THE UNIVERSITY OF MANITOBA

SYNTHESIZED URBAN RUNOFF

BY

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ABSTRACT

The purpose of this study is to evaluate the feasibility of a method proposed to develop a synthesized hydrograph of runoff from a design rainfall at the outlet of an urban watershed and any other selected point within the drainage system. The method has been developed by using independent hydraulic and hydrologic principles and relationships, and by combining the processes sequentially.

Initial losses are excluded from consideration and only the impervious portion of a watershed is considered to contribute to runoff. The surface flow simulation into an inlet point is accomplished using a two dimension approximation to overland flow. By using the characteristics method with specified intervals to route flows through storm drainage system, depths and velocities of flow at any point within the system are known simultaneously with discharge at that point. Input information required for simulation includes design rainfall hyetograph, surface and drainage physical and hydraulic characteristics; and the drainage system layout. A computer programme in FORTRAN language is developed for simulation purposes.

Application of the method is restricted to a watershed with relatively flat terrain. Its application to a design system is considered to be infeasible as the simulation required an excessive amount of storage and computer time.

ACKNOWLEDGEMENTS

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Last but not least, a special thanks to Faculty of Engineering, Khonkaen University, for granting a leave to the author to complete this study.

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LIST OF SYMBOLS

A	conduit cross section area, ft^2
B	water surface width, ft
D	conduit diameter, ft
D	surface detention, ft^3/ft
D_e	surface detention at equilibrium, ft^3/ft
L	average flow path length, ft
Q	discharge, ft^3/sec
R	hydraulic radius, ft
S	average slope, ft/ft
S_o	slope of conduit invert, ft/ft
S_f	energy gradient
V	mean cross section velocity, ft/sec
a	co-efficient in discharge-depth relationship
b	exponent in discharge-depth relationship
g	gravitational acceleration, ft/sec^2
i	rate of precipitation, in/hr
n	Manning's friction factor
q	unit discharge, $ft^3/sec/ft$
q_e	unit discharge at equilibrium, $ft^3/sec/ft$
t	time, sec
t_e	time at equilibrium, sec
x	distance, ft
y	depth of flow, ft
β	fraction of total flow
η	supply rate, $ft^3/sec/ft^2$

θ	angle at the center of a circle, radian
ξ	characteristic direction

CHAPTER I

INTRODUCTION

Hydrology in urban areas is the study of watersheds of limited size that are modified by variety of physical changes. The basic process of hydrologic response is the same as in general hydrologic response. The increase in impervious area alters runoff volumes, while channel lining and storm sewers influence the time distribution of runoff.

The effect of urbanization on water regimes has long been appreciated, and investigations to evaluate the factors involved have been common. In view of the tremendous urban and suburban development that has been experienced in recent times, there has been a continuous increase in the total activities of urban drainage. With the progressive increasing activities in urban storm drainage, the amount of investment in property has also increased enormously. Therefore, concern is building to reduce costs by keeping the total risk of overloading urban areas below a given probability level. It is reasonable, then, to expect an increase in public and private pressure for better methods of storm drain design, particularly for more accurate techniques of optimization between investment, maintenance, risk, and other uncertainties.

Estimation of urban storm drain discharge, in the past, has been carried out largely on the basis of empirical relationships. Too often constants in these empirical relations or the design storm were adjusted to match the available finance. Therefore, economic aspects of a drainage design could not be investigated and evaluated.

Mathematical methods for estimation of storm drain discharge existed as early as in 1940. However the application of simulation techniques did not become a feasible method for solving these mathematical relationships until the advent of modern computing facilities. Usually simulation solutions involved a large amount of repeated computations, therefore the simulation solution becomes a viable so solution only when analytical solutions are unattainable. (1) Continuous short time interval simulation avoids estimation of empirical constants. (2) More complete mathematical relationships can be used for better approximation to actual drainage discharge. These factors allow the application of engineering economy to drainage system design.

In this paper a digital simulation model is developed to solve the proposed mathematical relationships for estimation of urban storm drainage discharge. Design rainfall pattern is used as input. A two dimensional approximation to surface flow, with land surface physical characteristics as parameters, is used to simulate surface flows to inlets of the drainage system. Drainage network and drain pipe characteristics are used as parameters in routing flows through storm drains to the outlet point. The characteristic method of routing with specific intervals used enables simultaneous computations of depths, velocities, and discharges at any point in the drainage system. A complete outflow hydrograph or complete hydrographs at other specified points in the drainage system can be derived as output from the model. A computer programme based on FORTRAN language is developed for simulation of the model.

The feasibility studies of the application of the method for storm drainage designs is investigated. However, due to time and finance available, some limitations had to be imposed on the studies: (1) Initial losses are excluded from the studies. (2) Circular channel sections are the only type of drainage section used in the studies. (3) Inlet points in the system are assumed to be capable of passing any simulated surface flows to the points. (4) Surcharges on any components of the drainage system are excluded from present studies, for the design criteria provides that conduit will not flow under pressure for the design storm. This latter point can severely effect the economics of a storm sewer system.

Some methods used in the estimation of urban storm drainage discharge are briefly reviewed in Chapter II.

Chapter III contains details of developments and general theoretical considerations used in the method. The operations and sequences of input parameters and data required for simulation are explained in Chapter IV, and the results and discussions of experimental simulation runs are contained in Chapter V. Finally Chapter VI summarizes and concludes all aspects of the study with a discussion of some future prospects.

For convenience of future investigations, brief details of theories used, and computer flow charts and programmes are included in appendices.

CHAPTER II

LITERATURE REVIEW

In the past, estimations of urban runoff have been carried out largely by empirical relationships. Application of many of these relationships is generally confined to the region where they were first derived. Some methods of estimation of runoff in rural areas have been applied to urban area studies with a varying degree of success. The simulation approach to solve mathematical relationships became a feasible proposition after the advent of modern computing facilities.

In this chapter, a brief summary review of selected methods used in estimation of urban runoff is given. These reviews are intended to be only a background information on previously developed methods of an estimation of urban runoff. Detailed reviews of some of the methods reviewed in this chapter can be found elsewhere. (13, 27)

2.1. The Rational Method.

The method was proposed by Kuichling (15) in 1889 after collecting eleven years of storm sewer data from a built up area. Estimation of peak flow is based in concept, on the criterion that for storms of uniform intensity distributed evenly over the watershed, the maximum rate of runoff occurs when the entire watershed area is contributing at the outlet and that this rate of runoff is equal to a percentage of the rainfall intensity. The peak discharge rate is obtained from equation 2.1

$$Q_p = CiA \qquad .....2.1$$

where Q_p is the peak rate of runoff in cfs.,

C is the runoff coefficient based upon flood-producing characteristics of the watershed,

i is the rainfall intensity of a storm whose duration is equal to the time of concentration of the watershed, in inches/hour

A is the area of watershed in acres.

Obviously, the application of the rational method is not just a simple evaluation or substitution into the equation. Many simple guidlines to the use of the method can be found in several standard hydrology textbooks or handbooks. A comprehensive treatment including many judgment factors involved in using the rational method can be found in the paper by Stanley and Kaufman (25). An interesting probablilistic approach in evaluations of factors involved in the rational method is given by Schaak et.al. (24).

2.2. The Los Angeles Method.

The method was proposed by Hicks (8). The method was originally developed for use in the City of Los Angeles, California. Topographically, the area is of mixed mountain, valley, and coastal plain terrain. The Los Angeles Method is the first method of urban storm drainage discharge estimation in which hydraulic effects on flow conditions into and within the storm drainage system are recognized.

The method derived the complete runoff hydrograph from the desired gross mass rainfall curve. After subtraction of various losses, the varying depth of overland flow detention is deducted from the net mass rainfall curve to form the mass runoff-to-gutter hydrograph. The varying depth of gutter storage is then deducted from the mass runoff-to-gutter hydrograph to form the mass runoff-to-inlet hydrograph. Then the varying depth of conduit storage is deducted from the mass runoff-to-inlet hydrograph to form the mass runoff-in-conduit hydrograph. This allows the complete outflow hydrograph to be derived by summing up all runoff-in-conduit hydrographs with appropriate peak rate and time factors.

Most of the various mathematical relationships used in the computations of this method are derived from observations of rainfall-runoff records in the Los Angeles area. There are some doubts if some of the mathematical relationships are applicable elsewhere. It is also noted that some of the derived relationships closely resemble recently rigously derived general mathematical relationship (18).

At this time the method is considered rather a complex method; hence, it has not been widely received for general use.

2.3 The Chicago Hydrograph Method

The method is first presented by Tholin and Keifer (28) for estimation of urban runoff for the City of Chicago, Illinois. Topographically the area of Chicago is a flat terrain. The Chicago Method is the first method that provides a complete hydraulic treatment of flows from an urbanized watershed. The method described flow conditions on grassed areas, roofs, and paved streets; routing of flow through gutters and routing of flow through the storm drainage system to the outlet.

The watershed is first divided into elemental strips according to the type of land use. After subtracting all appropriate losses for each strip, the overland flow along any strip is computed. The computation of overland flow is based on relationships developed by Izzard (11). A simple storage routing technique is then used to route mixed flows from these strips through the street gutter detention to form inlet hydrograph entering any inlet or catch basin. The complete outflow hydrograph at the outlet is derived from routing inlet hydrographs through the drainage system using the time-offset technique.

Keifer (14) in subsequent studies presented a simplified Chicago Method. In this simplified method only impervious areas of the watershed are used as effective areas to compute the runoff from the watershed. The omission of the pervious areas contribution from runoff was shown to have insignificant effect on the peak rate of runoff.

Izzard and Armentrout (12) suggested a simplification by combining the overland flow routing and gutter routing into a simple routing procedure. The error in the combined procedure was shown to be insignificant.

2.4 The Road Research Laboratory Hydrograph Method (RRL Method)

The method was developed from extensive experimentation as described by Watkins (29). The method uses storm rainfall on an urban area as input and provides the storm runoff hydrograph as output.

The method of estimation of runoff is based on the computation of a virtual inflow hydrograph from the time-area curve of the watershed. The virtual inflow hydrograph is then routed through the storm drain net-work using a simplified one-step storage-routing technique. By this means the shape and timing of the virtual inflow hydrograph are altered to allow for the effects of temporary storage within the storm drainage system. The result is the complete computed runoff hydrograph which would result from the net storm rainfall specified as input.

In the estimation of runoff, the RRL method considers only the impervious areas of the watershed directly connected to the storm drainage system. This excludes consideration of all other watershed areas that may have covers of grass, trees, or impervious areas not directly connected to the storm drainage system. This may result in tendency to under predict the peak runoff, especially from intense or long duration rainstorms.

2.5 General Comments

Of all the methods reviewed, the rational method is probably the most widely used method for the estimation of urban runoff (1). The popularity of the method is probably due mainly to its simple form of relationship and ease in manipulation and computation. However, the rational method does not recognize separately the effect of land surface and the effect of the drainage system on peak rate of runoff. Furthermore, only the value of the peak rate of runoff is the result of computation.

The RRL method is a progressive step from the rational method in that inclusion of the hydraulic characteristics of the drainage system in the computation of runoff are included. The method has been probably specifically developed for practical design of storm drainage systems rather than for studies of urbanized watershed responses.

Methods in which land surface as well as drainage system characteristics of the watershed are used as parameters to compute the complete outflow hydrograph, are the most complete approach to the study of urbanized watershed responses. However these methods have one common practical application set back; that is, the large amount of computations involved. The Los Angeles Method tried to overcome this computational problem by using semi-graphical procedures. In the Chicago Method, a series of charts were developed for future computations.

With the modern computing facilities available, the problem of large amounts of computations can be readily accomodated if the method devised lends itself readily to repeditive procedures. The practical application of the method can then be achieved without serious economic restriction of the method.

CHAPTER III

THEORETICAL DEVELOPMENTS AND CONSIDERATIONS

In this chapter, a general consideration and development of the methematical relationships used for estimation of urban runoff are discussed. Details of the mathematical derivations can be found in the appendices.

3.1 General Considerations

In relation to the hydrologic cycle, the estimation or prediction of runoff from rainfall may be divided into two major parts,

i. estimation of rainfall excess which is essentially the residual when abstractions are made from the gross rainfall to allow for infiltration and other losses,

ii. the conversion of rainfall excess to hydrographs at the outlet.

If the whole process were going to be considered, great difficulties would arise due to the vast amount of information required for complete specification, and analyses. Therefore, some approximations and simplifying assumptions are always required to derive a workable method.

In estimation of runoff, all errors in i) are carried through to ii), and there exists no technique of adequate precision yet available for estimating rainfall excess. Furthermore, the variable conditions of land existing in urban areas make it much more difficult to estimate all the losses accurately.

Use of the Horton (9) or Philip (20) equation for estimation of infiltration loss is arbitrary, depending on personal preferences or available data. The method accounting for depression loss used in the Chicago Method is probably the best approach, but it still inadequately represents the actual depression loss in general.

With all these considerations it was decided that the problem of the initial losses should be excluded from the study, until more reliable methods are available. Hence, this study is simplified to only that of conversion of excess or design rainfall to the outlet hydrograph.

There exists many approaches in conversion of the excess rainfall to hydrograph at the outlet. The conceptual model approach, in which the watershed is approximated by series of storages, may be a satisfactory approach for study of the watershed responses. However, this approach is not readily adaptable for designing a storm drainage system. The empirical or semi-empirical approach such as the unitgraph or the inlet method (23), may be satisfactorily used for a limited size of urban area. The component approach in which the overland flow is separated from routing in the drainage system has been selected for this study. The approach offers flexibilities and can be easily improved whenever there is a better method available in any component. Furthermore, the separation of overland flow and routing in the drainage system helps to identify the relative importance of various parameters in the watershed. Since the drainage system characteristics are parameters included in the computation of runoff, the effects of various designs can be thoroughly investigated.

In the following sections, more detailed considerations and theoretical development of relationships used are discussed.

3.2 Overland flow

The movement of water on the surface (overland flow) is an important land-surface process. In a well developed urban watershed, impervious areas tend to dominate the peak rate of runoff (14). Therefore, pervious areas of the watershed can be neglected from overland flow considerations without significant consequences. The interaction between overland flow and infiltration need not then be considered; thus, the overland flow process can be simplified considerably.

Short high intensity rainfall bursts are attenuated by surface detention storage reducing the maximum outflow rate from overland flow. Thus, computations of the overland flow process required continuous estimations of detention storage as well as the continuous outflow rates from overland flow. Any calculation method used for overland flow should yield results that can be compared with the well known investigations of Izzard (10,11) and with other experimental and analysis results.

A wide range of methods for calculation of unsteady overland flow are available. The rigorious general method for simulating unsteady overland flow make use of the finite difference technique for the numerical solution of the governing partial differential equations, the continuity and momentum equations (19,22). Generally, average values are used in calculations for the surface parameters such as length and slope of overland flow. Thus, while watersheds are broken up into segments, the accuracy to be gained by using finite difference methods for overland flow is still subjected to question because of the limited accuracies of basic data available.

Approximations to simulation of unsteady overland flows are difficult to devise since the basic nature of the flow is not well established (31). For convenience, the flow can be described as laminar or turbulent based on undisturbed flow criteria, even though turbulence from raindrop impact clouds this distinction (36). Undisturbed flow criteria indicate that transitions from laminar to turbulent flow could occur in overland flow in typical natural watersheds.

Adaptation for simulation of both the laminar and turbulent range by an empirical equation was considered. The turbulent range equations were finally selected for adaptation since experimental measurements of surface detention showed a marked change in regime as turbulent becomes dominant (32), and high intensity rainfall often yield Reynold's numbers that indicate turbulent flow. Overland flows tend to collect and move along preferred paths, and a turbulent range approximation can be more logically adjusted to account for this effect.

The two dimension approximation to overland flow in the turbulent range is thus selected for computation of overland flow. Outlines and detailed derivations of various relationships can be found in Appendix A. The method is adapted from the overland flow component of Stanford model (5) for application to the urban watershed study. The basic relationship used in the computations are;

i) surface detention at equilibrium

$$D_e = \frac{0.000818 \quad i^{0.6} n^{0.6} L^{1.6}}{S^{0.3}} \qquad \text{......3.1}$$

ii) depth of overland flow

$$Y = \frac{D}{L} \left(1.0 + 0.6 \left(\frac{D}{D_e}\right)^3\right) \qquad \text{..... 3.2}$$

iii) discharge from overland flow

$$q = \frac{1.486}{n} y^{5/3} S^{1/2} \quad \ldots\ldots 3.3$$

In the simulation mode, a continuity equation

$$D_2 = D_1 + \Delta D - \bar{q}\Delta t \quad \ldots\ldots 3.4$$

is continuously solved for each increment of time interval.

This system of equations can be solved numerically with good accuracy if the time interval of the calculations is sufficiently small so that the value of discharge at any time interval remains a small fraction of the volume of surface detention. Calculation of discharge from overland flow in the simulation are made on a 2.5-minute time intervals. However other time intervals can be used if required by characteristics of the flow plane, or justified by the input rainfall data.

The impervious area, average length, average slope and estimated Manning's roughness of the overland flow plane to the inlet point are used as parameters in this simulation.

3.3 Routing In the Drainage System

The measured outflow hydrograph from a watershed reflects the importance of the land surface effects relative to time delay and attenuation in the channel system. In urban watersheds where the land surface is modified and many of the natural channels have been replaced by man-made drainage systems, the separation of the overland flow and routing in the drainage system helps to identify the effects of various parameters on the runoff.

There exists numerous methods for routing flow through a channel system. The Muskingham routing method (16), and the modified storage routing method (3), are typical of empirical and semi-empirical routing methods. Applications of these methods to routing flow through storm drains are limited (6). The time-lag routing method (4) and its variation (7) may offer a better approximation to flood routing through storm drains; however, they do not permit a direct evaluation of corresponding depths. Neither do they give the maximum depth determined as a function of position along the conduit or in time. Since maximum depth does not always occur at the same time as the maximum discharge, it is not to be expected that the routed discharge hydrograph would be an indication of maximum depth.

The rigorous general methods for slow routing through storm drains are the finite difference technique for numerical solution of the governing partial differential equations. In a circular channel the continuity and momentum equation of the unsteady free surface flow can be written as;

$$\frac{A}{VB}\frac{\partial V}{\partial x} + \frac{\partial Y}{\partial x} + \frac{1}{V}\frac{\partial Y}{\partial t} = 0 \qquad \ldots\ldots 3.5$$

and,

$$\frac{V}{g}\frac{\partial V}{\partial x} + \frac{1}{g}\frac{\partial V}{\partial t} + \frac{\partial y}{\partial x} = S_0 - S_f \qquad \ldots .\ 3.6$$

Various finite difference schemes to solve this system of equations are well discussed by Barnes and Yevjevich (34). In a comparison study, the method of characteristics is chosen to solve the above system of equations.

In the method of characteristics as described by Lister (17), the continuity and momentum equations of the unsteady free surface flow in the storm drains, equation 3.5 and 3.6 respectively, are replaced by four equivalent ordinary differential equations of the form;

$$\frac{dt}{dx})_+ = \xi_+ = \frac{1}{V+ gA/B} \qquad \ldots .\ 3.7$$

$$\frac{dt}{dx})_- = \xi_- = \frac{1}{V- gA/B} \qquad \ldots .\ 3.8$$

$$((\frac{A}{VB} - \frac{V}{g})\,\xi_+ + \frac{1}{g}\ \frac{dy}{dx} + \frac{A}{gVB}\,\frac{dV}{dx} + \frac{A}{VB}\,(S_o - S_f)\,\xi_+ = 0 \qquad \ldots .\ 3.9$$

$$((\frac{A}{VB} - \frac{V}{g})\,\xi_- + \frac{1}{g}\ \frac{dy}{dx} + \frac{A}{gVB}\,\frac{dV}{dx} + \frac{A}{VB}\,(S_o - S_f)\,\xi_- = 0 \qquad \ldots .\ 3.10$$

The equation 3.7 through 3.10 are known as the characteristic ordinary differential equations of the governing partial differential equations 3.5 and 3.6.

The specific intervals numerical solution with linear interpolation as described by Lister (17) and Pinkayan (21) is adopted for solving the characteristic equations. Advantages and limitations of this scheme is well discussed by

Lister (17).

In this scheme of solution, rectangular grids are used in a xt plane with specified intervals Δx and Δt in x and t co-ordinates, respectively, as shown in figure 3.1. The values of velocities V, and depth y, at points M_o, A_o, B_o,.....N are known at time t, or at the initial condition; the values of velocities V, and depth y, at time $t+\Delta t$, particularly at point M_1, A_1, B_1,..... can be computed from the characteristic equations, equations 3.7 through 3.10, and the boundary conditions. In this manner, V and y at any time $t+\Delta t$ can be computed at various points along distance x. This process can be continued as far as desired.

Detailed derivations and computation procedures of the characteristic method solution of routing through circular channels with specific intervals can be found in appendix B.

The major advantage of routing method used is the ability to compute simultaneously the velocities and depths along the channel, avoiding any empirical estimations in order to compute the discharge.

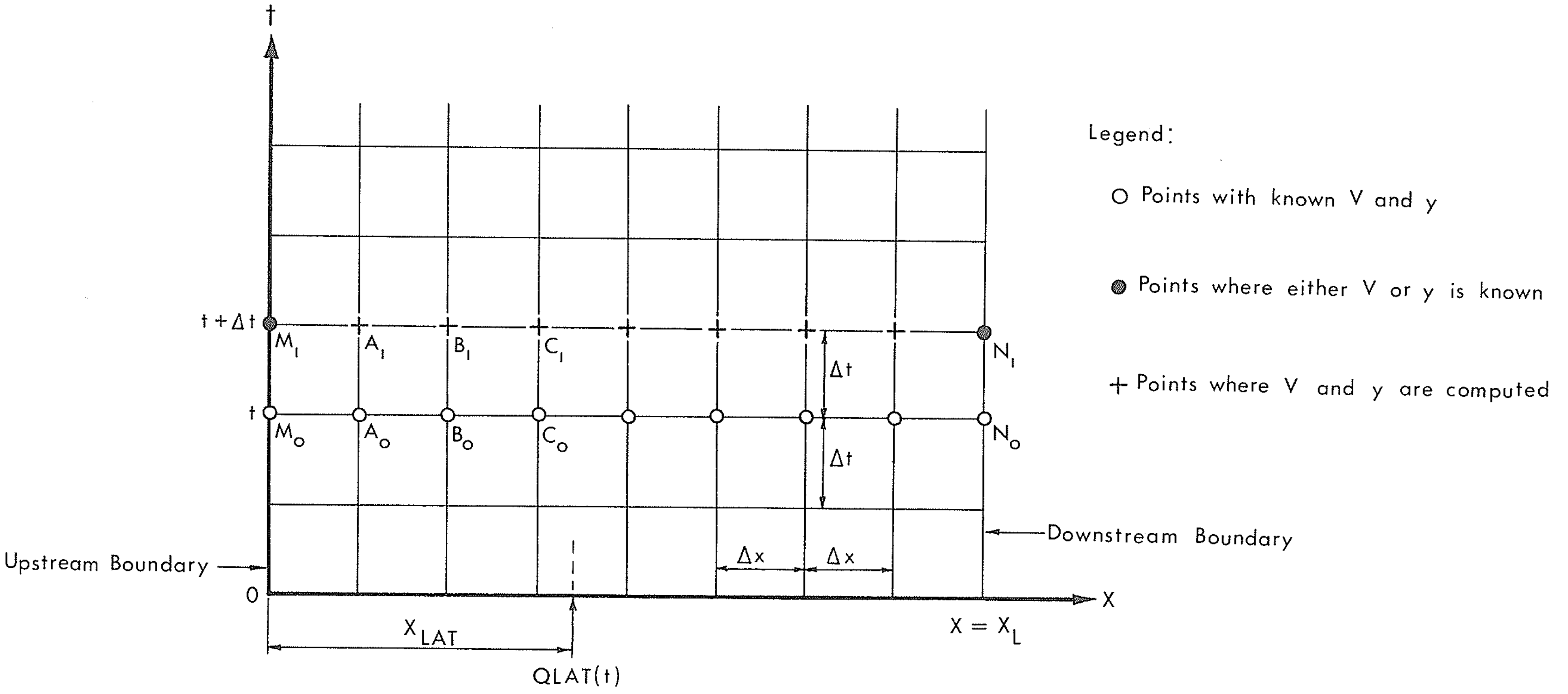


Figure 3.1 x-t plane for solution of the characteristics method with specified intervals

CHAPTER IV

MODEL STRUCTURE AND DESCRIPTIONS

4.1 General

It is quite obvious from the development in the previous chapter that a simulation model is needed in order to synthesize urban runoff from the theories considered.

In this chapter, the Model structure and description are explained. Also sequences of data required to simulate the model are explained as well as some guildlines for the selection of values of various parameters. A computer programme in FORTRAN language was developed for the simulation purpose. Some basic knowledge in computer use and the FORTRAN language are required in order to operate the model properly.

4.2 Structure

For simplicity and future development, the simulation model developed can be roughly separated into three sequencial submodels, namely, the precipitation, the surface flow and the routing through storm drains submodels. Each submodel is initially individually developed and tested.

Finally, all submodels were integrated into the simulation model. A block structure of the simulation model is shown in figure 4.1. Description of each individual submodel is given in the following sections. Detailed flow charts and the computer programme of the simulation model is contained in appendix D.

4.2.1 Precipitation Submodel

This submodel is partially interacted with the surface flow submodel. This interaction feature is included as a provision for future development in which initial losses are to be included.

Input into this submodel is the precipitation data. Two types of precipitation data are allowed. The first type, designated 0 (zero), is cumulative precipitation over the time interval in inches. The second type, designated 1 (one), is the rate of precipitation over the time interval in inches per hour.

The submodel is essentially converted precipitation data input into rate of precipitation over a specified time interval used in simulation of surface flow. The conversion is accomplished assuming constant interpolation of precipitation over the input time interval. If the total time of simulation run, if so desired, is longer than the precipitation time period, zero rate of precipitation is automatically gen-

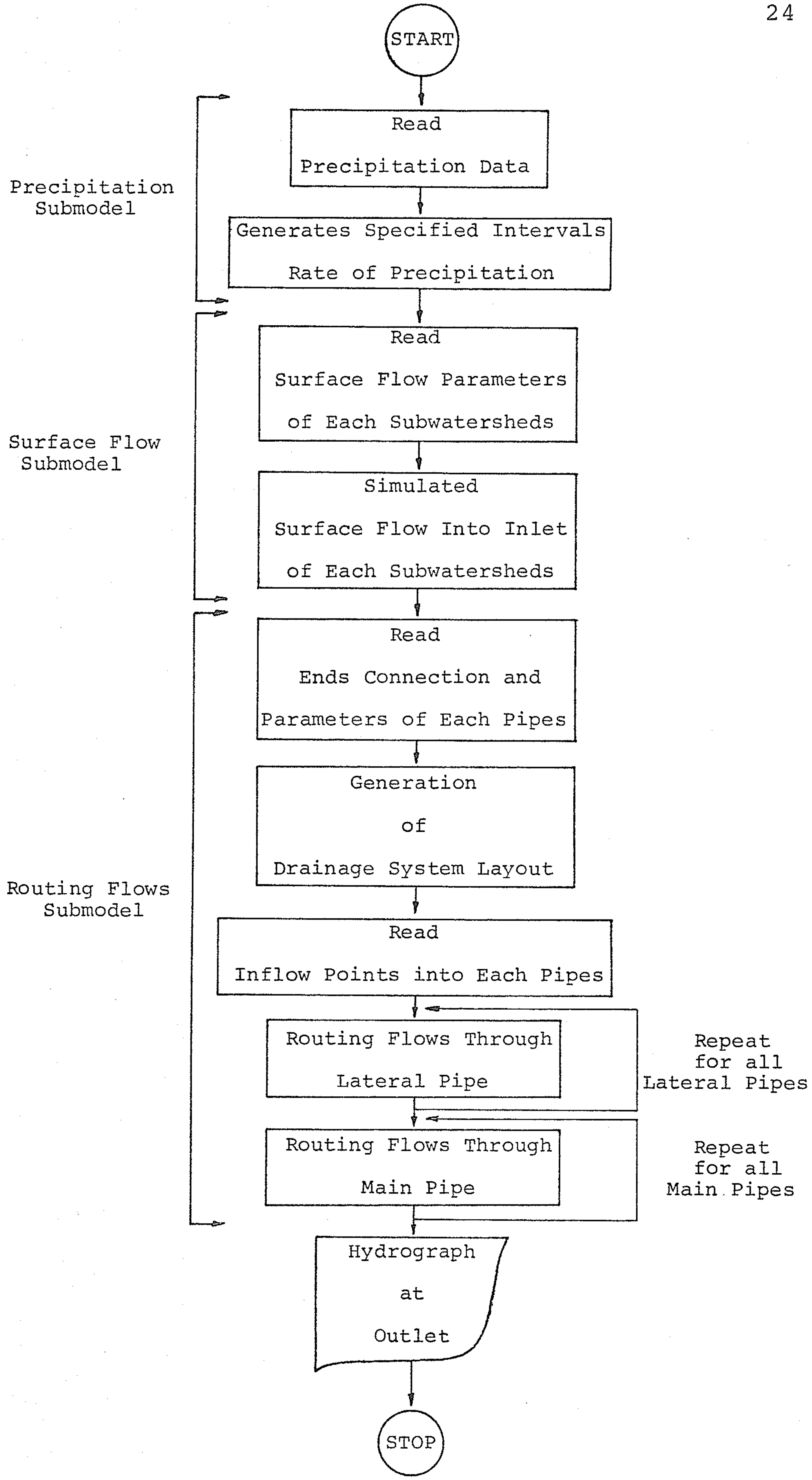


Figure 4.1 Structure of the simulation model

erated by the submodel for the exceeded time period.

4.2.2 Surface Flow Submodel

This submodel used inputs from the precipitation submodel together with land surface physical characteristics to simulate surface flow to various inlet points.

Initially, the watershed is divided into subwatersheds according to direction of flow into inlet points. For each subwatershed, the submodel simulates the surface flow by computing various quantities in relationship with the surface flow previously described in Section 3.2. The increment of detention storage during any time interval is taken simply as the product of the impervious area of subwatershed and the excess rate of precipitation during the time interval. At the present, it is assumed that any inlet point is capable of passing any flow into the drainage system. Therefore inlet properties are not included in computations of this submodel.

The output from this submodel is a complete hydrograph of flow to any inlet point. If so desired, printed output of any inlet hydrograph can be obtained by excercising one of the option feature available in the model.

4.2.3 Routing Through The Storm Drain Submodel

This submodel is composed of various sections in order that the routing through the system can be accomplished without any outside intervention. The submodel is first generated from the layout of the drainage system from the ends connection status of each pipe, and number of junction boxes in the system. Inflow points into each pipe are then identified and rearranged in order of their distance from the upstream end of the pipe if they are not already in the order. If there are more than one inflow hydrograph at the upstream end of a pipe, these hydrographs are first added before routing procedures are commenced. Routing through each pipe is carried out using the characteristics method with specified intervals previously described in Section 3.3. Since most upstream end inflow hydrographs start off with zero flow, and the routing method used can not commence computations with zero flow, a small initial base flow is added to the upstream end inflow hydrograph. This small initial flow is computed from the specified depth through the pipe using steady flow condition equations. When routing through each pipe is completed, this artificial base flow is subtracted in order not to accumulate this base flow through the system. Losses across any junction point are assumed to be zero since inclusion of these losses tend to underpredict flow through the pipe (21).

In order to generate the layout of the drainage system and routing in correct sequence, pipes in a drainage system are classified into two types according to their end connection status. If the upstream end of a pipe is not connected to any junction boxes, the pipe is classified as lateral pipe and the end connection is designated as 0 (zero). If the downstream end of a lateral pipe is only connected to a junction point, the end connection status is also 0, and this lateral pipe is considered as an inflow point into a main pipe. A main pipe is a pipe that has the upstream end connected to a junction box. Generally, lateral pipes can have only inflows from surface flows whereas a main pipe can have inflows from surface flow and inflows from lateral pipes.

Routing through all lateral pipes is carried out first so that hydrographs of all inflows into a main pipe are available. Routing through the main pipe is then followed in sequential order from the upstream end of watershed to the outlet point.

Outflow hydrographs and maximum flow quantities at specified intervals of any pipes can be printed out as part of output by exercising the option feature available.

4.3 Simulation Procedure Descriptions

In order to operate the programme to simulate the runoff, three sets of data are required, namely, the precipitation, the land surface parameters and drainage parameters, and drainage network layout data.

The first card in any data set for simulation is an identification of the watershed or the number of run. This information must not exceed twenty characters in length and must be contained in the first twenty columns of the data card. This is an option provided for convenience in identifying the outputs. A blank card must be substitued if no identification is so desired.

4.3.1 Precipitation Data Input

Precipitation data input can be either rate of precipitation in inches per hour or precipitation in inches during time interval, as described in the previous section 4.2.1. Therefore appropriate identification for each type of precipitation is required as part of precipitation data.

The first card in this data subset contains the information on the total number of precipitation intervals (INT), type of precipitation input (NTYPE) and total length of simulation run (TF) in minutes. Note that all time specifications must be in minutes only.

