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Flood Hydrograph Package

Users Manual

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HEC-1 is a ~~mathematical~~ watershed ~~model~~ designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process within a portion of the basin. A component may represent a surface runoff entity, a stream channel or a reservoir, defined by parameters specifying its characteristics and the mathematical relations describing the physical processes. The result of the modeling process is computation of streamflow hydrographs at desired locations in the river basin. All ordinary flood hydrograph computations associated with a single recorded or hypothetical storm can be accomplished with this package. Capabilities include rainfall-snowfall-snowmelt determinations, computations of basin precipitation, unit hydrographs, kinematic wave transforms, and hydrograph; routing by reservoir, storage-lag, multiple storage, straddle-stagger, Tatum, Muskingum, and kinematic wave methods; and complete stream system hydrograph combining and routing. Best-fit unit hydrograph, loss-rate, snowmelt, base freezing temperatures and routing coefficients can be derived automatically. Automatic printer plot routines are also provided. HEC-1 may also be used to simulate flow over and through breached dams. Expected annual flood damage can be also be computed for any location in the river basin.

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FOREWORD

The HEC-1, Flood Hydrograph Package, computer program was originally developed in 1967 by Leo R. Beard and other members of the Hydrologic Engineering Center staff. The first version of the HEC-1 package program was published in October 1968. It was expanded and revised and published again in 1969 and 1970. The first package version represented a combination of several smaller programs which had previously been operated independently. These computer programs are still available at the HEC as separate programs.

In 1973, the 1970 version of the program underwent a major revision. The computational methods used by the program remained basically unchanged; however, the input and output formats were almost completely restructured. These changes were made in order to simplify input requirements and to make the program output more meaningful and readable.

The present program again represents a major revision of the 1973 version of the program. The program input and output formats have been completely revised and the computational capabilities of the dam-break (HEC-1DB), project optimization (HEC-1GS) and kinematic wave (HEC-1KW) special versions of HEC-1 have been combined in the one program. The new program gives the powerful analysis features available in all the previous programs, together with some additional capabilities, in a single easy to use package.

Up-to-date information and copies of source code for the programs are available from the Center. While the Government is not responsible for the results obtained when using the programs, assistance in resolving malfunctions in the programs will be furnished to the extent that time and funds are available. It is desired that users notify the Center of inadequacies in, or desirable modifications to, the program.

A microcomputer version (PC version) of the HEC-1 program was developed in late 1984 and is being released with the printing of this document. The PC version contains all the hydrologic and hydraulic computation capabilities of the mainframe HEC-1; however, the flood damage and ogee spillway capabilities were not included because of microcomputer memory and compiler limitations at that time. These limitations may change as PC Fortran compilers improve; contact the HEC for current information.

This manual was reprinted (with minor revisions) in March 1987.

Section 1

INTRODUCTION

1.1 Model Philosophy

The HEC-1 model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process within a portion of the basin, commonly referred to as a subbasin. A component may represent a surface runoff entity, a stream channel, or a reservoir. Representation of a component requires a set of parameters which specify the particular characteristics of the component and mathematical relations which describe the physical processes. The result of the modeling process is the computation of streamflow hydrographs at desired locations in the river basin.

1.2 Overview of Manual

This manual describes the concepts, methodologies, input requirements and output formats used in HEC-1. A brief description of each of the model capabilities and the organization of this manual is given below.

Stream Network Model Concepts and Methodologies

Sections 2, 3, and 4: A general description of the components of the HEC-1 watershed (stream network) simulation capability is given in Section 2. The stream network capability (i.e., simulating the precipitation-runoff process in a river basin) is of central importance to virtually any application of HEC-1. Other capabilities of HEC-1 are built around this stream network function. Section 3 describes the detailed computational methods used to simulate the stream network. The use of automatic techniques to determine best estimates of the model parameters is described in Section 4.

Additional Flood Hydrograph Simulation Options

Section 5: Multiplan-multiflood analysis allows the simulation of up to nine ratios of a design flood for up to five different plans (or characterizations) of a stream network in a single computer run.

Section 6: Dam-break simulation provides the capability to analyze the consequences of dam overtopping and structural failures.

Section 7: The depth-area option computes flood hydrographs preserving a user-supplied precipitation depth versus area relation throughout a stream network.

Flood Damage Analysis

Section 8: The economic assessment of flood damage can be determined for damage reaches defined in a multiplan-multiflood analysis. The expected annual damage occuring in a damage reach and the benefits accrued due to a flood control plan are calculated based on user-supplied damage data and on calculated flows for the reach.

Section 9: The optimal size of a flood control system can be estimated using an optimization procedure provided by HEC-1. The option utilizes data provided for the economic assessment option together with data on flood control project costs to determine a system which maximizes net benefits with or without a specified degree of protection level for the components.

Program Usage

Section 10: The data input conventions are discussed, emphasizing the data card groups used for the various program options.

Section 11: Program output capabilities and error messages are explained.

Section 12: Test examples are displayed, including example input data and computed output generated by the program.

Section 13: The computer hardware requirements are discussed, and computer run times for the example problems are given. A programmers supplement provides detailed information about the operational characteristics of the computer program.

Section 14: References

Appendix A: The input description details the use of each data card and input variable in the program. The input description is contained in under seperate cover.

Appendix B: A description of the HEC-1 interface capabilities with the HEC Data Storage System.

1.3 Theoretical Assumptions and Limitations

A river basin is represented as an interconnected group of subareas. The assumption is made that the hydrologic processes can be represented by model parameters which reflect average conditions within a subarea. If such averages are inappropriate for a subarea then it would be necessary to consider smaller subareas within which the average parameters do apply. Model parameters represent temporal as well as spatial averages. Thus the time interval to be used should be small enough such that averages over the computation interval are applicable.

There are several important limitations of the model. Simulations are limited to a single storm due to the fact that provision is not made for soil moisture recovery during periods of no precipitation. The model results are in terms of discharge and not stage, although stages can be printed out by the program based on a user specified rating curve. A hydraulic computer program (HEC-2 for example) is generally used in conjunction with HEC-1 to obtain stages. Streamflow routings are performed by hydrologic routing methods and do not reflect the full St. Venant equations which are required for very flat river slopes. Reservoir routings are based on the modified Puls techniques which are not appropriate where reservoir gates are operated to reduce flooding at downstream locations.

1.4 Computer Requirements

The HEC-1 program requires 377,000 octal words (130,000 decimal) of core storage. Disk storage is needed for the 16 output and scratch files used by the program. For further information on the program's computer requirements, see Section 13 and the Programmers Supplement.

A version of HEC-1 is also available for microcomputers (PC's). The PC version has all the same capabilities as the mainframe version except: the number of plans is 3 instead of 5, and the flood damage economics and ogee spillway options were removed. These limitations may change as PC Fortran compilers improve; contact the HEC for current information. The PC version requires: 512 k memory, a MS-DOS compatible operating system, and a hard disk.

1.5 Acknowledgments

This manual was written by Messrs. David Goldman and Paul Ely. Mr. Ely was also responsible for the design and implementation of the new computer code. Mr. John Tracy modified the code for use on microcomputers. Messrs. John Peters, Darryl Davis and Arthur Pabst made many excellent contributions to the development of the modeling concepts and the documentation. The development of this new version of HEC-1 was managed by Mr. Arlen D. Feldman, Chief of the HEC Research Branch. Mr. Bill S. Eichert was the Director of the HEC during this time. The word processing for this document was performed by Ms. Cathy Lewis.

Section 2

MODEL COMPONENTS

The stream network model is the foundation capability of the HEC-1 program. All other program computation options build on this option's capability to calculate flood hydrographs at desired locations in a river basin. Section 2.1 discusses the conceptual aspects of using the HEC-1 program to formulate a stream network model from river basin data. Section 2.2 discusses the model formulation as a *step-by-step process*, where the physical characteristics of the river basin are systematically represented by an interconnected group of HEC-1 model components. Sections 2.3 - 2.8 discuss the functions of each component in representing individual characteristics of the river basin.

2.1 Stream Network Model Development

A river basin is subdivided into an interconnected system of stream network components (e.g., Fig. 2.1) using topographic maps and other geographic information. A basin schematic diagram (e.g., Fig. 2.2) of these components is developed by the following steps:

(1) The study area watershed boundary is delineated first. In a natural or open area this can be done from a topographic map. However, supplementary information, such as municipal drainage maps, may be necessary to obtain an accurate depiction of an urban basin's extent.

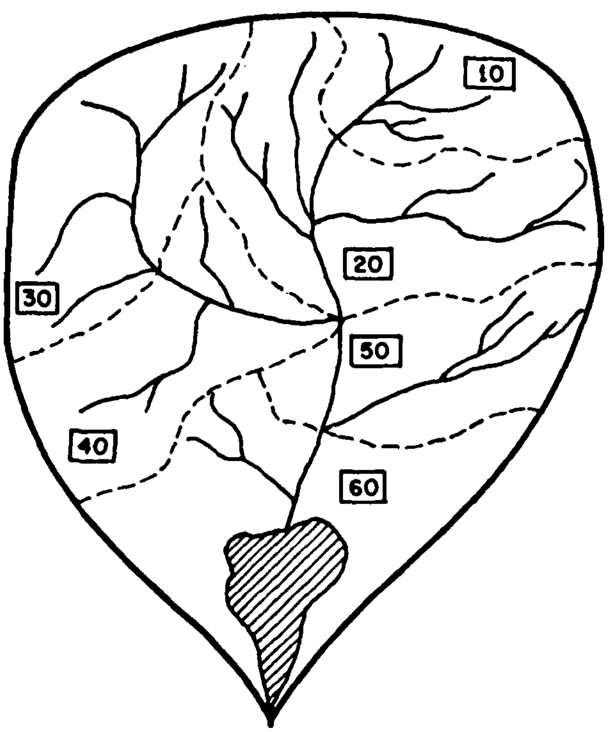


Figure 2.1 Example River Basin

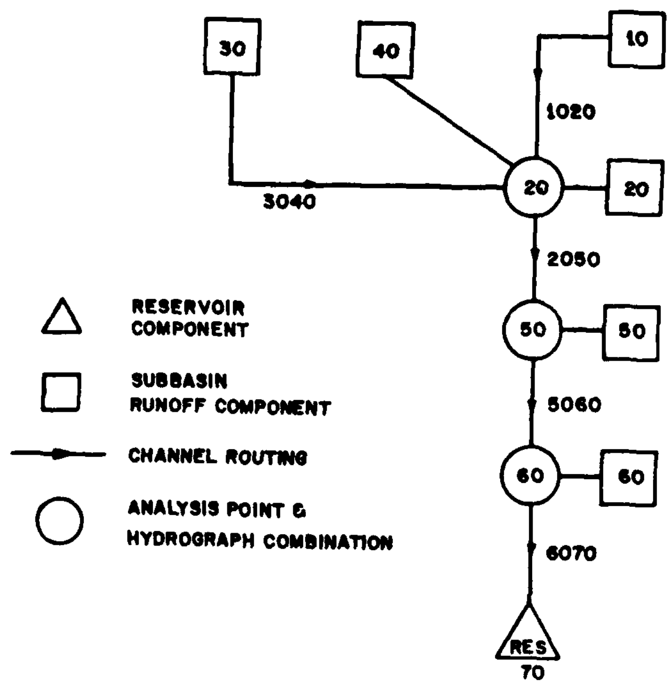


Figure 2.2 Example River Basin Schematic

(2) Segmentation of the basin into a number of subbasins determines the number and types of stream network components to be used in the model. Two factors impact on the basin segmentation: the study purpose and the hydrometeorological variability throughout the basin. First, the study purpose defines the areas of interest in the basin, and hence, the points where subbasin boundaries should occur.

Second, the variability of the hydrometeorological processes and basin characteristics impacts on the number and location of subbasins. Each subbasin is intended to represent an area of the watershed which, on the average, has the same hydraulic/hydrologic properties. Further, the assumption of uniform precipitation and infiltration over a subbasin becomes less accurate as the subbasin becomes larger. Consequently, if the subbasins are chosen appropriately, the average parameters used in the components will more accurately model the subbasins.

(3) Each subbasin is to be represented by a combination of model components. Subbasin runoff, river routing, reservoir, diversion and pump components are available to the user.

(4) The subbasins and their components are linked together to represent the connectivity of the river basin. HEC-1 has available a number of methods for combining or linking together outflow from different components. This step finalizes the basin schematic.

2.2 Land Surface Runoff Component

The subbasin land surface runoff component, such as subbasins 10, 20, 30, etc. in Fig. 2.1 or equivalently as element 10 in Fig. 2.2, is used to represent the movement of water over the land surface and in stream channels. The input to this component is a precipitation hyetograph. Precipitation excess is computed by subtracting infiltration and detention losses based on a soil water infiltration rate function. Note that the rainfall and infiltration are assumed to be uniform over the subbasin. The resulting rainfall excesses are then routed by the unit hydrograph or kinematic wave techniques to the outlet of the subbasin producing a runoff hydrograph. The unit hydrograph technique produces a runoff hydrograph at the most downstream point in the subbasin. If that location for the runoff computation is not appropriate, it may be necessary to further subdivide the subbasin or use the kinematic wave method to distribute the local inflow.

