Net flux      Rel sat
   1  0.0750  -0.402   0.4349   0.000000386   -0.00000096     1.000
   2  0.2250 -0.8285   0.4171   0.000000211   -0.00001148     0.959
   3  0.3750 -2.2778   0.3610   0.000000040   0.000073128     0.830
   4  0.5250 -2.6715   0.3468   0.000000025   -0.00000945     0.797
   5  0.6750 -5.4902   0.3610   0.000000003   0.000016334     0.800
   6  0.8250 -5.4902   0.3610   0.000000003   0.000022338     0.800
   7  0.9750 -2.2348   0.3252   0.000000033   -0.00000928     0.901
   8  1.1250 -1.4852   0.3393   0.000000075   -0.00000775     0.940
   9  1.2750 -1.1906   0.3447   0.000000102   -0.00000647     0.955
  10  1.4250 -1.0718   0.3468   0.000000117   -0.00000565     0.961

Balance check on soil column water status =    -0.063968
Balance check as  column water vol.     = -11.7231504 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0292
Cumulative infiltration  =   0.010700
Cumulative drainage       =   0.001071

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  2.250


SOIL COLUMN CONDITIONS   2.500 HRS SINCE RAIN BEGAN

Cell  Depth     SWP     Theta     Hyd cond      Net flux      Rel sat
   1  0.0750  -0.402   0.4347   0.000000386   -0.00000290     0.999
   2  0.2250 -0.8510   0.4162   0.000000204   -0.00000644     0.957
   3  0.3750 -2.2778   0.3610   0.000000040   0.000069795     0.830
   4  0.5250 -2.6966   0.3459   0.000000024   -0.00000859     0.795
   5  0.6750 -5.4902   0.3610   0.000000003   0.000015697     0.800
   6  0.8250 -5.4902   0.3610   0.000000003   0.000020902     0.800
   7  0.9750 -2.2792   0.3244   0.000000031   -0.00000841     0.899
   8  1.1250 -1.5264   0.3386   0.000000071   -0.00000720     0.938
   9  1.2750 -1.2256   0.3440   0.000000098   -0.00000624     0.953
  10  1.4250 -1.1029   0.3463   0.000000113   -0.00000563     0.959

Balance check on soil column water status =    -0.065599
Balance check as  column water vol.     = -12.0379328 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0302
Cumulative infiltration  =   0.011716
Cumulative drainage       =   0.001174

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  2.500
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```
SOIL COLUMN CONDITIONS   2.750 HRS SINCE RAIN BEGAN

 Cell  Depth    SWP    Theta     Hyd cond       Net flux      Rel sat
    1  0.0750  -0.497  0.4299  0.000000338   -0.00003988     0.988
    2  0.2250 -0.8778  0.4151  0.000000197   -0.00001666     0.954
    3  0.3750 -2.2778  0.3610  0.000000040   0.000065988     0.830
    4  0.5250 -2.7195  0.3450  0.000000023   -0.00000781     0.793
    5  0.6750 -5.4902  0.3610  0.000000003   0.000015126     0.800
    6  0.8250 -5.4902  0.3610  0.000000003   0.000019630     0.800
    7  0.9750 -2.3194  0.3236  0.000000029   -0.00000761     0.896
    8  1.1250 -1.5649  0.3379  0.000000069   -0.00000675     0.936
    9  1.2750 -1.2595  0.3434  0.000000095   -0.00000606     0.951
   10  1.4250 -1.1338  0.3457  0.000000109   -0.00000556     0.958

Balance check on soil column water status =   -0.067155
Balance check as  column water vol.   = -12.3551773 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0305
Cumulative infiltration  =   0.011970
Cumulative drainage       =   0.001274

Detention capacity exceeded
Runoff total in the last period 0.0000000  m
Runoff total in the last period 0.0000000  ins  2.750


SOIL COLUMN CONDITIONS   3.000 HRS SINCE RAIN BEGAN

 Cell  Depth    SWP    Theta     Hyd cond       Net flux      Rel sat
    1  0.0750 -0.5510  0.4279  0.000000311   -0.00001778     0.984
    2  0.2250 -0.9206  0.4134  0.000000186   -0.00001647     0.950
    3  0.3750 -2.2778  0.3610  0.000000040   0.000060459     0.830
    4  0.5250 -2.7403  0.3443  0.000000022   -0.00000712     0.792
    5  0.6750 -5.4902  0.3610  0.000000003   0.000014611     0.800
    6  0.8250 -5.4902  0.3610  0.000000003   0.000018499     0.800
    7  0.9750 -2.3558  0.3228  0.000000028   -0.00000694     0.894
    8  1.1250 -1.6010  0.3372  0.000000066   -0.00000635     0.934
    9  1.2750 -1.2924  0.3428  0.000000092   -0.00000587     0.950
   10  1.4250 -1.1641  0.3452  0.000000105   -0.00000546     0.956

Balance check on soil column water status =   -0.068606
Balance check as  column water vol.   = -12.6464275 %

Cumulative evaporation    =   0.00000000
Cumulative precipitation =   0.0310
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