The remaining precipitation data subset contains informations on the desired precipitation-time histogram. Each card contains only a single coordinate point of the histogram, with the time ordinate(TIME) preceeding the precipitation ordinate (PREC). The values of precipitation ordinates are taken as the values at the end of the precipitation interval, with the exception of time zero, where precipitation is zero.

Refering to the sample precipitation-time histogram, figure 4.2, the total number of precipitation intervals (INT) is six, and the type of precipitation is as designated, zero. The total time of simulation run (TF) is taken to be equal to the total time of precipitation which is thirty minutes long. Therefore, the information contained on the first card of this data subset is 6,0, and 30. The format of data input for this card are I5, I5, and F5.0 for INT, NTYPE, and TF respectively.

The precipitation-time information on each of the rest of this data subset is the time ordinate and precipitation ordinate values of each points of the histogram. Hence, information on each card for the example will be 0. 0.;5. 0.25..., 30. 0.10. The formates of input data for each of these cards are F10.2, F10.2 for TIME and PREC respectively. The sample input data set for the precipitation sample of figure 4.2 is shown in figure 4.3.

4.3.2 Land Surface Parameters

Land surface physical characteristics used as parameters in the simulation of overland flow to inlet points are fed in as part of the data input. The land surface of a watershed is divided into appropriate subwatersheds. Each subwatershed overland flow is considered to contribute directly to an inlet or catch basins of the drainage system.

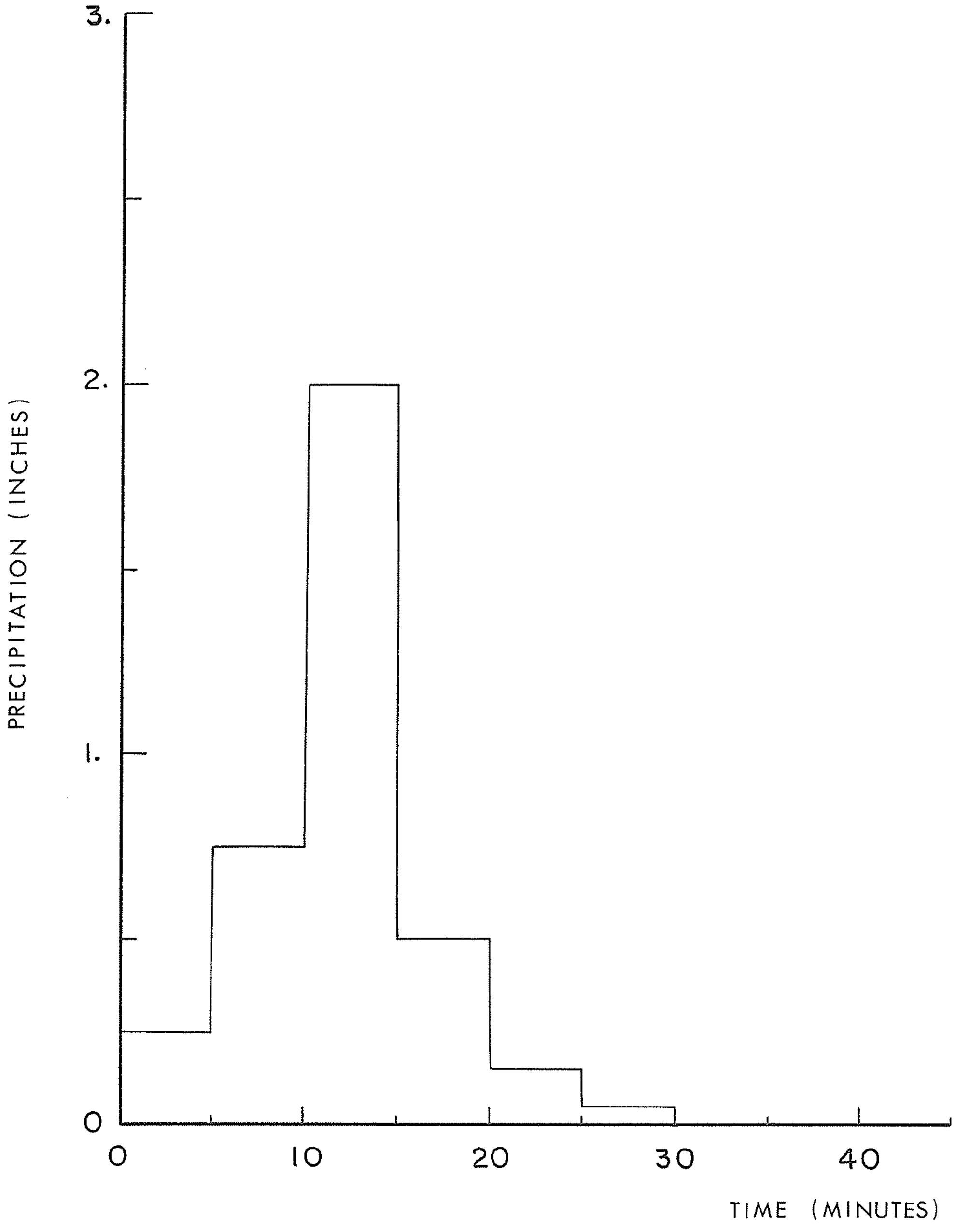
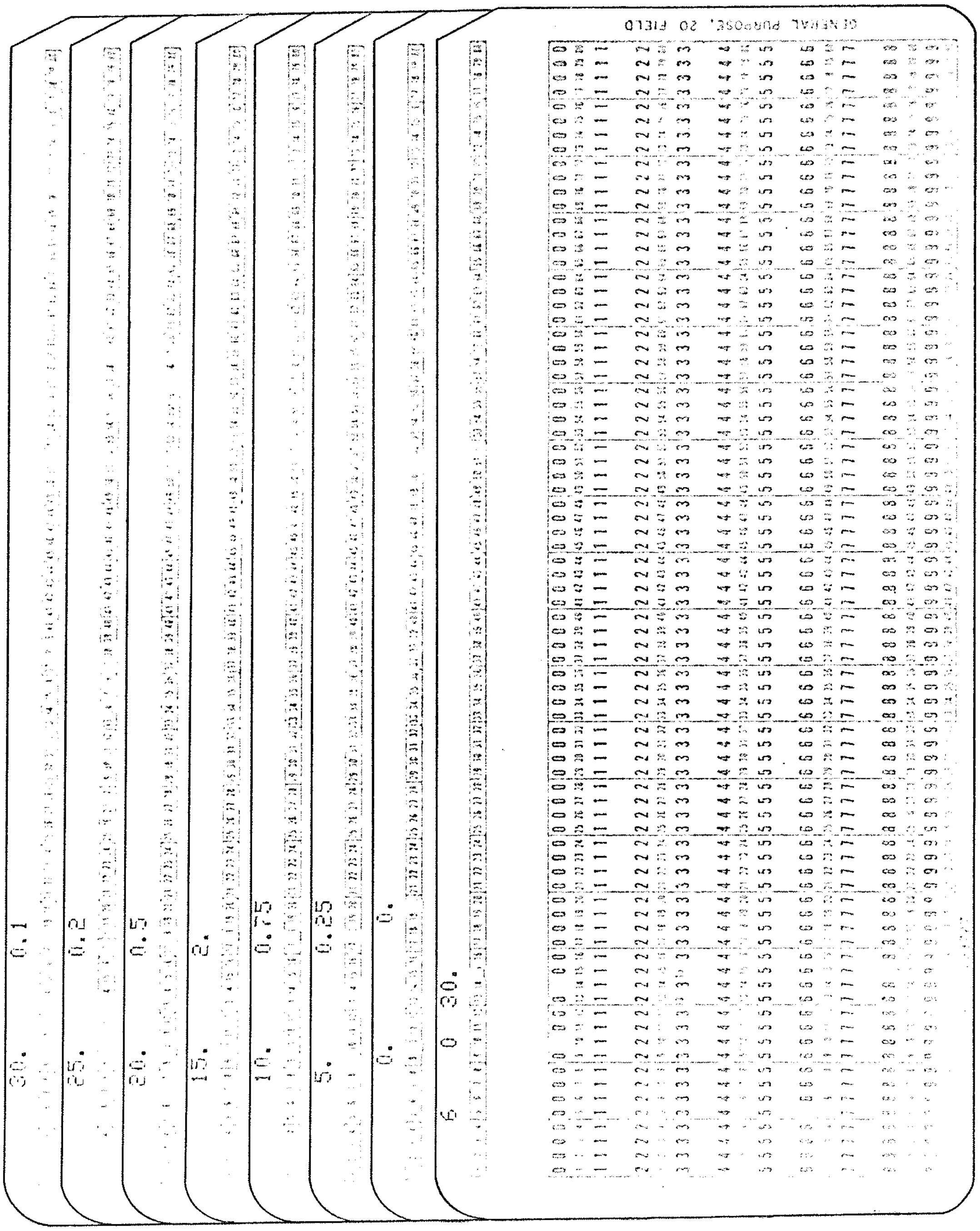


Figure 4.2 Sample of precipitation data



30. 0.1

25. 0.2

20. 0.5

15. 2.

10. 0.75

5. 0.25

0. 0.

6 0 30.

GENERAL PURPOSE, 20 FIELD

Figure 4.3 Sample of precipitation data input

Only directly connected impervious areas in each subwatershed are considered to contribute to runoff. Therefore, only the gross impervious area of each subwatershed is used and roof surfaces should be converted into an equivalent area at ground surface. The slope of the subwatershed to the inlet is taken as an average slope of flow path to that inlet. The value of flow path length is also an average value, which can be estimated from an available map of the area. A guildline value of surface Manning's friction factor is shown on table 4.1. More details of the estimation guildlines and the value to be selected can be found elsewhere (2).

The first card in the land surface parameters data subset contains information on the number of land surface subwatersheds (NBL). Each card of the remainder of the data subset contains information on land surface characteristics of each subwatershed, namely, impervious areas of subwatershed (square feet), average flow path length (feet), average slope (feet per foot) and estimated surface Manning friction factor.

The format of the first card containing information on the number of subwatersheds is I5. Formats for information on each subwatershed are F10.5, F10.2, F10.6 and F10.5, respectively.

4.3.3 Drainage Parameters and Layout

In order to route flow through storm drainage system

TABLE 4.1

Estimated Manning Friction Factor For Overland Flow

Watershed Cover	Manning's n for Overland Flow
Smooth Asphalt	0.012
Asphalt or Concrete Paving	0.014
Packed Clay	0.03
Light Turf	0.20
Dense Turf	0.35

to the outlet, physical characteristics of each individual pipe in the drainage system as well as drainage lay-out including positions of various inflow points need to be known.

To generate layout of the drainage system, pipe end connections to various junction boxes are needed. This information and physical characteristics of each pipe is the first of two parts of this drainage data subset. Information on the numbers and location of inflow points of each pipe is the second part. The inflow points can be inflow from inlets, inflow from lateral pipes or a combination of the two.

The first card in this data subset consists of information on the number of pipes and junction boxes in the drainage system. Numbering of pipes can be in any sequential order. However, numbering of junction boxes must proceed in sequential order, that is, a junction box at the downstream end must always have a higher numerical number than junction box proceeding immediately upstream.

Referring to figure 4.4, the drainage system consists of 14 pipes and 3 junction boxes. Pipes number 3, 4, 5, 6, 11 and 10 are considered to be lateral inlow pipes since pipe numbers 7 and 13 are taken to be unbroken at those connecting points. Numbering of the junction boxes proceeded sequentially as follows; junction boxes at the upstream end of pipe number 7 and 13 are to be numbered first since the downstream end of both pipe are connected to the same junction box. Therefore,

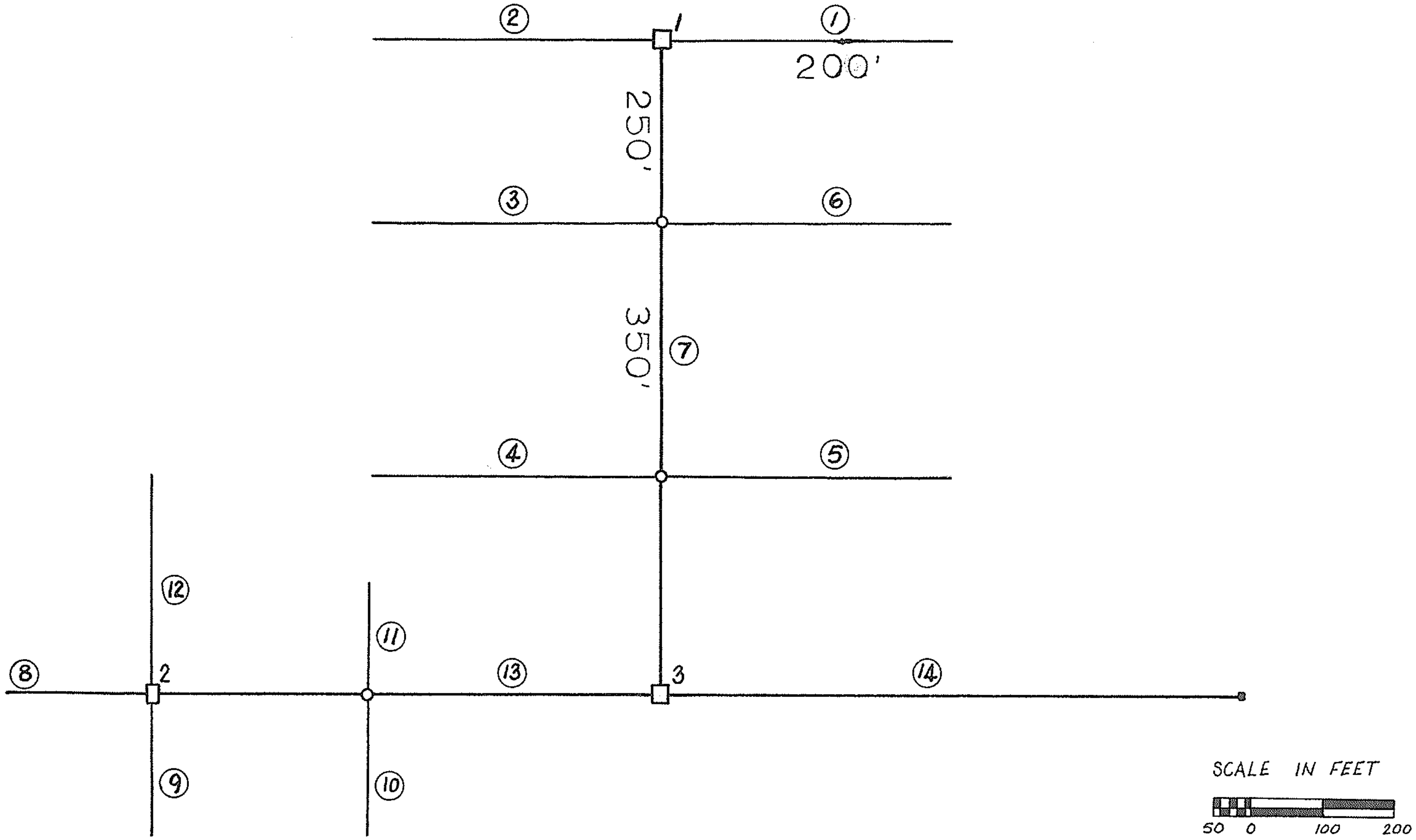


Figure 4.4 Sample of drainage system layout

numbers 1 and 2 are assigned to the upstream end of pipes number 7 and 13, respectively. The downstream end of both these pipes connecting to the same junction box were assigned number 3. The last junction box at the end of pipe number 14 or the outflow point need not be numbered. Therefore, information on the first card of the data subset of the first part are 14 for the total number of pipes in the system and 3 for the total number of junction boxes in this system.

The following cards consist of information on end connections (MCON) and physical properties (PIPE) of each pipe. The end connection of any pipe must be specified in the direction of flow, that is, the upstream end first then the down stream end. If a pipe end does not directly connect to any junction box, 0 (zero) or blank space is used to designate this end status. The physical properties of a pipe consists of length (feet), diameter (inches), Manning friction factor, slope (foot per foot), and outflow control coefficient and exponent. If, however, the end flow is considered to be a free flow, both coefficient and exponent become zero as the discharge is computed from critical depth criteria instead.

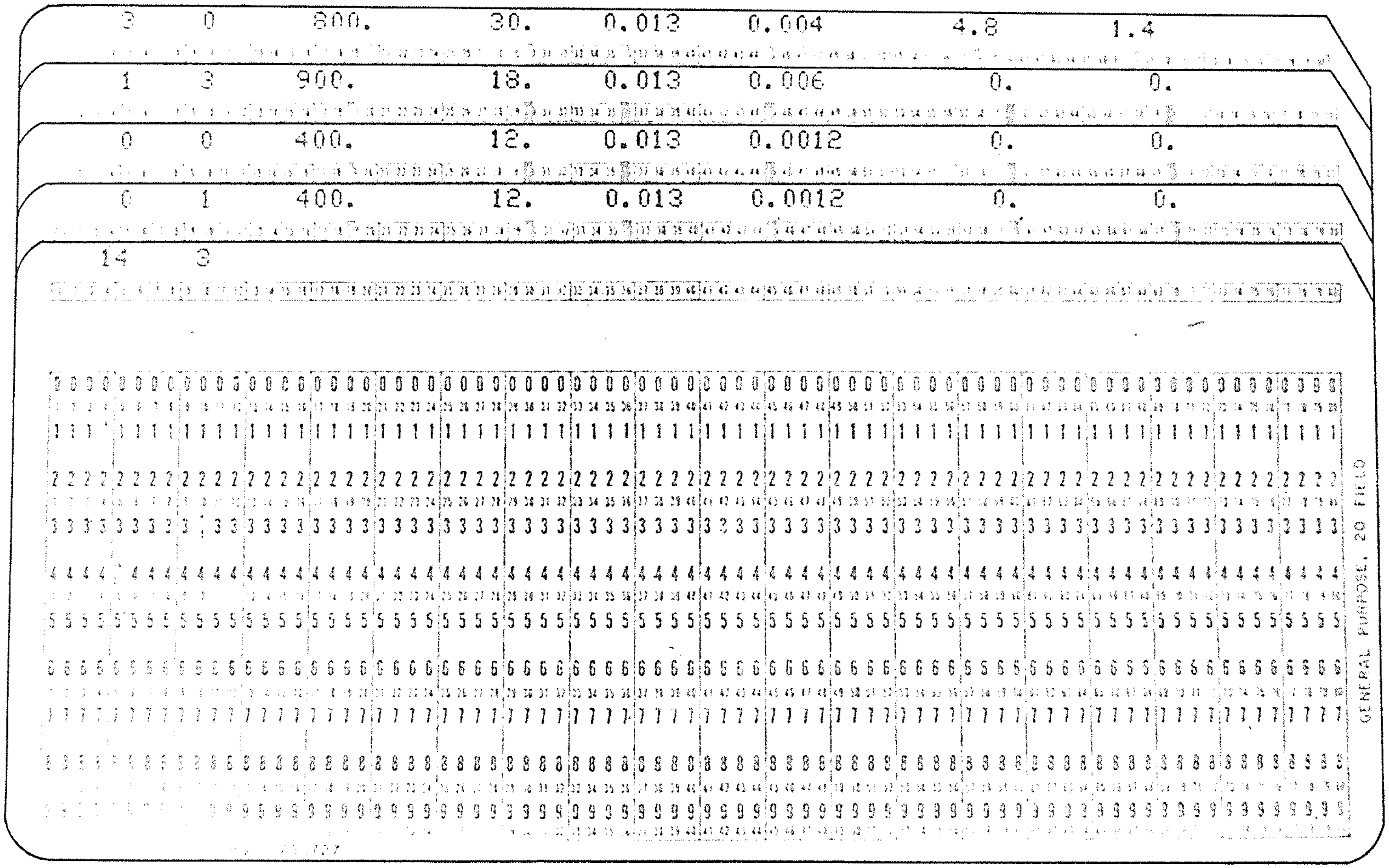
The format used for the card containing information on the total number of pipes (NP) and the total number of junction boxes (NJ) of the system are both I5. The formats for cards containing information on end connections (MCON) and pipe physical properties (PIPE) are I5, I5, F10.2, F10.2, F10.5, F10.5, F10.2 and F10.2, respectively.

The sample data input for the first part of this data subset using figure 4.4 as a sample system is shown in figure 4.5. In this sample the first card, contains information on pipes number 1, 6, 7 and 14, respectively. Note that the end flow condition of all pipes are assumed to be free flow except that of pipe number 14 in which outflow is controlled.

The second part of this data subset consists of information on inflow points in the drainage system. This inflow point information must be read in sequence order of pipe number. For each pipe, the information is further divided into two parts. The first part consists of information on the number of surface flow inflow points (NLS), followed then by the number of each inlet point (LATS) and its distance (XLATS) measured in feet from the upstream end of the pipe. If there is no inflow point from the surface flow, a zero or blank is required before proceeding to the second part.

The format used for the card containing information on the number of surface inflow points (NLS) is I5. Each of the cards containing information on the number (LATS) and distances (XLATS) of each inlet uses format I5, F10.2.

The second part of this sub-subset consists of information on the number of pipe inflow points (NLP), followed by



```
    3    0     800.       30.     0.013    0.004      4.8      1.4
    1    3     900.       18.     0.013    0.006      0.       0.
    0    0     400.       12.     0.013    0.0012     0.       0.
    0    1     400.       12.     0.013    0.0012     0.       0.
   14    3
```

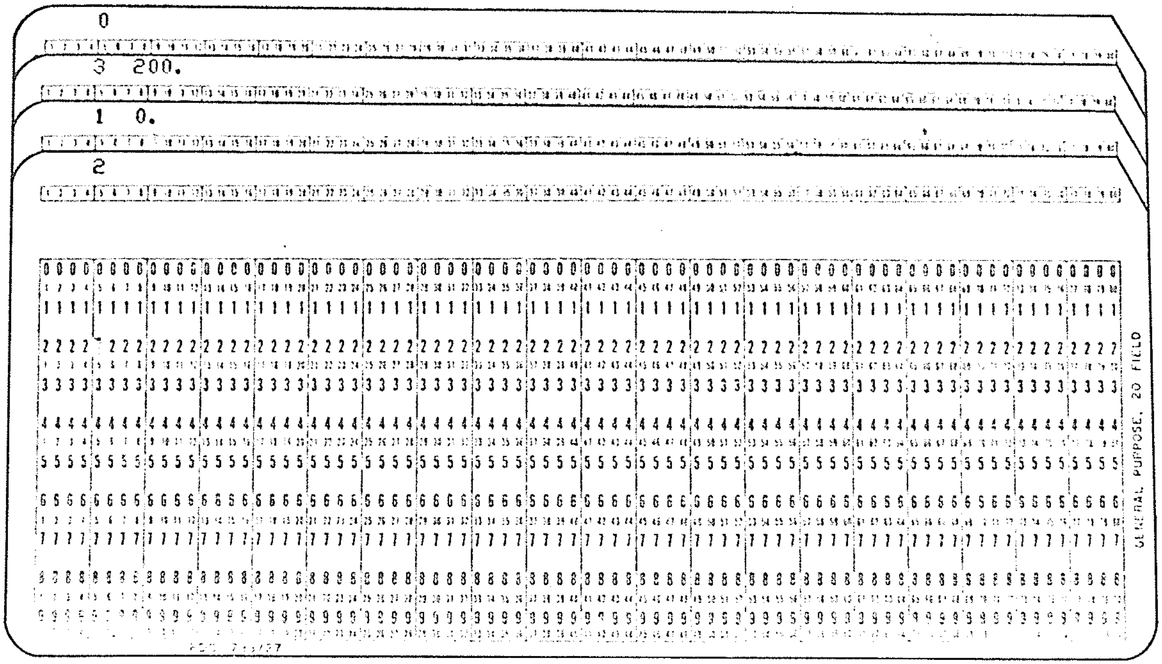
Figure 4.5 Sample of drainage system and physical characteristics Data Input the number of pipe inflows (LATP) and their distance (XLATP) measured in feet from the upstream end of the main pipe. General descriptions and the sequence of data input including the format of this second part are the same as in the first part.

Figure 4.6(a) and 4.6(b) show sample data input on inflow points of pipes number 1 and number 7, respectively. For pipe number 1, there are two surface inflow points, inlet number 1 at zero distance and inlet number 2 at 200 feet from the upstream end of the pipe; and, there is no pipe inflow pipe. For pipe number 7, there is no surface inflow point; hence, zero on the first card. There are however 4 pipe inflow points, pipes number 3, 6, 4, 5 at distances of 250 feet, 250 feet, 600 feet and 600 feet from the upstream end of pipe number 7, respectively. Note that information on surface inlow points must preceed the information on pipe inflow points.

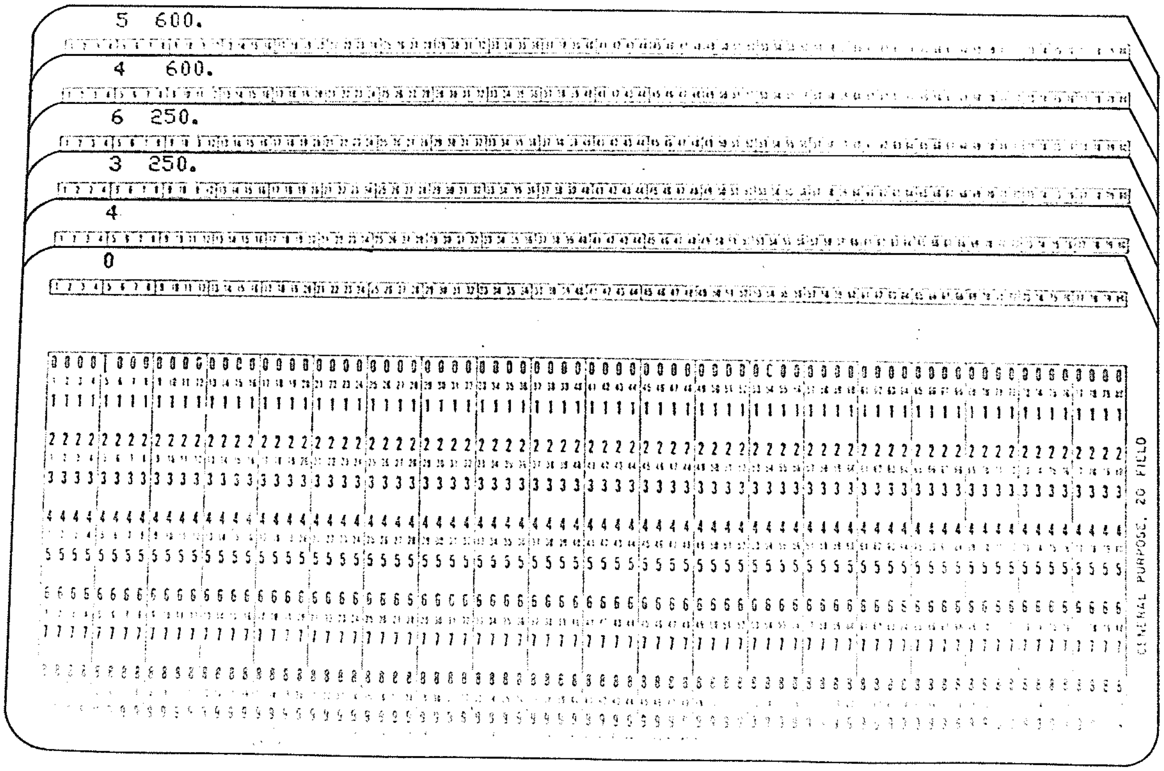
4.3.4 Option on Output

At the present time, three options of output are available, namely, outflow from any pipe in the system, maximum quantities at any specified distance interval of any pipe in the system, and the hydrograph of land surface flow.

If none of the options is exercised, a blank card or zero in various appropriate columns is needed as the last



(a)



(b)

Figure 4.6 Sample of inflow points into drainage system data input of (a) pipe number 1, (b) pipe number 7 card of the data set. If the first or the third option is to be excercised, number 1 must appear in the appropriate column in this data card. However, if the second option is excercised, an appropriate number corresponding to the interval at which the maximum quantities are required must be used.

The field of data input for this option card is I5 for all options.

4.4 Summary of Data Input

The data deck for simulation of the model is composed of the following data;

i) Identification card, input can be either alphabetic or numeric or a combination of the two. This data should not exceed twenty characters in length.

ii) Precipitation data, composed of data on intervals, type of precipitation and total time of simulation run on one card followed by the time and precipitation values at end interval.

iii) Surface characteristics parameters, composed of the number of subwatersheds card followed by characteristics of each subwatersheds.

iv) Drainage layout and parameters, composed of the number of pipes and junction boxes in the system, followed by the ends connection status and characteristics of each pipe, then data on inflow points of each pipe. Each pipes inflow points data is composed of the total number of inflow points followed by the number of distance from the upstream end of that inflow point. For each pipe, surface inflow point data is read in first, followed by lateral inflow points data.

v) The last card is the options card that are to be excercised regarding output.

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 Results

Pulberry subdivision of the municipality of St. Vital, Winnipeg, Manitoba was chosen for testing the model. Subdivision of the watershed and the lay-out of the storm drainage system as modified from the proposed layout by Templeton Engineering of Winnipeg is shown in figure 5.2.

The watershed is semi-arbitrarily divided into subwatersheds according to the previous explanation in section 4.3.2. The two ends of the boundary of a subwatershed is chosen to coincide with the crest on the roadway through the subwatershed. The other two ends boundary are arbitrary divided between two roadways. The total number of subwatersheds is seventy-five.