The kinematic wave rainfall excess-to-runoff transformation allows for the uniform distribution of the land surface runoff along the length of the main channel (e.g., subbasin 60, Fig. 2.2, runoff could be laterally distributed between points 50 and 60 instead of being lumped at point 60). This uniform distribution of local inflow (subbasin runoff) is particularly important in areas where many lateral channels contribute flow along the length of the main channel.

Base flow is computed relying on an empirical method and is combined with the surface runoff hydrograph to obtain flow at the subbasin outlet. The methods for simulating subbasin precipitation, infiltration and runoff are described in Sections 3.1 through 3.5.

2.3 River Routing Component

A river routing component, element 1020, Fig. 2.2, is used to represent flood wave movement in a river channel. The input to the component is an upstream hydrograph resulting from individual or combined contributions of subbasin runoff, river routings or diverions. If the kinematic wave method is used, the local subbasin distributed runoff (e.g., subbasin 60 as described above) is also input to the main channel and combined with the upstream hydrograph as it is routed to the end of the reach. The hydrograph is routed to a downstream point based on the characteristics of the channel. There are a number of techniques available to route the runoff hydrograph which are described in Section 3.6 of this report.

2.4 Combined Use of River Routing and Subbasin Runoff Components

Consider the use of subbasin runoff components 10 and 20 and river routing reach 1020 in Fig. 2.2 and the corresponding subbasins 10 and 20 in Fig. 2.1 The runoff from component 10 is calculated and routed to control point 20 via routing reach 1020. The runoff hydrograph at analysis point 20 can be calculated by methods employing either the unit hydrograph or kinematic wave techniques. In the case that the unit hydrograph technique is employed, runoff from component 10 is calculated and routed to control point 20 via routing reach 1020. Runoff from subbasin 20 is calculated and combined with the outflow hydrograph from reach 1020 at analysis point 20. Alternatively, runoff from subbasins 10 and 20 can be combined before routing in the case that the lateral inflows from subarea 20 are concentrated near the upstream end of reach 1020. In the case, that the kinematic wave technique is employed, the runoff from subbasin 20 is modeled as a uniformly distributed lateral inflow to reach 1020. The runoff from subbasin 10 is routed in combination with this lateral inflow via reach 1020 to analysis point 20.

A suitable combination of the subbasin runoff component and river routing components can be used to represent the intricacies of any rainfall-runoff and stream routing problem. The connectivity of the stream network components is implied by the order in which the data components are arranged. Simulation must always begin at the uppermost subbasin in a branch of the stream network. The simulation (succeeding data components) proceeds downstream until a confluence is reached. Before simulating below the confluence, all flows above that confluence must be computed and routed to that confluence. The flows are combined at the confluence and the combined flows are routed downstream. In Fig. 2.2, all flows tributary to control point 20 must be combined before routing through reach 2050.

2.5 Reservoir Component

Use of the reservoir component is similar to that of the river routing component described in Section 2.3. The reservoir component can be used to represent the storage-outflow characteristics of a reservoir, lake, detention pond, highway culvert, etc. The reservoir component functions by receiving upstream inflows and routing these inflows through a reservoir using storage routing methods described in Section 3.6. Reservoir outflow is solely a function of storage (or water surface elevation) in the reservoir and not dependent on downstream controls.

2.6 Diversion Component

The diversion component is used to represent channel diversions, stream bifurcations, or any transfer of flow from one point of a river basin to another point in or out of the basin. The diversion component receives an upstream inflow and divides the flow according to a user prescribed rating curve as described in Section 3.7.

2.7 Pump Component

The pump component can be used to simulate action of pumping plants used to lift runoff out of low lying ponding areas such as behind levees. Pump operation data describes the number of pumps, their capacities, and "on" and "off" elevations. Inflow to the pump station comes from the river channel.

Pumping simulation is accomplished in the level-pool routing option described in Section 3.6.5. Pump flow can either be lost from the system during routing, or after routing, can be retrieved in the same manner as diverted flow.

2.8 Hydrograph Transformation

The Hydrograph Transformation options provide a capability to alter computed flows based on user-defined criteria. Although this does not represent a true watershed component, the hydrograph transformation options may be useful in performing a sensitivity analysis or for parameter estimation. The hydrograph transformation options are: ratios of ordinates; hydrograph balance; and local flow computation from a given total flow. The ratio of ordinates and hydrograph balance adjust the computed hydrograph by a constant fraction or a volume-duration relationship, respectively (see BA and HB records in Appendix A, Input Description). The local flow option has a dual purpose (see HL record in the Input Description). First, the difference between a computed and a given hydrograph (e.g., observed flow) is determined and shown as the local flow. Second, the given hydrograph is substituted for the computed hydrograph for the remaining watershed simulations.

Section 3

RAINFALL-RUNOFF SIMULATION

The HEC-1 model components are used to simulate the rainfall-runoff process as it occurs in an actual river basin. The model components function based on simple mathematical relationships which are intended to represent individual meteorologic, hydrologic and hydraulic processes which comprise the precipitation-runoff process. These processes are separated into precipitation, interception/infiltration, transformation of precipitation excess to subbasin outflow, addition of baseflow and flood hydrograph routing. The subsequent sections discuss the parameters and computation methodologies used by the model to simulate these processes. The computation equations described are equally applicable to English or metric units except where noted.

3.1 Precipitation

3.1.1 Precipitation Hyetograph

A precipitation hyetograph is used as the input for all runoff calculations. The specified precipitation is assumed to be a basin average (i.e., uniformly distributed over the subbasin). Any of the options used to specify precipitation produce a hyetograph such as that shown in Fig. 3.1. The hyetograph represents average precipitation (either rainfall or snowfall) depths over a computation interval.

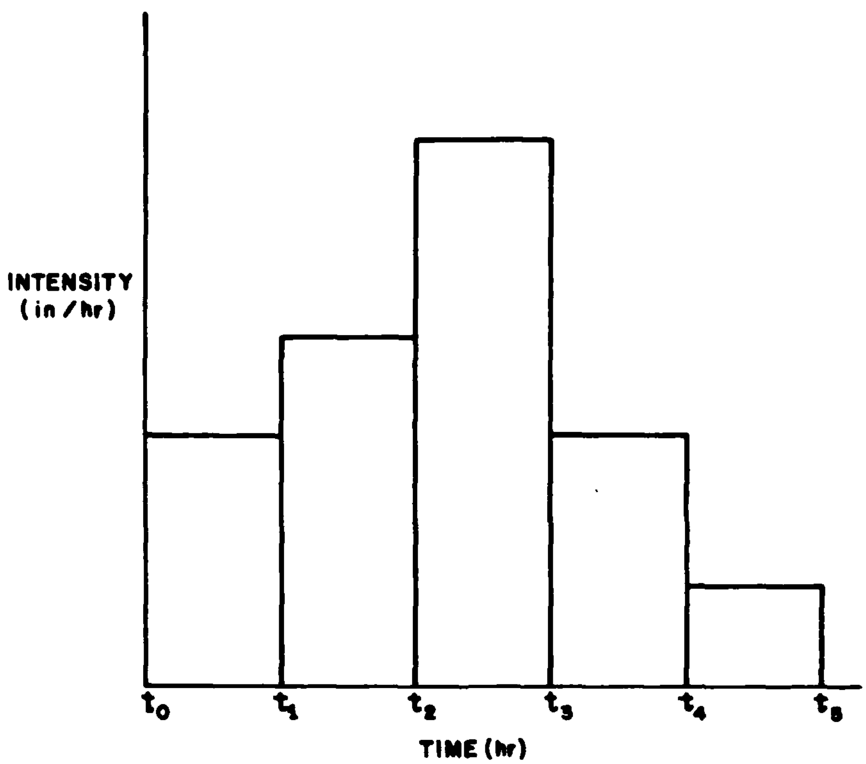


Figure 3.1 Rainfall Hyetograph

3.1.2 Historical Storms

Precipitation data for an observed storm event can be supplied to the program by either of two methods:

(i) Basin-average Precipitation. Any storm may be specified for a subbasin as a total amount of precipitation for the storm and a temporal pattern for distributing the total precipitation.

(ii) Weighted Precipitation Gages. The total storm precipitation for a subbasin may be computed as the weighted average of measurements from several gages according to the following equations:

$$PRCPA = \frac{\sum_{J=1}^{n} PRCPN(J) * WTN(J)}{\sum_{J=1}^{n} WTN(J)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

where PRCPA is the subbasin-average total precipitation, PRCPN(J) is the total precipitation for gage J, WTN(J) is the relative weight for gage J, and n is the number of gages.

If normal annual precipitation for the subbasin is given, equation (3.1) is modified to include weighting by station normal annual precipitation.

$$PRCPA = SNAP * \frac{\sum_{J=1}^{n} PRCPN(J) * WTN(J)}{\sum_{J=1}^{n} ANAPN(J) * WTN(J)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

where ANAPN is the station normal annual precipitation, and SNAP is the subbasin-average normal annual precipitation. Use of this option may be desirable in cases where precipitation measurements are known to be biased. For example, data obtained from a gage located on the floor of a valley may consistently underestimate subbasin average precipitation for higher elevations. ANAPN may be used to adjust for this bias.

The temporal pattern for distribution of the storm-total precipitation is computed as a weighted average of temporal distributions from recording stations:

$$PRCP(I) = \frac{\sum_{J=1}^{n} PRCPR(I,J) * WTR(J)}{\sum_{J=1}^{n} WTR(J)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

where PRCP(I) is the basin-average precipitation for the Ith time interval, PRCPR(I, J) is the recording station precipitation for the Ith time interval, and WTR(J) is the relative weight for gage J.

The subbasin-average hyetograph is computed using the temporal pattern, PRCP, to distribute the total, PRCPA.

3.1.3 Synthetic Storms

Synthetic storms are frequently used for planning and design studies. Criteria for synthetic storms are generally based on a detailed analysis of long term precipitation data for a region. There are three methods in HEC-1 for generating synthetic storm distributions:

(i) Standard Project Storm. The procedure for computing Standard Project Storms, SPS, programmed in HEC-1 is applicable to basins of area 10 to 1,000 square miles located east of 105° longitude. The SPS is determined by specifying an index precipitation, SPFE, a storm reduction coefficient, TRSPC, and the area over which the storm occurs, TRSDA. SPFE and TRSPC are determined by referring to manual EM-1110-2-1411 (Corps of Engineers, 1952). A total storm depth is determined and distributed over a 96-hour duration based on the following formulas which were derived from design charts in the referenced manual.

$$R24HR(3) = 182.15 - 14.3537 * LOG_e\ (TRSDA + 80.) \quad \ldots\ldots\ldots\ (3.4)$$

$$R24HR(1) = 3.5$$

$$R24HR(2) = 15.5$$

$$R24HR(4) = 6.0$$

where R24HR(I) is the percent of the index precipitation occurring during the Ith 24-hour period.

Each 24-hour period is divided into four 6-hour periods. The ratio of the 24-hour precipitation occurring during each 6-hour period is calculated as

$$R6HR(3) = \frac{13.42}{(SPFE + 11.0)^{.93}} \quad \ldots\ldots\ldots\ (3.5)$$

$$R6HR(2) = 0.055 * (SPFE - 6.0)^{0.51} \quad \ldots\ldots\ldots\ (3.6)$$

$$R6HR(4) = 0.5 * (1. - R6HR(3) - R6HR(2)) + 0.0165$$

$$R6HR(1) = R6HR(4) - 0.033$$

where R6HR(I) is the ratio of 24-hour precipitation occurring during the Ith 6-hour period and SPFE is the index precipitation in inches.

The precipitation for each time interval, except during the peak 6-hour period, is computed as

$$PRCP = 0.01 * R24HR * R6HR * SPFE * \frac{TRHR}{6} \quad \ldots\ldots\ldots\ (3.7)$$

where TRHR is the computation time interval in hours.

The peak 6-hour precipitation of each day is distributed according to the percentages in Table 3.1 If time intervals less than one hour are used, the peak 1-hour precipitation is distributed according to the percentages in Table 3.2. The time interval must divide evenly into one hour. When the time interval is larger than shown in Tables 3.1 and 3.2, the percentage for the peak time interval is the sum of the highest percentages; e.g. for a 2-hour time interval, the values are (14+12)%, (38+15)%, and (11+10)%. The interval with the largest percentage is preceded by the second largest and followed by the third largest. The second largest percentage is preceded by the fourth largest, the third largest percentage is followed by the fifth largest, etc.