The impervious area of each subwatershed is estimated as a percentage of the total area. The estimated impervious area of each subwatershed ranges from thirty five percent to over fifty percent of the total area. It is assumed that the flow path of surface flow into an inlet of any subwatershed is dominated by the contour of the roadway crossing the sub-

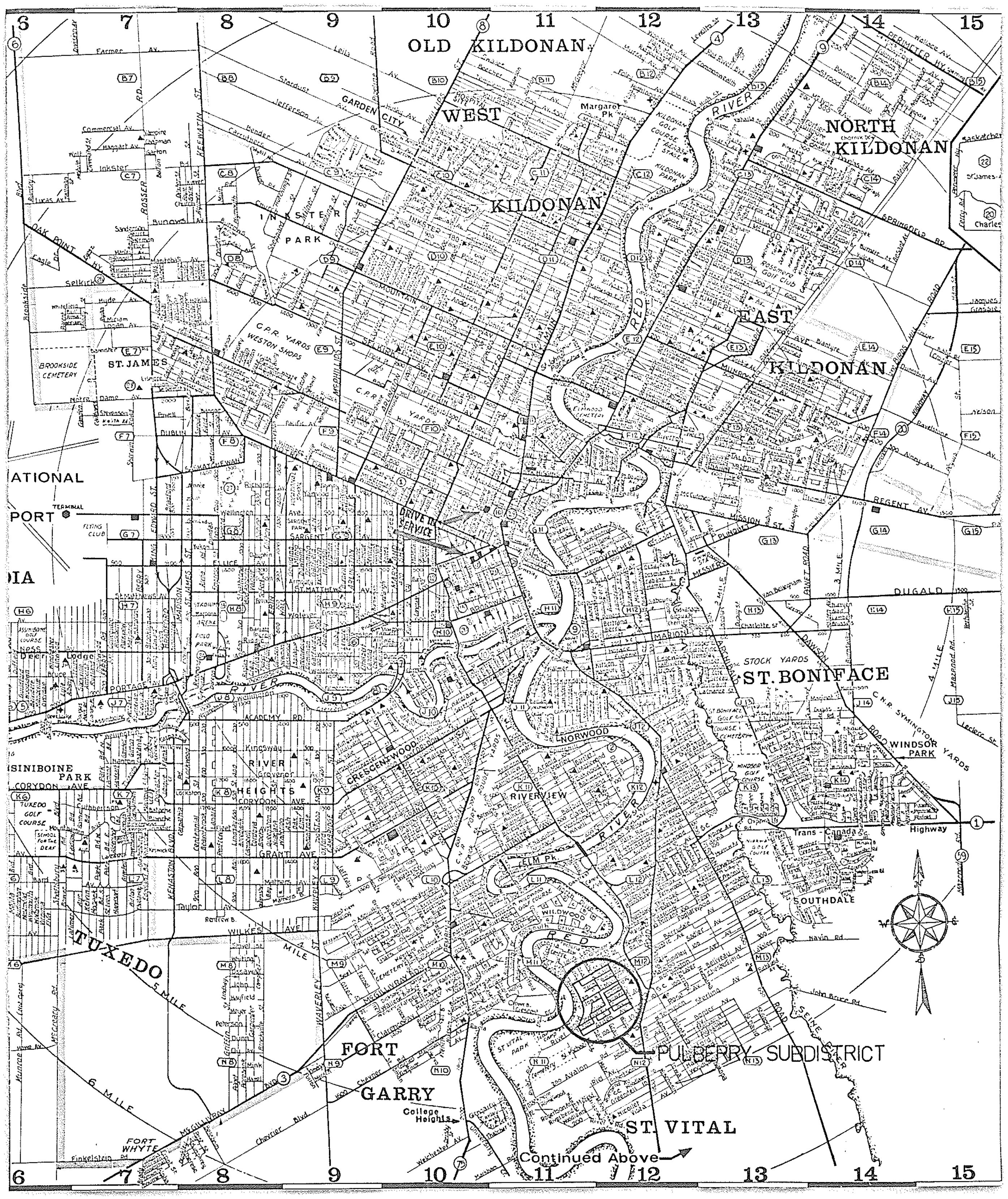


Figure 5.1 Location map of Pulberry subdivision

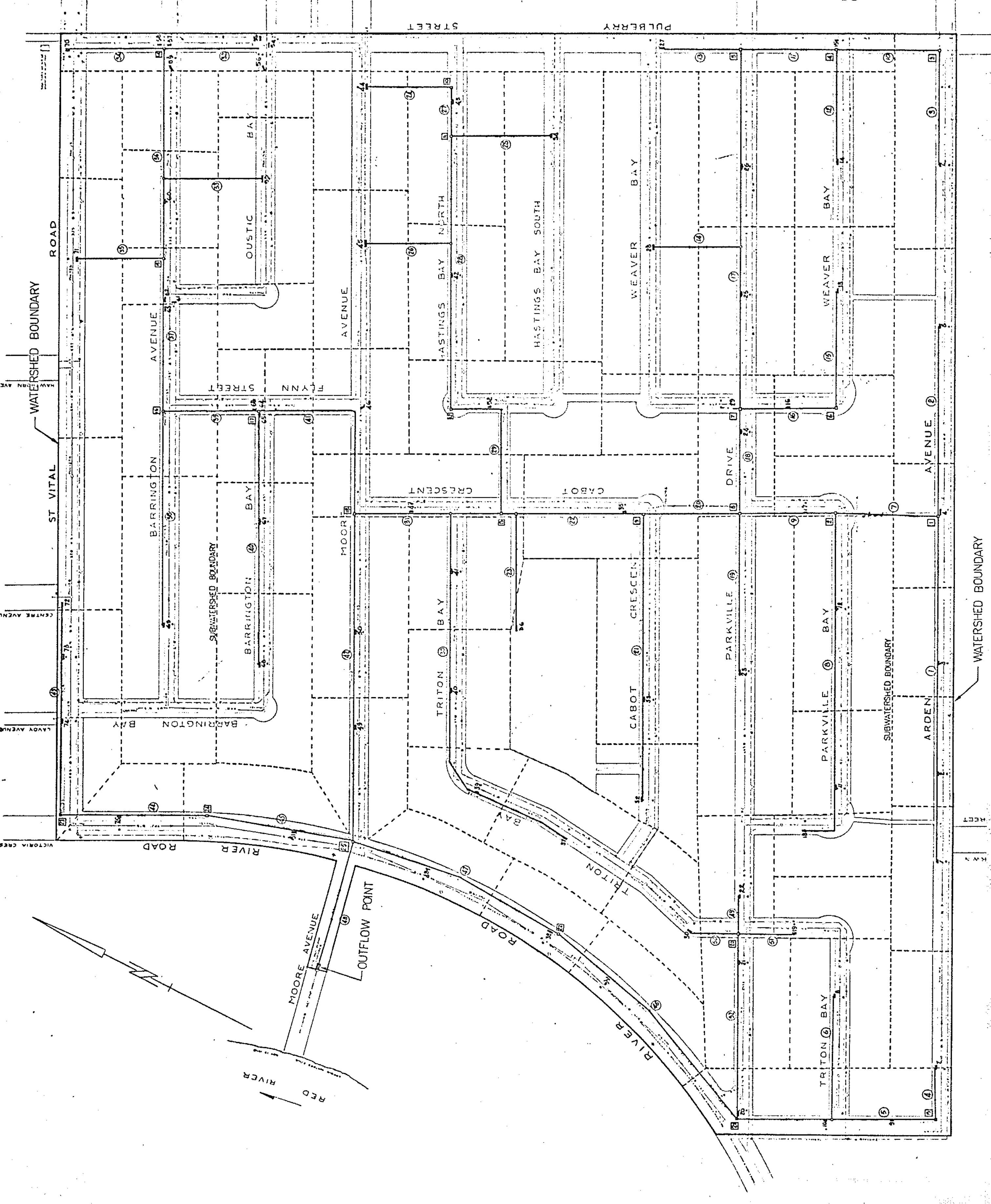


Figure 5.2 Watershed subdivision and layout of storm drainage system

watershed. Hence the average slope of any subwatershed is estimated from the average slope of the roadway. Also, Manning's friction factor of each subwatershed is estimated based on road surface criteria, the average value usually taken as 0.016.

Pipes and junction boxes in the drainage system are numbered as previously explained in chapter 4.3.3. The Manning's friction factor of all pipe is taken as 0.013 (30), as pipes used are reinforced concrete pipe. Pipe outflows are also assumed to be free flow. The length, slope and diameter of each pipe are estimated from proposed design of the drainage system by Templeton Engineering of Winnipeg.

To study runoff from the watershed, a synthesized five-year return period storm of the Winnipeg area, as shown in figure 5.3, was used as precipitation input.

Preliminary studies on surface runoff from the five-year storm in the Winnipeg area have been carried out as part of testing the surface runoff submodel. It is evident from these studies that the partial precipitation period from 30-minute to 90-minute interval can be substituted for the full 120-minute precipitation period for simulation of surface runoff with an insignificant difference in the peak rate of runoff. Only part of the rising limp of the simulated hydrographs show any appreciable difference as indicated in figure 5.4. There-

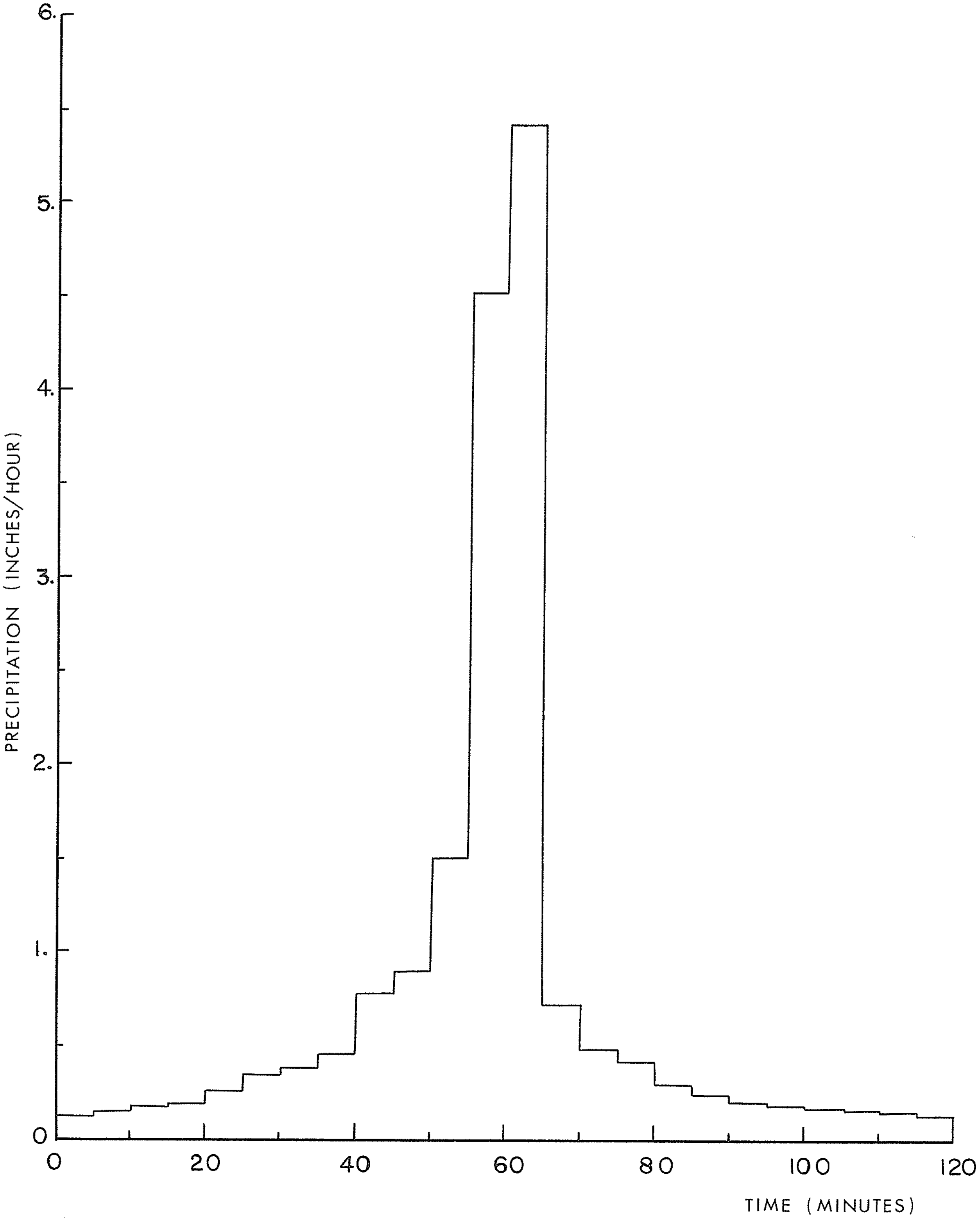


Figure 5.3 Five-year return period storm of Winnipeg area

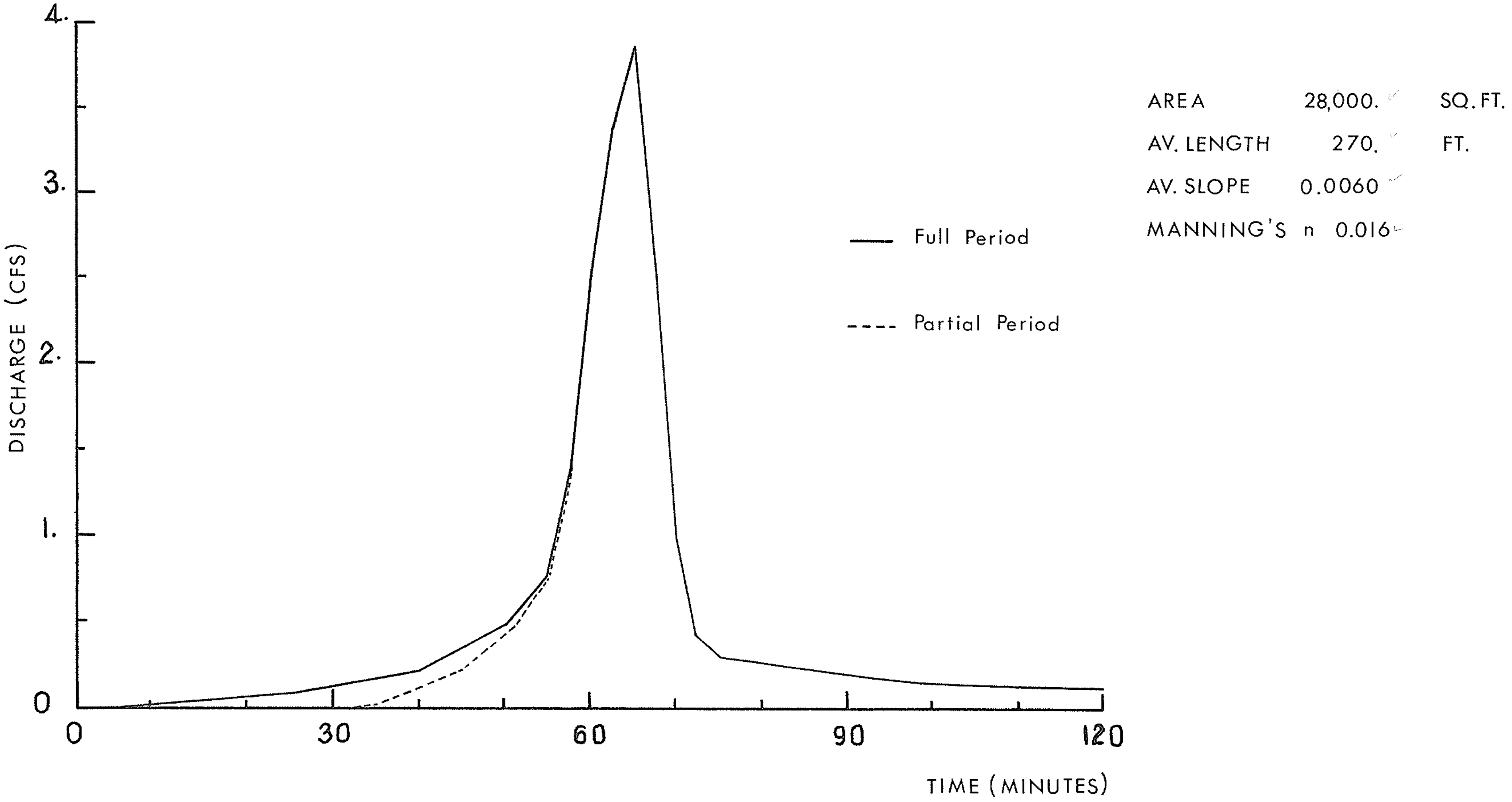


Figure 5.4 Comparison of simulated overland flow hydrographs

fore, in this particular case a partial precipitation period can be substitued for the full precipitation period in subsequent studies. The difference in computer time required for simulation of surface runoff between a partial precipitation period and a full precipitation period for each subwatershed is only a small fraction of a second CPU time. However over a considerable number of subwatersheds as in this study, saving in computer time is substantial. Furthermore, the routing period can also be reduced.

Routing through the storm drainage system submodel was developed and tested successfully against the Colorado State University data (34,35). The testing data always has an appreciable amount of base flow. When the submodel is integrated and a very small base flow is introduced to start the computation, the routing procedure has to be modified to handle this very small initial flow. The routing computations become exceedingly lengthy in time and required considerable more computer storage than the initial procedure. The computer time required for routing in each pipe comes to the order of two minutes CPU time. For this watershed where there are fifty two pipes in the drainage system, the total time required for routing alone is estimated to be in the order of two hours CPU time. This time requirement is considered to be far too excessive to run the complete synthesized watershed. Therefore, it was decided to terminate the study at this point.

5.2 Discussions

Generally, exclusion of initial losses from considerations of runoff processes would result in overprediction of peak rate of runoff and early responses of the watershed. If actual measured runoff and simulation runoff of a watershed are to be compared, initial losses have to be included for a better understanding of the effects of various parameters on the watershed response. However, for designing purposes, neglecting the initial losses has only marginal effect since precipitation data used is generally a synthesized data that already has a limited accuracy.

Consideration of runoff from only the impervious part of a watershed does simplify computation considerably. However, the exclusion of the pervious area contribution to runoff has resulted in a tendency to underpredict the peak rate of runoff. Approximation of a single average flow plane into an inlet point applies fairly well to a relatively flat watershed, especially if the outlet is located at the end of the flow path. In most of the actual subwatersheds, however, inlet points are generally within the watershed. Under this condition a multiple flow planes approximation should yield a better approximation to actual runoff than the single flow plane assumption. The accuracies that might be gained from this consideration may be limited by the basic available data of a watershed.

The relationships adopted here for simulation of surface flow are tailored for the purpose intended; rapid simulation of overland flow from limited available data. They are not intended to compete with the more general or precise solutions for unsteady two dimension flow. The relationships adopted are substitued for the more exact method to gain simplicity and calculating speed, while attempting to maintain a reasonable approximation to physical behaviours. Constant theoretical resistance parameters for overland flow with rainfall have not yet been developed, and even the division between the laminar and turbulent range is still difficult to establish. Manning's equation is used although there is considerable experimental evidence that Manning's n is not constant with depth decreases and Reynold's numbers approach the lower limit of the turbulent range. Despite the limitations of these assumptions, particularly the use of constant Manning's n, the relationships used appear to give a reasonable approximation to actual physical behaviours.

The approximation of free outflow at the end of a pipe into any junction point is certainly not accurate over the whole range of outflow conditions particularly at high flow where back water effects become pronounced. However there is no study that can indicate a simple accurate discharge-depth relationship at the end of a pipe under all conditions of flow. Inclusion of losses across a junction tend to under-estimate flow; furthermore, there is no study that covers losses across all type of junctions that exist. However neglecting losses across a junction does simplify computations even though there is a tendency to overpredict the flow. Introduction of a small base flow is a necessity to start the routing procedure. This initial flow is considered to be sufficiently small so that errors in prediction of maximum flow quantities should be insignificant. Furthermore this initial flow is not accumulated through the system.

At very low flow, the curvature of characteristics become so acute that a linear approximation is applied only at very small intervals. Since the method used the same specified intervals throughout the computation, the scheme then required a large amount of storage and computer time in routing flow through a storm drain. Hence the scheme becomes less efficient if the initial flow is very small. The assumption of a constant Manning's n throughout the whole range of flow may not be quite correct, particularly at very low flow. It is suspected that this assumption may also introduce some inaccuracy and difficulty in the computations at small flow.

The relationships adopted for routing of flow through the drainage system is the most general method for computation of unsteady free surface flow. The application of the method is justified if accurate estimations of basic data are available. In this study, it is apparent that the method of characteristics is neither justified due to limited data available nor feasible due to excessive computer time requirement. Alternative routing methods should be investigated and substituted to improve the efficiency of the model.

The digital simulation approach should not be considered to design an isolated storm drain. Considerable background information is required for this approach, primarily for the development of an accurate estimation of various parameters. However, it is the thorough analysis of flow and precipitation data that replaces subjective estimates of runoff, and allows realistic derivation of flows at selected frequencies. If several watersheds in the same region are involved, the cost of urban drainage provides ample justification for an advanced design method.

The relationships outlined are for flows with a free surface and would not apply with a storm drain surcharge or flow under pressure. They do not apply well to a large area with areal variation in rainfall intensity. Effects of various factors excluded from consideration in order to simplify the various relationships are not intended to compensate for each other. Their compensating effects are merely a coincidence.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A mathematical method to synthesize urban runoff has been presented. A simulation model was developed as a means of providing a practical solution to the proposed mathematical method. The model is capable of computing runoff hydrographs as well as velocities and depths of flow at desired points within an urban watershed. The model requires data on physical characteristics of the watershed, its drainage system and local hydrology.

The model developed is derived from sequencial integration of three submodels, namely, (1) precipitation, (2) surface flow and (3) routing through storm drainage system submodels. The precipitation submodel generates excess precipitation at specified intervals from precipitation data input. The surface flow submodel simulates surface flow to inlet points of each subwatershed using a two dimensional approximation to the overland flow method. The routing through the storm drainage system derived an outflow hydrograph from routing inflow hydrographs into the drainage system using the characteristics method with specified intervals.

By virtue of the assumptions used in the derivation of the various mathermatical relationships, applications of the model are restricted to watersheds of relatively flat terrain.

From test studies of the model using data from the Pulberry watershed, it is evident that the model is not feasible for practical use in designing a storm drainage system due to the excessive requirement of storage and computer time on its routing through the storm drainage submodel.

6.2 Recommendations

Future studies of the various processes involved in urban runoff should include an analysis of the initial losses. Inclusion of these losses into the model may yield a better prediction of runoff.

In areas where a bare soil surface shows a tendency of imperviousness, studies of the contribution of runoff from such areas should be carried out before any decision is made to exclude such contributing areas. The possibility of using multiple flow planes in simulation of the inlet hydrograph should be considered if sufficient data are available. Restriction of the flow into an inlet point in terms of the inlet characteristics may be included in considerations if such data are available.

A simpler routing procedure should be considered as substitution of the existing routing procedure in the model in future studies. Other routing methods as appear from time to time in various publications should be investigated and evaluated.

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APPENDIX A

Overland Flow : A Theoretical Consideration

The movement of overland flow toward channels is generally assumed to be two dimensional or to take place in a thin sheet of infinite width. Overland sheet flow is considered to be initially laminar, becoming turbulent as the depth and velocity of the flow increase sufficiently before a channel is reached.

However, in this appendix only a simple analytical approximation for turbulent two dimensional flow will be outlined.

A.1 Approximation For Two Dimensional Flow

The features of overland flow that are of primary interest are those that govern the response to various patterns of uniform rainfall. For turbulent flow the discharge is related to flow depth in the form

$$q = ay^{b} \qquad .. \text{A1}$$

Assuming the validity of Manning equation, q becomes

$$q = \frac{1.486}{n} S^{\frac{1}{2}} y^{5/3} \qquad .. \text{A2}$$

where the hydraulic radius of the flow is assumed equal to the flow depth, and the energy gradient is assumed equal to the gradient of the flow plane.

The continuity equation for two dimensional flow is

$$\frac{\partial q}{\partial x} = \eta - \frac{\partial y}{\partial t} \qquad \text{.. A3}$$

where η is the inflow or supply rate in $ft^3/sec/ft^2$.

Two useful conclusions can be drawn from equation A3. At equilibrium $\frac{\partial y}{\partial t}$ is zero, and

$$q_e = \eta x \qquad \text{.. A4}$$

where q_e is discharge in $ft^3/sec/ft$ at any section x on the flow plane. As Wolf (33) points out, the change in discharge as a function of x on a uniformly sloping plane must be zero, before local equilibrium is reached. Hence the depth at any point on the plane is

$$y = \eta t \qquad \text{.. A5}$$

prior to local equilibrium.

For overland flow on the plane in figure A1, with depth y at a distance x along the flow plane, the general shape of overland flow hydrograph between $t = 0$ and $t = t_e$, is shown in figure A2.

The outflow at equilibrium is $q_e = L$, and the total inflow between time $t = 0$ and time $t = t_e$ is t_e L.

The volume of surface detention at $t = t_e$, is

$$D_e = \int_0^L y \, dx \qquad \text{.. A6}$$

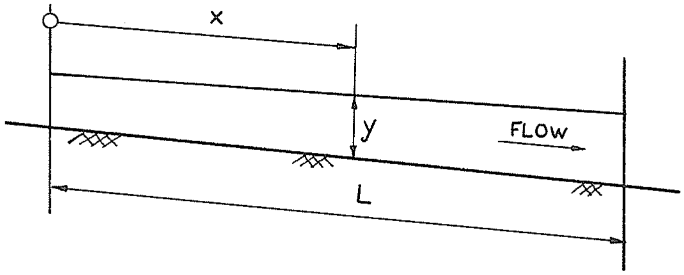


Figure A1 Overland flow plane

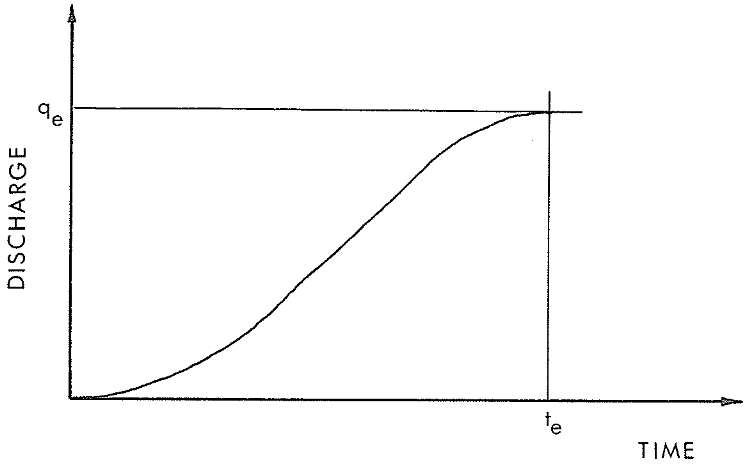


Figure A2 Overland flow rising limp of a hydrograph

The total runoff from time $t = 0$ to $t = t_e$ is some fraction β, of the total inflow during the period. Hence,

$$\beta t_e \eta L = \int_o^{t_e} q \, dt \qquad .. \text{ A7}$$

The total inflow is

$$t_e \eta L = D_e + \beta t_e \eta L \qquad .. \text{ A8}$$

or the time to equilibrium is

$$t_e = \frac{D_e}{\eta L (1.0 - \beta)} \qquad .. \text{ A9}$$

From equation A5 the depth near the lower edge of the flow plane should be

$$y_e = (\frac{t}{t_e}) \, y_e \qquad .. \text{ A10}$$

from $t = 0$ to $t = t_e$.

From equation A1 and A10

$$q = ay^b = a(\frac{t}{t_e})^b \, y_e^b \qquad .. \text{ A11}$$

Hence, from equation A7

$$\beta t_e \eta L = \frac{a y_e^b}{t_e^b} \int_o^{t_e} t^b \, dt \qquad .. \text{ A12}$$

and $$\beta = \frac{1}{b + 1} \qquad .. \text{ A13}$$

The detention at equilibrium is $\int_0^L y \, dx$ where y from equation A1 is $(\frac{q}{a})^{1/b}$, and $q = \eta x$ at equilibrium. Hence

$$D_e = \frac{\eta^{1/b}}{a^{1/b}} \int_o^L x^{\frac{1}{b}} \, dx \qquad \text{.. A14}$$

or

$$D_e = \frac{b\eta^{\frac{1}{b}} L^{(1+\frac{1}{b})}}{a^{\frac{1}{b}} (1+b)} \qquad \text{.. A15}$$

Substituting equation A15 in equation A19, the general expression for time to equilibrium is

$$t_e = \frac{\eta^{(\frac{1}{b} - 1)} L^{\frac{1}{b}}}{a^{\frac{1}{b}}} \qquad \text{.. A16}$$

Substituting the values of the parameters a and b from equation A2 into equation A13, A15 and A16, the following expressions are found

$$b = 5/3$$

$$\beta = 3/8$$

Then

$$D_e = \frac{0.492 \, \eta^{3/5} n^{3/5} L^{8/5}}{S^{3/10}} \qquad \text{.. A17}$$

or

$$D_e = 0.000818 \frac{L^{3/5} n^{3/5} L^{8/5}}{S^{3/10}} \qquad \text{.. A18}$$

for surface detention in ft^3/ft.

The time to equilibrium in minutes are,

$$t_e = \frac{1.6\ D_e}{60\ L} \quad ..\ A19$$

or

$$t_e = \frac{0.0132\ n^{3/5}\ L^{3/5}}{\eta^{2/5}\ S^{3/10}} \quad ..\ A20$$

or

$$t_e = \frac{0.94\ n^{3/5}\ L^{3/5}}{i^{2/5}\ S^{3/10}} \quad ..\ A21$$

In equations above, the surface detention D_e is in ft^3/ft, where η is in $ft^3/sec/ft^2$. Equations for rainfall or supply rate in inches per hour are obtained by substituting $i = 43200\eta$.

A.2 Simulation of Overland Flow

Continuous surface detention storage can be calculated as explained in the previous section. The volume of surface detention can then be selected as the parameter to be related to discharge. Since no fixed relation exists between detention storage and discharge from overland flow when flow is unsteady, then approximations to the natural behaviour have to be made.

To calculate continuous overland flow from total surface detention storage the depth "y" must be related to surface detention storage. This is easily done at equilibrium where

$$y = \frac{8\ D_e}{5\ L}, \qquad \text{.. A22}$$

but for other conditions some approximations are needed. In the unsteady overland flow, three general conditions will occur. Initially, as rain begins the depth of overland flow will be uniform along the flow plane. Therefore, at time (a) a transition from a uniform depth to an equilibrium profile is taking place. If rainfall continues the equilibrium profile is reached at time (b), and when rainfall stops recession flow occurs (c) from water in storage.

The minimum value of y must equal the mean depth D/L where D is the current surface detention storage in ft^3/ft. Therefore, y must be in the range

$$\frac{D}{L} \leqslant y \leqslant \frac{8\ D_e}{5\ L}. \qquad \text{.. A23}$$

The current detention storage D, divided by the detention storage required at equilibrium D_e for the current rate of inflow, is used as an index to the distribution of water in the overland flow plane.

The most satisfactory empirical relationship found between outflow depth and detention storage for reproducing an experimental hydrograph is

$$y = (\frac{D}{L})\ (1.0 + 0.6(\frac{D}{D_e})^3) \qquad \text{.. A24}$$

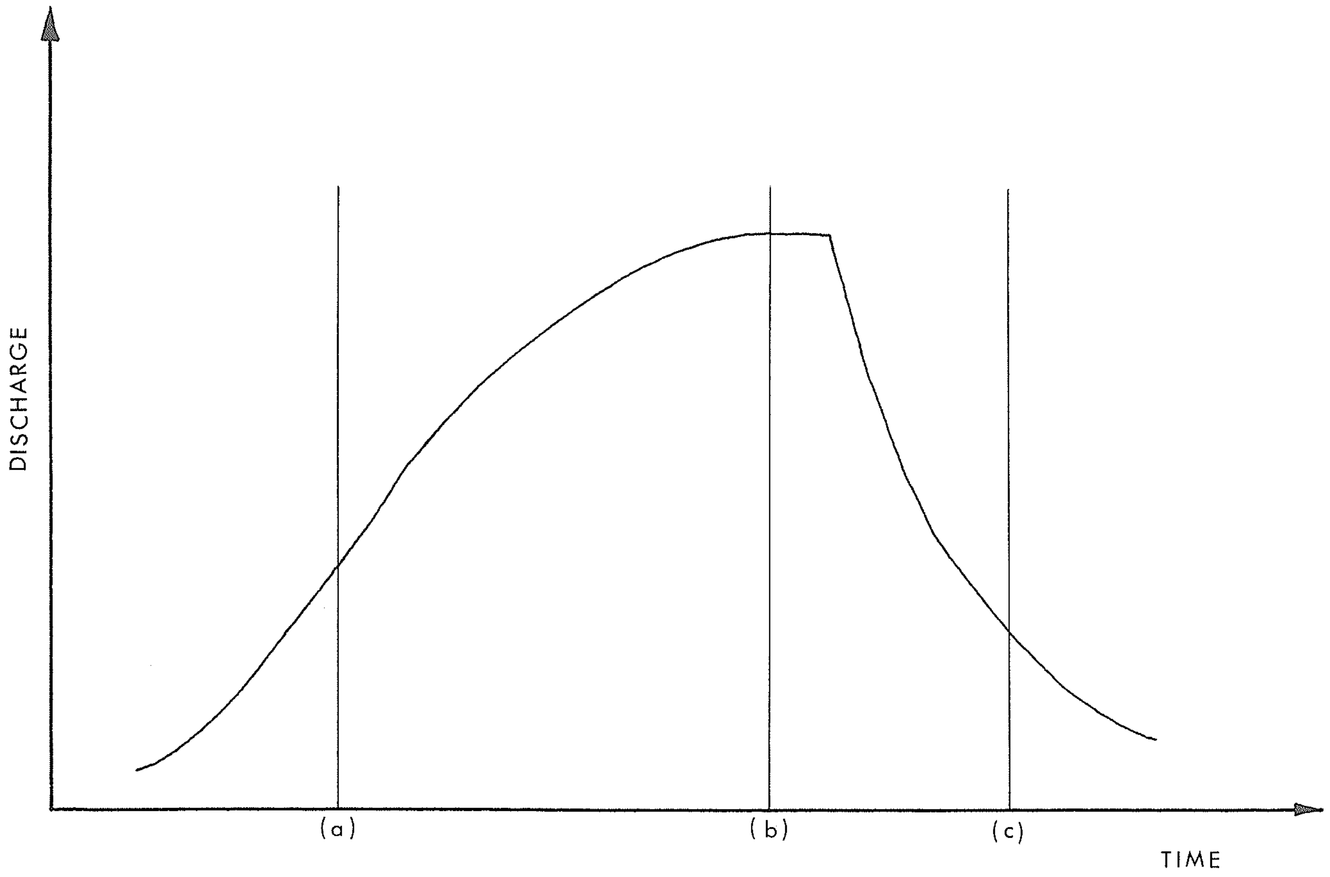


Figure A3 Transformation stages in overland flow

Substituting equation A24 in equation A2, the rate of discharge from overland flow in $ft^3/sec/ft$ is

$$q = \frac{1.486}{n} S^{\frac{1}{2}} \left(\frac{D}{L}\right)^{\frac{5}{3}} \left(1.0 + 0.6\left(\frac{D}{D_e}\right)^3\right)^{\frac{5}{3}} \qquad .. \text{ A25}$$

where D_e is the function of current supply rate to overland flow and is calculated from equation A18. During recession flow when D_e is less than D the ratio $\frac{D}{D_e}$ is assumed to be 1.

Now the overland flow at anytime can be computed by solving a continuity equation

$$D_2 = D_1 + \Delta D - \bar{q}\Delta t \qquad .. \text{ A26}$$

where Δt is the time interval used, D_2 is the surface detention at the end of the current time interval, D_1 is the surface detention at the end of the previous time interval, ΔD is the increment added to surface detention during the time interval, and $\bar{q}$ is the overland flow into the channel during the time interval. The discharge $\bar{q}$ is a function of moisture supply rate and of $(D_1 + D_2)/2$, the average detention storage during the time interval.

APPENDIX B

ROUTING BY THE CHARACTERISTIC METHOD

The following section presents a brief theoretical consideration of flow routing in a circular channel by the characteristic method.

B.1 Definition of characteristics

The two partial differential equations for gradually varied unsteady free surface flow in conduits, with two dependent variables (V,y), and the two independent variables (x,t), can be written as

$$\frac{A}{VB}\frac{\partial V}{\partial x} + \frac{\partial y}{\partial x} + \frac{1}{V}\frac{\partial y}{\partial t} = 0 \qquad \text{...B 1}$$

for continuity, and

$$\frac{V}{g}\frac{\partial V}{\partial x} + \frac{1}{g}\frac{\partial V}{\partial t} + \frac{\partial y}{\partial x} - (S_o - S_f) = 0 \qquad \text{...B 2}$$

for the momentum equation.

The energy gradient, measuring the energy head loss along the conduit, is expressed by Manning equation in the form

$$S_f = \frac{n^2 V^2}{2.2082\ R^{4/3}} \qquad \text{...B 3}$$

The following assumptions are incorporated in derivation of equation B 1 and B 2

(i) There is no uniformly distributed lateral inflow.

(ii) Vertical acceleration can be neglected in comparison with horizontal acceleration.

(iii) The gradually varied unsteady flow has the hydrostatic pressure distribution along the vertical.

(iv) Flow patterns in vertical planes parallel to the longitudinal axis of the channel are the same.

(v) Velocity distribution along a vertical in unsteady flow is the same as the velocity distribution in steady flow for the same water depth.

(vi) Friction resistance in unsteady flow is the same as the friction resistance in steady flow.

(vii) Conduit slope is small enough that $\cos(S_o)$ can be replaced by unity and $\sin(S_o)$ by $\tan(S_o)$.

Now consider the (x,t) plane, assuming a curve is given as t(x). Then $\frac{dt}{dx}$ is the tangent or the direction of this curve with V(x,t) and y(x,t) as the solutions of equations B 1 and B 2. For this case, the total differentials are,

$$dV = \frac{\partial v}{\partial x} dx + \frac{\partial v}{\partial t} dt \qquad \ldots \text{ B 4}$$

and

$$dy = \frac{\partial y}{\partial x} dx + \frac{\partial y}{\partial t} dt \qquad \ldots \text{ B 5}$$

The four equations B 1, B 2, B 3 and B 4, with four unknowns $\frac{\partial v}{\partial x}$, $\frac{\partial v}{\partial t}$, $\frac{\partial y}{\partial x}$ and $\frac{\partial y}{\partial t}$ can be written into a single matrix equation as

$$\begin{bmatrix} \frac{A}{VB} & 0 & 1 & \frac{1}{V} \\ \frac{V}{g} & \frac{1}{g} & 1 & 0 \\ dx & dt & 0 & 0 \\ 0 & 0 & dx & dt \end{bmatrix} \begin{bmatrix} \frac{\partial V}{\partial x} \\ \frac{\partial V}{\partial t} \\ \frac{\partial y}{\partial x} \\ \frac{\partial y}{\partial t} \end{bmatrix} = \begin{bmatrix} 0 \\ S_o - S_f \\ dV \\ dy \end{bmatrix} \quad \ldots \text{B } 6$$

Solving the system of equations B 6, the four derivatives are

$$\frac{\partial v}{\partial x} = \frac{\Delta_1}{\Delta}$$

$$\frac{\partial v}{\partial t} = \frac{\Delta_2}{\Delta}$$

$$\frac{\partial y}{\partial x} = \frac{\Delta_3}{\Delta}$$

$$\frac{\partial y}{\partial t} = \frac{\Delta_4}{\Delta}$$

with,

$$\Delta = \begin{vmatrix} \frac{A}{VB} & 0 & 1 & \frac{1}{V} \\ \frac{V}{g} & \frac{1}{g} & 1 & 0 \\ dx & dt & 0 & 0 \\ 0 & 0 & dx & dt \end{vmatrix} \quad \ldots \text{B } 7$$

The system has a unique solution whence the determinant (Δ) is zero if and only if all other determinants (Δ_i) are also zero. This particular solution of the system of equations is known as the characteristics of the system of equations.

By expanding $\Delta = 0$, the two characteristic direction equations are obtained as

$$\left(\frac{dt}{dx}\right)_+ = \xi_+ = \frac{1}{V+\sqrt{gA/B}} \qquad \ldots \text{B 8}$$

and

$$\left(\frac{dt}{dx}\right)_- = \xi_- = \frac{1}{V-\sqrt{gA/B}} \qquad \ldots \text{B 9}$$

Similarly, by expanding any $\Delta_i = 0$ and replacing $\frac{dt}{dx}$ by ξ_+ and ξ_- respectively, the two ordinary differential equations for V and y along the characteristic curves are

$$\left(\left(\frac{A}{VB} - \frac{V}{g}\right) \xi_+ + \frac{1}{g}\right) \frac{dy}{dx} + \frac{A}{gVB} \frac{dV}{dx} + \frac{A}{VB} (S_o - S_f) \xi_+ = 0 \qquad \ldots \text{B 10}$$

and

$$\left(\left(\frac{A}{AB} - \frac{V}{g}\right) \xi_- + \frac{1}{g}\right) \frac{dy}{dx} + \frac{A}{gVB} \frac{dV}{dx} + \frac{A}{VB} (S_o - S_f) \xi_- = 0 \qquad \ldots \text{B 11}$$

Equation B 8 through B 11 are called the four characteristic ordinary differential equations and are equivalently set to the two partial differential equations B 1 and B 2.

B. 2 Numerical solutions

There exists numerous numerical methods to solve the system of characteristic equations B 8 through B 11; a method chosen is known as the numerical solution by specific intervals system. The advantages of this scheme for automatic computation is well documented by Lister (17).

In this method, V and y at point P on the (x,t) plane of figure B 1 are to be computed from the initial conditions or from previous values of V and y at points A, B and C using the following assumptions:

(i) Δt is sufficiently small so that the part of the characteristics between P and R and between P and S may be considered as straight lines.

(ii) the slope of the straight lines PR at point P is the positive characteristic direction of the position C, $(\xi_+)_C$, and the slope of the straight line PS at point P is the negative characteristic direction of the position C, $(\xi_-)_C$, and

(iii) the values of Δt satisfies the Caurant condition in which

$$\Delta t \leqslant \frac{\Delta x}{V + \sqrt{gA/B}} \qquad \ldots \text{B } 12$$

Since x_p and t_p are known, the velocity at point P, V_p, and the depth at point P, y_p, can then be computed. The computations proceed as follow:

(i) the co-ordinates of R and S are determined from the relations of $(\xi_+)_C$, $(\xi_-)_C$, and the geometry of the grid by

$$t_p - t_R = (\xi_+)_C (x_P - x_R) \qquad \ldots \text{B } 13$$

and,

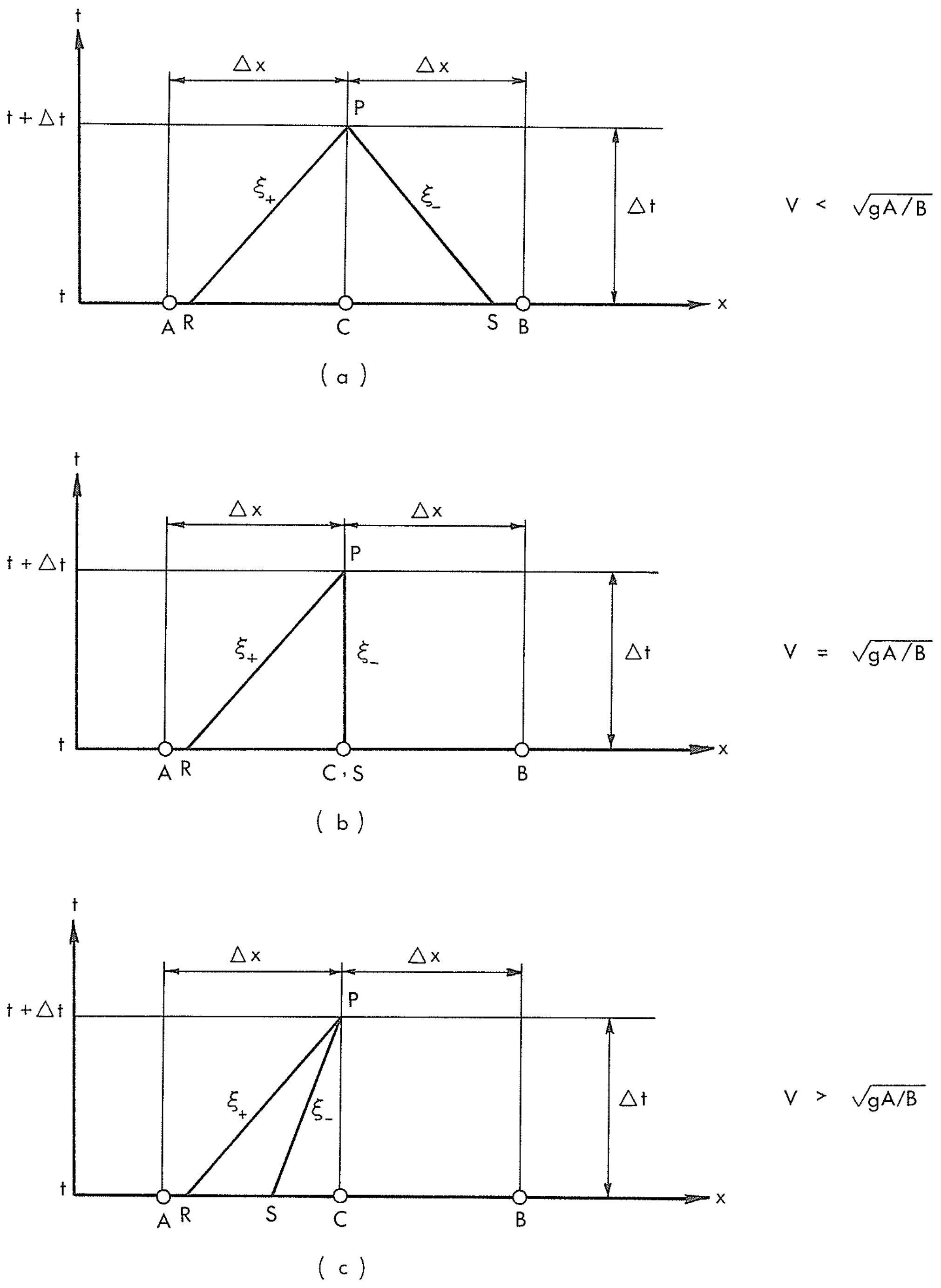


Figure B1 Rectangular grid for the solution by the system of specified intervals, Δt and Δx; (a) subcritical flow, (b) critical flow, (c) supercritical flow

$$t_P - t_S = (\xi_-)_C(x_P - x_S) \qquad \ldots \text{B 14}$$

in which (ξ_+) and (ξ_-) are computed respectively, at point C,

(ii) the values of V_R, V_S, y_R and y_S are determined from linear interpolation of the corresponding values at A, B and C. Thus the values of the function ($U = V$ or y) at points R and S are then

$$U_R = U_C(1 + UP) - U_A.UP \qquad \ldots \text{B 15}$$

in which

$$UP = -\left(\frac{\Delta t}{\Delta x}\right)/\left(\frac{dt}{dx}\right)_+ \qquad \ldots \text{B 16}$$

and,

$$U_S = U_C(1 + UN) - U_B.UN \qquad \ldots \text{B 17}$$

in which

$$UN = -\left(\frac{\Delta t}{\Delta x}\right)/\left(\frac{dt}{dx}\right)_- \qquad \ldots \text{B 18}$$

from which V_R, V_S, y_R and y_S can be computed knowing the value of V and y at points A, B and C.

(iii) the values of V_P and y_P are obtained by solving simultaneously the finite difference forms of equations B 10 and B 11, that is

$$(F_+)_C(y_P - y_R) + (G_+)_C(V_P - V_R) + (S_+)_C(x_P - x_R) = 0 \qquad \ldots \text{B 19}$$

and

$$(F_-)_C(y_P - y_S) + (G_-)_C(V_P - V_S) + (S_-)_C(x_P - x_S) = 0 \qquad \ldots \text{B 20}$$

in which

$$\left.\begin{aligned}
(F_+)_C &= \left(\frac{A}{VB} - \frac{V}{g}\right)_C (\xi_+)_C + \frac{1}{g} &&; \\
(G_+)_C &= \left(\frac{A}{gVB}\right)_C &&; \\
(S_+)_C &= \frac{A}{VB} (S_f - S_o)_C (\xi_+)_C &&; \\
(F_-)_C &= \left(\frac{A}{VB} - \frac{V}{g}\right)_C (\xi_-)_C + \frac{1}{g} &&; \\
(G_-)_C &= \left(\frac{A}{gVB}\right)_C &&; \text{ and} \\
(S_-)_C &= \frac{A}{VB} (S_f - S_o)_C (\xi_-)_C &&
\end{aligned}\right\} \quad \ldots \text{ B 21}$$

By these computations, velocities and depths at time $t + \Delta t$ are obtained for all points along the channel, except for the two boundary points. The values for the boundary points are provided by computations of known boundary conditions.

B.3 Initial Conditions

The necessary initial conditions for the unsteady free surface flow are that all velocities and depths of water along the channel must be known at given time.

B.4 Boundary Conditions

The two governing partial differential equations for unsteady flow required two independent boundary conditions relating velocity and depth at certain locations along the channel. One of these conditions is the discharge-time relation existing at the inlet end. This relation can be either expressed in a mathematical form, or given as discrete points of discharge at selected intervals of time.

The other boundary condition imposed on the problem is that of a discharge-versus-depth relation at the downstream end characterised either by a control structure or by the critical depth at a free outfall. This is the boundary condition that exists for subcritical flow of the base flow.

B. 4.1 Upstream Boundary Conditions

The boundary condition at the upstream inlet is given by an inflow hydrograph, Q(t), with no limitation on the shape of the hydrograph.

The depths and the velocities at the upstream boundary point P, figure B 2, which is at $x=0$ and at time $t+\Delta t$, can be computed from initial conditions at C and B, with the boundary conditions given by the inflow hydrograph

$$Q(t) = AV \qquad \text{... B 22}$$

in which A is the cross sectional area and V is the velocity at point P.

Using previously discussed assumptions and procedures of computing velocities and depths at other points along the channel, the negative characteristic direction at point C is also given by the initial conditions. The relation between the depth y_P and velocity V_P at point P can be determined from equation B 11.

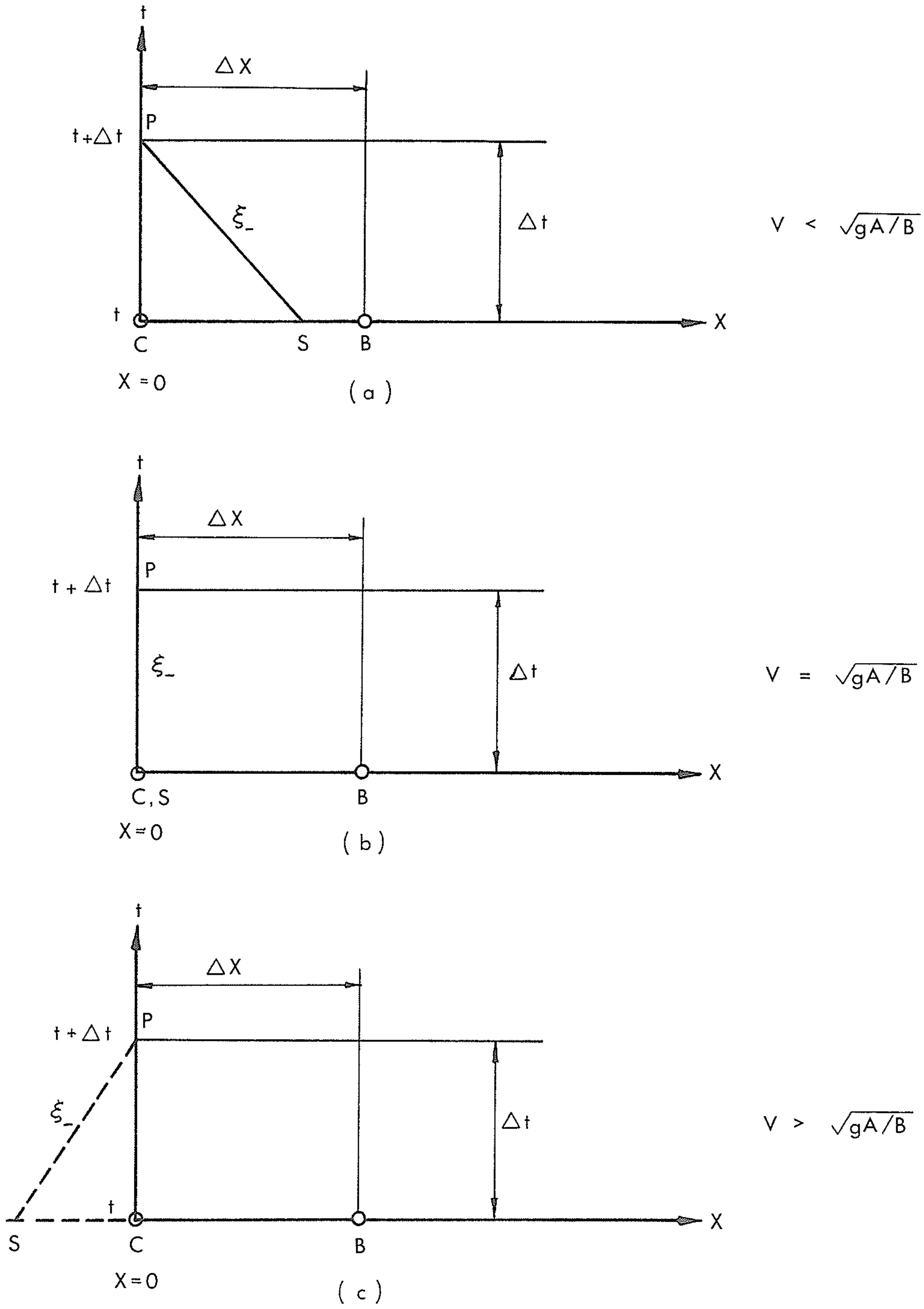


Figure B2 Upstream boundary conditions (a) subcritical flow, (b) critical flow, (c) supercritical flow

Substituting the boundary condition of equation B 22, into equation B 20, gives,

$$Y_P = Y_S - \frac{(G_-)_C(\frac{Q(t)}{A} - V_S) + (S_-)_C(x_P - x_S)}{(F_-)_C} \qquad \text{... B 23}$$

Solving for y_P from equation B 23 and substituting y_P into equation B 22 makes it possible to determine V_P.

B 4.2 Downstream Boundary Conditions

The boundary conditions at the downstream outlet can generally be given by a stage-discharge relation. However for free outfall at the end of conduit, a critical flow at the down stream end exists

$$\frac{V}{gA/B} = 1. \qquad \text{... B 24}$$

For free outfall, it can be assumed that critical depth occured at a distance of 4.5 times the critical depth from the end. This assumption was also applied to the unsteady case, with the critical depth computed from base flow, Q_b. Therefore, the total distance x_L from the inlet to the downstream boundary is determined by

$$x_L = x_F - 4.5\, y_c \qquad \text{... B 25}$$

in which x_F is the total length of the channel and y_c is the critical depth for discharge Q_b.

The depth and the velocities at the downstream boundary point P, figure B 3, at time t+Δt can be computed from the initial conditions at A and C, and from the boundary conditions given by equation B 24.

Using the same assumptions and computation procedures as previously described, the initial conditions also give the relation between the depth y_P and the velocity V_P by applying equation B 10. Substituting the boundary condition of equation B 24 into equation B 19 result in

$$Y_P = Y_R - \frac{(G+)_C(\ gA/B - V_R) + (S_+)_C(x_P - x_R)}{(F_+)_C} \qquad \text{... B 26}$$

Solving y_P from equation B 26 and back substituting y_P makes it possible to determine V_P.

B. 4.3 Boundary Condition at a Lateral Junction

Figure B 4 shows the x-t plane of a lateral junction at J with the distance x_{LAT} from the upstream inlet. The velocities and the depths at the time t+Δt at point P are computed to satisfy only the continuity condition since any losses across the junction is neglected.

The discharge at point P is given by continuity condition

$$Q_P = Q_O + QLAT \qquad \text{... B 26}$$

and

$$Q_P = V_P A_P . \qquad \text{... B 27}$$

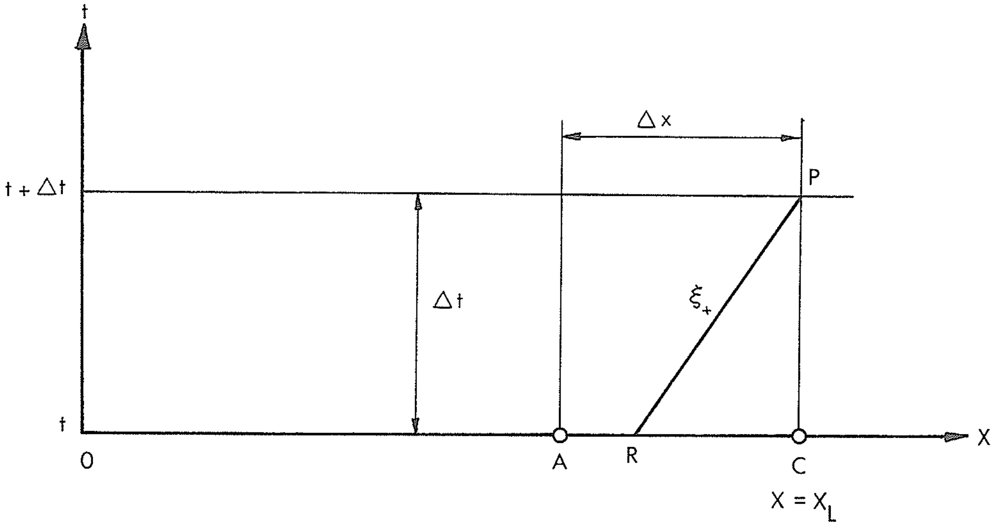


Figure B3 Downstream boundary conditions for subcritical flow, with x_L the computational conduit length

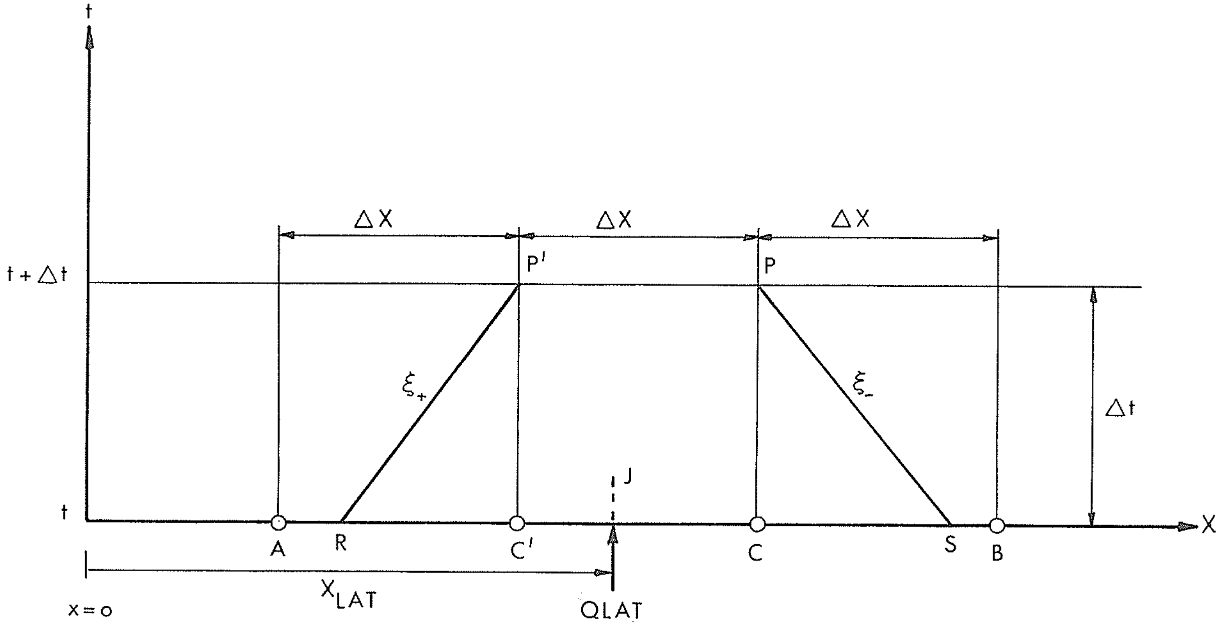


Figure B4 Boundary conditions at a lateral junction

The relationship between depth Y_P and velocity V_P at point P can be determined from equation B 11. Substituting the continuity condition of equation B 27 into equation B 19 gives

$$Y_P = Y_S - \frac{(G_-)_C \left(\frac{AP}{AP} - V_S\right) + (S_-)_C (x_p - x_s)}{(F_-)_C}$$

Solving for Y_P from equation B 28 and substituting Y_P into equation B 27 makes it possible to determine V_P.

It should be noted that in solving these relationships iteration procedures were required since the relationships are not linear in y.

APPENDIX C

CIRCULAR CHANNEL SECTION PARAMETERS

To facilitate the computations for the wave in part-full conduits, some geometric and hydraulic characteristics of the circular channel section are supplied in the following section, assuming that the Manning formula is valid.

.1 Characteristics of Circular Channel Section

As shown in figure C1 the geometric parameters of a circular cross section which influence the flow of a free surface liquid are defined as follows

1 - Diameter, D
2 - Depth, Y
3 - Central angle, 0
4 - Wetted perimeter, P
5 - Surface width, B
6 - Area, A

Derived parameters of significance are:

1 - Hydraulic depth, $y_* = A/B$
2 - Hydraulic radius, $R = A/P$

.2 Relationships of Circular Channel Section

Each of parameters in section A .1 can be expressed as the ratio of its value at a specific depth to diameter of

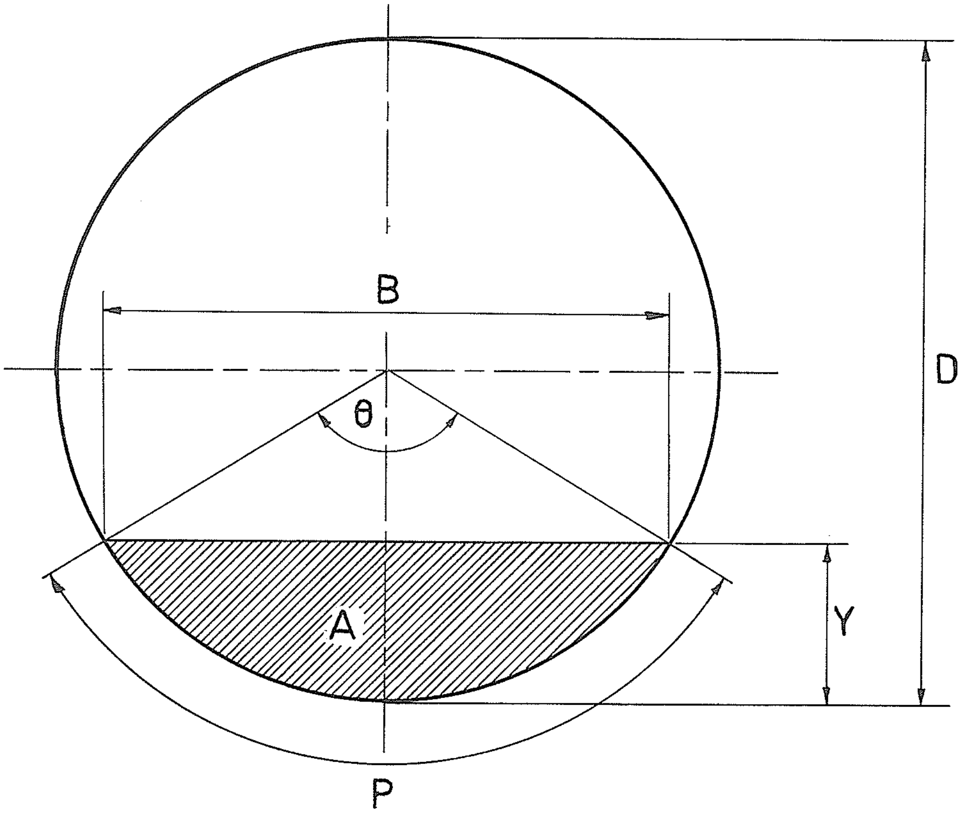


Figure Cl Definition sketch for parameters of a circular channel section the section as follows:

1 - Central angle, θ, defined as,

$$\theta = 2\cos^{-1}\left(1 - \frac{2Y}{D}\right) \quad \text{for } 0<\theta<\pi \qquad \text{C 1a}$$

or

$$\theta = 2\pi - 2\cos^{-1}\left(\frac{2Y}{D} - 1\right) \quad \text{for } \pi<\theta<2\pi \qquad \text{C 1b}$$

2 - Wetted perimeter, P, defined as

$$P = \frac{D}{2}\theta \qquad \text{C 2}$$

3 - Surface width, B, defined as

$$B = D\sin\left(\frac{\theta}{2}\right) \qquad \text{C 3}$$

4 - Area, A, defined as

$$A = \frac{D^2}{\theta}(\theta - \sin\theta) \qquad \text{C 4}$$

APPENDIX D

FLOW CHARTS AND PROGRAMME OF SIMULATION MODEL

PROGRAMME VARIABLES

A	area of circular secment
AREAS	impervious area of a subwatershed
AVL	average length of overland flow
AVS	average slope of overland flow
B	free surface width
CD	pipe discharge coefficient
CN	negative characteristic direction
CO	-DT/DX
CP	positive characteristic direction
D	depth of flow at time T
DC	critical depth
DE	surface detention at equilibrium
DD	increment of surface detention during time interval
DDT	depth of flow at time T+DT
DIA	pipe diameter
DM	hydraulic depth
DN	normal depth
DT	increment of time
DTOL	maximum relative error in depth calculation
DX	increment of distance
ED	pipe discharge exponent
F	pipe Manning's friction factor
FS	land surface Manning's friction factor
GR	gravitational acceleration

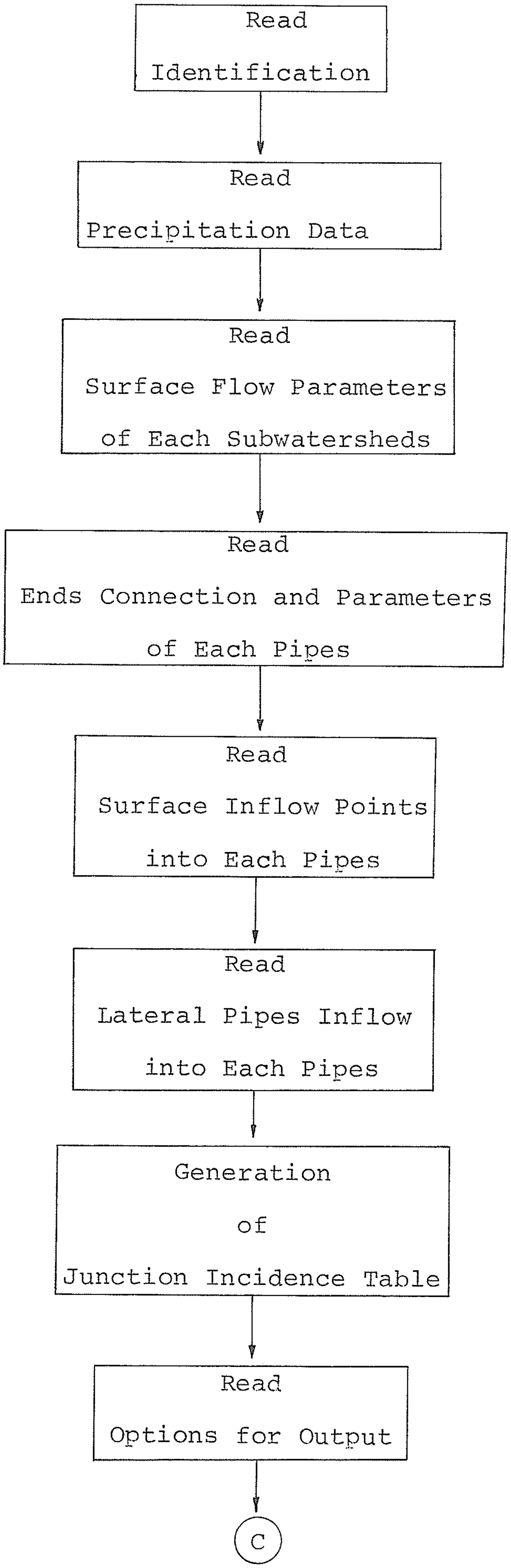
INT	number of precipitation intervals
LATP	lateral pipe inflow number
LATS	overland inflow number
MC	backwater profile code
MI	pipe ends connection
N	number of x intervals
NBL	number of subwatersheds
NCOUNT	iteration counter
NJ	number of junction boxes in a drainage system
NL	total number of lateral inflow points of a pipe
NLP	number of lateral pipe inflow points of a pipe
NLS	number of overland inflow points of a pipe
NOPT	option code
NQP	number of hydrograph points
NP	number of pipes in a drainage system
NT	number of time intervals
NTYPE	input precipitation type code
PIPE	pipe physical properties
PREC	input precipitation
PRECT	rate of precipitation at specified time interval
PROPL	land surface physical properties
Q	discharge at time T
QB	base flow
QD	pipe outflow hydrograph
QDT	discharge at time T+DT
QI	upstream end inflow hydrograph