TABLE 3.1

Distribution of Maximum 6-hour SPS Or PMP In Percent of 6-hour Amount

Duration Hours	EM 1110-2-1411 Criteria (Default)	Southwestern Division* Criteria for PMP (Optional)
1	10	4
2	12	8
3	15	19
4	38	50
5	14	11
6	11	8

TABLE 3.2

Distribution Of Maximum 1-Hour SPS OR PMP*

Duration Hours	Percent of Maximum 1-Hour Precipitation in Each Time Interval	Accumulated Percent of Precipitation
5	3	3
10	4	7
15	5	12
20	6	18
25	9	27
30	17	44
35	25	69
40	11	80
45	8	88
50	5	93
55	4	97
60	3	100

* Distribution of 100-yr precipitation at St. Louis, MO, based on NOAA Technical Memorandum NWS Hydro - 35.

(ii) Probable Maximum Precipitation. Current Probable Maximum Precipitation, PMP, computation methods are not available in HEC-1. The PMP must be determined according to the National Weather Service's Hydrometeorological Reports Nos. 36, 43, 49, 51, 52, or 55, depending upon geographic location. Computer program HMR52 (HEC, 1984) is available to assist with PMP and Probable Maximum Storm determination for the eastern United States. The PMP computed from HMR52 or any other method may be input to HEC-1 to calculate runoff.

The PMP computation procedure programmed in HEC-1 is that required by the outdated Hydrometeorological Report No. 33 (HMR No. 33, National Weather Service, 1956). HMR No. 33 has been superseded by HMR Nos. 51 and 52. The following HMR No. 33 procedure has been retained in HEC-1 for recomputation of previous studies. The method requires an index precipitation, PMS, which can be determined by referring to HMR No. 33 (National Weather Service, 1956). The minimum duration of a PMP is 24 hours, and it may last up to 96 hours. The day with the largest amount of precipitation is preceded by the second largest and followed by the third largest. The fourth largest precipitation day precedes the second largest. The distribution of 6-hour precipitation during each day is according to the following ratios:

$$R6HR(1) = 0.4 \frac{(R24 - R12)}{R24} \quad \text{(3.8a)}$$

$$R6HR(2) = \frac{R12 - R6}{R24} \quad \text{(3.8b)}$$

$$R6HR(3) = \frac{R6}{R24} \quad \text{(3.8c)}$$

$$R6HR(4) = 0.6 \frac{(R24 - R12)}{R24} \quad \text{(3.8d)}$$

where R6HR(I) is the ratio of 24-hour precipitation occurring during Ith 6-hour period of a day, R6 is the maximum 6-hour precipitation in percent of the PMS index precipitation, R12 is the maximum 12-hour precipitation in percent of PMS, and R24 is the maximum 24-hour precipitation in percent of PMS. Precipitation is then distributed as for the standard project storm.

A transposition coefficient can be applied to reduce the precipitation on a river basin when the storm area is larger than the river basin area. The transposition coefficient may be supplied or computed by the following equation in accordance with the Corps Engineering Circular EC 1110-2-27 (1968).

$$TRSPC = 1 - \frac{0.3008}{TRSDA^{0.17718}} \quad \text{(3.9)}$$

where TRSPC is the ratio of river basin precipitation to storm precipitation (minimum value is 0.80) and TRSDA is the river basin area in square miles.

(iii) Synthetic storms from depth-duration data. A synthetic storm of any duration from 5 minutes to 10 days can be generated based on given depth-duration data. A triangular precipitaion distribution is constructed such that the depth specified for any duration occurs during the central part of the storm. This is referred to as a "balanced storm." If TP-40 (National

Weather Service, 1961) data are used, the program will automatically make the partial-to-annual series conversion using the factors in Table 3.3 (which is table 2 of TP-40) if desired.

TABLE 3.3

Partial-duration to Equivalent-Annual Series Conversion Factors

Return Period	Frequency	Conversion Factor
2 year	50%	0.88
5	20	0.96
10	10	0.99

Depths for 10-minute and 30-minute durations are interpolated from 5-, 15-, and 60-minute depths using the following equations from HYDRO-35 (National Weather Service, 1977):

$$D_{10} = 0.59 D_{15} + 0.41 D_5 \quad (3.10)$$

$$D_{30} = 0.49 D_{60} + 0.51 D_{15} \quad (3.11)$$

where D_n is the precipitation depth for n-minute duration.

Point precipitation is adjusted to the area of the subbasin using the following equation (based on Fig. 15, National Weather Service, 1961).

FACTOR = 1. - BV * (1. -EXP (-.015 * AREA)) . . . . (3.12)

where FACTOR is the coefficient to adjust point rainfall, BV is the maximum reduction of point rainfall (from Table 3.4), and AREA is the subbasin area in square miles.

Cumulative precipitation for each time interval is computed by log-log interpolation of depths from the depth-duration data. Incremental precipitation is then computed and rearranged so the second largest value precedes the largest value, the third largest value follows the largest value, the fourth largest precedes the second largest, etc.

3.1.4 Snowfall and Snowmelt

Where snowfall and snowmelt are considered, there is provision for separate computation in up to ten elevation zones within a subbasin. These zones are usually considered to be in elevation increments of 1,000 feet, but any equal increments of elevation can be used as long as the air temperature lapse rate (TLAPS) corresponds to the change in elevation within the zones. See Fig. 12.3 in Example Problems, Section 12. The input temperature data are those corresponding to the bottom of the lowest elevation zone. Temperatures are reduced by the lapse rate in degrees per increment of elevation zone. The base temperature (FRZTP) at which melt will occur, must be specified because

TABLE 3.4
Point-to-Areal Rainfall Conversion Factors

Duration (hours)	BV (Equation 3.12)
0.5	.48
1	.35
3	.22
6	.17
24	.09
48	.068
96	.055
168	.049
240	.044

variations from 32°F (0°C) might be warranted considering both spatial and temporal fluctuations of temperature within the zone.

Precipitation is assumed to fall as snow if the zone temperature (TMPR) is less than the base temperature (FRZTP) plus 2 degrees. The 2-degree increase is the same for both English and metric units. Melt occurs when the temperature (TMPR) is equal to or greater than the base temperature, FRZTP. Snowmelt is subtracted and snowfall is added to the snowpack in each zone.

Snowmelt may be computed by the degree-day or energy-budget methods. The basic equations for snowmelt computations are from EM 1110-1-1406 (Corps, 1960). These energy-budget equations have been simplified for use in this program.

(i) Degree-Day Method. The degree-day method uses the equation

$$SNWMT = COEF\ (TMPR - FRZTP) \quad \quad (3.13)$$

where SNWMT is the melt in inches (mm) per day in the elevation zone, TMPR is the air temperature in °F or °C lapsed to the midpoint of the elevation zone, FRZTP is the temperature in °F or °C at which snow melts, and COEF is the melt coefficient in inches (mm) per degree-day (°F or °C).

(ii) Energy-Budget Method. Snowmelt by the energy-budget method is accomplished by equations 20 and 24 in EM 1110-2-1406 (Corps, 1960) for rainy and rainfree periods of melt, respectively. For use in this program, k and k' in the aforementioned equations are assumed to be 0.6 and 1.0, respectively. Note that the following equations for snowmelt are for English units of measurement. The program has similar equations for the metric system which use the same variables with coefficients relevant to metric units. The program computes melt during rain by equation (3.14), below. This equation is applicable to heavily forested areas as noted in EM 1101-2-1406.

$$SNWMT = COEF\ (.09 + (.029 + .00504\ WIND + .007\ RAIN)\ (TMPR - FRZTP)) \quad \quad (3.14)$$

Equation (3.15), below, is for melt during rainfree periods in partly forested areas (the forest cover has been assumed to be 50 percent).

$$SNWMT = COEF\ (.002\ SOL\ (1-ALBDO) + (.0011\ WIND + .0145) + (TMPR - FRZTP) + .0039\ WIND\ (DEWPT - FRZPT)) \quad \ldots\ldots\ (3.15)$$

where SNWMT is the melt in inches per day in the elevation zone, TMPR is the air temperature in °F lapsed at the rate TLAPS to midpoint of the elevation zone, DEWPT is the dewpoint temperature in °F lapsed at a rate 0.2 TLAPS to the midpoint of the elevation zone. A discussion of the decrease in dewpoint temperature with higher elevations is found in (Miller, 1970). FRZTP is the freezing temperature in °F, COEF is the dimensionless coefficient to account for variation from the general snowmelt equation referenced in EM 1110-2-1406, RAIN is the rainfall in inches per day, SOL is the solar radiation in langleys per day, ALBDO is the albedo of snow, $.75/(D^{\cdot 2})$, constrained above .4, D is the days since last snowfall, and WIND is the wind speed in miles per hour, 50 feet above the snow.

3.2 Interception/Infiltration

Land surface interception, depression storage and infiltration are referred to in the HEC-1 model as precipitation losses. Interception and depression storage are intended to represent the surface storage of water by trees or grass, local depressions in the ground surface, in cracks and crevices in parking lots or roofs, or in an surface area where water is not free to move as overland flow. Infiltration represents the movement of water to areas beneath the land surface.

Two important factors should be noted about the precipitation loss computation in the model. First, precipitation which does not contribute to the runoff process is considered to be lost from the system. Second, the equations used to compute the losses do not provide for soil moisture or surface storage recovery. (the Holtan loss rate option, described in Section 3.2.4, is an exception in that soil moisture recovery occurs by percolation out of the soil moisture storage.) This fact dictates that the HEC-1 program is a single-event-oriented model.

The precipitation loss computations can be used with either the unit hydrograph or kinematic wave model components. In the case of the unit hydropraph component, the precipitation loss is considered to be a subbasin average (uniformly distributed over an entire subbasin). On the other hand, separate precipitation losses can be specified for each overland flow plane (if two are used) in the kinematic wave component. The losses are assumed to be uniformly distributed over each overland flow plane.

In some instances, there are negligible precipitation losses for a portion of a subbasin. This would be true for an area containing a lake, reservoir or impervious area. In this case, precipitation losses will not be computed for a specified percentage of the area labeled as impervious.

There are four methods that can be used to calculate the precipitation loss. Using any one of the methods, an average precipitation loss is determined for a computation interval and subtracted from the rainfall/snowmelt hyetograph as shown in Fig. 3.2. The resulting precipitation excess is used to compute an outflow hydrograph for a subbasin. A percent imperviousness factor can be used with any of the loss rate methods to guarantee 100% runoff from that portion of the basin.

A percent impervious factor can be used with any of the loss rate methods; it guarantees 100% runoff from that percent of the subbasin.

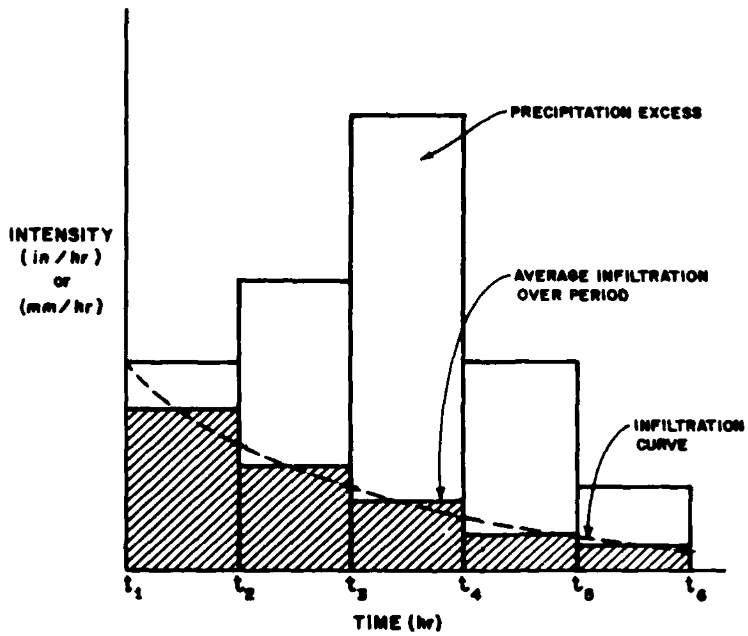


Figure 3.2 Loss Rate, Rainfall Excess Hyetograph

3.2.1 Initial and Uniform Loss Rate.

An initial loss, STRTL (units of depth), and a constant loss rate, CNSTL (units of depth/hour), are specified for this method. All rainfall is lost until the volume of initial loss is satisfied. After the initial loss is satisfied, rainfall is lost at the constant rate, CNSTL.

3.2.2 Exponential Loss Rate.

This is an empirical method which relates loss rate to rainfall intensity and accumulated losses. Accumulated losses are representative of the soil moisture storage. The equations for computation of loss are given below and shown graphically in Fig. 3.3.

$$\text{ALOSS} = (\text{AK} + \text{DLTK})\ \text{PRCP}^{\text{ERAIN}} \quad (3.16a)$$

$$\text{DLTK} = 0.2\ \text{DLTKR}\ (1 - (\text{CUML}/\text{DLTKR}))^2 \quad (3.16b)$$

for $\text{CUML} \leq \text{DLTKR}$

$$\text{AK} = \text{STRKR}/(\text{RTIOL}^{0.1\ \text{CUML}}) \quad (3.16c)$$

where ALOSS is the potential loss rate in inches (mm) per hour during the time interval, AK is the loss rate coefficient at the beginning of the time interval, and DLTK is the incremental increase in the loss rate coefficient during the first DLTKR inches (mm) of accumulated loss, CUML. The accumulated loss, CUML, is determined by summing the actual losses computed for each time interval. Note that there is not a direct conversion between metric and English units for coefficients of this method, consequently separate calibrations to rainfall data are necessary to derive the coefficients for both units of measure.