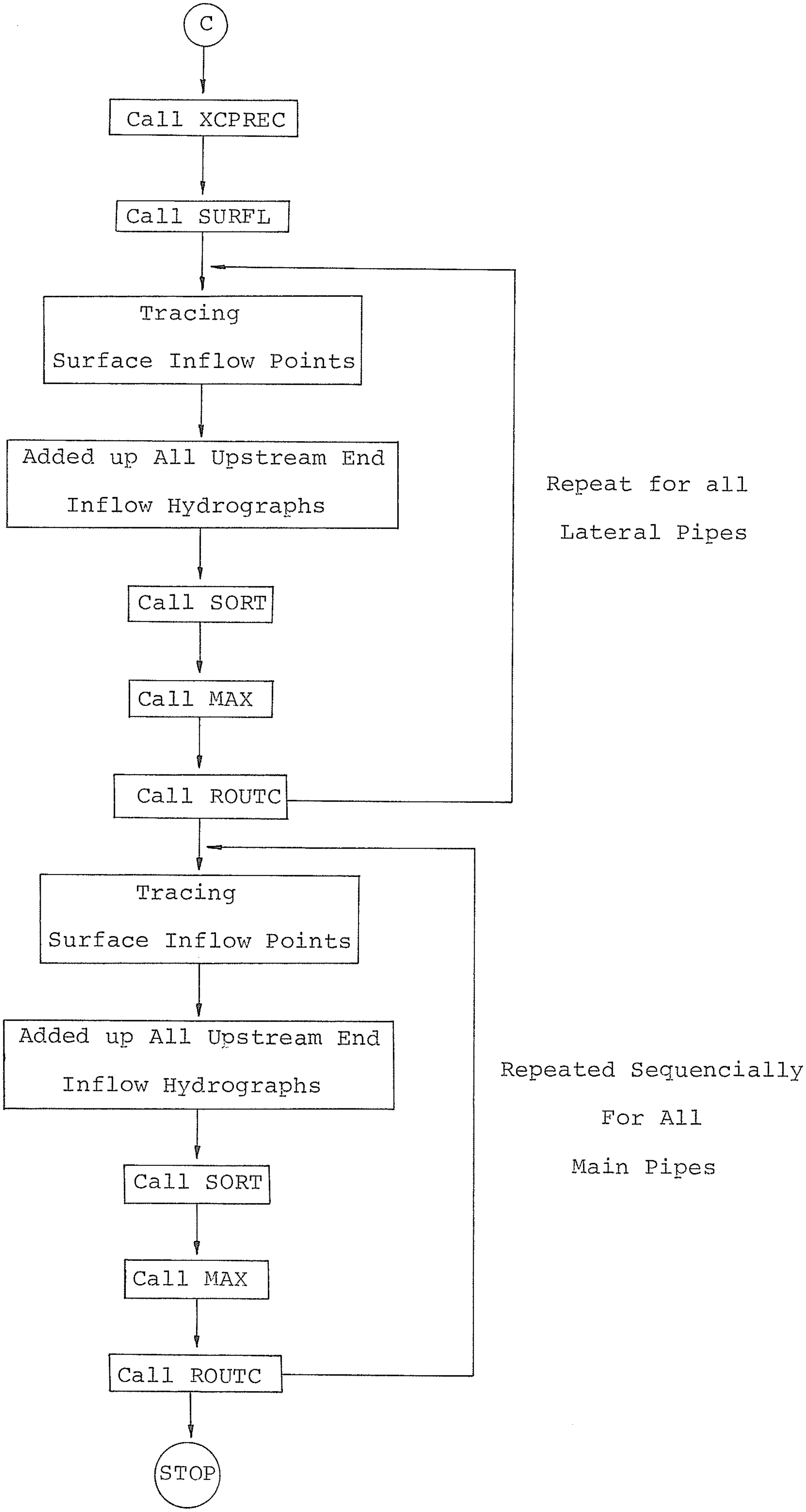
QLAT	lateral inflow hydrograph
QP	peak discharge of QI
QS	overland flow hydrograph
R	hydraulic radius
SF	friction slope
SO	invert slope
T	time
TF	final time for simulation
THETA	central angle subtended by free surface
TIME	precipitation time
TQ	hydrograph time
V	velocity at time T
VC	critical velocity
VDT	velocity at time T+DT
VH	velocity head
WP	wetted perimeter
X	distance along a pipe
XE	computed length of a pipe
XF	total length of a pipe
XLAT	distance from upstream end of an inflow point
XLATP	distance from upstream end of a lateral pipe inflow
XLATS	distance from upstream end of a overland inflow

FLOW CHART AND PROGRAMME

OF

MAIN PROGRAMME


Read Identification
Read Precipitation Data
Read Surface Flow Parameters of Each Subwatersheds
Read Ends Connection and Parameters of Each Pipes
Read Surface Inflow Points into Each Pipes
Read Lateral Pipes Inflow into Each Pipes
Generation of Junction Incidence Table
Read Options for Output
C


C
Call XCPREC
Call SURFL
Tracing
Surface Inflow Points
Added up All Upstream End
Inflow Hydrographs
Call SORT
Call MAX
Call ROUTC
Repeat for all
Lateral Pipes
Tracing
Surface Inflow Points
Added up All Upstream End
Inflow Hydrographs
Call SORT
Call MAX
Call ROUTC
Repeated Sequencially
For All
Main Pipes
STOP

```
FORTRAN IV G LEVEL  20.1                MAIN                DATE = 72322          15/04/44                P175 0001

        C
        C     THIS PROGRAM TO SYNTHESIZE RUNOFF FROM URBAN WATERSHED
        C
0001        DIMENSION JI(20,4),LATP(50,5),LATS(50,5),LP(50),LS(50),MI(50,2)
0002        DIMENSION NAME(5),NOPT(5),NPIJ(20),PIPE(50,6),PREC(30),PRECT(50)
0003        DIMENSION PROPL(50,4),QD(50,50),QI(50),QLAT(9,50),QS(50,50)
0004        DIMENSION TIME(30),TQ(50),XLAT(9),XLATP(50,5),XLATS(50,5)
        C
        C   READING RUN NUMBER OR WATERSHAD NAME OPTION
        C
0005        READ(5,900) NAME
0006    900 FORMAT(5A4)
0007        WRITE(6,902) NAME
0008    902 FORMAT('1',////,5X,5A4,//)
0009        WRITE(6,904)
0010        WRITE(6,906)
0011        WRITE(6,908)
0012        WRITE(6,906)
0013        WRITE(6,910)
0014        WRITE(6,906)
0015        WRITE(6,912)
0016        WRITE(6,906)
0017        WRITE(6,904)
0018    904 FORMAT(' ',T40,'* * * * * * * * * * * * * * * * * *')
0019    906 FORMAT(' ',T40,'*                                 *')
0020    908 FORMAT(' ',T40,'*     UNIVERSITY OF MANITOBA      *')
0021    910 FORMAT(' ',T40,'* DEPARTMENT OF CIVIL ENGINEERING *')
0022    912 FORMAT(' ',T40,'*       URBAN RUNOFF MODEL        *')
        C
        C     PRECIPITATION DATA
        C
        C     PRECIPITATION HISTOGRAM INPUT
        C     READ NUMBER OF INTERVAL,TYPE OF PRECIPITATION,AND TOTAL TIME
        C
0023        READ(5,914) INT,NTYPE,TF
0024    914 FORMAT(2I5,F5.0)
0025        INT=INT+1
        C
        C     HISTOGRAM DATA INPUT
        C     TIME IN MINUTE AND
        C   TYPE  0  IF
        C     PRECIPITATION AT THE TIME IN INCHES
        C   TYPE  1  IF
        C     PRECIPITATION AT THE TIME IN INCHES PER HOUR
        C
0026        WRITE(6,916)
0027        WRITE(6,918)
0028    916 FORMAT(' ',//,' ',5X,'PRECIPITATION DATA',/)
0029    918 FORMAT(' ','  TIME',6X,'PRECIPITATION',/)
0030        DO 10 I=1,INT
0031        READ(5,920) TIME(I),PREC(I)
0032        WRITE(6,922) TIME(I),PREC(I)
0033    920 FORMAT(2F10.2)
0034    922 FORMAT(F6.0,9X,F6.2)
0035     10 CONTINUE
        C
        C     LAND SURFACE PHYSICAL PROPERTIES
        C
```

```
        FORTRAN IV G LEVEL  20.1                    MAIN                DATE = 72322            15/04/44                    P175 0002

                        C          TOTAL NUMBER OF LAND BLOCKS IN THE AREA
          0036                 READ(5,926) NBL
          0037             926 FORMAT(I5)
                        C
                        C      DATA REQUIRED FOR EACH BLOCK
                        C          AREA IN SQ.FT.
                        C          AVERAGE LENGTH TO INLET IN FEET
                        C          AVERAGE SLOPE IN FT/FT
                        C          MANNING FRICTION FACTOR
                        C
          0038                 WRITE(6,928)
          0039                 WRITE(6,930)
          0040             928 FORMAT('1',///,' ',5X,'LAND SURFACE PHYSICAL PROPERTIES',/)
          0041             930 FORMAT('0','BLOCK',6X,'AREA',6X,'AVERAGE',7X,'AVERAGE',7X,
                              1'MANNING',/,' ',' NO.',6X,'SQ.FT.',4X,'LENGTH(FT)',6X,
                              2'SLOPE',4X,'FRICTION FACTOR',/)
                        C
          0042                 DO 20 I=1,NBL
          0043                 READ(5,932) (PROPL(I,J),J=1,4)
          0044                 WRITE(6,934) I,(PROPL(I,J),J=1,4)
          0045             932 FORMAT(F10.5,F10.2,F10.6,F10.5)
          0046             934 FORMAT(' ',I4,4X,F8.0,4X,F6.0,9X,F7.5,9X,F6.4)
          0047              20 CONTINUE
                        C
          0048                 WRITE(6,938)
          0049             938 FORMAT('1',///,' ',5X,'DRAINAGE NETWORK',//)
                        C
                        C      PIPE PROPERTIES AND DRAINAGE NETWORK
                        C
                        C      READ NUMBER OF PIPES AND REACHES,NUMBER OF JUNCTIONS
                        C
          0050                 READ(5,940) NP,NJ
          0051                 WRITE(6,942) NP,NJ
          0052             940 FORMAT(2I5)
          0053             942 FORMAT(' ',5X,'NUMBER OF PIPES AND REACHES',I5,5X,
                              1'NUMBER OF JUNCTIONS',I5)
                        C
          0054                 WRITE(6,944)
          0055                 WRITE(6,946)
          0056                 WRITE(6,948)
          0057             944 FORMAT('0',5X,'PIPE INCIDENCES',35X,'PIPE PROPERTIES',/)
          0058             946 FORMAT(' ',1X,'PIPE',5X,'START',6X,'END',6X,'LENGTH',4X,'DIAMETER'
                              1,5X,'FRICTION',4X,'SLOPE',10X,'OUTFLOW')
          0059             948 FORMAT(' ',32X,'FT',9X,'IN',9X,'FACTOR',15X,'CO-EFF',3X,'EXPONENT'
                              1,/)
                        C
                        C      DATA REQUIRED FOR EACH PIPE REACH
                        C          CONNECTIONS AT START AND END IN DIRECTION OF FLOW
                        C          PIPE LENGTH IN FT
                        C          PIPE DIAMETER IN INCHES
                        C          PIPE MANNING FRICTION FACTOR
                        C          PIPE SLOPE IN FT/FT
                        C          PIPE OUTFLOW CO-EFFICIENT
                        C          PIPE OUTFLOW EXPONENTIAL
                        C
          0060                 DO 30 I=1,NP
          0061                 READ(5,950) MI(I,1),MI(I,2),(PIPE(I,J),J=1,6)
          0062                 IF(PIPE(I,3).EQ.0.) PIPE(I,3)=0.013
```

```
            WRITE(6,952) I,MI(I,1),MI(I,2),(PIPE(I,J),J=1,6)
        950 FORMAT(2I5,2F10.2,2F10.5,2F10.2)
        952 FORMAT(' ',3(I4,6X),F6.1,5X,F6.2,3X,2(4X,F6.4),2(6X,F4.2))
         30 CONTINUE
      C
      C         LATERAL INFLOW FROM OVERLAND FLOW TO EACH PIPE
      C
            WRITE(6,954)
        954 FORMAT('0',2X,'PIPE',5X,'C.B.',5X,'NUMBER',5X,'DISTANCE',5X,
           1'PIPE',5X,'NUMBER',5X,'DISTANCE',/)
            DO 40 I=1,NP
      C
      C         READ NUMBER OF OVERLAND INFLOW POINTS
      C
            READ(5,926) NLS
            LS(I)=NLS
            IF(NLS.EQ.0) GO TO 50
            WRITE(6,956) I,NLS
        956 FORMAT(' ',2(I5,4X))
            DO 45 J=1,NLS
      C
      C         READ INFLOW POINT NUMBER AND DISTANCE FROM INLET
      C
            READ(5,958) LATS(I,J),XLATS(I,J)
            WRITE(6,960) LATS(I,J),XLATS(I,J)
        958 FORMAT(I5,F10.2)
        960 FORMAT(' ',19X,I5,6X,F6.0)
         45 CONTINUE
      C
      C         LATERAL INFLOW FROM PIPE FLOW TO EACH PIPE
      C
      C
      C         READ NUMBER OF PIPE INFLOW POINTS
      C
         50 READ(5,926) NLP
            LP(I)=NLP
            IF(NLP.EQ.0) GO TO 40
            WRITE(6,957) NLP
        957 FORMAT(' ',42X,I5)
            DO 55 J=1,NLP
      C
      C         READ INFLOW POINT NUMBER AND DISTANCE FROM INLET
      C
            READ(5,958) LATP(I,J),XLATP(I,J)
            WRITE(6,961) LATP(I,J),XLATP(I,J)
        961 FORMAT(' ',52X,I5,6X,F6.0)
         55 CONTINUE
         40 CONTINUE
      C
      C         GENERATION OF JUNCTION INCIDENCE TABLE
      C
            DO 60 J=1,NJ
            NPIJ(J)=0
            DO 60 M=1,4
            JI(J,M)=0
         60 CONTINUE
            DO 70 M=1,NP
            J=MI(M,1)
```

```
FORTRAN IV G LEVEL  20.1                MAIN                DATE = 72322          15/04/44                P175 0004

 0099               IF(J.EQ.0) GO TO 65
 0100               NPIJ(J)=NPIJ(J)+1
 0101               K=NPIJ(J)
 0102               JI(J,K)=-M
 0103            65 J=MI(M,2)
 0104               IF(J.EQ.0) GO TO 70
 0105               NPIJ(J)=NPIJ(J)+1
 0106               K=NPIJ(J)
 0107               JI(J,K)=M
 0108            70 CONTINUE
 0109               WRITE(6,962)
 0110               WRITE(6,964)
 0111           962 FORMAT('0',5X,'JUNCTION BOXES INCIDENCES TABLE',//)
 0112           964 FORMAT(' ',3X,'JUNCTION',5X,'TOTAL',10X,'PIPE NUMBER',/)
 0113               DO 80 I=1,NJ
 0114               WRITE(6,966) I,NPIJ(I),(JI(I,J),J=1,4)
 0115           966 FORMAT(' ',3X,I5,6X,I5,6X,4I5)
 0116            80 CONTINUE
 0117               WRITE(6,968)
 0118           968 FORMAT('0',5X,'NOTE +VE FOR FLOW INTO THE JUNCTION',/,
                  1       ' ',5X,'     -VE FOR FLOW OUT FROM THE JUNCTION')
              C
              C        OPTIONS FOR OUTPUT
              C
 0119               READ(5,970) (NOPT(I),I=1,3)
 0120           970 FORMAT(3I5)
              C
              C        COMPUTE EXCESS RATE OF PRECIPITATION FOR THE RUN
              C
 0121               CALL XCPREC(PREC,TIME,INT,NTYPE,TF,PRECT,TQ,DTS,NQP)
              C
              C        COMPUTE OVERLAND FLOW TO EACH INLET POINT
              C
 0122               CALL SURFL(NOPT,PRECT,PROPL,TQ,DTS,NBL,NQP,QS)
              C
              C        ROUTING IN PRIMARY LATERAL PIPES
              C
 0123               DO 90 I=1,NP
 0124               IF(MI(I,1).NE.0) GO TO 90
              C
              C        INITIALISE INFLOW
              C
 0125               DO 95 K=1,NQP
 0126               QI(K)=0.
 0127            95 CONTINUE
              C
              C     TRACING LATERAL INFLOWS FROM SURFACE FLOWS
              C
 0128               NL=0
 0129               NLS=LS(I)
 0130               DO 100 J=1,NLS
 0131               NQL=LATS(I,J)
 0132               XLT=XLATS(I,J)
 0133               IF(XLT.EQ.0.) GO TO 105
 0134               NL=NL+1
 0135               XLAT(NL)=XLT
 0136               DO 110 K=1,NQP
 0137               QLAT(NL,K)=QS(NQL,K)
```

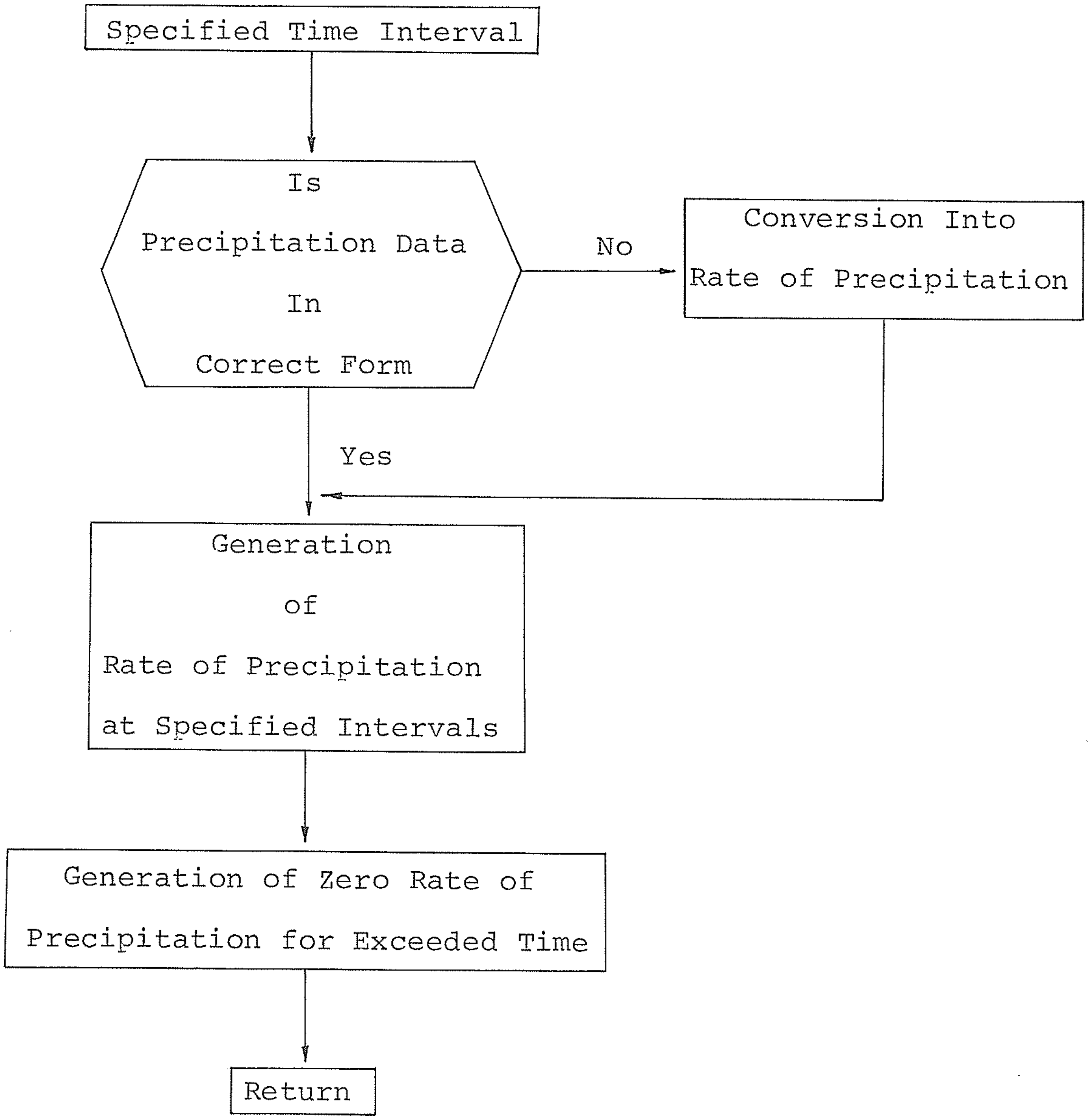
```
0138              110 CONTINUE
0139                  GO TO 100
0140              105 DO 115 K=1,NQP
0141                  QI(K)=QI(K)+QS(NQL,K)
0142              115 CONTINUE
0143              100 CONTINUE
0144                  CALL SORT(QLAT,XLAT,NL,NQP)
0145                  CALL MAX(QI,NQP,QP)
0146                  CALL ROUTE(PIPE,QD,QI,QLAT,TQ,XLAT,NL,I,NQP,QP)
0147               90 CONTINUE
            C
            C             ROUTING IN MAIN PIPE NETWORK
            C
0148                  DO 120 I=1,NJ
            C
            C             INITIALISE INFLOW
            C
0149                  DO 125 K=1,NQP
0150                  QI(K)=0.
0151              125 CONTINUE
            C
            C             TRACING ALL INFLOW PIPES INTO THE JUNCTION
            C
0152                  JP=NPIJ(I)
0153                  DO 130 J=1,JP
0154                  IF(JI(I,J).LT.0) GO TO 135
0155                  IN=JI(I,J)
            C
            C             ADDING EACH INFLOWS TO INFLOW INTO JUNCTION
            C
0156                  DO 140 K=1,NQP
0157                  QI(K)=QI(K)+QD(IN,K)
0158              140 CONTINUE
0159                  GO TO 130
0160              135 NOP=-JI(I,J)
0161              130 CONTINUE
            C
            C         TRACING INFLOW FROM LATERAL PIPES
            C
0162                  NL=0
0163                  NLP=LF(NOP)
0164                  IF(NLP.EQ.0) GO TO 170
0165                  DO 150 J=1,NLP
0166                  XLT=XLATP(NOP,J)
0167                  NQL=LATP(NOP,J)
0168                  IF(XLT.EQ.0.) GO TO 155
0169                  XLAT(NL)=XLT
0170                  NL=NL+1
0171                  DO 160 K=1,NQP
0172                  QLAT(NL,K)=QD(NQL,K)
0173              160 CONTINUE
0174                  GO TO 150
0175              155 WRITE(6,972) NQL
0176              972 FORMAT('0','PIPE NUMBER',I5,/,' ',
                     1'ERROR IN LATERAL CONNECTION DISTANCE',/)
0177                  STOP
0178              150 CONTINUE
            C
```

```
C          TRACING LATERAL FLOWS FROM SURFACE FLOW
C
      170 NLS=LS(NOP)
          IF(NLS.EQ.0) GO TO 200
          DO 180 J=1,NLS
          XLT=XLATS(NOP,J)
          NQL=LATS(NOP,J)
          IF(XLT.EQ.0.) GO TO 185
          NL=NL+1
          XLAT(NL)=XLT
          DO 190 K=1,NQP
          QLAT(NL,K)=QS(NQL,K)
      190 CONTINUE
          GO TO 180
      185 DO 195 K=1,NQP
          QI(K)=QI(K)+QS(NQL,K)
      195 CONTINUE
      180 CONTINUE
          CALL SORT(QLAT,XLAT,NL,NQP)
      200 CALL MAX(QI,NQP,QP)
          IF(MI(NOP,2).EQ.0) NOPT(1)=1
          CALL ROUTC(PIPE,QO,QI,QLAT,TQ,XLAT,NL,NOP,NQP,QP)
      120 CONTINUE
          STOP
          END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE XCPREC

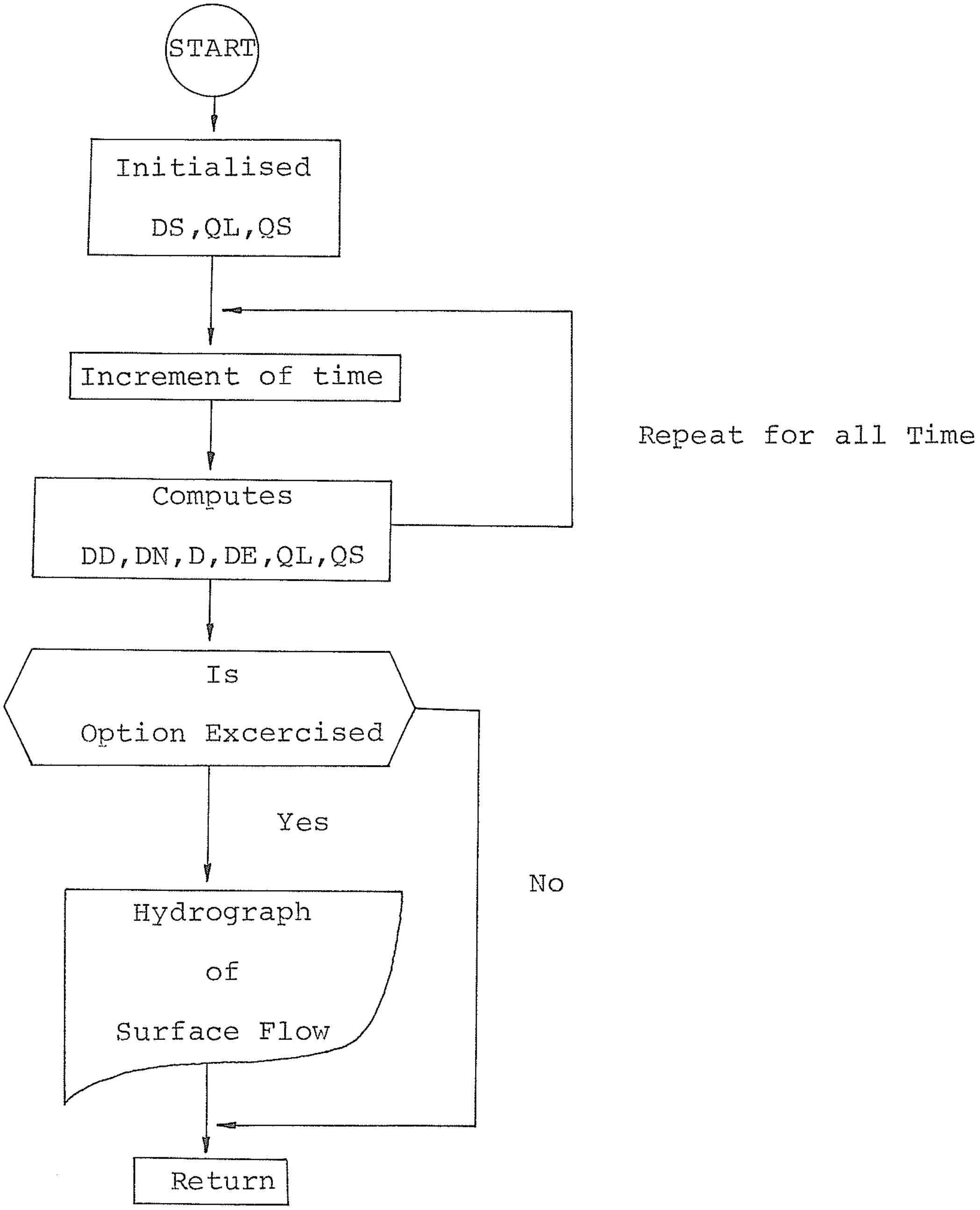

Specified Time Interval
Is Precipitation Data In Correct Form
No
Conversion Into Rate of Precipitation
Yes
Generation of Rate of Precipitation at Specified Intervals
Generation of Zero Rate of Precipitation for Exceeded Time
Return

```
FORTRAN IV G LEVEL  20.1              XCPREC              DATE = 72322          15/04/44                 P175 0001

  0001                    SUBROUTINE XCPREC(PREC,TIME,INT,NTYPE,TF,PRECT,TQ,DTS,NOP)
                 C
                 C           THIS SUBROUTINE TO COMPUTE EXCESS PRECIPITATION AND CONVERT THE
                 C           HISTOGRAM TO RATE OF EXCESS PRECIPITATION
                 C
  0002                    DIMENSION PREC(30),PRECT(50),TIME(30),TQ(50)
                 C
                 C           LOSSES
                 C           ANY LOSSES CALCULATIONS IN THE FUTURE SHOULD BE INCLUDED IN THIS
                 C           SUBROUTINE
                 C
                 C           LINEAR INTERPOLATION OF PRECIPITATION AND CONVERSION TO RATE
                 C           OF PRECIPITATION
                 C
  0003                    INT=INT-1
  0004                    DTS=2.5
  0005                    J=1
  0006                    TQ(J)=TIME(J)
  0007                    PRECT(J)=PREC(J)
  0008                    DO 20 I=1,INT
  0009                    IF (NTYPE.EQ.1) GO TO 30
  0010                    TINT=TIME(I+1)-TIME(I)
  0011                    PREC(I+1)=PREC(I+1)*60./TINT
  0012                 30 IF(TQ(J).GE.TIME(I+1)) GO TO 20
  0013                    J=J+1
  0014                    TQ(J)=TQ(J-1)+DTS
  0015                    PRECT(J)=PREC(I+1)
  0016                    GO TO 30
  0017                 20 CONTINUE
                 C
                 C           OPTIONAL PROCEDURE FOR PERIOD AFTER TERMINATION OF PRECIPITATION
                 C
  0018                    NOP=TF/DTS+1.
  0019                    JP1=J+1
  0020                    DO 40 K=JP1,NOP
  0021                    TQ(K)=TQ(K-1)+DTS
  0022                    PRECT(K)=0.
  0023                 40 CONTINUE
  0024                    RETURN
  0025                    END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE SURFL



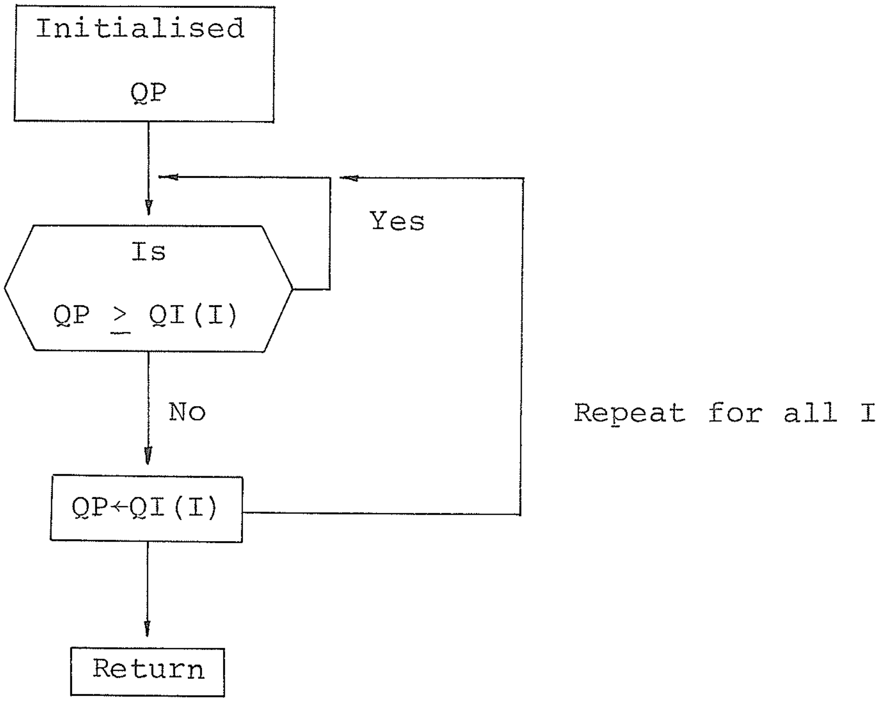
Repeat for all Subwatersheds

```
FORTRAN IV G LEVEL  20.1              SURFL            DATE = 72322           15/04/44                  PAGE 0001

                    SUBROUTINE SURFL(NOPT,PRECT,PROPL,TQ,DTS,NBL,NQP,QS)
              C
              C        THIS SUBROUTINE TO COMPUTE OVERLAND FLOW BY 2-D APPROXIMATION
              C
                    DIMENSION QS(50,50),PRECT(50),TQ(50),PROPL(50,4),NOPT(5)
                    DO 10 I=1,NBL
                    AREAS=PROPL(I,1)
                    AVL=PROPL(I,2)
                    AVS=PROPL(I,3)
                    FS=PROPL(I,4)
                    DS=0.
                    QS(I,1)=0.
                    QL=0.
                    DO 20 J=2,NQP
                    DD=PRECT(J)*AVL*DTS/720.
                    DN=DS+DD-QL*DTS*60.
                    D=(DS+DN)/2.
                    DE=(0.000818*(PRECT(J)*FS)**0.6*(AVL**1.6))/(AVS**0.3)
                    IF(DE.LT.0) DE=0
                    Y=(D/AVL)*(1.0+0.6*(D/DE)**3)
                    IF(Y.LE.(D/AVL)) Y=D/AVL
                    IF(Y.GE.(DE/AVL)) Y=DE/AVL
                    QL=(1.486/FS)*AVS**0.5*(Y**1.667)
                    AVW=AREAS/AVL
                    DS=DN
                    QS(I,J)=QL*AVW
                 20 CONTINUE
              C
              C        CHECK OPTION IF OUTPUT IS REQUIRED
              C
                    IF(NOPT(2).EQ.0) GO TO 10
                    WRITE(6,910) I
                    WRITE(6,920) AREAS,AVL,AVS
                    WRITE(6,930)
                910 FORMAT('1',//,'0',5X,'LAND BLOCK NO.',I5,/)
                920 FORMAT(' ',10X,'AREA:',10X,F8.0,4X,'SQ.FT.',/,
                   1       ' ',10X,'AVERAGE LENGTH:',F8.0,4X,'FT.',/,
                   2       ' ',10X,'AVERAGE SLOPE:',3X,F6.4,/)
                930 FORMAT(' ',5X,'TIME',9X,'DISCHARGE',/,
                   1       ' ',4X,'(MIN.)',10X,'(CFS)')
                    DO 30 J=1,NQP
                    WRITE(6,940) TQ(J),QS(I,J)
                940 FORMAT(4X,F6.1,8X,F7.2)
                 30 CONTINUE
                 10 CONTINUE
                    RETURN
                    END
```