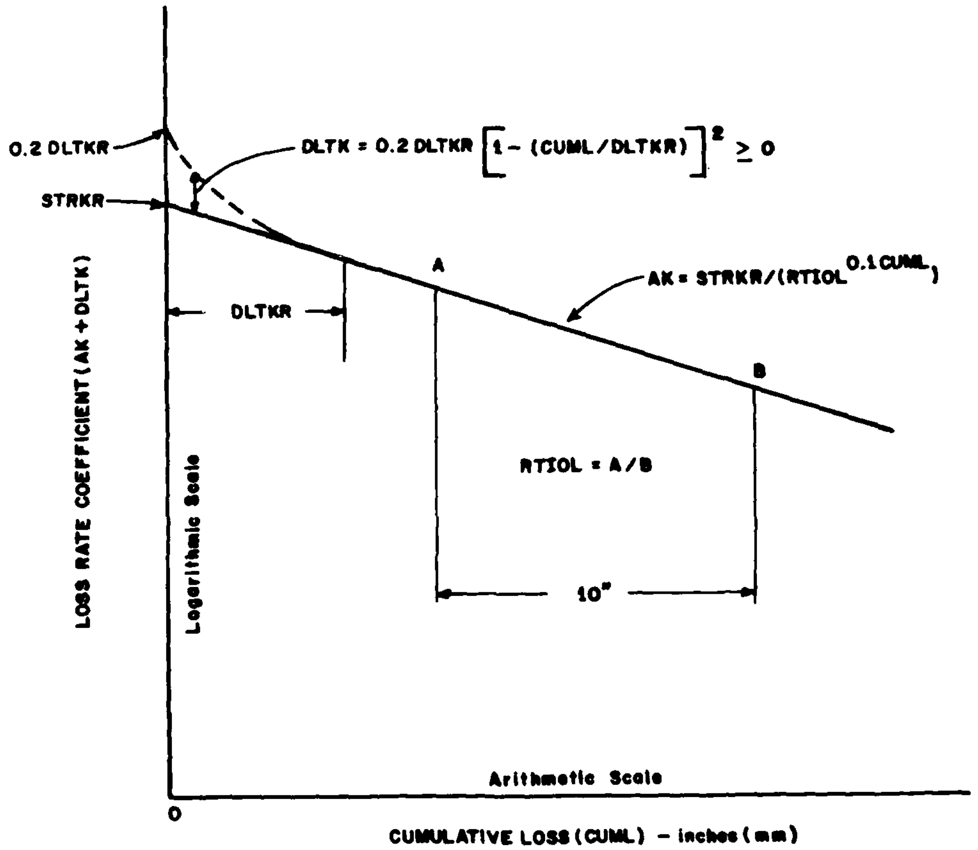


Figure 3.3 General HEC Loss Rate Function for Snow-free Ground

DLTKR is the amount of initial accumulated rain loss during which the loss rate coefficient is increased. This parameter is considered to be a function primarily of antecedent soil moisutre deficiency and is usually storm dependent. STRKR is the starting value of loss coefficient on exponential recession curve for rain losses (snow-free ground). The starting value is considered a function of infiltration capacity and thus depends on such basin characteristics as soil type, land use and vegetal cover.

RTIOL is the ratio of rain loss coefficient on exponential loss curve to that corresponding to 10 inches (10 mm) more of accumulated loss. This variable may be considered a function of the ability of the surface of a basin to absorb precipitation and should be reasonably constant for large rather homogeneous areas. ERAIN is the exponent of precipitation for rain loss function that reflects the influence of precipitation rate on basin-average loss characteristics. It reflects the manner in which storms occur within an area and may be considered a characteristic of a particular region. ERAIN varies from 0.0 to 1.0.

Under certain circumstances it may be more convenient to work with the exponential loss rate as a two parameter infiltration model. To obtain an initial and constant loss rate function, set ERAIN=0 and RTIOL=1.0. To obtain a loss rate function that decays exponentially with no initial loss, set ERAIN=0.0 and DLTKR=0.0.

Estimates of the parameters of the exponential loss function can be obtained by employing the HEC-1 parameter optimization option described in Section 4.

A similar loss rate function is used for snowmelt. See the input description for the additional variables used in snowmelt loss simulation.

3.2.3 SCS Curve Number

The Soil Conservation Service (SCS), U.S. Department of Agriculture, has instituted a soil classification system for use in soil survey maps across the country. Based on experimentation and experience, the agency has been able to relate the drainage characteristics of soil groups to a curve number, CN (SCS, 1972 and 1975). The SCS provides information on relating soil group type to the curve number as a function of soil cover, land use type and antecedent moisture conditions.

Precipitation loss is calculated based on supplied values of CN and IA (where IA is an initial surface moisture storage capacity in units of depth). CN and IA are related to a total runoff depth for a storm by the following relationships:

$$ACEXS = \frac{(ACRAN - IA)^2}{ACRAN - IA + S} \quad \ldots \quad (3.17)$$

$$S = \frac{1000 - 10 * CN}{CN} \quad \text{or} \quad S = \frac{25400-254*CN}{CN} \text{ (Metric Units)} \quad \ldots \quad (3.18)$$

where ACEXS is the accumulated excess in inches (mm), ACRAN is the accumulated rainfall depth in inches (mm), and S is the currently available soil moisture storage deficit in inches (mm).

In the case that the user does not wish to specify IA, a default value is computed as

$$IA = .2 * S \quad \ldots \quad (3.19)$$

This relation is based on empirical evidence established by the Soil Conservation Service.

Since the SCS method gives total excess for a storm, the incremental excess (the difference between rainfall and precipitation loss) for a time period is computed as the difference between the accumulated excess at the end of the current period and the accumulated excess at the end of the previous period.

3.2.4 Holtan Loss Rate

Holtan et al. (1975) compute loss rate based on the infiltration capacity given by the formula:

$$f = GIA * SA^{BEXP} + FC \quad (3.20)$$

where f is the infiltration capacity in inches per hour, GIA is the product of GI a "growth index" representing the relative maturity of the ground cover and A the infiltration capacity in inches per hour (inch$^{1.4}$ of available storage), SA is the equivalent depth in inches of pore space in the surface layer of the soil which is available for storage of infiltrated water, FC is the constant rate of percolation of water through the soil profile below the surface layer, and BEXP is an empirical exponent, typically taken equal to 1.4.

The factor "A" is interpreted as an index of the pore volume which is directly connected to the soil surface. The number of surface-connected pores is related to the root structure of the vegetation, so the factor "A" is related to the cover crop as well as the soil texture. Since the surface-connected porosity is related to root structure, the growth index, GI, is used to indicate the development of the root system and in agricultural basins GI will vary from near zero when the crop is planted to 1.0 when the crop is full-grown.

Holtan et al. (1975) have made estimates of the value of "A" for several vegetation types. Their estimates were evaluated at plant maturity as the percent of the ground surface occupied by plant stems or root crowns.

Estimates of FC can be based on the hydrologic soil group given in the SCS Handbook (1972 and 1975). Musgrave (1955) has given the following values of FC in inches per hour for the four hydrologic soil groups: A, 0.45 to 0.30; B, 0.30 to 0.15; C, 0.15 to 0.05; D, 0.05 or less.

The available storage, SA, is decreased by the amount of infiltrated water and <u>increased at the percolation rate</u>, FC. Note, by calculating SA in this manner, soil moisture recovery occurs at the deep percolation rate. The amount of infiltrated water during a time interval is computed as the smaller of 1) the amount of available water, i.e., rain or snowmelt, or 2) the average infiltration capacity times the length of the time interval.

In HEC-1 the infiltration equation used is

$$F = \frac{F1 + F2}{2} * TRHR \quad (3.21)$$

where F1 and F2 and SA1 and SA2 are the infiltration rates and available storage, respectively, at the beginning and end of the time interval TRHR, and

$$F1 = GIA * SA1^{BEXP} + FC \quad (3.22)$$

$$F2 = GIA * SA2^{BEXP} + FC \quad (3.23)$$

$$SA2 = SA1 - F + FC * TRHR \quad (3.24)$$

3.3 Unit Hydrograph

The unit hydrograph technique has been discussed extensively in the literature (Corps of Engineers, 1959, Linsley et al., 1975, and Viessman et al., 1972). This technique is used in the subbasin runoff component to transform rainfall/snowmelt excess to subbasin outflow. A unit hydrograph can be directly input to the program or a synthetic unit hydrograph can be computed from user supplied parameters.

3.3.1 Basic Methodology

A 1-hour unit hydrograph is defined as the subbasin surface outflow due to a unit (1 inch or mm) rainfall excess applied uniformly over a subbasin in a period of one hour. Unit hydrograph durations other than an hour are common. HEC-1 automatically sets the duration of unit excess equal to the computation interval selected for watershed simulation.

The rainfall excess hyetograph is transformed to a subbasin outflow by utilizing the general equation:

$$Q(i) = \sum_{j=1}^{i} U(j)*X(i-j+1) \qquad \text{.......... (3.25)}$$

where Q(i) is the subbasin outflow at the end of computation interval i, U(j) is the jth ordinate of the unit hydrograph, X(i) is the average rainfall excess for computation interval i.

The equation is based on two important assumptions. First, the unit hydrograph is characteristic for a subbasin and is not storm dependent. Second, the runoff due to excess from different periods of rainfall excess can be linearly superposed.

3.3.2 Synthetic Unit Hydrographs

The parameters for the synthetic unit hydrograph can be determined from gage data by employing the parameter optimization option described in Section 4. Otherwise, these parameters can be determined from regional studies or from guidelines given in references for each synthetic technique. There are three synthetic unit hydrograph methods available in the model.

(i) Clark Unit Hydrograph. The Clark method (1945) requires three parameters to calculate a unit hydrograph: TC, the time of concentration for the basin, R, a storage coefficient, and a time-area curve. A time-area curve defines the cumulative area of the watershed contributing runoff to the subbasin outlet as a function of time (expressed as a proportion of TC).

In the case that a time area curve is not supplied, the program utilizes a dimensionless time area curve:

$$AI = 1.414T^{1.5} \qquad 0 \leq T < .5 \qquad \text{.......... (3.26)}$$

$$1 - AI = 1.414\,(1-T)^{1.5} \qquad .5 < T < 1 \qquad \text{.......... (3.27)}$$

where AI is the cumulative area as a fraction of total subbasin area and T is the fraction of time of concentration. The ordinates of the time-area curve are converted to volume of runoff per second for unit excess and interpolated to the given time interval. The resulting translation hydrograph is then routed through a linear reservoir to simulate the storage effects of the basin; and the resulting unit hydrograph for instantaneous excess is averaged to produce the hydrograph for unit excess occurring in the given time interval.

The linear reservoir routing is accomplished using the general equation:

$$Q(2) = CA * I + CB * Q(1) \quad \ldots\ldots (3.28)$$

The routing coefficients are calculated from:

$$CA = \Delta t/(R + .5 * \Delta t) \quad \ldots\ldots (3.29)$$

$$CB = 1 - CA \quad \ldots\ldots (3.30)$$

$$QUNGR = .5(Q(1) + Q(2)) \quad \ldots\ldots (3.31)$$

where Q(2) is the instantaneous flow at end of period, Q(1) is the instantaneous flow at the beginning of period, I is the ordinate of the translation hydrograph, Δt is the computation time interval in hours (also duration of unit excess), R is the basin storage factor in hours, and QUNGR is the unit hydrograph ordinate at end of computation interval. The computation of unit hydrograph ordinates is terminated when its volume exceeds 0.995 inch (mm) or 150 ordinates, whichever occurs first.

(ii) Snyder Unit Hydrograph The Snyder method (1938) determines the unit graph peak discharge, time to peak, and widths of the unit graph at 50 and 75% of the peak discharge. The method does not produce the complete unit graph required by HEC-1. Thus, HEC-1 uses the Clark method to affect a Snyder unit graph. The initial Clark parameters are estimated from the given Snyder's parameters, Tp and Cp. A unit hydrograph is computed using Clark's method and Snyder parameters are computed from the resulting unit hydrograph by the following equations:

$$CPTMP = QMAX * \frac{Tpeak - 0.5 * \Delta t}{C * A} \quad \ldots\ldots (3.32)$$

$$ALAG = 1.048 * (Tpeak - 0.75 * \Delta t) \quad \ldots\ldots (3.33)$$

where CPTMP is Snyder's Cp for computed unit hydrograph, QMAX is the maximum ordinate of unit hydrograph, Tpeak is the time when QMAX occurs, in hours, Δt is the duration of excess, in hours, A is the subbasin area in square miles (sq km), C is a conversion factor, and ALAG is Snyder's standard Lag, Tp for the computed unit hydrograph. Snyder's standard Lag is for a unit hydrograph which has a duration of excess equal to Tp/5.5. The coefficient, 1.048, in equation results from converting the duration of excess to the given time interval.