FLOW CHART AND PROGRAMME

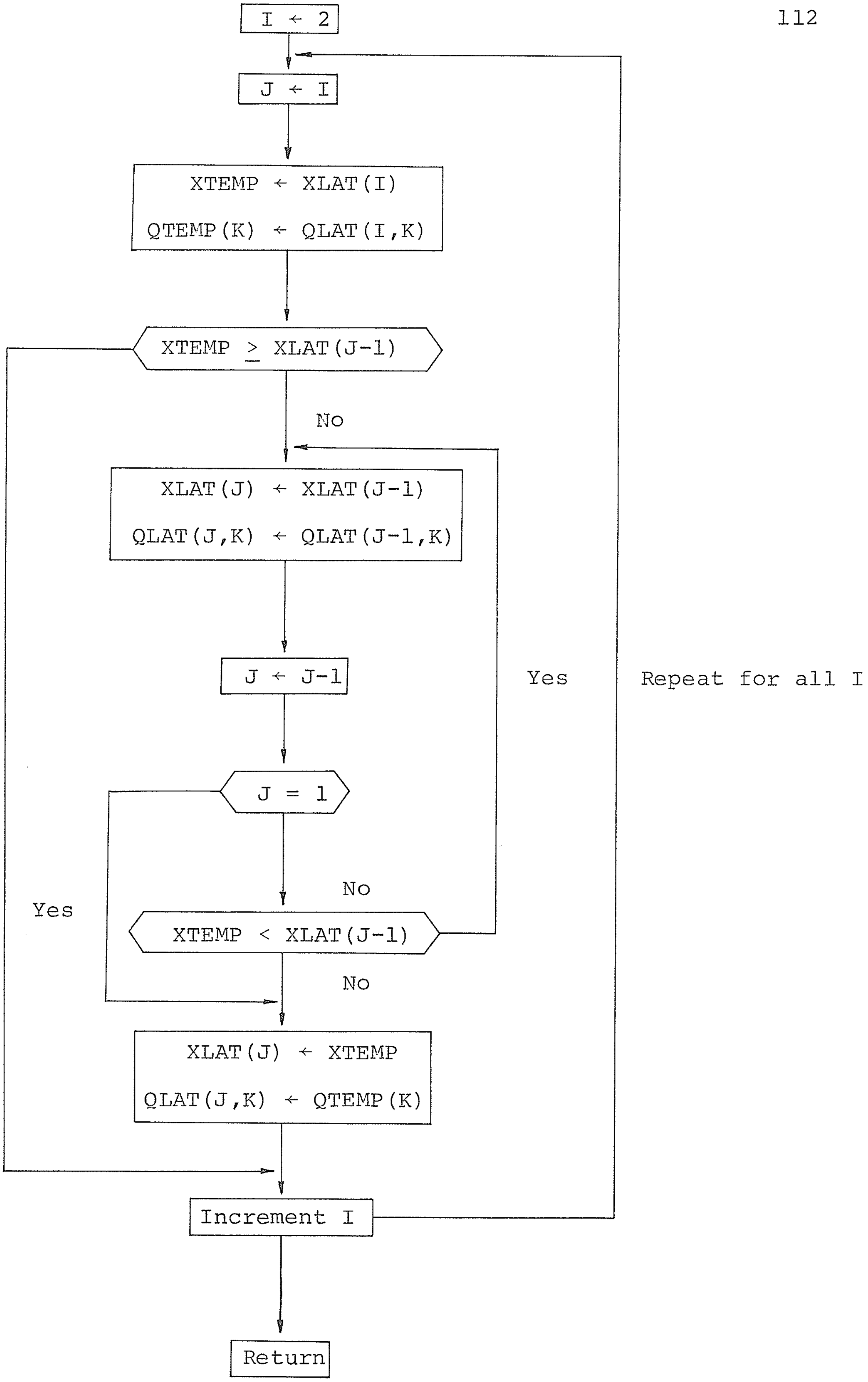
OF

SUBROUTINE MAX


Initialised
QP
Is
QP ≥ QI(I)
Yes
No
QP←QI(I)
Repeat for all I
Return

```
FORTRAN IV G LEVEL  20.1                 MAX                DATE = 72322          15/04/44                    P175 0001

 0001                  SUBROUTINE MAX(QI,NQP,CP)
                 C
                 C        THIS SUBROUTINE TO SORT OUT THE MAXIMUM INFLOW
                 C
 0002                  DIMENSION QI(50)
 0003                  CP=QI(1)
 0004                  DO 10 I=2,NQP
 0005                  IF(CP.GE.QI(I)) GO TO 10
 0006                  CP=QI(I)
 0007               10 CONTINUE
 0008                  RETURN
 0009                  END
```

FLOW CHART AND PROGRAMME
OF
SUBROUTINE SORT

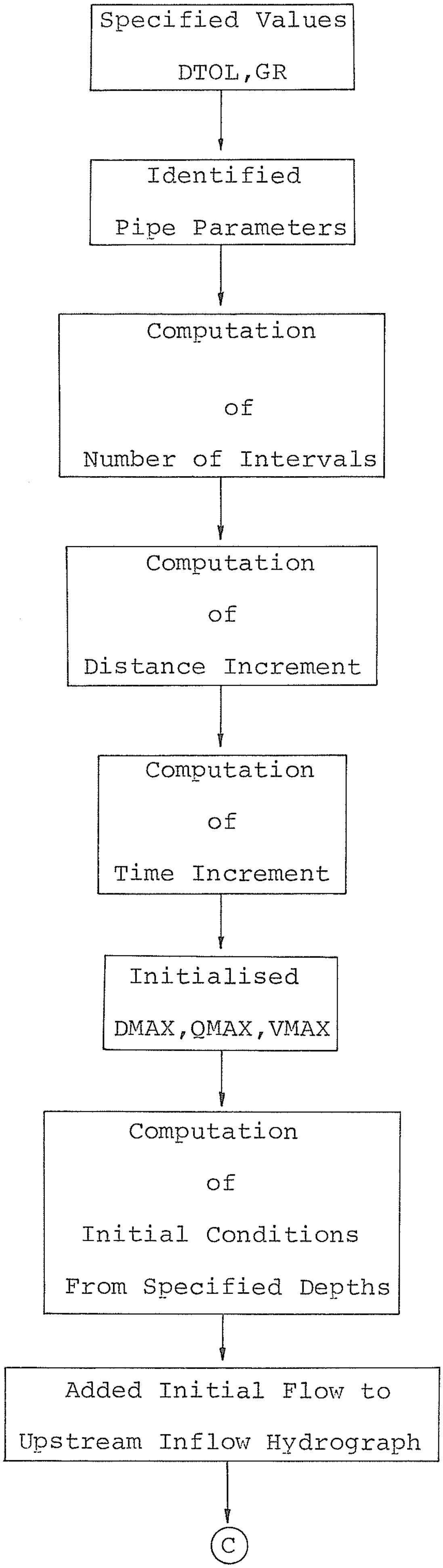

I ← 2
J ← I
XTEMP ← XLAT(I)
QTEMP(K) ← QLAT(I,K)
XTEMP ≥ XLAT(J-1)
No
XLAT(J) ← XLAT(J-1)
QLAT(J,K) ← QLAT(J-1,K)
J ← J-1
Yes
Repeat for all I
J = 1
No
Yes
XTEMP < XLAT(J-1)
No
XLAT(J) ← XTEMP
QLAT(J,K) ← QTEMP(K)
Increment I
Return

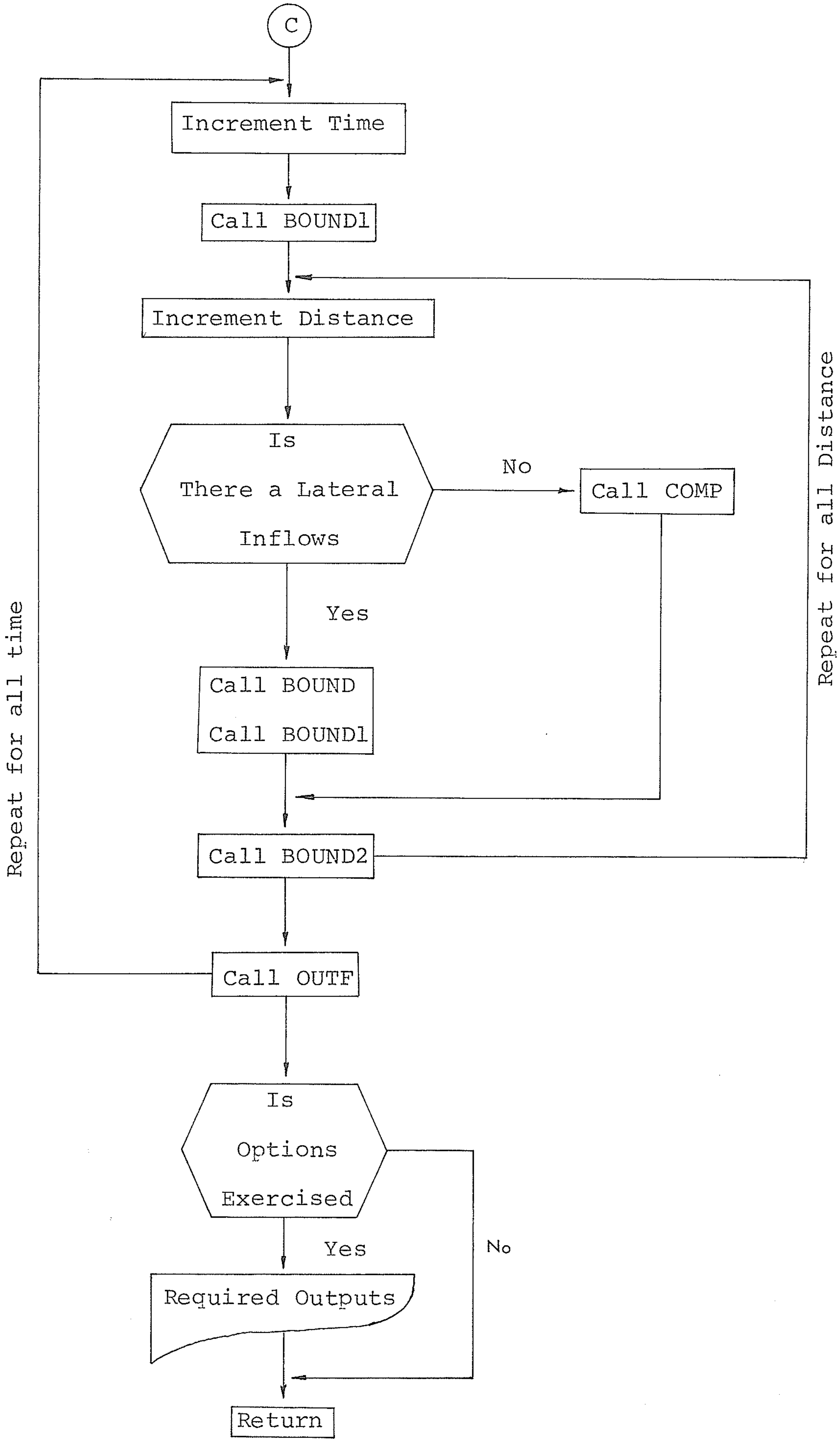
```
 FORTRAN IV G LEVEL  20.1              SORT                 DATE = 72322            15/04/44              P175 0001

   0001                   SUBROUTINE SORT(QLAT,XLAT,NL,NQP)
                   C
                   C         THIS SUBROUTINE TO REARRANGE LATERAL FLOW IN ORDER
                   C         OF DISTANCE FROM INLET
                   C
   0002                   DIMENSION QLAT(9,50),QTEMP(50),XLAT(9)
   0003                   DO 10 I=2,NL
   0004                   J=I
   0005                   XTEMP=XLAT(I)
   0006                   DO 15 K=1,NQP
   0007                   QTEMP(K)=QLAT(I,K)
   0008                15 CONTINUE
   0009                   IF(XTEMP.GE.XLAT(J-1)) GO TO 10
   0010                20 XLAT(J)=XLAT(J-1)
   0011                   DO 25 K=1,NQP
   0012                   QLAT(J,K)=QLAT(J-1,K)
   0013                25 CONTINUE
   0014                   J=J-1
   0015                   IF(J.EQ.1) GO TO 30
   0016                   IF(XTEMP.LT.XLAT(J-1)) GO TO 20
   0017                30 XLAT(J)=XTEMP
   0018                   DO 35 K=1,NQP
   0019                   QLAT(J,K)=QTEMP(K)
   0020                35 CONTINUE
   0021                10 CONTINUE
   0022                   RETURN
   0023                   END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE ROUTC


Specified Values DTOL,GR
Identified Pipe Parameters
Computation of Number of Intervals
Computation of Distance Increment
Computation of Time Increment
Initialised DMAX,QMAX,VMAX
Computation of Initial Conditions From Specified Depths
Added Initial Flow to Upstream Inflow Hydrograph
C


C
Increment Time
Call BOUND1
Increment Distance
Is There a Lateral Inflows
No
Call COMP
Yes
Call BOUND
Call BOUND1
Call BOUND2
Call OUTF
Repeat for all time
Repeat for all Distance
Is Options Exercised
Yes
No
Required Outputs
Return

```
FORTRAN IV G LEVEL  20.1                ROUTC               DATE = 72322         15/04/44                    P175 0001

0001                   SUBROUTINE ROUTC(PIPE,QD,QI,QLAT,TQ,XLAT,NL,NOP,NQP,QP)
               C
               C          THIS SUBROUTINE TO PERFORM ROUTING IN CERCULAR CHANNEL SECTION
               C          BY METHOD OF CHARACTERISTICS
               C
0002                   COMMON/CIR/DEPTH,DIA,A,B,DM,R,THETA,WP/COF/DD,VV,AB,AC,AD,AE,BC,BD
0003                   COMMON/FLOW/CD,D,Q,V,X,DDT,VDT,QDT,T,DT/FLOWO/DTOL,F,GR,SO
0004                   COMMON/MAXI/DMAX,QMAX,VMAX,TDMAX,TQMAX,TVMAX
0005                   DIMENSION D(50),DDT(50),DMAX(50),DO(50),NOPT(5),PIPE(50,6),Q(50)
0006                   DIMENSION QD(50,50),QDT(50),QI(50),QLAT(9,50),QMAX(50),QO(50)
0007                   DIMENSION TDMAX(50),TQ(50),TQMAX(50),TVMAX(50),V(50),VDT(50)
0008                   DIMENSION VMAX(50),VO(50),X(50),XLAT(9)
0009                   DTOL=0.0005
0010                   GR=32.175
               C
0011                   I=NOP
0012                   XF=PIPE(I,1)
0013                   DIA=PIPE(I,2)/12.
0014                   F=PIPE(I,3)
0015                   SO=PIPE(I,4)
0016                   CD=PIPE(I,5)
0017                   ED=PIPE(I,6)
               C
               C          SPECIFIED INITIAL DEPTH
               C
0018                   DD=0.01*DIA
               C
               C          CONVERSION OF TIME INTERVAL INTO SECOND
               C
0019                   DO 10 I=1,NOP
0020                   TQ(I)=TQ(I)*60.
0021                10 CONTINUE
               C
               C          COMPUTATION OF INTERVAL
               C
0022                   XTEMP=20.
0023                   N=XF/XTEMP+1
0024                   IF(N.GE.40) N=40
0025                   N1=N+1
               C
               C          COMPUTATION OF DISTANCE INTERVAL
               C
0026                   IF(CD) 20,30,20
0027                20 MC=1
0028                   XX=0.
0029                   DOUT=(QB/CD)**(1./ED)
0030                   GO TO 40
0031                30 MC=2
0032                   XX=4.5*DD
0033                   DOUT=DD
0034                40 XE=XF-XX
0035                   DX=XE/N
               C
               C          COMPUTATION OF TIME INCREMENT DT
               C
0036                   CALL DCRIT(QP,DC)
0037                   DEPTH=DC
0038                   CALL CIRCLE
```

```
 0039                  VC=QP/A
 0040                  DEPTH=0.82*DIA
 0041                  CALL CIRCLE
 0042                  DTMAX=DX/(VC+SQRT(GR*A/B))
 0043                  DT=DTMAX*0.5
 0044                  CC=-DT/DX
 0045                  NT=TQ(NQP)/DT+1.
             C
             C            INITAILISE MAXIMUM QUANTITIES
             C
 0046                  DO 50 I=1,N1
 0047                  DMAX(I)=0.
 0048                  QMAX(I)=0.
 0049                  VMAX(I)=0.
 0050               50 CONTINUE
             C
             C            COMPUTATION OF INITIAL CONDITION FROM SPECIFIED DEPTH
             C
 0051                  DEPTH=DD
 0052                  CALL CIRCLE
 0053                  VV=(1.486/F)*S0**0.5*R**(2./3.)
 0054                  QB=VV*A
 0055                  XX=0.
 0056                  DO 60 I=1,N1
 0057                  D(I)=DD
 0058                  V(I)=VV
 0059                  Q(I)=QB
 0060                  X(I)=XX
 0061                  XX=XX+DX
 0062               60 CONTINUE
             C
             C         ADD ARTIFICIAL BASEFLOW TO INFLOW HYDROGRAPH
 0063                  DO 70 I=1,NQP
 0064                  QI(I)=QI(I)+QB
 0065               70 CONTINUE
             C
             C            COMMENCE ROUTING COMPUTATION
             C
 0066                  CIN=QB
 0067                  T=TQ(1)
 0068                  DO(1)=D(N1)
 0069                  VO(1)=V(N1)
 0070                  QO(1)=Q(N1)
 0071                  M=2
 0072                  DO 80 J=2,NT
 0073                  T=T+DT
             C
             C            COMPUTATION OF VELOCITY AND DEPTH FOR THE INLET AT TIME T
             C
 0074                  CALL BOUND1(QI,TQ,J,NQP,CIN)
             C
             C            COMPUTATION OF VELOCITY AND DEPTH AT TIME T
             C
 0075                  DO 90 I=2,N
 0076                  IF(NL.EQ.0) GO TO 100
 0077                  DO 95 K=1,NL
 0078                  IF(X(I).LT.XLAT(K).AND.XLAT(K).LT.X(I+1)) GO TO 102
 0079                  IF(X(I).GT.XLAT(K).AND.XLAT(K).GT.X(I-1)) GO TO 105
```

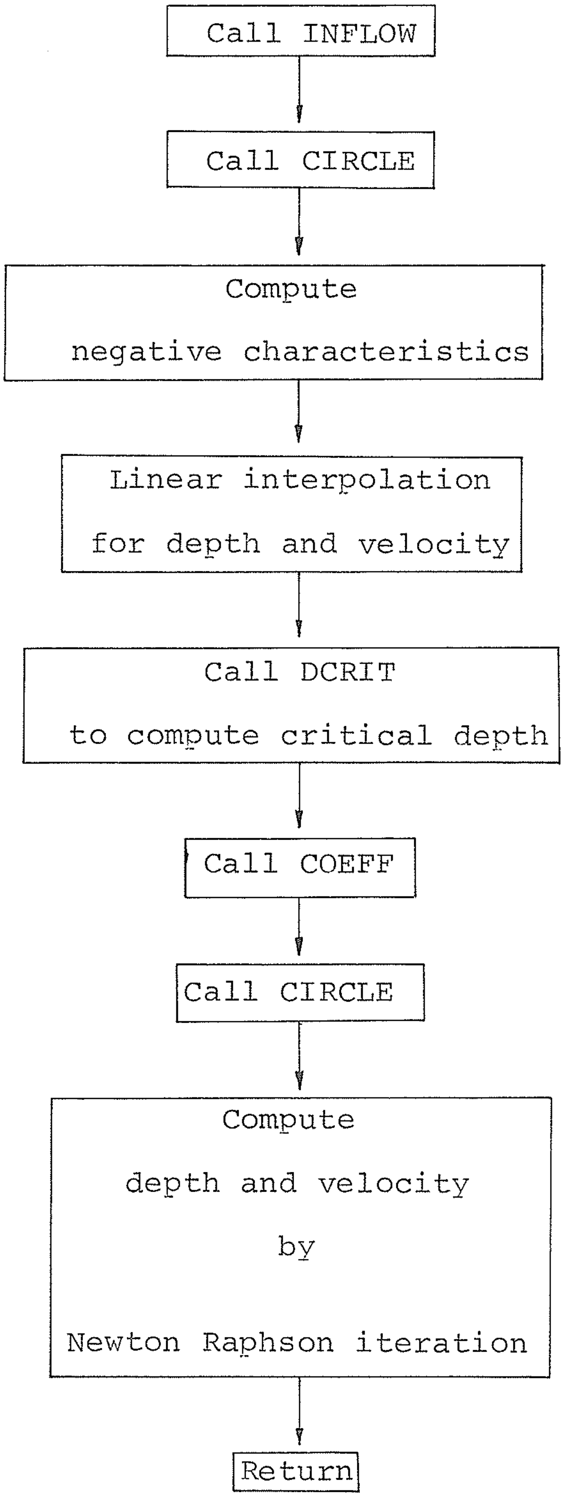
```
  FORTRAN IV G LEVEL  20.1                 ROUTC               DATE = 72322          15/04/44                 P175 0003

   0080                95 CONTINUE
   0081               100 CALL COMP(I)
   0082                   GO TO 90
   0083               102 CALL BOUND(I)
   0084                   GO TO 90
   0085               105 CALL BOUNDL(QLAT,TQ,J,NQP,I,K)
   0086                90 CONTINUE
                C
                C          COMPUTATION OF VELOCITY AND DEPTH FOR THE OUTLET AT TIME T
                C
   0087                   CALL BOUND2(CD,ED,MC,K,N1)
                C
   0088                   CALL OUTF(TQ,N1,NQP,M,DO,QO,VO)
                C
                C          REDEFINED QUANTITIES FOR THE NEXT TIME INCREMENT
                C
   0089                   DO 110 I=1,N1
   0090                   Q(I)=QDT(I)
   0091                   D(I)=DDT(I)
   0092                   V(I)=VDT(I)
   0093               110 CONTINUE
   0094                80 CONTINUE
   0095                   DO 120 K=1,NQP
   0096                   QD(NOP,K)=QO(K)-QB
   0097               120 CONTINUE
                C
                C          CHECK OPTION FOR OUTFLOW OUTPUT
                C
   0098                   IF(NOPT(1).EQ.0) GO TO 140
   0099                   WRITE(6,900) NOP
   0100               900 FORMAT(' ',///,' ','PIPE NUMBER',I5,/)
   0101                   WRITE(6,920) XF,DIA,SC,NL
   0102               920 FORMAT('0',10X,'LENGTH',9X,F6.0,9X,'FT',/,
                     1         ' ',10X,'DIAMETER',7X,F6.2,9X,'FT',/,
                     2         ' ',10X,'AVERAGE SLOPE',3X,F6.4,/,
                     3         ' ',10X,'NO. OF LATERAL INFLOW POINTS',I4,//)
   0103                   WRITE(6,930)
   0104               930 FORMAT(' ',20X,'OUTFLOW',/,'0',3X,'TIME',6X,'DEPTH',4X,'VELOCITY',
                     12X,'DISCHARGE',/,' ',3X,'MIN.',7X,'FT',8X,'FPS',8X,'CFS',/)
   0105                   DO 130 I=1,NQP
   0106                   TQ(I)=TQ(I)/60.
   0107                   WRITE(6,940) TQ(I),DO(I),VO(I),QO(I)
   0108               940 FORMAT(' ',2X,4(F6.2,4X))
   0109               130 CONTINUE
   0110                   I=N1
   0111                   WRITE(6,950)
   0112                   WRITE(6,960)
   0113                   WRITE(6,970) TDMAX(I),DMAX(I),TVMAX(I),VMAX(I),TQMAX(I),QMAX(I)
   0114               950 FORMAT('0',20X,'MAXIMUM OUTFLOW',/)
   0115               960 FORMAT(' ',3X,'TIME',3X,'DEPTH',5X,
                     1'TIME',3X,'VELOCITY',5X,'TIME',3X,'DISCHARGE',/,' ',3X,'MIN.',4X,
                     2'FT',7X,'MIN.',5X,'FPS',8X,'MIN.',6X,'CFS',/)
   0116               970 FORMAT(' ',2X,F6.2,1X,F6.2,4X,F6.2,2X,F6.2,6X,F6.2,3X,F6.2)
                C
                C          MAXIMUM QUANTITIES OUTPUT  AT SPECIFIED DISTANCE INTERVAL
                C
                C          CHECK FOR OUTPUT OPTION
                C
```

```
  140 IXC=NOPT(2)
      IF(IXO.EQ.0) RETURN
      WRITE(6,980)
      WRITE(6,985)
  980 FORMAT(' ',20X,'MAXIMUM DEPTHS,VELOCITIES AND DISCHARGES',//)
  985 FORMAT('0',5X,'DISTANCE',5X,'TIME',3X,'DEPTH',3X,'TIME',3X,
     1'VELOCITY',5X,'TIME',3X,'DISCHARGE',/,' ',3X,'FT',8X,'MIN.',5X,
     2'FT',6X,'MIN.',6X,'FPS',7X,'MIN.',6X,'CFS',/)
      DO 150 I=1,N
      IND=I-(I/IXO)*IXO
      IF(IND.GT.0) GO TO 150
      WRITE(6,990) X(I),IDMAX(I),DMAX(I),IVMAX(I),VMAX(I),IQMAX(I),
     1QMAX(I)
  990 FORMAT(' ',2(5X,F6.1),2X,F6.2,2(3X,F6.1),5X,F6.1,4X,F6.1)
  150 CONTINUE
      RETURN
      END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE BOUND1


Call INFLOW
Call CIRCLE
Compute negative characteristics
Linear interpolation for depth and velocity
Call DCRIT to compute critical depth
Call COEFF
Call CIRCLE
Compute depth and velocity by Newton Raphson iteration
Return

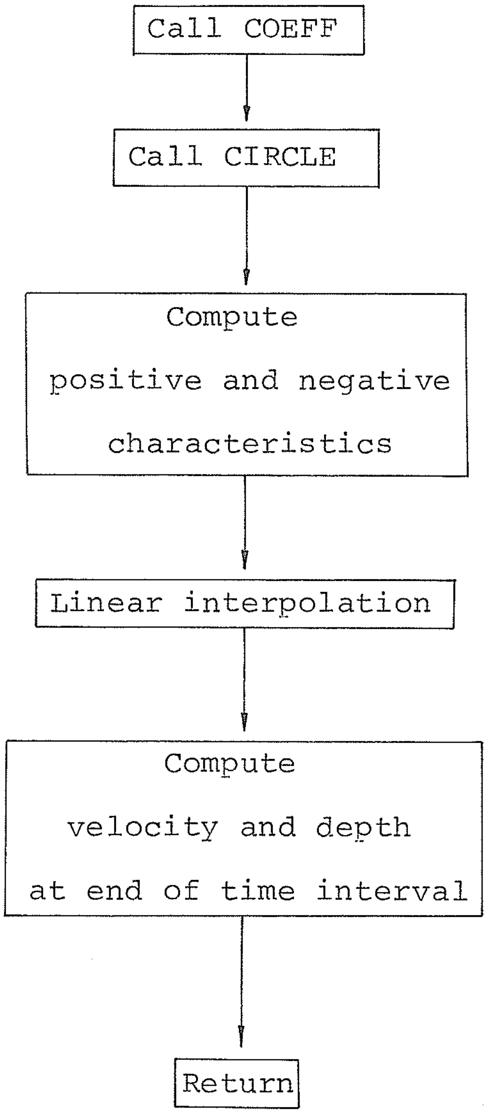
```
      SUBROUTINE BOUND1(QI,TQ,J,NQP,QIN)
C
C        THIS SUBROUTINE TO COMPUTE UPSTREAM BOUNDARY CONDITION
C
      COMMON/FLOW/CQ,D,Q,V,X,DDT,VDT,QDT,T,DT/FLOWD/DTOL,F,GR,SO
      COMMON/CIR/DEPTH,DIA,A,B,DM,R,THETA,WP/COF/DD,VV,AB,AC,AD,AE,BC,BD
      COMMON/MAXI/DMAX,QMAX,VMAX,TDMAX,TQMAX,TVMAX
      DIMENSION D(50),DDT(50),DMAX(50),Q(50),QDT(50),QI(50),QMAX(50)
      DIMENSION TDMAX(50),TQ(50),TQMAX(50),TVMAX(50),V(50),VDT(50)
      DIMENSION VMAX(50),X(50)
C
      CALL INFLOW(QI,TQ,T,NQP,QIN)
      DEPTH=D(1)
      CALL CIRCLE
C
C        NEGATIVE CHARACTERISTIC
      CN=1./(V(1)-SQRT(GR*A/B))
      IF(CN) 10,20,30
   10 UN=CQ/CN
C
C        LINEAR INTERPOLATION
C
      DS=D(1)*(1.+UN)-D(2)*UN
      VS=V(1)*(1.+UN)-V(2)*UN
      GO TO 40
   20 XS=X(1)
      DS=D(1)
      VS=V(1)
      GO TO 40
   30 QQ=QIN
      CALL DCRIT(QQ,DC)
      DP=DC
      GO TO 70
   40 DD=D(1)
      VV=V(1)
      CALL COEFF
      FCN=AC*CN-BC
      GCN=AB
      SCN=AE*CN
      ASMALL=DS-(SCN*CN*DT-GCN*VS)/FCN
      BSMALL=-QIN*GCN/FCN
      DP1=D(1)
      NCOUNT=0
   50 RD=2.*DP1/DIA-1.
      DEPTH=DP1
      CALL CIRCLE
      FDP1=DP1-ASMALL-(BSMALL/A)
      FDP1P=1.+(BSMALL/A**2)*((DIA*(1.-COS(THETA))/2.)*(1./SQRT(1.-RD**2
     1)))
C
C        NEWTON RAPHSON ITERATION
C
      DP2=DP1-FDP1/FDP1P
      DEL=ABS((DP2-DP1)/DP2)
      IF(DEL.LE.DTOL) GO TO 60
      DP1=ABS((DP1+DP2)/2.)
      NCOUNT=NCOUNT+1
      IF(NCOUNT.LE.20) GO TO 50
```

```
FORTRAN IV G LEVEL  20.1                BOUNDI             DATE = 72322           15/04/44                P175 0002

 0046                    WRITE(6,910)
 0047                910 FORMAT(' ','UPSTREAM BOUNDARY CONDITION DOES NOT CONVERGE')
 0048                    STOP
                C
                C           END OF NEWTON RAPHSON
                C
 0049                 60 DP=DP2
 0050                 70 IF(DP.LE.(0.82*DIA)) GO TO 80
 0051                    WRITE(6,900) X(I),T
 0052                900 FORMAT(' ','FLOW IS FULL AT X =',F7.2,'  FT',3X,'  T =',F6.0,
                       1'  SECOND')
 0053                    STOP
 0054                 80 DEPTH=DP
 0055                    CALL CIRCLE
 0056                    VP=QIN/A
 0057                    DDT(1)=DP
 0058                    VDT(1)=VP
 0059                    QDT(1)=QIN
                C
                C           MAXIMUM DEPTH,VELOCITY,DISCHARGE AND THEIR ASSOCIATED TIMES
                C
 0060                    IF (DDT(1).LE.DMAX(1)) GO TO 90
 0061                    DMAX(1)=DDT(1)
 0062                    TDMAX(1)=T/60.
 0063                 90 IF (VDT(1).LE.VMAX(1)) GO TO 100
 0064                    VMAX(1)=VDT(1)
 0065                    TVMAX(1)=T/60.
 0066                100 IF (QDT(1).LE.QMAX(1)) GO TO 110
 0067                    QMAX(1)=QDT(1)
 0068                    TQMAX(1)=T/60.
 0069                110 RETURN
 0070                    END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE COMP


Call COEFF
Call CIRCLE
Compute positive and negative characteristics
Linear interpolation
Compute velocity and depth at end of time interval
Return

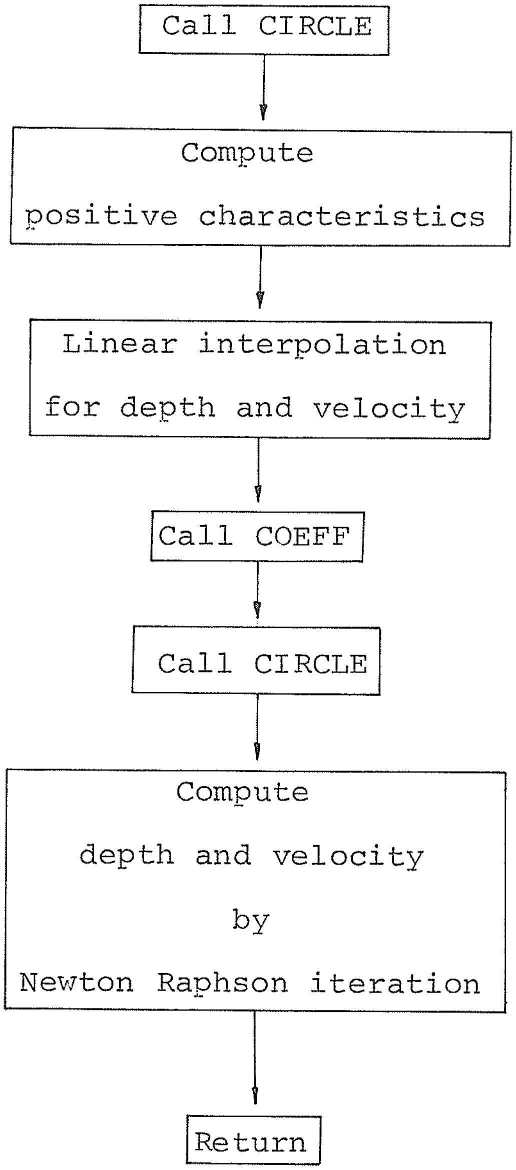
```
FORTRAN IV G LEVEL  20.1                 COMP                 DATE = 72322            15/04/44                    PAGE 0001