Clark's TC and R are adjusted to compensate for differences between values of Tp and Cp calculated by equations 3.32 and 3.33 and the given values. A new unit hydrograph is computed using these adjusted values. This procedure continues through 20 iterations or until the differences between computed and given values of Tp and Cp are less than one percent of the given values.

(iii) <u>SCS Dimensionless Unit Hydrograph</u>. Input data for the Soil Conservation Service, SCS, dimensionless unit hydrograph method (1972) consists of a single parameter, TLAG, which is equal to the lag (hrs) between the center of mass of rainfall excess and the peak of the unit hydrograph. Peak flow and time to peak are computed as:

$$TPEAK = .5 * \Delta t + TLAG \quad (3.34)$$

$$QPK = 484 * AREA/TPEAK \quad (3.35)$$

where TPEAK is the time to peak of unit hydrograph in hours, Δt is the duration of excess in hours or computation interval, QPK is the peak flow of unit hydrograph in hours, and AREA is the subbasin area in square miles. The unit hydrograph is interpolated for the specified computation interval and computed peak flow from the dimensionless unit hydrograph shown in Fig. 3.4.

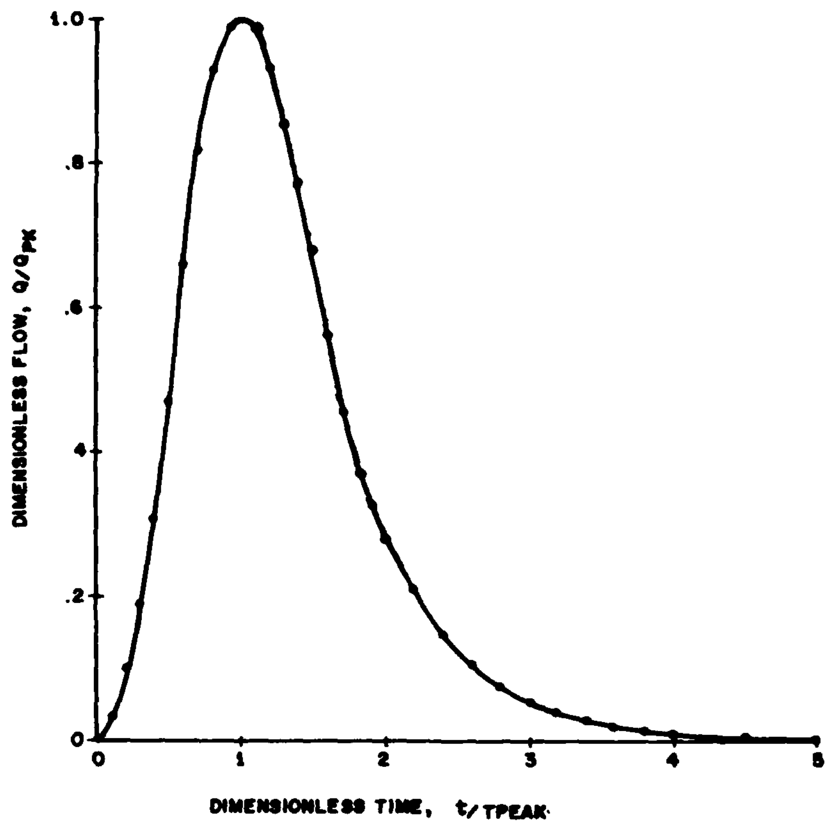


Figure 3.4 SCS Dimensionless Unit Graph

The selection of the program computation interval, which is also the duration of the unit hydrograph, is based on the relationship $\Delta t = .2*TPEAK$ (SCS, 1972, Chapters 15, 16). There is some latitude allowed in this relationship; however, the duration of the unit graph should not exceed $\Delta t \leq .25*Tpeak$. These relations are based on an empirical relationship, $TLAG = .6*Tc$, and $1.7*TPEAK = \Delta t+Tc$ where Tc is the time of concentration of the watershed. Using these relationships, along with equation (3.34) it is found that the duration should not be greater than $\Delta t \leq .29*TLAG$.

3.4 Kinematic Wave

In determining subbasin runoff by the kinematic wave method three conceptual elements are used: flow planes, collector channels, and a main channel, Fig. 3.5. The kinematic wave technique transforms rainfall excess into subbasin outflow. This section deals with the application of the kinematic wave equations in HEC-1. Refer to HEC, 1979, for details on development of the kinematic wave equations.

3.4.1 Basic Concepts

In the kinematic wave interpretation of the equations of motion, it is assumed that the bed slope and water surface slope are equal and acceleration effects are negligible (parameters given in metric units are converted to

Figure 3.5 Relationship Between Flow Elements

English units for use in these equations). The momentum equation then simplifies to

$$S_f = S_o \quad \text{(3.36)}$$

where S_f is the friction slope and S_o is the channel bed slope. Thus flow at any point in the channel can be computed from Manning's formula.

$$Q = \frac{1.486}{n} S^{1/2} R^{2/3} A \quad \text{(3.37)}$$

where Q is flow, S is the channel bed slope, R is hydraulic radius, A is cross-sectional area, and n is Manning's resistance factor. Equation (3.37) can be simplified to

$$Q = \alpha A^m \quad \text{(3.38)}$$

where α and m are related to flow geometry and surface roughness. Figure 3.6 gives relations for α and m for channel shapes used in HEC-1. Note that flow depths greater than the diameter of the circular channel shape are possible, which only approximates the storage characteristics of a pipe or culvert.

Since the momentum equation has been reduced to a simple functional relation between area and discharge, the movement of a flood wave is described solely by the continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \quad \text{(3.39)}$$

3.4.2 Solution Procedure

The governing equations for either overland flow or channel routing are solved in the same manner. The method assumes that inflows, whether it be rainfall excess or lateral inflows, are constant within a time step and uniformly

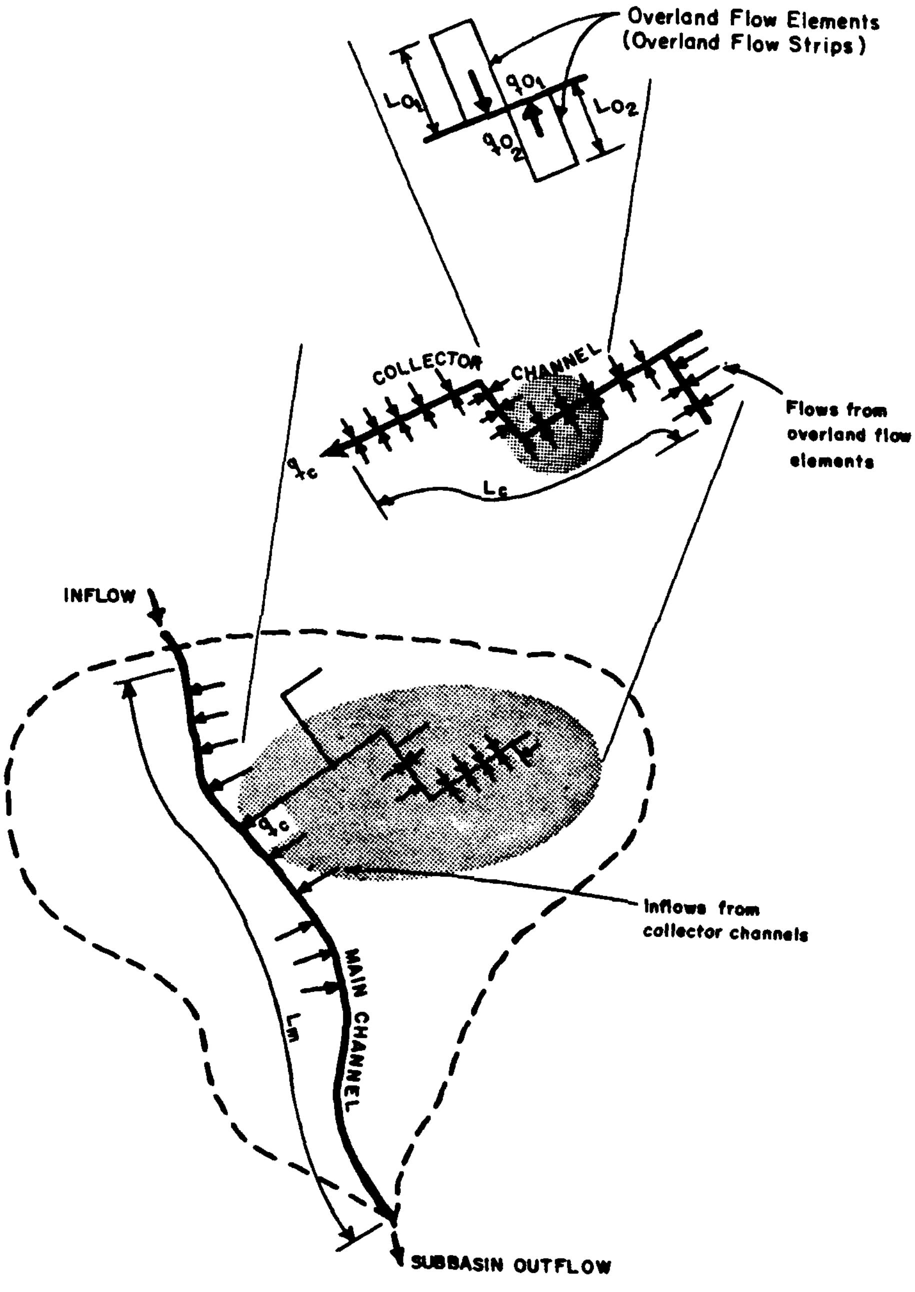
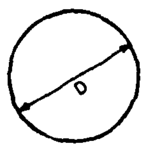


Figure 3.5 Relationship Between Flow Elements

distributed along the element. By combining equations 3.38 and 3.39, the governing equation is obtained as:

$$\frac{\partial A}{\partial t} + \alpha m \; A^{(m-1)} \frac{\partial A}{\partial x} = q \quad \text{. . . . .(3.40)}$$

CIRCULAR

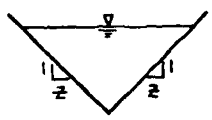


$\alpha = \frac{.804}{n} S^{1/2} D^{1/6}$

(APPROXIMATE)

$m = 5/4$

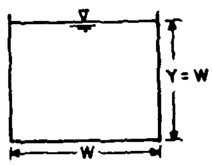
TRIANGULAR



$\alpha = \frac{0.94}{n} S^{1/2} \left(\frac{Z}{1+Z^2}\right)^{1/3}$

$m = 4/3$

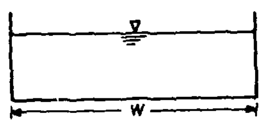
SQUARE



$\alpha = \frac{.72}{n} S^{1/2}$

$m = 4/3$

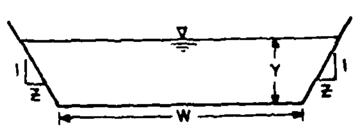
RECTANGULAR



$\alpha = \frac{1.49}{n} S^{1/2} W^{-2/3}$

$m = 5/3$

TRAPEZOIDAL



$Q = \frac{1.49}{n} S^{1/2} A^{5/3} \left(\frac{1}{W+2Y\sqrt{1+Z^2}}\right)^{2/3}$

Figure 3.6 Kinematic Wave Parameters for Various Channel Shapes

A is the only dependent variable in the equation; a and m are considered constant. The standard form of the finite difference approximation to this equation is developed as:

$$\frac{A_{(i,j)} - A_{(i,j-1)}}{\Delta t} + \alpha m \left[\frac{A_{(i,j-1)} + A_{(i-1,j-1)}}{2}\right]^{m-1} * \left[\frac{A_{(i,j-1)} - A_{(i-1,j-1)}}{\Delta x}\right] = \bar{q} \quad \ldots\ldots\ldots\ldots (3.41)$$

This is referred to as the "standard form" of the finite difference equation where $\bar{q}$ is defined as:

$$\bar{q} = \frac{q_{(i,j)} + q_{(i,j-1)}}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.42)$$

The indices of the approximation refer to positions on a space-time grid (Fig. 3.7). The grid indicates the position of the solution scheme as it solves for the unknown values of A at various positions and times. The index i indicates the current position of the solution scheme along the length of the channel,

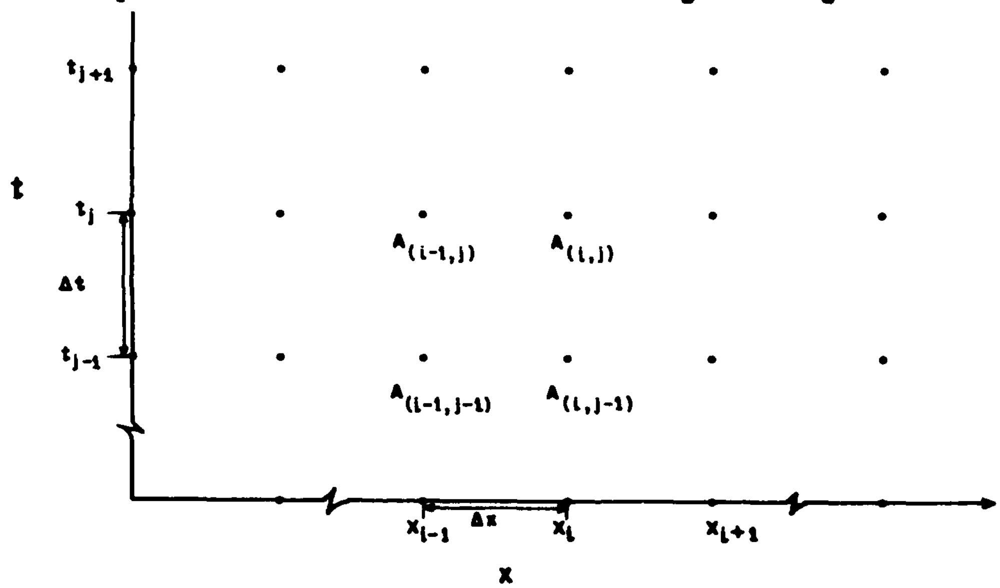


Figure 3.7 Finite Difference Method Space-Time Grid

j indicates the current time step of the solution scheme. i-1, j-1 indicate, respectively, positions and times removed a value Δx and Δt from the current position of the solution scheme. The only unknown value in the equation is the current value $A_{(i,j)}$. All other values are known from either a solution of the equation at a previous position i-1 and time j-1, or from a boundary condition. Solving for the unknown:

$$A_{(i,j)} = \bar{q}\,\Delta t + A_{(i,j-1)} - \alpha m \left(\frac{\Delta t}{\Delta x}\right) \left[\frac{A_{(i,j-1)} + A_{(i-1,j-1)}}{2}\right]^{m-1} * [A_{(i,j-1)} - A_{(i-1,j-1)}] \quad \ldots\ldots (3.43)$$

Once $A_{(i,j)}$ is known, the flow can be computed as:

$$Q_{(i,j)} = \alpha[A_{(i,j)}]^m \quad \text{.......................(3.44)}$$

The "standard form" of the equation applies if the wave celerity, c, is less than the ratio of the space to time step, e.g., $c < \Delta x/\Delta t$, where c is computed as the average change of flow divided by the average flow area for a particular routing reach. If this is not true, the "conservation form" of the continuity equation is used to insure numerical stability and equation 3.40 is approximated as:

$$\frac{Q_{(i,j)} - Q_{(i-1,j)}}{\Delta x} + \frac{A_{(i-1,j)} - A_{(i-1,j-1)}}{\Delta t} = \bar{q} \quad \text{.........(3.45)}$$

where $Q_{(i,j)}$ is the only unknown. Solving for the unknown:

$$Q_{(i,j)} = Q_{(i-1,j)} + \bar{q}\,\Delta x - \frac{\Delta x}{\Delta t}[A_{(i-1,j)} - A_{(i-1,j-1)}] \quad \text{.....(3.46)}$$

knowing the value of $Q_{(i,j)}$

$$A_{(i,j)} = [Q_{(i,j)}/\alpha]^{1/m} \quad \text{.......................(3.47)}$$

The space increment Δx and time step Δt are chosen by the program to insure the scheme stability and convergence, and are based on experience in the use of the scheme. Δx is computed by the program to fall between the limits:

$$\frac{LREACH}{50} \leq \Delta x \leq \frac{LREACH}{2} \quad \text{.......................(3.48)}$$

where LREACH is the length of a channel reach. Δt has a minimum value based on variable array requirements which are defined as:

$$\Delta t \geq \frac{NQ-1}{600} * TRHR \quad \text{.......................(3.49)}$$

where NQ is the number of hydrograph ordinates, and TRHR is the computation interval.

3.4.3 Element Application

(i) Overland Flow. The overland flow element is a wide rectangular channel of unit width; so, referring to Fig. 3.6, $\alpha = 1.486S^{1/2}N$ and m=5/3. Notice that Manning's n has been replaced by an overland flow roughness factor, N. Typical values of N are shown in Table 3.5. When applying equations (3.43) and (3.46) to an overland flow element, the lateral inflow is rainfall excess (previously computed using methods described in Section 3.2) and the outflow is a flow per unit width.

An overland flow element is described by four parameters: a typical overland flow length, L, which is also LREACH in equation (3.48), slope and roughness factor which are used to compute α, and the percent of the subbasin area represented by this element.

TABLE 3.5

Effective Roughness Parameters for Overland Flow

Surface	N
Dense Growth*	0.4 -0.5
Pasture*	0.3 -0.4
Lawns*	0.2 -0.3
Bluegrass Sod**	0.2 -0.5
Short Grass Prairie**	0.1 -0.2
Sparse Vegetation**	0.05-0.13
Bare Clay-Loam Soil (Eroded)**	0.01-0.03
Concrete/Asphalt - Very Shallow Depths* (depths less than 1/4 inch)	0.10-0.15
- Small Depths* (depths on the order of 1/4 inch to several inches)	0.05-0.10

* from Crawford and Linsley (1966)
** from Woolhiser (1975)

Two overland flow elements may be used for each subbasin. The total discharge, Q, from each element is computed as

$$Q = q * \frac{AREA}{L} \quad (3.50)$$

where q is the discharge per unit width from each overland flow element computed from equations (3.44) or (3.46), AREA is the area represented by each element, and L is the overland flow length.

(ii) Channel Elements. Flow from the overland flow elements travels to the subbasin outlet through one or two successive channel elements, Fig. 3.5. A channel is defined by length, slope, roughness, shape, width or diameter, and side slope, Fig. 3.6. The last channel in a subbasin is called the main channel, and any intermediate channels between the overland flow elements and the main channel are called collector channels. Use of a collector channel is optional.

Lateral inflow into a channel element from overland flow is the sum of the total discharge computed by equation (3.50) for both elements divided by the channel length. If the channel is a collector, the area used in equation (3.50) is the area serviced by the collector. Lateral inflow, q, from a collector channel is computed as

$$q = Q * \frac{AREA2}{AREA1} * \frac{1}{L} \quad (3.51)$$

where Q is the discharge from the collector, AREA1 is a typical area served by this collector, AREA2 is the area served by the channel receiving flow from the collector, and L is the length of the receiving channel. If the receiving channel is the main channel, AREA2 is the subbasin area.

(iii) Element Combination. The relationship between the overland flow elements and collector and main channels is best described by an example (see Fig. 3.5). Consider that the subbasin being modeled is in a typical suburban community and has a drainage area of one square mile. The typical suburban housing block is approximately .05 square miles. Runoff from this area (lawns, roofs, driveways, etc.) is intercepted by a local drainage system of street gutters and drainage pipes (typically 10-15 inch diameter). Flow from local drainage systems is intercepted by drainage pipes (typically 21 to 27 inches in diameter) and conveyed to a small stream flowing through the community. Typically each of the drainage pipes service about a .25 square mile area.

One approach to modeling the subbasin employs two overland flow elements, two collector channels and a main channel. Each overland flow plane could be used to model runoff from different land uses in the basin (for example housing lots and commercial developments such as a shopping center). The first collector channel models the local drainage system, the second collector channel model the interceptor drainage system and the main channel models the stream. The model parameters which might typically be used to characterize the runoff from the subbasin are shown in Table 3.6. These parameters can be obtained from topographic maps, town or city drainage maps or any other source of land survey information. Note that the parameters are average or typical for the subbasin and do not necessarily reflect any particular drainage component in the subbasin (i.e., these are parameters which are representative for the entire subbasin).

The model requires that at least one overland flow plane and one main channel be used in kinematic wave applications. In the above example, fewer elements might have been used depending on the level of detail required for the hydrologic analysis.

3.5 Base Flow

Two distinguishable contributions to a stream flow hydrograph are direct runoff (described earlier) and base flow which results from releases of water from subsurface storage. The HEC-1 model provides means to include the effects of base flow on the streamflow hydrograph as a function of three input parameters, STRTQ, QRCSN and RTIOR. Fig. 3.8 defines the relation between the streamflow hydrograph and these variables.

The variable STRTQ represents the initial flow in the river. It is affected by the long term contribution of groundwater releases in the absence of precipitation and is a function of antecedent conditions (e.g., the time between the storm being modeled and the last occurrence of precipitation). The variable QRCSN indicates the flow at which an exponential recession begins on the receding limb of the computed hydrograph. Recession of the starting flow and "falling limb" follow a user specified exponential decay rate, RTIOR, which is assumed to be a characteristic of the basin. RTIOR is equal to the ratio of a recession limb flow to the recession limb flow occurring one hour later. The program computes the recession flow Q as:

TABLE 3.6
Typical Kinematic Wave Data

	Overland Flow Plane Data			
Identification	Overland Flow Length (ft)	Average Slope (ft/ft)	Roughness Coefficient	Percentage of Subbasin Area
Housing	200	.01	.3	80%
Commercial	100	.01	.1	20%

	Channel Data				
	Channel Length (ft)	Channel Slope (ft/ft)	Channel Roughness	Contributing Area (sq mi)	Shape
Collector Channel	500	.005	.02	.05	2.0 (ft) (Diameter)
Collector Channel	1500	.001	.015	.25	2.0 (ft) (Diameter)
Main Channel	4000	.001	.03	1.0*	Trapezoidal

*Main channel always assumed to service total subbasin area.

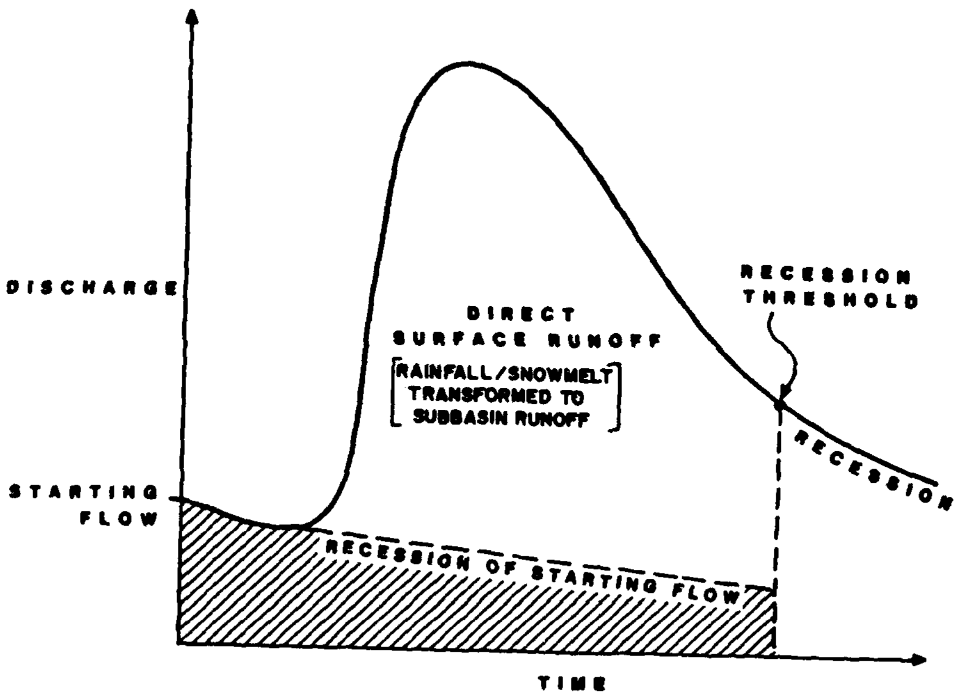


Figure 3.8 Base Flow Diagram

$$Q = Q_o \, (RTIOR)^{-n \, \Delta t} \quad \text{(3.52)}$$

where Q_o is STRTQ or QRCSN, and $n\Delta t$ is the time in hours since recession was initiated. QRCSN and RTIOR can be obtained by plotting the log of observed flows versus time. The point at which the recession limb fits a straight line defines QRCSN and the slope of the straight line is used to define RTIOR. Alternatively, QRCSN can be specified as a ratio of the peak flow. For example, the user can specify that the exponential recession is to begin when the "falling limb" discharge drops to 0.1 of the calculated peak discharge.

The rising limb of the streamflow hydrograph is adjusted for base flow by adding the recessed starting flow to the computed direct runoff flows. The falling limb is determined in the same manner until the computed flow is determined to be less than QRCSN. At this point, the time at which the value of QRCSN is reached is estimated from the computed hydrograph. From this time on, the streamflow hydrograph is computed using the recession equation unless the computed flow rises above the base flow recession. This is the case of a double peaked streamflow hydrograph where a rising limb of the second peak is computed by combining the starting flow recessed from the beginning of the simulation and the direct runoff.