                             SUBROUTINE COMP(I)
                   C
                   C            THIS SUBROUTINE TO COMPUTE DEPTH AND VELOCITY AT END OF TIME INTERVALS
                   C
                             COMMON/CIR/DEPTH,DIA,A,B,DN,K,THETA,WP/COF/DD,VV,AB,AC,AD,AE,BC,BD
                             COMMON/FLOW/CO,D,Q,V,X,DDT,VDT,QDT,T,DT/FLOWD/DTOL,F,GR,SO
                             COMMON/MAXI/DMAX,QMAX,VMAX,TDMAX,TQMAX,TVMAX
                             DIMENSION D(50),DDT(50),DMAX(50),Q(50),QDT(50),QMAX(50),TDMAX(50)
                             DIMENSION TQMAX(50),TVMAX(50),V(50),VDT(50),VMAX(50),X(50)
                   C
                   C            COMPUTATION OF VELOCITY AND DEPTH AT TIME T+DT BY KNOWING THE
                   C            VELOCITY AND DEPTH AT THE TIME T
                   C
                             DD=D(I)
                             VV=V(I)
                             CALL COEFF
                             DEPTH=D(I)
                             CALL CIRCLE
                   C
                   C            POSITIVE CHARACTERISTIC
                   C
                             CP=1./(V(I)+SQRT(GR*A/B))
                   C
                   C            NEGATIVE CHARACTERISTIC
                   C
                             CN=1./(V(I)-SQRT(GR*A/B))
                             UP=CO/CP
                             UN=CO/CN
                   C
                   C            LINEAR INTERPOLATION
                   C
                             DR=D(I)*(1.+UP)-D(I-1)*UP
                             VR=V(I)*(1.+UP)-V(I-1)*UP
                             DS=D(I)*(1.+UN)-D(I+1)*UN
                             VS=V(I)*(1.+UN)-V(I+1)*UN
                             FCP=AC*CP-BC
                             FCN=AC*CN-BC
                             GCP=AB
                             GCN=AB
                             SCP=AE*CP
                             SCN=AE*CN
                             TCP=FCP*DR+GCP*VR-SCP*DT/CP
                             TCN=FCN*DS+GCN*VS-SCN*DT/CN
                   C
                   C            VELOCITY AND DEPTH AT END OF TIME INTERVAL
                   C
                             VP=(FCP*TCN-FCN*TCP)/(FCP*GCN-FCN*GCP)
                             DP=(TCP*GCN-TCN*GCP)/(FCP*GCN-FCN*GCP)
                             IF(DP.LE.(0.82*DIA)) GO TO 10
                             WRITE(6,900) X(I),T
                         900 FORMAT(' ','FLOW IS FULL AT X =',F7.2,'  FT',3X,' T =',F6.0,
                            1'  SECOND')
                             STOP
                          10 DEPTH=DP
                             CALL CIRCLE
                             QDT(I)=A*VP
                             DDT(I)=DP
                             VDT(I)=VP
```

```
   FORTRAN IV G LEVEL  20.1                CCMP                DATE = 72322         15/04/44                P175 0002

                  C
                  C       MAXIMUM DEPTH,VELOCITY,DISCHARGE AND THEIR ASSOCIATED TIMES
                  C
 0039                    IF (DDT(I).LE.DMAX(I)) GO TO 20
 0040                    DMAX(I)=DDT(I)
 0041                    TDMAX(I)=T/60.
 0042                 20 IF (VDT(I).LE.VMAX(I)) GO TO 30
 0043                    VMAX(I)=VDT(I)
 0044                    TVMAX(I)=T/60.
 0045                 30 IF (QDT(I).LE.QMAX(I)) GO TO 40
 0046                    QMAX(I)=QDT(I)
 0047                    TQMAX(I)=T/60.
 0048                 40 RETURN
 0049                    END
```

FLOW CHART AND PROGRAMME

OF

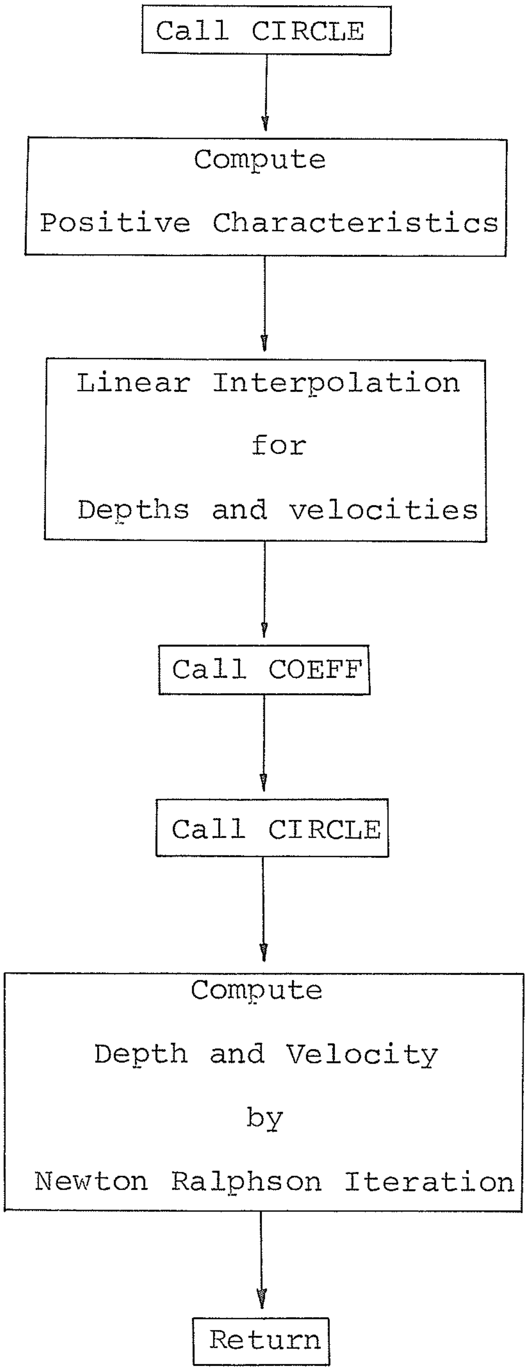
SUBROUTINE BOUND2


Call CIRCLE
Compute positive characteristics
Linear interpolation for depth and velocity
Call COEFF
Call CIRCLE
Compute depth and velocity by Newton Raphson iteration
Return

```
FORTRAN IV G LEVEL  20.1              BOUND2              DATE = 72322          15/04/44                    P175 0001

 0001                 SUBROUTINE BOUND2(CD,ED,MC,N,N1)
                C
                C        THIS SUBROUTINE TO COMPUTE DOWNSTREAM BOUNDARY CONDITION
                C
 0002                 COMMON/CIR/DEPTH,DIA,A,B,CM,R,THETA,WP/COF/DD,VV,AB,AC,AD,AE,BC,BD
 0003                 COMMON/FLOW/CO,D,Q,V,X,DDT,VDT,QDT,T,DT/FLOAD/DTOL,F,GR,SD
 0004                 COMMON/MAXI/DMAX,QMAX,VMAX,TDMAX,TQMAX,TVMAX
 0005                 DIMENSION D(50),DDT(50),DMAX(50),Q(50),QDT(50),QMAX(50),TDMAX(50)
 0006                 DIMENSION TQMAX(50),TVMAX(50),V(50),VDT(50),VMAX(50),X(50)
                C
 0007                 DEPTH=D(N1)
 0008                 CALL CIRCLE
                C
                C        POSITIVE CHARACTERISTIC
                C
 0009                 CP=1./(V(N1)+SQRT(GR*A/B))
 0010                 UP=CD/CP
                C
                C        LINEAR INTERPOLATION
                C
 0011                 DR=D(N1)*(1.+UP)-D(N)*UP
 0012                 VR=V(N1)*(1.+UP)-V(N)*UP
 0013                 DD=D(N1)
 0014                 VV=V(N1)
 0015                 CALL COEFF
 0016                 FCP=AC*CP-BC
 0017                 GCP=AB
 0018                 SCP=AE*CP
 0019                 CSMALL=DR-(SCP*CP*DT-GCP*VR)/FCP
 0020                 DSMALL=-GCP/FCP
 0021                 DP1=D(N1)
 0022                 NCOUNT=0
 0023              10 RD=DP1*2./DIA-1.
 0024                 DEPTH=DP1
 0025                 CALL CIRCLE
 0026                 GO TO (20,30),MC
 0027              20 FD=CD*DP1**ED
 0028                 FD1=CD*ED*DP1**(ED-1.)
 0029                 U=FD/A
 0030                 FDP1=DP1-CSMALL-DSMALL*U
 0031                 THETA2=THETA/2.
 0032                 DADD=(DIA/2.)*(1.-COS(THETA))*(1./SQRT(1.-RD**2))
 0033                 DUDD=((A*FD1)-(FD*DADD))/(A*A)
 0034                 GO TO 40
 0035              30 U=SQRT(GR*A/B)
 0036                 FDP1=DP1-CSMALL-DSMALL*U
 0037                 THETA2=THETA/2.
 0038                 DUDD=(2./DIA)*(1./SQRT(1.-RD**2))*(1./U)*((DIA**2*(1.-COS(THETA)))
                     1/(8.*B)-(A*(DIA/2.)*COS(THETA2)/B**2))
 0039              40 FDP1P=1.-DSMALL*DUDD
                C
                C        NEWTON RAPHSON ITERATION
                C
 0040                 DP2=DP1-FDP1/FDP1P
 0041                 DEL=ABS((DP2-DP1)/DP2)
 0042                 IF(DEL.LE.DTOL) GO TO 50
 0043                 DP1=ABS((DP1+DP2)/2.)
 0044                 NCOUNT=NCOUNT+1
```

```
FORTRAN IV G LEVEL  20.1              BCOND2            DATE = 72322          15/04/44                   P175 0002

 0045                   IF(NCOUNT.LE.20) GO TO 10
 0046                   WRITE(6,910)
 0047               910 FORMAT(' ','DOWNSTREAM BOUNDARY CONDITION DOES NOT CONVERGE')
 0048                   STOP
               C
               C           END OF ITERATION
               C
 0049                50 DEPTH=DP2
 0050                   IF(DEPTH.LE.(0.82*DIA)) GO TO 60
 0051                   WRITE(6,900) X(I),T
 0052               900 FORMAT(' ','FLOW IS FULL AT X =',F7.2,'  FT',3X,'  T =',F6.0,
                      1'  SECOND')
 0053                   STOP
 0054                60 CALL CIRCLE
 0055                   DDT(N1)=DEPTH
 0056                   GO TO (70,80),MC
 0057                70 QDT(N1)=CD*DEPTH**ED
 0058                   VDT(N1)=QDT(N1)/A
 0059                   GO TO 90
 0060                80 VDT(N1)=SQRT(GR*A/B)
 0061                   QDT(N1)=VDT(N1)*A
               C
               C           MAXIMUM DEPTH,VELOCITY,DISCHARGE AND THEIR ASSOCIATED TIMES
               C
 0062                90 I=N1
 0063                   IF (DDT(I).LE.DMAX(I)) GO TO 100
 0064                   DMAX(I)=DDT(I)
 0065                   TDMAX(I)=T/60.
 0066               100 IF (VDT(I).LE.VMAX(I)) GO TO 110
 0067                   VMAX(I)=VDT(I)
 0068                   TVMAX(I)=T/60.
 0069               110 IF (QDT(I).LE.QMAX(I)) GO TO 120
 0070                   QMAX(I)=QDT(I)
 0071                   TQMAX(I)=T/60.
 0072               120 RETURN
 0073                   END
```

FLOW CHART AND PROGRAMME
OF
SUBROUTINE BOUND


Call CIRCLE
Compute Positive Characteristics
Linear Interpolation for Depths and velocities
Call COEFF
Call CIRCLE
Compute Depth and Velocity by Newton Ralphson Iteration
Return

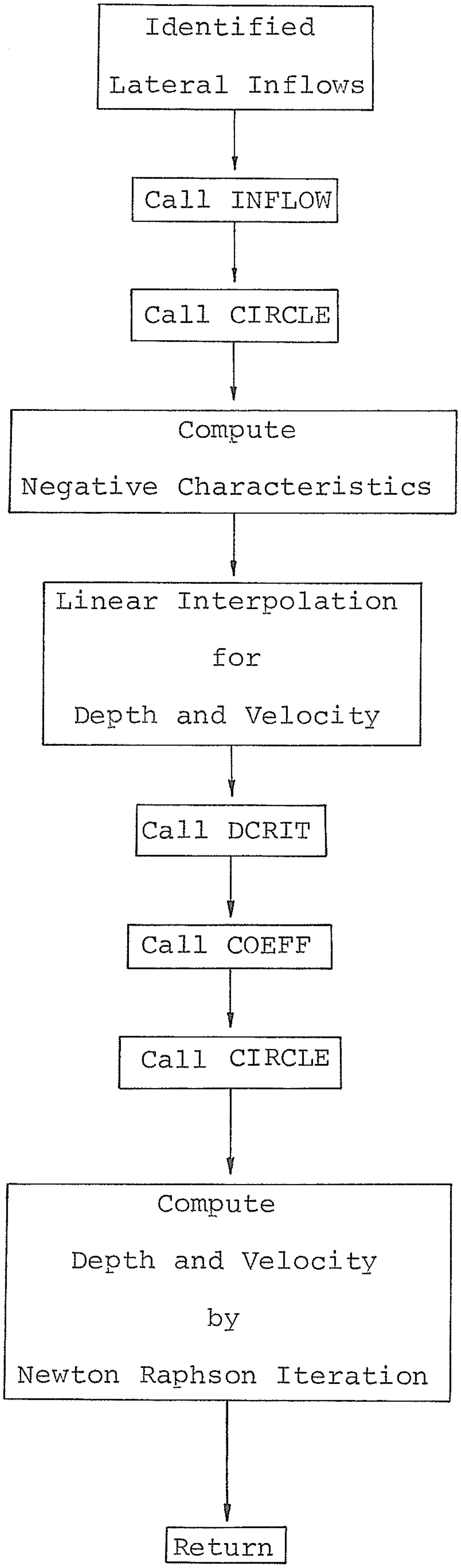
```
     FORTRAN IV G LEVEL  20.1                 BOUND             DATE = 72322          15/04/44                    PAGE 0001

      0001                  SUBROUTINE BOUND(I)
                      C
                      C        THIS SUBROUTINE TO COMPUTE DEPTHS,VELOCITIES AND DISCHARGE
                      C        JUST UPSTREAM FROM LATERAL JUNCTION
                      C
      0002                  COMMON/CIR/DEPTH,DIA,A,B,DM,R,THETA,WP/COF/DD,VV,AB,AC,AD,AE,BC,BD
      0003                  COMMON/FLOW/CO,D,Q,V,X,DDT,VDT,QDT,T,DT/FLOWD/DTOL,F,GR,SO
      0004                  COMMON/MAXI/DMAX,QMAX,VMAX,TDMAX,TQMAX,TVMAX
      0005                  DIMENSION D(50),DDT(50),DMAX(50),Q(50),QDT(50),QMAX(50),TDMAX(50)
      0006                  DIMENSION TQMAX(50),TVMAX(50),V(50),VDT(50),VMAX(50),X(50)
      0007                  DEPTH=D(I)
      0008                  CALL CIRCLE
                      C
                      C        POSITIVE CHARACTERISTIC
                      C
      0009                  CP=1./(V(I)+SQRT(GR*A/B))
      0010                  UP=CO/CP
                      C
                      C        LINEAR INTERPOLATION
                      C
      0011                  DR=D(I)*(1.+UP)-D(I-1)*UP
      0012                  VR=V(I)*(1.+UP)-V(I-1)*UP
      0013                  DD=D(I)
      0014                  VV=V(I)
      0015                  CALL COEFF
      0016                  FCP=AC*CP-BC
      0017                  GCP=AB
      0018                  SCP=AE*CP
      0019                  CSMALL=DR-(SCP*CP*DT-GCP*VR)/FCP
      0020                  DSMALL=-(QDT(I-1)*GCP)/FCP
      0021                  DPI=D(I)
      0022                  NCOUNT=0
      0023               10 RD=DPI*2./DIA-1.
      0024                  DEPTH=DPI
      0025                  CALL CIRCLE
      0026                  FDPI=DPI-CSMALL-(DSMALL/A)
      0027                  FDPIP=1.+(DSMALL/A**2)+((DIA*(1.-COS(THETA))/2.)+(1./SQRT(1.-RD**2
                           1)))
                      C        NEWTON RAPHSON ITERATION
      0028                  DPJ=DPI-FDPI/FDPIP
      0029                  DEL=ABS((DPJ-DPI)/DPJ)
      0030                  IF(DEL.LE.DTOL) GO TO 20
      0031                  DPI=ABS((DPI+DPJ)/2.)
      0032                  NCOUNT=NCOUNT+1
      0033                  IF(NCOUNT.LE.20) GO TO 10
      0034                  WRITE(6,910)
      0035              910 FORMAT(' ','UPSTREAM JUNCTION BOUNDARY DOES NOT CONVERGE')
      0036                  STOP
                      C
                      C        END OF ITERATION
                      C
      0037               20 DP=DPJ
      0038                  IF(DP.LE.(0.82*DIA)) GO TO 30
      0039                  WRITE(6,900) X(I),T
      0040              900 FORMAT(' ','FLOW IS FULL AT X =',F7.2,'  FT',3X,'  T =',F6.0,
                           1'  SECOND')
      0041                  STOP
      0042               30 DEPTH=DP
```

```
FORTRAN IV G LEVEL  20.1                BOUND               DATE = 72322           15/04/44                    PAGE 0002

 0043                CALL CIRCLE
 0044                VP=QDT(I-1)/A
 0045                DDT(I)=DP
 0046                VDT(I)=VP
 0047                QDT(I)=QDT(I-1)
             C
             C          MAXIMUM DEPTH,VELOCITY,DISCHARGE AND THEIR ASSOCIATED TIMES
             C
 0048                IF (DDT(I).LE.DMAX(I)) GO TO 40
 0049                DMAX(I)=DDT(I)
 0050                TDMAX(I)=T/60.
 0051             40 IF (VDT(I).LE.VMAX(I)) GO TO 50
 0052                VMAX(I)=VDT(I)
 0053                TVMAX(I)=T/60.
 0054             50 IF (QDT(I).LE.QMAX(I)) GO TO 60
 0055                QMAX(I)=QDT(I)
 0056                TQMAX(I)=T/60.
 0057             60 RETURN
 0058                END
```

FLOW CHART AND PROGRAMME

OF

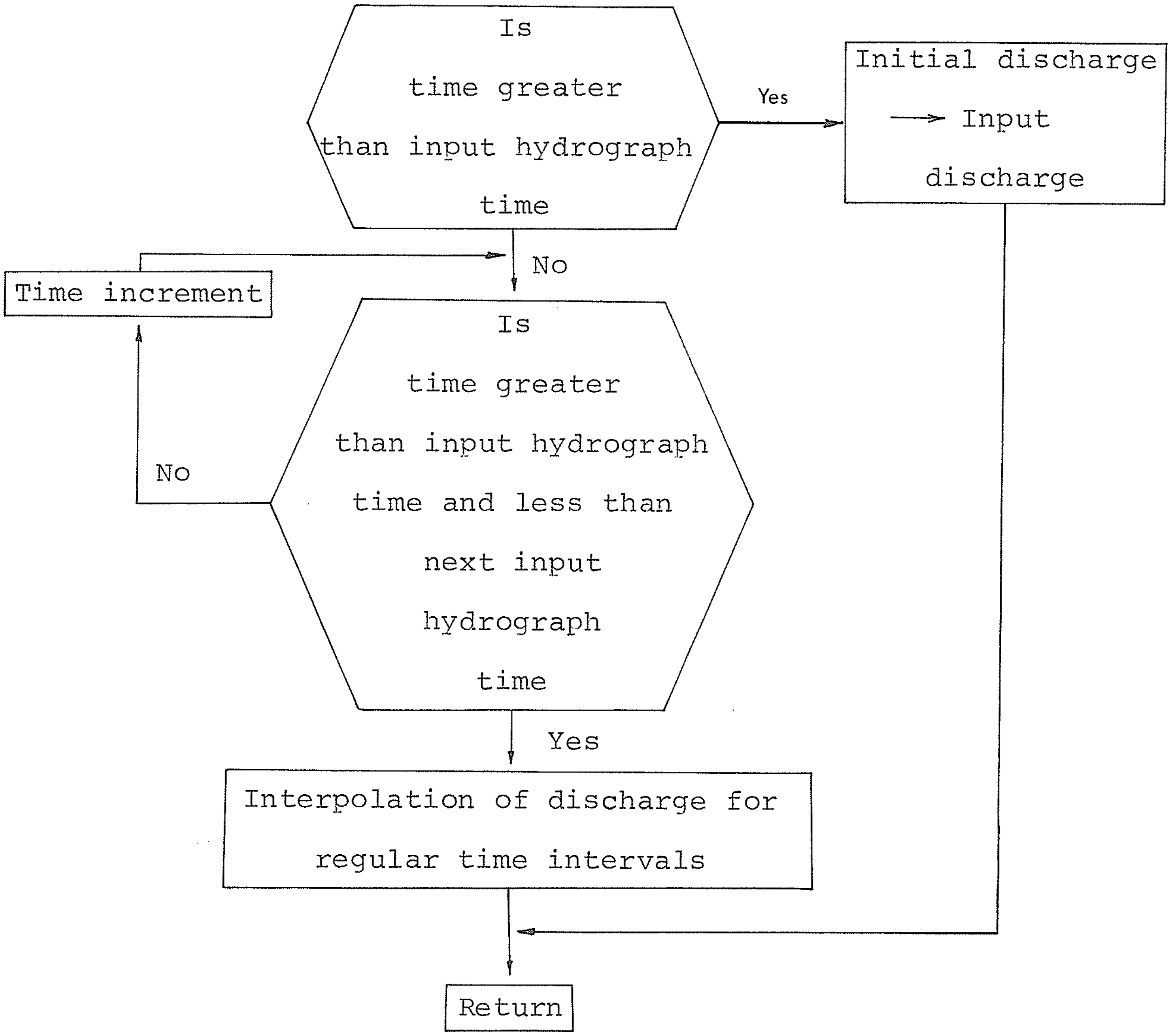
SUBROUTINE BOUNDL


Identified
Lateral Inflows
Call INFLOW
Call CIRCLE
Compute
Negative Characteristics
Linear Interpolation
for
Depth and Velocity
Call DCRIT
Call COEFF
Call CIRCLE
Compute
Depth and Velocity
by
Newton Raphson Iteration
Return

```
      FORTRAN IV G LEVEL  20.1               BOUNDL              DATE = 72322          15/04/44                   P175 0001

      0001                 SUBROUTINE BOUNDL(QLAT,TQ,J,NQP,I,K)
                     C
                     C        THIS SUBROUTINE TO COMPUTE  BOUNDARY CONDITION AT JUNCTION
                     C        ASSUMED THAT POWER LOSSES ACROSS IS NEGLIGIBLE
      0002                 COMMON/CIR/DEPTH,DIA,A,B,DX,R,THETA,WP/COF/DD,VV,AB,AC,AD,AE,BC,BD
      0003                 COMMON/FLOW/CO,D,Q,V,X,DDT,VOT,QOT,T,DT/FLOWD/DTOL,F,GR,SO
      0004                 COMMON/MAXI/DMAX,QMAX,VMAX,TDMAX,TQMAX,TVMAX
      0005                 DIMENSION D(50),DDT(50),DMAX(50),Q(50),QOT(50),QLAT(9,50),QLT(50)
      0006                 DIMENSION QMAX(50),TDMAX(50),TQ(50),TQMAX(50),TVMAX(50),V(50)
      0007                 DIMENSION VOT(50),VMAX(50),X(50)
      0008                 DO 5 L=1,NCP
      0009                 QLT(L)=QLAT(K,L)
      0010               5 CONTINUE
      0011                 CALL INFLOW(QLT,TQ,T,NCP,QL)
      0012                 QIN=QOT(I-1)+QL
      0013                 DEPTH=D(I)
      0014                 CALL CIRCLE
                     C
                     C        NEGATIVE CHARACTERISTIC
                     C
      0015                 CN=1./(V(I)-SQRT(GR*A/B))
      0016                 IF(CN) 10,20,30
      0017              10 UN=CO/CN
                     C
                     C        LINEAR INTERPOLATION
                     C
      0018                 DS=D(I)*(1.+UN)-D(I+1)*UN
      0019                 VS=V(I)*(1.+UN)-V(I+1)*UN
      0020                 GO TO 40
      0021              20 XS=X(I)
      0022                 DS=D(I)
      0023                 VS=V(I)
      0024                 GO TO 40
      0025              30 QQ=QIN
      0026                 CALL DCRIT(QQ,DC)
      0027                 DP=DC
      0028                 GO TO 70
      0029              40 DD=D(I)
      0030                 VV=V(I)
      0031                 CALL COEFF
      0032                 FCN=AC*CN-BC
      0033                 GCN=AB
      0034                 SCN=AE*CN
      0035                 ASMALL=DS-(SCN*CN*DT-GCN*VS)/FCN
      0036                 BSMALL=-QIN*GCN/FCN
      0037                 DPI=D(I)
      0038                 NCOUNT=0
      0039              50 RD=2.*DPI/DIA-1.
      0040                 DEPTH=DPI
      0041                 CALL CIRCLE
      0042                 FDPI=DPI-ASMALL-(BSMALL/A)
      0043                 FDPIP=1.+(BSMALL/A**2)*((DIA*(1.-COS(THETA))/2.)*(1./SQRT(1.-RD**2
                          1)))
                     C
                     C        NEWTON RAPHSON ITERATION
                     C
      0044                 DPJ=DPI-FDPI/FDPIP
      0045                 DEL=ABS((DPJ-DPI)/DPJ)
```

```
      IF(DEL.LE.DTOL) GO TO 60
      DPI=ABS((DPI+DPJ)/2.)
      NCOUNT=NCOUNT+1
      IF(NCOUNT.LE.20) GO TO 50
      WRITE(6,910)
  910 FORMAT(' ','DOWNSTREAM BOUNDARY CONDITION DOES NOT CONVERGE')
      STOP
C
C        END OF ITERATION
C
   60 DP=DPJ
   70 IF(DP.LE.(0.82*DIA)) GO TO 80
      WRITE(6,900) X(I),T
  900 FORMAT(' ','FLOW IS FULL AT X =',F7.2,'  FT',3X,'  T =',F6.0,
     1'  SECOND')
      STOP
   80 DEPTH=DP
      CALL CIRCLE
      VP=QIN/A
      DDT(I)=DP
      VDT(I)=VP
      QDT(I)=QIN
C
C        MAXIMUM DEPTH,VELOCITY,DISCHARGE AND THEIR ASSOCIATED TIMES
C
      IF (DDT(I).LE.DMAX(I)) GO TO 90
      DMAX(I)=DDT(I)
      TDMAX(I)=T/60.
   90 IF (VDT(I).LE.VMAX(I)) GO TO 100
      VMAX(I)=VDT(I)
      TVMAX(I)=T/60.
  100 IF (QDT(I).LE.QMAX(I)) GO TO 110
      QMAX(I)=QDT(I)
      TQMAX(I)=T/60.
  110 RETURN
      END
```

FLOW CHART AND PROGRAMME
OF
SUBROUTINE INFLOW

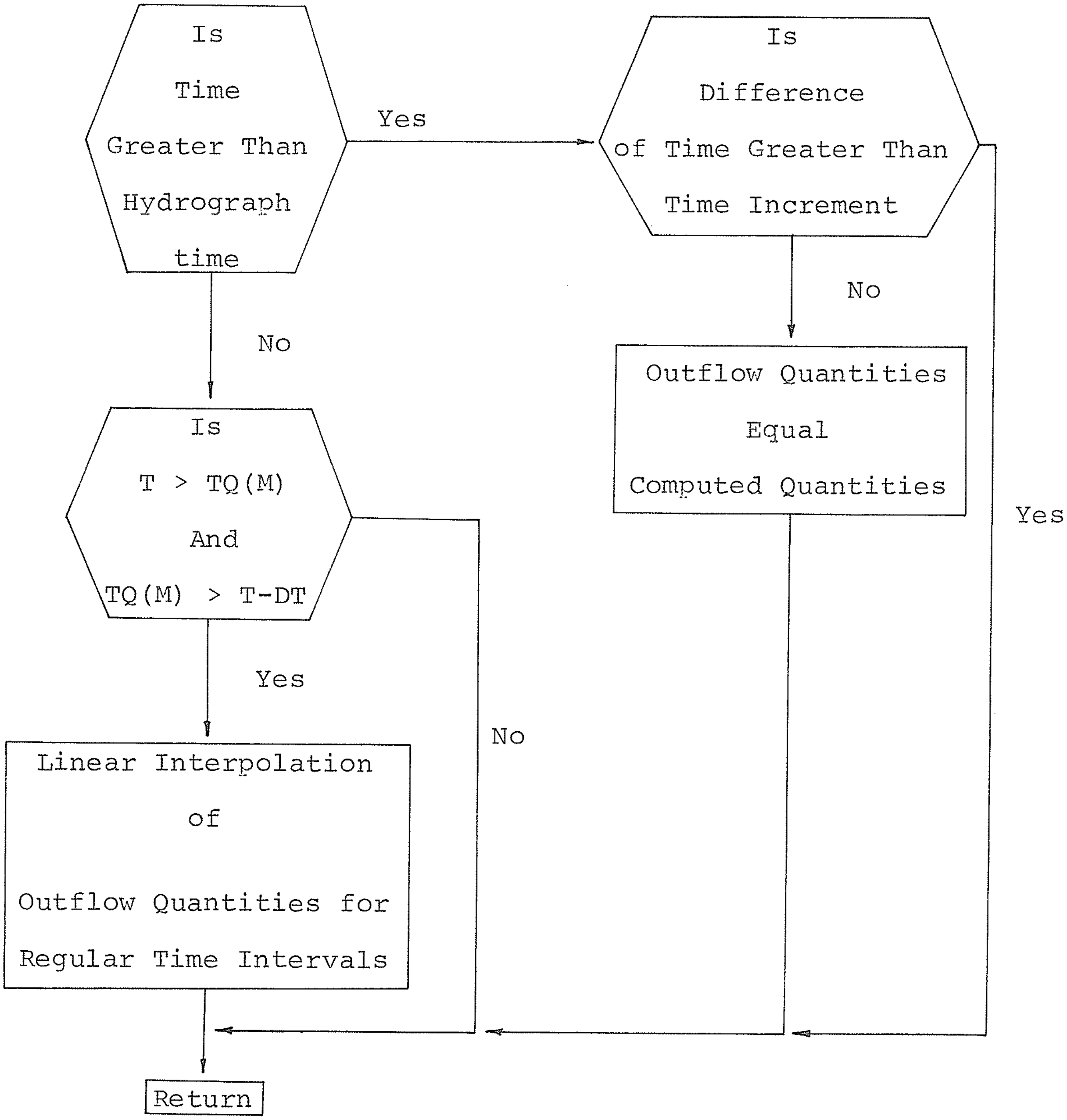

Is time greater than input hydrograph time
Yes
Initial discharge → Input discharge
No
Time increment
Is time greater than input hydrograph time and less than next input hydrograph time
No
Yes
Interpolation of discharge for regular time intervals
Return