3.6 Flood Routing

Flood routing is used to simulate flood wave movement through river reaches and reservoirs. Most of the flood-routing methods available in HEC-1 are based on the continuity equation and some relationship between flow and storage or stage. These methods are Muskingum, Kinematic wave, Modified Puls, Working R and D, and Level-pool reservoir routing. In all of these methods, routing proceeds on an independent-reach basis from upstream to downstream; neither backwater effects nor discontinuities in the water surface such as jumps or bores are considered.

Storage routing methods in HEC-1 are those methods which require data that define the storage characteristics of a routing reach or reservoir. These methods are: modified Puls, working R and D, and level-pool reservoir routing.

There are also two routing methods in HEC-1 which are based on lagging averaged hydrograph ordinates. These methods are not based on reservoir storage characteristics, but have been used on several rivers with good results.

3.6.1 Channel Infiltration

Channel infiltration losses may be simulated by either of two methods. The first method simulates losses by using the following equation:

$$Q(I) = [QIN(I) - QLOSS] * (1 - CLOSS) \quad \text{(3.53)}$$

where QIN(I) is the inflowing hydrograph ordinate at time I before losses, QLOSS is a constant loss in cfs (m^3/sec), CLOSS is a fraction of the remaining flow which is lost, and Q(I) is the hydrograph ordinate after losses have been removed. Hydrographs are adjusted for losses after routing for all methods except modified Puls; for modified Puls losses are computed before routing.

A second methods computes channel loss during storage routing based on a constant channel loss (cfs/acre) per unit area and the surface area of channel flow. The surface area of channel flow is computed as:

$$WTACRE = STR(I)/DEPTH \quad (3.54)$$

where STR(I) is the channel storage at time I corresponding to the routed outflow at the end of a period, WTACRE is the corresponding channel surface area, and the depth of flow is the average flow depth in the channel. The flow depth in the channel is computed as:

$$DEPTH = FLOELV(I) - ELVINV \quad (3.55)$$

where FLOELV(I) is the flow elevation corresponding to STR(I) and ELVINV is the channel invert elevation. ELVINV must be chosen carefully to give the proper values for WTACRE. The resulting hydrograph is then computed as:

$$QO(I) = Q(I) - WTACRE * PERCRT \quad (3.56)$$

where Q(I) is the routed outflow and QO(I) is the flow adjusted for the constant channel loss rate PERCRT (cfs/acre).

3.6.2 Muskingum

The Muskingum method (Corps of Engineers, 1960) computes outflow from a reach using the following equation:

$$QOUT(2) = (CA-CB) * QIN(1) + (1-CA) * QOUT(1) + CB * QIN(2) \quad (3.57)$$

$$CA = \frac{2 * \Delta t}{2 * AMSKK * (1-X) + \Delta t} \quad (3.58)$$

$$CB = \frac{\Delta t - 2 * AMSKK * X}{2 * AMSKK * (1-X) + \Delta t} \quad (3.59)$$

where QIN is the inflow to the routing reach in cfs (m^3/sec), QOUT is the outflow from the routing reach in cfs (m^3/sec), AMSKK is the travel time through the reach in hours, and X is the Muskingum weighting factor ($0 \leq X \leq .5$). The routing procedure may be repeated for several subreaches (designated as NSTPS) so the total travel time through the reach is AMSKK. To insure the method's computational stability and the accuracy of computed hydrograph, the routing reach should be chosen so that:

$$\frac{1}{2(1-X)} \leq \frac{AMSKK}{NSTPS*\Delta t} \leq \frac{1}{2x} \quad (3.60)$$

3.6.3 Modified Puls

The modified Puls routing method (Chow, 1964) is a variation of the storage routing method described by Henderson (1966). It is applicable to both channel and reservoir routing. Caution must be used when applying this method to channel routing. The degree of attenuation introduced in the routed flood wave varies depending on the river reach lengths chosen, or alternatively, on the number of routing steps specified for a single reach. The number of routing steps (variable NSTPS) is a calibration parameter for the storage routing methods; it can be varied to produce desired routed hydrographs. A storage indication function is computed from given storage and outflow data.

$$STRI(I) = C * \frac{STOR(I)}{\Delta t} + \frac{OUTFL(I)}{2} \quad \text{.......... (3.61)}$$

where STRI is the storage indication in cfs (m^3/sec), STOR is the storage in the routing reach for a given outflow in acre-ft (1000 m^3), OUTFL is the outflow from routing reach in cfs (m^3/sec), C is the conversion factor from acre-ft/hr to cfs (1000 m^3/hr to m^3/sec), Δt is the time interval in hours, and I is a subscript indicating corresponding values of storage and outflow. Storage indication at the end of each time interval is given by

$$STRI(2) = STRI(1) + QIN - Q(1) \quad \text{.......... (3.62)}$$

where QIN is the average inflow in cfs (m^3/sec), and Q is the outflow in cfs (m^3/sec), and subscripts 1 and 2 indicate beginning and end of the current time interval.

The outflow at the end of the time interval is interpolated from a table of storage indication (STRI) versus outflow (OUTFL). Storage (STR) is then computed from

$$STR = (STRI - \frac{Q}{2}) * \frac{\Delta t}{C} \quad \text{.......... (3.63)}$$

When stage data are given, stages are interpolated for computed storages.

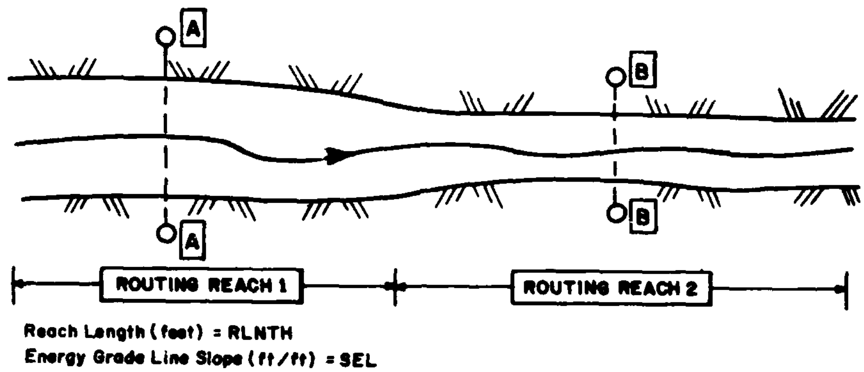
Initial conditions can be specified in terms of storage, outflow, or stage. The corresponding value of storage or outflow is computed from the given initial value.

(i) <u>Given Storage versus Outflow Relationship</u>. The modified Puls routing may be accomplished by providing a storage versus outflow relationship as direct imput to HEC-1. Such a relationship can be derived from water surface profile studies or other hydraulic analyses of rivers or reservoirs.

(ii) <u>Normal-Depth Storage and Outflow</u>. Storage and outflow data for use in modified Puls or working R&D (see next subsection) routing may be computed from channel characteristics. The program uses an 8-point cross section which is representative of the routing reach (Fig. 3.9). Outflows are computed for normal depth using Manning's equation. Storage is cross-sectional area times reach length. Storage and outflow values are computed for 20 evenly-spaced stages beginning at the lowest point on the cross section to a specified maximum stage. The cross section is extended vertically at each end to the maximum stage.

As shown in Fig. 3.9, the input variables to the program are the hydraulic and geometric data: ANL, ANCH, ANR, RLNTH, SEL, ELMAX, and (X,Y) coordinates. ANL, ANCH, ANR are Manning's n values for left overbank, main channel, and right overbank, respectively. RLNTH is routing reach length in feet (meters). SEL is the energy gradient used for computing outflows. (X,Y) are coordinates of an 8-point cross section.

Storage and outflow should not be calculated from normal depth when the storage limits and conveyance limits are significantly different. Also, if the cross section is "representative" for a reach that is not uniform, the stages will not be applicable to any specific location. Generally, the stages produced by the method are of limited value because downstream effects are not taken into account.



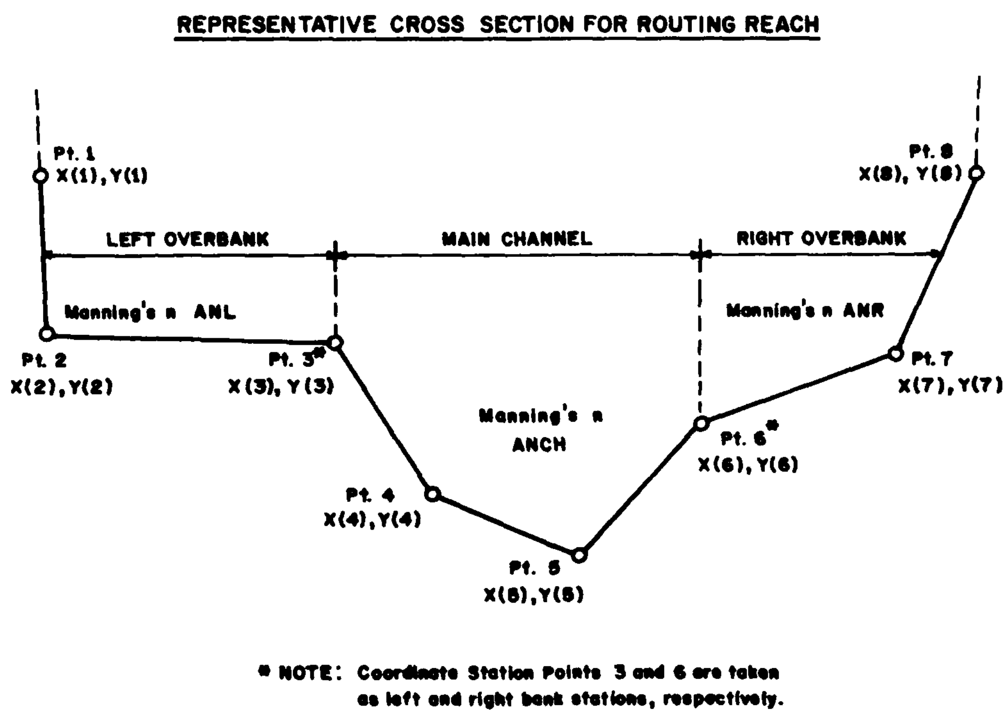


Figure 3.9 Normal Depth Storage-Outflow Channel Routing

3.6.4 Working R and D

The working R and D method (Corps of Engineers, 1960) is a variation of modified Puls method which accounts for wedge storage as in the Muskingum method. The number of steps and the X factor are calibration parameters of the method and can have a significant effect on the routed hydrograph.

The "working discharge", D, is given by

$$D = X * I + (1-X) * O \qquad (3.64)$$

and storage indication, R, is given by

$$R = \frac{S}{\Delta t} + \frac{D}{2} \qquad (3.65)$$

where I is the inflow hydrograph ordinate, O is the outflow hydrograph ordinate, S is the storage volume in routing reach, and X is the Muskingum coefficient which accounts for wedge storage. The calculation sequence is as follows:

1) set initial D and R from initial inflow, outflow, and storage
2) compute R for next step from

$$R_2 = R_1 + \frac{I_1 + I_2}{2} - D_1 \qquad (3.66)$$

3) interpolate D_2 from R vs. D data
4) compute outflow from

$$O_2 = D_2 - \frac{X}{1-X} * (I_2 - D_2) \qquad (3.67)$$

The storage versus outflow relationship may be specified as direct input or computed by the normal-depth option as described above.

3.6.5 Level-Pool Reservoir Routing

Level-pool reservoir routing assumes a level water surface behind the reservoir. It is used in conjunction with the pump option described in Section 3.8 and with the dam-break calculation described in Section 6. Using the principle of conservation of mass, the change in reservoir storage, S, for a given time period, Δt, is equal to average inflow, I, minus average outflow, O.