```
FORTRAN IV G LEVEL  20.1              INFLOW              DATE = 72322          15/04/44                    P175 0001

 0001                       SUBROUTINE INFLOW(QI,TQ,T,NQCD,QIN)
                  C
                  C            THIS SUBROUTINE TO COMPUTE INFLOW HYDROGRAPH AT IRREGULAR TIME
                  C            INTERVALS
                  C
 0002                       DIMENSION QI(50),TQ(50)
                  C
 0003                       IQ=1
                  C
                  C            INTERPOLATION FOR REGULAR TIME INTERVAL
                  C
 0004                       IF(T.GE.TQ(NQCD)) GO TO 30
 0005                    10 IF(T.GE.TQ(IQ).AND.T.LT.TQ(IQ+1)) GO TO 20
 0006                       IQ=IQ+1
 0007                       GO TO 10
 0008                    20 QIN=QI(IQ)+(QI(IQ+1)-QI(IQ))*(T-TQ(IQ))/(TQ(IQ+1)-TQ(IQ))
 0009                       RETURN
 0010                    30 QIN=QI(NQCD)
 0011                       RETURN
 0012                       END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE OUTF

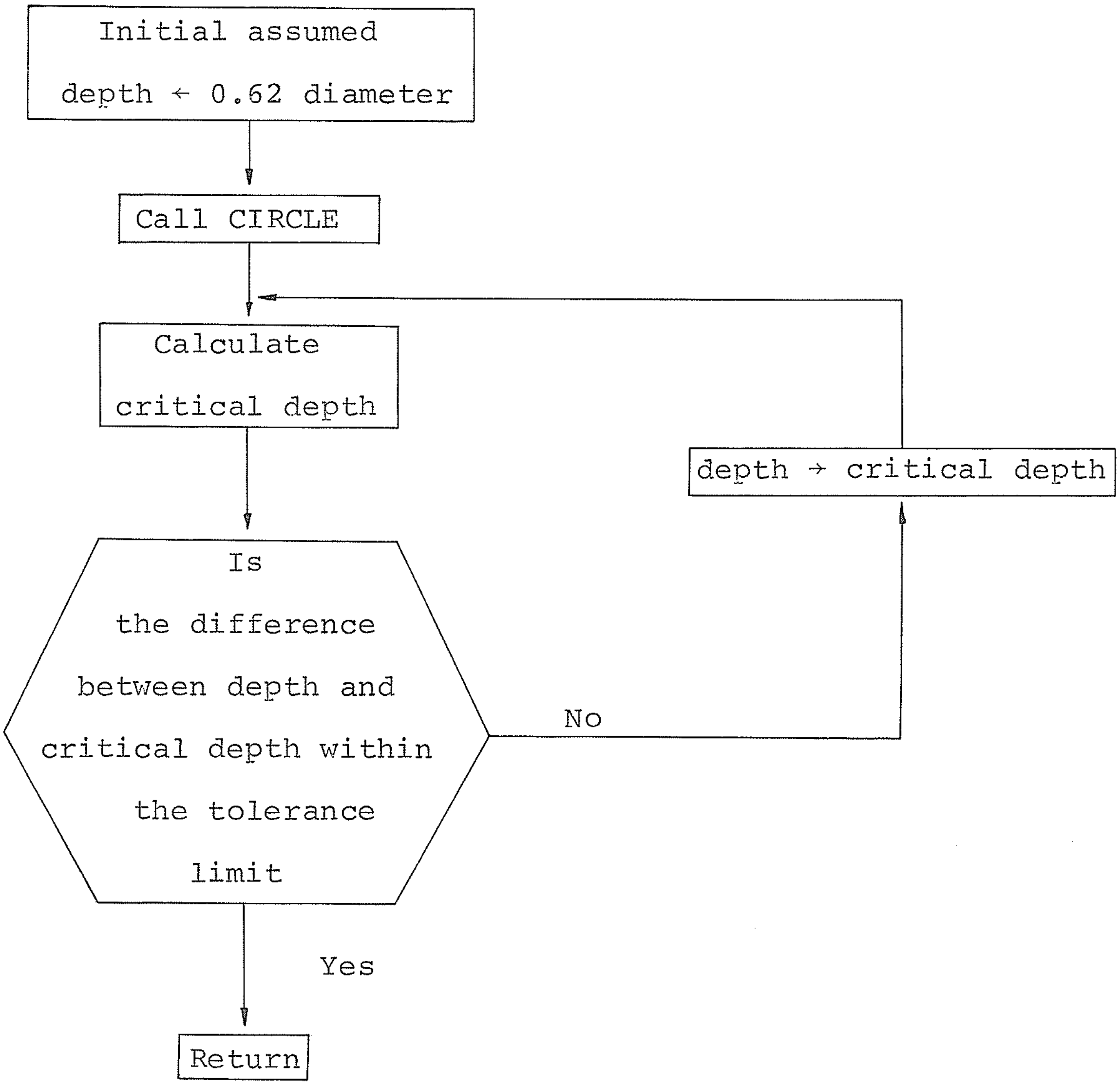

Is Time Greater Than Hydrograph time
Yes
Is Difference of Time Greater Than Time Increment
No
No
Outflow Quantities Equal Computed Quantities
Is T > TQ(M) And TQ(M) > T-DT
Yes
Yes
No
Linear Interpolation of Outflow Quantities for Regular Time Intervals
Return

```
FORTRAN IV G LEVEL  20.1                  OUTF                DATE = 72322           15/04/44                  P175 0001

0001                SUBROUTINE OUTF(TQ,N1,NQCD,M,DO,QO,VO)
              C
              C        THIS SUBROUTINE TO COMPUTE DISCHARGE AT REGULAR SPECIFIED INTERVAL
              C
0002                COMMON/FLOW/CO,D,Q,V,X,DDT,VDT,QDT,T,DT
0003                DIMENSION D(50),DDT(50),DO(50),Q(50),QDT(50),QO(50),V(50),VDT(50)
0004                DIMENSION VO(50),TQ(50),X(50)
              C
              C        CHECK IF TIME IS EXCEEDING
              C
0005                IF(M.GE.NQCD) GO TO 20
0006                IF(T.GT.TQ(M).AND.TQ(M).GT.(T-DT)) GO TO 10
0007                RETURN
0008             10 FACT=(T-TQ(M))/DT
0009                DO(M)=DDT(N1)-(DDT(N1)-D(N1))*FACT
0010                QO(M)=QDT(N1)-(QDT(N1)-Q(N1))*FACT
0011                VO(M)=VDT(N1)-(VDT(N1)-V(N1))*FACT
0012                M=M+1
0013                RETURN
0014             20 IF((TQ(M)-T).GT.DT) RETURN
0015                DO(M)=DDT(N1)
0016                QO(M)=QDT(N1)
0017                VO(M)=VDT(N1)
0018                RETURN
0019                END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE DCRIT

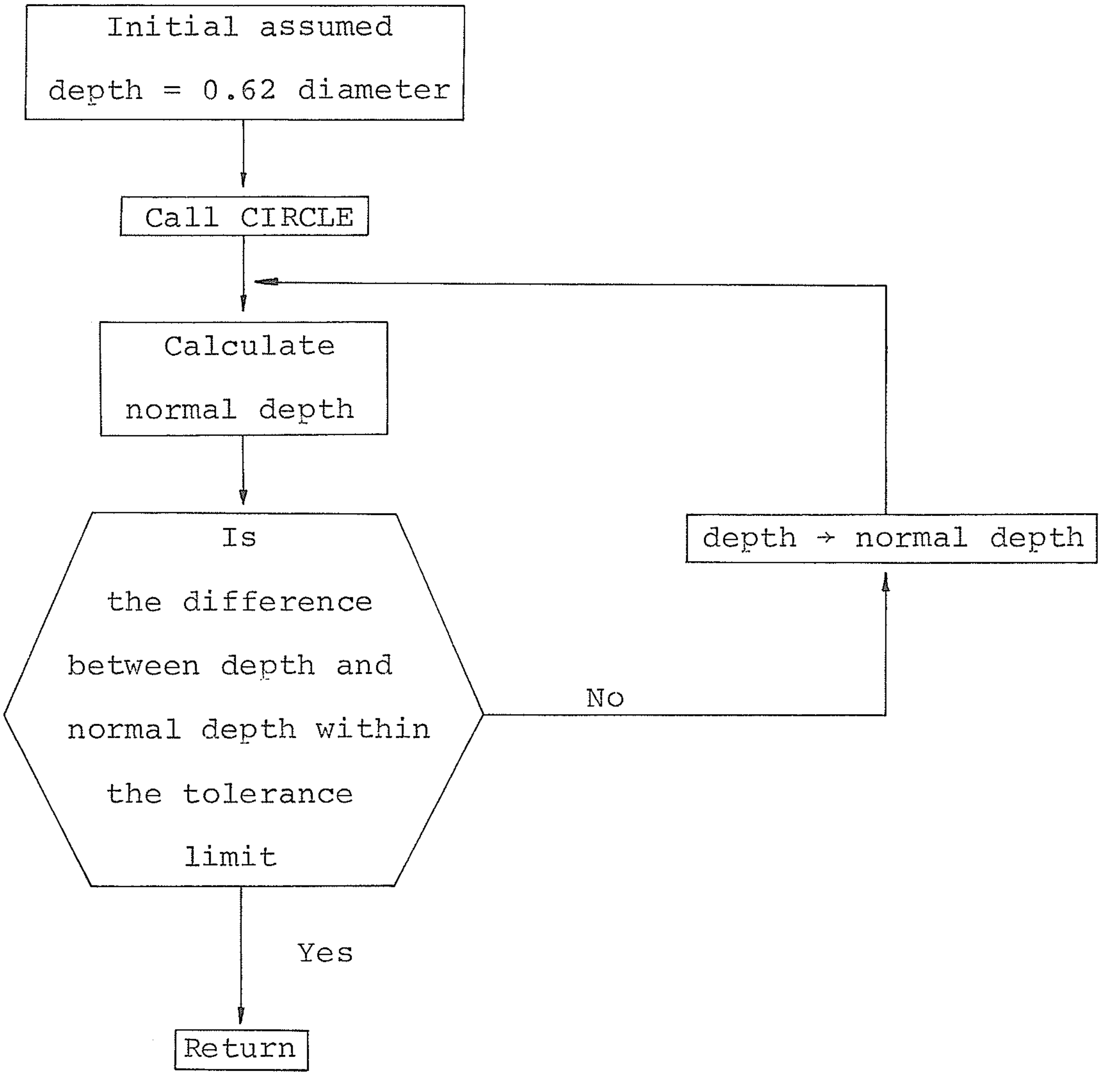

Initial assumed
depth ← 0.62 diameter
Call CIRCLE
Calculate
critical depth
depth → critical depth
Is
the difference
between depth and
critical depth within
the tolerance
limit
No
Yes
Return

```
FORTRAN IV G LEVEL  20.1                DCRIT              DATE = 72322          15/04/44                P175 0001

 0001                     SUBROUTINE DCRIT(QQ,DC)
                C
                C            THIS SUBROUTINE TO COMPUTE CRITICAL DEPTH
                C
 0002                     COMMON/CIR/DEPTH,DIA,A,B,DM,R,THETA,WP/FLOWD/DTOL,F,GR,SO
                C
 0003                     DEPTH=0.62*DIA
 0004                  10 CALL CIRCLE
                C
                C            NEWTON-RAPHSON ITERATION
                C
 0005                     DC=DEPTH-(B*(A**3)-((B*QQ)**2)/GR)/(3.*((B*A)**2)-(2.*(A**3)*COS
                         1(THETA/2.))/(SIN(THETA/2.)))
 0006                     DEL=ABS((DC-DEPTH)/DC)
 0007                     IF(DEL-DTOL) 30,30,20
 0008                  20 DEPTH=DC
 0009                     GO TO 10
 0010                  30 RETURN
 0011                     END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE DNORM

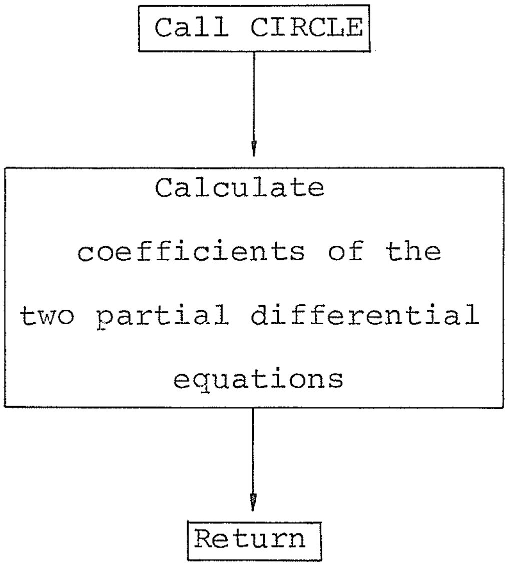

Initial assumed
depth = 0.62 diameter
Call CIRCLE
Calculate
normal depth
Is
the difference
between depth and
normal depth within
the tolerance
limit
No
depth → normal depth
Yes
Return

```
FORTRAN IV G LEVEL  20.1              DNORM              DATE = 72322          15/04/44                P175 0001

 0001                    SUBROUTINE DNORM(QQ,DN)
                C
                C           THIS SUBROUTINE TO COMPUTE NORMAL DEPTH
                C
 0002                    COMMON/CIR/DEPTH,DIA,A,B,DM,R,THETA,WP/FLOWD/DTOL,F,GR,SO
 0003                    DEPTH=0.62*DIA
 0004                 10 CALL CIRCLE
 0005                    VV=QQ/A
 0006                    FF=(F*F*8.*GR)/(2.2082*R**(1./3.))
                C
                C           NEWTON-RAPHSON ITERATION
                C
 0007                    DN=DEPTH-(WP-(FF*(QQ**2))/(8.*GR*SO*(R**2)*A))/((5.*B)/R-2./SIN(
                        1THETA/2.))
 0008                    DEL=ABS((DN-DEPTH)/DN)
 0009                    IF(DEL-DTOL) 30,30,20
 0010                 20 DEPTH=DN
 0011                    GO TO 10
 0012                 30 RETURN
 0013                    END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE COEFF

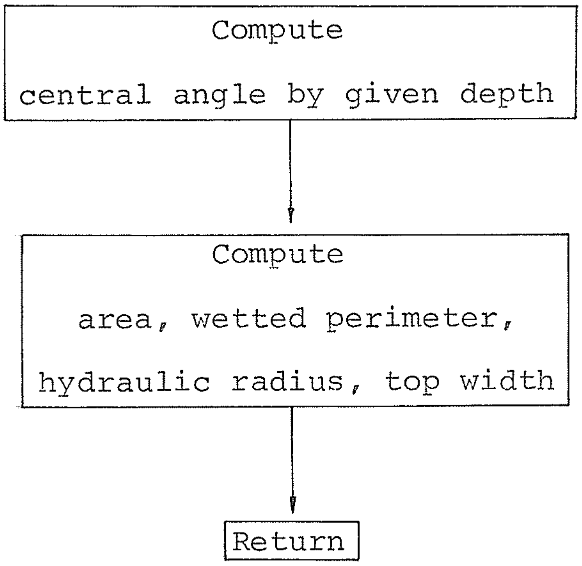

Call CIRCLE
Calculate coefficients of the two partial differential equations
Return

```
FORTRAN IV G LEVEL  20.1                COEFF              DATE = 72322          15/04/44                    P175 0001

  0001                    SUBROUTINE COEFF
                C
                C            THIS SUBROUTINE TO COMPUTE COEFFICIENTS IN ORDINARY DIFFERENTIAL
                C            EQUATIONS
                C
  0002                    COMMON/CIR/DEPTH,DIA,A,B,DM,R,THETA,WP/COF/DD,VV,AB,AC,AD,AE,BC,BD
  0003                    COMMON/FLOWD/DTOL,F,GR,SO
                C
  0004                    DEPTH=DD
  0005                    CALL CIRCLE
  0006                    A1=A/(VV*B)
  0007                    D1=1./VV
  0008                    A2=VV/GR
  0009                    B2=1./GR
                C
                C            ENERGY SLOPE
                C
  0010                    SF=(F*VV/(1.486*R**(2./3.)))**2
  0011                    E2=SF-SO
  0012                    AB=A1*B2
  0013                    AC=A1-A2
  0014                    AD=-A2*D1
  0015                    AE=A1*E2
  0016                    BC=-B2
  0017                    BD=-B2*D1
  0018                    RETURN
  0019                    END
```

FLOW CHART AND PROGRAMME

OF

SUBROUTINE CIRCLE


Compute
central angle by given depth
Compute
area, wetted perimeter,
hydraulic radius, top width
Return

```
FORTRAN IV G LEVEL  20.1                  CIRCLE               DATE = 72322          15/04/44                    P175 0001

 0001                     SUBROUTINE CIRCLE
                 C
                 C           THIS SUBROUTINE TO COMPUTE PARAMETERS OF CIRCULAR SEGMENT
                 C
 0002                     COMMON/CIR/DEPTH,DIA,A,B,DM,R,THETA,WP
                 C
                 C           TEST TO INSURE DEPTH LESS THAN 0.82 DIA
                 C
 0003                     IF (DEPTH) 10,20,20
 0004                  10 WRITE(6,900)
 0005                 900 FORMAT(' ','DEPTH IS NEGATIVE')
 0006                     STOP
                 C
 0007                  20 IF(DEPTH-0.82*DIA) 40,40,30
 0008                  30 WRITE(6,110)
 0009                 110 FORMAT(' ','FLOW IS FULL')
 0010                     STOP
                 C
 0011                  40 IF(DIA/2.-DEPTH) 60,50,70
 0012                  50 THETA=3.14159
 0013                     GO TO 90
                 C
                 C           SUBTENDED ANGLE
 0014                  60 THETA=6.28318-2.*ATAN((SQRT(DIA*DEPTH-DEPTH*DEPTH))/(DEPTH-DIA/2.)
                        1)
 0015                     GO TO 90
                 C
 0016                  70 THETA=2.*ATAN((SQRT(DIA*DEPTH-DEPTH*DEPTH))/(DIA/2.-DEPTH))
 0017                     IF(THETA)80,90,90
 0018                  80 THETA=THETA+6.28318
                 C
                 C           AREA
 0019                  90 A=0.125*(THETA-SIN(THETA))*(DIA**2)
                 C
                 C           WET PERIMETER
 0020                     WP=(DIA/2.)*THETA
                 C
                 C           HYDRAULIC RADIUS
 0021                     R=A/WP
                 C
                 C           SURFACE WIDTH
 0022                     B=DIA*SIN(THETA/2.)
                 C
                 C           HYDRAULIC DEPTH
 0023                     DM=A/B
 0024                     RETURN
 0025                     END
```

SAMPLE OUTPUTS

```
PULBERRY TESTING

                              * * * * * * * * * * * * * * * * * *
                              *                                 *
                              *     UNIVERSITY OF MANITOBA      *
                              *                                 *
                              * DEPARTMENT OF CIVIL ENGINEERING *
                              *                                 *
                              *       URBAN RUNOFF MODEL        *
                              *                                 *
                              * * * * * * * * * * * * * * * * * *

  PRECIPITATION DATA

TIME       PRECIPITATION

  0.           0.00
  5.           0.12
 10.           0.15
 15.           0.17
 20.           0.19
 25.           0.26
 30.           0.33
 35.           0.38
 40.           0.45
 45.           0.78
 50.           0.90
 55.           1.50
 60.           4.52
 65.           5.42
 70.           0.72
 75.           0.48
 80.           0.42
 85.           0.30
 90.           0.24
 95.           0.20
100.           0.19
105.           0.18
110.           0.17
115.           0.16
120.           0.14
```

```
     LAND SURFACE PHYSICAL PROPERTIES

  BLOCK        AREA       AVERAGE          AVERAGE         MANNING
   NO.        SQ.FT.     LENGTH(FT)         SLOPE     FRICTION FACTOR

    1        23000.        270.           0.00600          0.0160
    2        21000.        220.           0.00380          0.0160
    3        21000.        230.           0.00300          0.0160
    4        24000.        200.           0.00380          0.0160
    5        40000.        420.           0.00300          0.0160
    6        45000.        300.           0.00300          0.0160
    7        24000.        300.           0.00300          0.0160
    8        30000.        200.           0.00400          0.0160
    9        22000.        200.           0.00420          0.0160
   10        21000.        160.           0.00500          0.0160
   11        25000.        200.           0.00420          0.0160
   12        52000.        280.           0.00530          0.0160
   13        44000.        220.           0.01000          0.0160
   14        44000.        230.           0.00420          0.0160
   15        20000.        200.           0.00280          0.0140
   16        16000.        120.           0.00440          0.0170
   17        16000.        120.           0.00540          0.0160
   18        22000.        180.           0.00540          0.0160
   19        23000.        150.           0.00500          0.0160
   20        24000.        110.           0.00500          0.0140
   21        27000.        250.           0.00400          0.0160
   22        19000.        130.           0.00500          0.0160
   23        60000.        400.           0.00400          0.0160
   24        20000.        200.           0.00400          0.0160
   25        35000.        200.           0.00650          0.0160
   26        42000.        230.           0.00420          0.0160
   27        27000.        250.           0.00350          0.0140
   28        81000.        390.           0.00600          0.0160
   29        26000.        300.           0.00400          0.0160
   30        19000.        200.           0.00400          0.0160
   31        35000.        320.           0.00450          0.0160
   32        28000.        180.           0.00700          0.0160
   33        46000.        350.           0.00480          0.0160
   34        70000.        380.           0.00800          0.0160
   35        48000.        250.           0.00760          0.0160
   36        27000.        470.           0.00350          0.0250
   37        38000.        190.           0.00450          0.0160
   38        20000.        140.           0.00400          0.0160
   39        20000.         90.           0.00580          0.0160
   40        31000.        160.           0.01000          0.0160
   41        29000.        150.           0.00820          0.0160
   42        34000.        170.           0.00400          0.0160
   43        39000.        300.           0.01200          0.0160
   44        31000.        240.           0.01000          0.0160
   45        40000.        210.           0.00470          0.0160
   46        30000.        150.           0.00850          0.0160
   47        39000.        300.           0.00700          0.0160
   48        26000.        190.           0.00400          0.0160
   49        29000.        250.           0.00480          0.0160
   50        47000.        240.           0.00650          0.0160
   51        33000.        270.           0.00450          0.0160
```

```
 52       49000.      250.        0.00850       0.0160
 53       40000.      250.        0.00550       0.0160
 54       36000.      700.        0.00370       0.0140
 55        9200.      150.        0.01450       0.0160
 56        7800.      150.        0.00350       0.0140
 57        6200.      110.        0.00850       0.0140
 58       20000.      240.        0.00600       0.0140
 59       20000.      250.        0.00720       0.0160
 60       25000.      120.        0.00650       0.0160
 61       15000.      100.        0.00750       0.0160
 62       16000.      200.        0.00400       0.0140
 63       44000.      450.        0.00400       0.0160
 64        9400.      150.        0.00500       0.0180
 65       18000.      200.        0.00600       0.0160
 66       11000.      150.        0.00400       0.0160
 67       30000.      180.        0.00400       0.0160
 68       44000.      230.        0.00870       0.0160
 69       75000.      380.        0.00400       0.0160
 70       19000.      300.        0.00300       0.0160
 71       46000.      340.        0.00450       0.0160
 72       32000.      450.        0.00350       0.0160
 73       22000.      180.        0.00400       0.0160
 74       16000.      250.        0.00600       0.0160
 75       22000.      170.        0.00400       0.0160
```

```
DRAINAGE NETWORK

NUMBER OF PIPES AND REACHES   52     NUMBER OF JUNCTIONS   25

PIPE INCIDENCES                              PIPE PROPERTIES

 PIPE      START       END      LENGTH     DIAMETER     FRICTION     SLOPE          OUTFLOW
                                  FT          IN         FACTOR                  CO-EFF   EXPONENT

   1         0           1       910.0      15.00       0.0130      0.0045       0.00      0.00
   2         0           1       520.0      12.00       0.0130      0.0042       0.00      0.00
   3         0           3       316.0      12.00       0.0130      0.0054       0.00      0.00
   4         0          19       130.0      12.00       0.0130      0.0037       0.00      0.00
   5        19          21       530.0      18.00       0.0130      0.0049       0.00      0.00
   6         0           0       322.0      12.00       0.0130      0.0029       0.00      0.00
   7         1           2       270.0      30.00       0.0130      0.0019       0.00      0.00
   8         0           2       840.0      15.00       0.0130      0.0032       0.00      0.00
   9         2           8       249.0      36.00       0.0130      0.0065       0.00      0.00
  10         3           4       264.0      30.00       0.0130      0.0023       0.00      0.00
  11         4           5       251.0      36.00       0.0130      0.0040       0.00      0.00
  12         0           4       293.0      12.00       0.0130      0.0105       0.00      0.00
  13         0           5       205.0      12.00       0.0130      0.0105       0.00      0.00
  14         0           0       221.0      15.00       0.0130      0.0050       0.00      0.00
  15         0           6       305.0      12.00       0.0130      0.0020       0.00      0.00
  16         6           7       247.0      12.00       0.0130      0.0088       0.00      0.00
  17         5           7       942.0      42.00       0.0130      0.0015       0.00      0.00
  18         7           8       274.0      42.00       0.0130      0.0020       0.00      0.00
  19         0           8       440.0      15.00       0.0130      0.0083       0.00      0.00
  20         8           9       251.0      48.00       0.0130      0.0011       0.00      0.00
  21         0           9       755.0      12.00       0.0130      0.0016       0.00      0.00
  22         9          13       364.0      48.00       0.0130      0.0014       0.00      0.00
  23         0           0       300.0      12.00       0.0130      0.0022       0.00      0.00
  24         0          10       219.0      12.00       0.0130      0.0084       0.00      0.00
  25         0          11       254.0      15.00       0.0130      0.0042       0.00      0.00
  26         0           0       297.0      12.00       0.0130      0.0172       0.00      0.00
  27        10          11       131.0      12.00       0.0130      0.0025       0.00      0.00
  28        11          12       717.0      21.00       0.0130      0.0020       0.00      0.00
  29        12          13       406.0      21.00       0.0130      0.0022       0.00      0.00
  30         0           0      1047.0      15.00       0.0130      0.0034       0.00      0.00
  31        13          18       480.0      48.00       0.0130      0.0021       0.00      0.00
  32         0          14       248.0      12.00       0.0130      0.0047       0.00      0.00
  33         0           0       254.0      12.00       0.0130      0.0088       0.00      0.00
  34         0          14       278.0      21.00       0.0130      0.0024       0.00      0.00
  35         0          15       212.0      15.00       0.0130      0.0014       0.00      0.00
  36        14          15       547.0      24.00       0.0130      0.0020       0.00      0.00
  37        15          16       401.0      30.00       0.0130      0.0038       0.00      0.00
  38         0          16       565.0      12.00       0.0130      0.0070       0.00      0.00
  39        16          17       248.0      30.00       0.0130      0.0023       0.00      0.00
  40         0          17       670.0      15.00       0.0130      0.0038       0.00      0.00
  41        17          18       550.0      36.00       0.0130      0.0020       0.00      0.00
  42        18          25       831.0      54.00       0.0130      0.0024       0.00      0.00
  43         0          23       546.0      15.00       0.0130      0.0074       0.00      0.00
  44        23          24       385.0      18.00       0.0130      0.0035       0.00      0.00
  45        24          25       394.0      21.00       0.0130      0.0017       0.00      0.00
  46        21          22       590.0      24.00       0.0130      0.0032       0.00      0.00
  47        22          25       560.0      24.00       0.0130      0.0044       0.00      0.00
```

```
   48        25         0       326.0      54.00       0.0130    0.0023      0.00       0.00
   49         0        20        80.0      12.00       0.0130    0.0133      0.00       0.00
   50         0        20       123.0      12.00       0.0130    0.0131      0.00       0.00
   51         0        20       144.0      12.00       0.0130    0.0172      0.00       0.00
   52        20        21       485.0      18.00       0.0130    0.0038      0.00       0.00

  PIPE      C.B.     NUMBER    DISTANCE     PIPE     NUMBER     DISTANCE

    1         3
                        1          0.
                        2        225.
                        3        540.
    2         1
                        5          0.
    3         1
                        6          0.
    4         1
                        7          0.
    5         2
                        9        150.
                       10        310.
                                             1
                                                        6         284.
    6         1
                        8          0.
    7         1
                        4          0.
    8         3
                       18          0.
                       11        115.
                       12        560.
    9         1
                       17         75.
   11         1
                       15          0.
   12         1
                       14          0.
   13         1
                       27          0.
   14         1
                       28          0.
   15         1
                       13          0.
   16         1
                       16        115.
   17         2
                       26        310.
                       25        665.
                                             1
                                                       14         524.
   18         2
                       29          0.
                       24         60.
   19         1
                       23          0.
   21         2
                       32          0.
                       33        270.
   22         1
                       35         50.
```

```
                                               1
                                                        23        364.
  23        1
                      36          0.
  24        1
                      44          0.
  25        1
                      34          0.
  26        1
                      45          0.
  27        1
                      43          0.
  28        1
                      42        365.
  29        1
                      52        115.
  30        4
                      37          0.
                      39        285.
                      40        560.
                      41        375.
  31        1
                      48        235.
                                               1
                                                        30        130.
  32        3
                      54          0.
                      55          0.
                      56          0.
  33        1
                      53          0.
  34        1
                      70          0.
  35        1
                      71          0.
  36        4
                      57          0.
                      58          0.
                      59          0.
                      60        410.
                                               1
                                                        33        335.
  37        3
                      61        100.
                      62        100.
                      63        100.
  38        1
                      69          0.
  40        2
                      68          0.
                      67        380.
  41        4
                      64          0.
                      65          0.
                      66          0.
                      46        247.
  42        2
                      51        280.
                      50        530.
  43        3
```

```
                          72          0.
                          73        140.
                          74        250.
      44        1
                          75        160.
      45        1
                          52        205.
      46        2
                          20          0.
                          32        410.
      47        2
                          38          0.
                          48        360.
      49        1
                          22          0.
      50        1
                          30          0.
      51        1
                          19          0.
      52        1
                          21         80.

        JUNCTION BOXES INCIDENCES TABLE

      JUNCTION      TOTAL              PIPE NUMBER

          1           3           1     2    -7     0
          2           3           7     8    -9     0
          3           2           3   -10     0     0
          4           3          10   -11    12     0
          5           3          11    13   -17     0
          6           2          15   -16     0     0
          7           3          16    17   -18     0
          8           4           9    18    19   -20
          9           3          20    21   -22     0
         10           2          24   -27     0     0
         11           3          25    27   -28     0
         12           2          28   -29     0     0
         13           3          22    29   -31     0
         14           3          32    34   -36     0
         15           3          35    36   -37     0
         16           3          37    38   -39     0
         17           3          39    40   -41     0
         18           3          31    41   -42     0
         19           2           4    -5     0     0
         20           4          49    50    51   -52
         21           3           5   -46    52     0
         22           2          46   -47     0     0
         23           2          43   -44     0     0
         24           2          44   -45     0     0
         25           4          42    45    47   -48

        NOTE +VE FOR FLOW INTO THE JUNCTION
             -VE FOR FLOW OUT FROM THE JUNCTION
```

LAND BLOCK NO. 1

AREA: 28000. SQ. FT.
AVERAGE LENGTH: 270. FT.
AVERAGE SLOPE: 0.0060

TIME (MIN.)	DISCHARGE (CFS)
30.0	0.00
32.5	0.00
35.0	0.02
37.5	0.07
40.0	0.13
42.5	0.23
45.0	0.24
47.5	0.33
50.0	0.42
52.5	0.56
55.0	0.76
57.5	1.38
60.0	2.52
62.5	3.45
65.0	3.87
67.5	2.61
70.0	0.99
72.5	0.42
75.0	0.30
77.5	0.28
80.0	0.27
82.5	0.26
85.0	0.24
87.5	0.22
90.0	0.20

LAND BLOCK NO. 1

AREA:	28000.	SQ. FT.
AVERAGE LENGTH:	270.	FT.
AVERAGE SLOPE:	0.0060	

TIME (MIN.)	DISCHARGE (CFS)
0.0	0.00
2.5	0.00
5.0	0.00
7.5	0.01
10.0	0.02
12.5	0.03
15.0	0.05
17.5	0.06
20.0	0.06
22.5	0.08
25.0	0.08
27.5	0.11
30.0	0.13
32.5	0.15
35.0	0.18
37.5	0.20
40.0	0.23
42.5	0.28
45.0	0.35
47.5	0.43
50.0	0.49
52.5	0.61
55.0	0.78
57.5	1.39
60.0	2.52
62.5	3.44
65.0	3.86
67.5	2.61
70.0	0.99
72.5	0.42
75.0	0.30
77.5	0.28
80.0	0.27
82.5	0.26
85.0	0.24
87.5	0.22
90.0	0.20
92.5	0.19
95.0	0.17
97.5	0.16
100.0	0.15
102.5	0.14
105.0	0.14
107.5	0.13
110.0	0.13
112.5	0.12
115.0	0.12
117.5	0.11
120.0	0.11