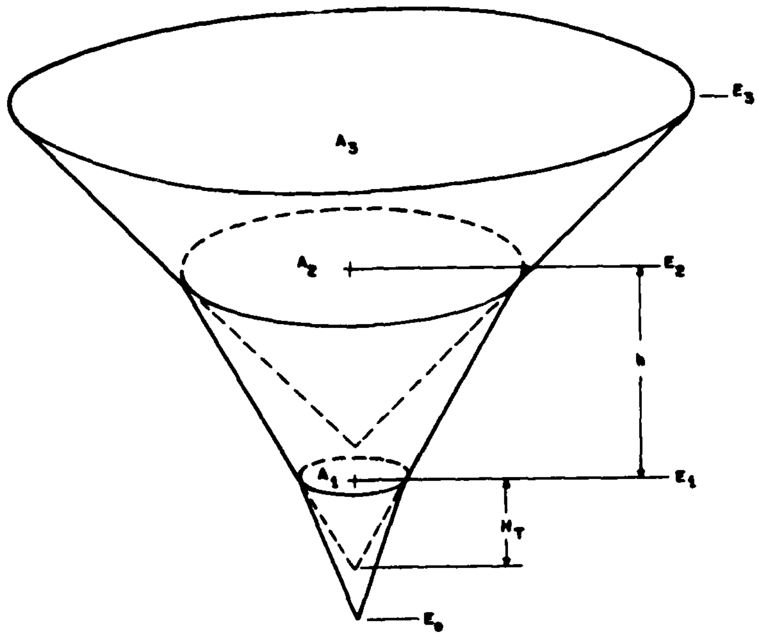
$$\frac{S_2 - S_1}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2} \qquad (3.68)$$

An iterative procedure is used to determine end-of-period storage, S_2, and outflow, O_2. An initial estimate of the water surface elevation at the end of the time period is made. S_2 and O_2 are computed for this elevation and substituted in the following equation:

$$Y = \frac{S_2 - S_1}{\Delta t} - \frac{I_1 + I_2}{2} + \frac{O_1 + O_2}{2} \qquad (3.69)$$

where Y is the continuity error for the estimated elevation. The estimated elevation is adjusted until Y is within ± 1 cfs (m^3/sec).

(i) <u>Reservoir Storage Data</u>. A reservoir storage volume versus elevation relationship is required for level-pool reservoir routing. The relationship may be specified in two ways: 1) direct input of precomputed storage versus elevation data, or 2) computed from surface area versus elevation data. The conic method is used to compute reservoir volume from surface area versus elevation data, Fig. 3.10. The volume is assumed to be zero at the lowest



$$\Delta V_{12} = \frac{h}{3}(A_1 + A_2 + \sqrt{A_1 A_2})$$

$$H_T = h/(\sqrt{A_2/A_1} - 1)$$

Where

ΔV_{12} = volume between base areas 1 and 2,

A_i = surface area of base i,

E_i = elevation of base i,

h = vertical distance ($E_2 - E_1$) between bases A_1 and A_2, and

H_T = height of truncated part of cone.

Figure 3.10 Conic Method for Reservoir Volumes

elevation given, even if the surface area is greater than zero at that point.

Reservoir outflow may be computed from a description of the outlet works (low-level outlet and spillway). There are two subroutines in HEC-1 which compute outflow rating curves. The first uses simple orifice and weir flow equations while the second computes outflow from specific energy or design graphs and corrects for tailwater submergence.

(ii) Orifice and Weir Flow. This option is often used in spillway adequacy investigations of dam safety, see Example Problems, Sections 12.7 and 12.8.

Flow through a low-level outlet is computed from

$$Q = COQL * CAREA * \sqrt{2g} * (WSEL - ELEVL)^{EXPL} \quad \quad (3.70)$$

where Q is the computed outflow, COQL is an orifice coefficient, CAREA is the cross-sectional area of conduit, WSEL is the water surface elevation, ELEVL is the elevation at center of low-level outlet, and EXPL is an exponent.

Flow over the spillway is computed from

$$Q = COQW * SPWID * (WSEL - CREL)^{EXPW} \quad \quad (3.71)$$

where Q is computed outflow, COQW is a weir coefficient, SPWID is the effective width of spillway, WSEL is the water surface elevation, CREL is the spillway crest elevation, and EXPW is an exponent.

If pumps or dam breaks are not being simulated, an outflow rating curve is computed for 20 elevations which span the range of elevations given for storage data. Storages are computed for those elevations. The routing is then accomplished by the modified Puls method using the derived storage-outflow relation. For level-pool reservoir routing with pumping or dam-break simulation, outflows are computed for the orifice and weir equations for each time interval.

(iii) Trapezoidal and Ogee Spillways Trapezoidal and ogee spillways (Corps of Engineers, 1965) may be simulated as shown in Fig. 3.11. The outflow rating curve is computed for 20 stages which span the range of given storage data. If there is a low-level outlet, the stages are evenly spaced between the low-level outlet and the maximum elevation, with the spillway crest located at the tenth elevation. In the absence of a low-level outlet, the second stage is at the spillway crest.

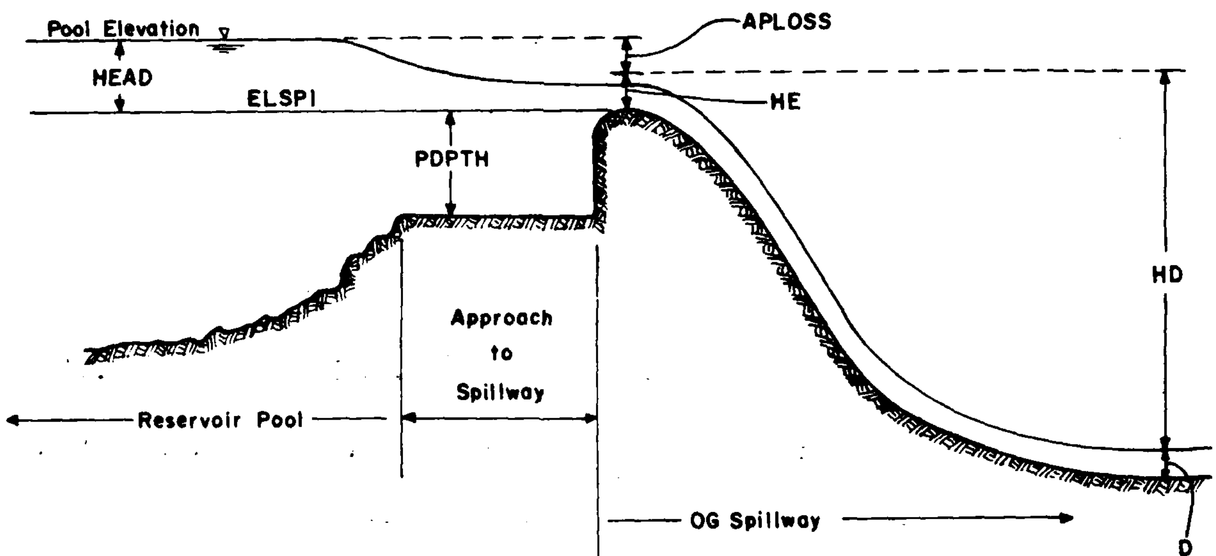


Figure 3.11 Ogee Spillway

The available energy head HE for flow over the spillway is computed as

$$HE = HEAD - [APLOSS * \frac{HEAD}{DESHD}] \quad (3.72)$$

where APLOSS is the approach loss at design head, HEAD is the water surface elevation minus spillway crest elevation, and DESHD is the design head. Design head is the difference between the normal maximum pool elevation and the spillway crest elevation.

Pier and abutment energy losses are computed by interpolation of the data shown in Table 3.7 based on HE/DESHD.

TABLE 3.7

Spillway Rating Coefficients

Specific Energy/ Design Head, HE/DESHD	Discharge Coefficient, CC	Approach Depth Adjustment Exponent, EC	Pier Contraction Coefficients, KP (3)	Abutment Contraction Coefficients, KA	
				Concrete (1)	Earth (2)
0	3.100	0	.123	-.008	.005
.1	3.205	.0059	.101	.023	.030
.2	3.320	.0090	.082	.045	.053
.3	3.415	.0114	.063	.062	.074
.4	3.520	.0135	.046	.074	.092
.5	3.617	.0155	.034	.081	.112
.6	3.710	.0174	.026	.089	.123
.7	3.800	.0191	.017	.093	.137
.8	3.880	.0208	.009	.097	.150
.9	3.943	.0224	.003	.099	.162
1.0	4.000	.0241	0	.100	.174
1.1	4.045	.0260	-.006	.100	.182
1.2	4.070	.0281	-.012	.100	.189
1.3	4.090	.0307	-.013	.100	.194

(1) Abutment contraction coefficients for adjacent concrete non overflow section using Waterways Experiment Station (W.E.S.). Hydraulic Design Chart III - 3/1 dated August 1960 and making KA = .1 and HE/HD = 1.0.

(2) Abutment contraction coefficients for adjacent embankment non-overflow section from W.E.S. Hydraulic Design Chart III - 3/2 Rev. January 1964.

(3) Pier contraction coefficients for type 3 piers are from Plate 7 of EM 1110-2-1603 (Corps of Engineers, 1965).

Effective length of the spillway crest ZEFFL is computed as

$$ZEFFL = SPWID - 2 * HE * (N * KP + KA) \qquad (3.73)$$

where SPWID is the spillway crest length, N is the number of piers, KP is the pier contraction coefficient, and KA is the abutment contraction coefficient.

For a trapezoidal spillway, outflow is computed from critical depth; submergence of the spillway and low-level outlet are not considered. The expression for velocity head HV at critical depth D is

$$HV = \frac{V^2}{2g} = \frac{A}{2T} \qquad (3.74)$$

where A is the cross-sectional area of flow, and T is the top width at critical depth. The velocity head is computed by trial and error until HE = HV + D ± .001.

For an ogee spillway the discharge coefficient COFQ is

$$COFQ = CC * \frac{PDPTH}{DESHD}^{EC} \qquad (3.75)$$

where PDPTH is the approach depth to spillway, and CC and EC are interpolated from Table 3.5 based on HE/DESHD. The spillway discharge QFREE assuming no tailwater submergence is

$$QFREE = COFQ * ZEFFL * HE^{1.5} \qquad (3.76)$$

Tailwater elevation may be computed from specific energy or by interpolation from a tailwater rating table. If tailwater elevation is computed from specific energy, the downstream specific energy is assumed to be

$$h_{et} = 0.9 * (HE + ELSPI / APEL) \qquad (3.77)$$

where h_{et} is the specific energy at toe of spillway, HE is the specific energy at crest of spillway, ELSPI is the spillway crest elevation, and APEL is the spillway apron (toe) elevation. Tailwater depth is then computed by trial and error until

$$(h_{et} - D) * D^2 = \frac{1}{2g} * (QASSM/APWID)^2 \pm 0.001 \qquad (3.78)$$

where D is the tailwater depth, APWID is the spillway apron width, and QASSM is the assumed spillway discharge corrected for tailwater submergence.

A submergence coefficient is interpolated from Table 3.8 using:

$$\frac{HD + D}{HE} = \frac{HE + ELSPI - APEL}{HE} \qquad (3.79)$$

and $$\frac{HD}{HE} = \frac{HE + ELSPI - APEL - D}{HE} \qquad (3.80)$$

The corrected flow is then

$$QCORR = QFREE - 0.01 * SUBQ * QFREE \qquad (3.81)$$

where QCORR is the spillway discharge corrected for tailwater submergence, and SUBQ is the submergence coefficient in percent. A new corrected discharge is assumed, and tailwater and submergence correction is computed until the change in QCORR is less than one percent.

TABLE 3.8

Submergence Coefficients

(HE + D)/HE																		HD/HE
1.07	1.10	1.15	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00	2.25	2.50	3.00	3.50	4.00	4.50	
PERCENT SUBMERGENCE																		
100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	.00
55.0	54.0	52.0	49.0	45.0	42.0	40.0	39.0	38.0	38.0	37.5	39.0	40.5	43.0	53.0	58.0	60.0	60.0	.05
36.5	35.0	33.0	31.0	27.0	23.5	21.0	19.0	18.5	18.0	18.785	18.88	19.52	21.15	26.25	29.0	31.0	32.0	.10
27.5	25.0	22.0	19.5	17.5	15.5	14.0	13.5	13.0	12.5	12.45	12.21	12.63	13.44	15.0	17.0	18.3	21.0	.15
21.0	18.0	17.0	15.0	13.0	11.3	9.8	9.0	8.5	8.2	8.0	8.0	8.19	8.56	9.41	11.2	12.0	13.0	.20
18.0	15.5	13.5	12.0	10.0	8.4	7.2	6.0	5.4	5.0	4.9	4.914	5.375	5.888	7.0	7.85	8.5	9.0	.25
16.0	13.5	12.0	10.5	8.0	6.1	4.3	3.7	3.3	3.1	3.00	3.02	3.333	3.82	5.123	6.08	6.66	7.0	.30
15.0	13.0	10.0	8.0	5.5	3.6	2.5	1.8	1.7	1.5	1.450	1.438	1.625	1.888	2.717	3.73	4.19	4.5	.40
15.0	13.0	10.0	8.0	5.5	3.3	2.0	1.2	.96	.87	.857	.842	.853	.933	1.62	2.24	2.70	2.9	.50
15.0	13.0	10.0	8.0	5.5	3.3	2.0	1.1	.90	.75	.525	.515	.562	.600	.860	1.27	1.65	1.8	.60
15.0	13.0	10.0	8.0	5.5	3.3	2.0	1.1	.80	.50	.475	.450	.390	.385	.470	.69	0.93	1.0	.70
15.0	13.0	10.0	8.0	5.5	3.3	2.0	1.1	.70	.49	.450	.415	.323	.250	.110	.20	0.34	0.3	.80
15.0	13.0	10.0	8.0	5.5	3.3	2.0	1.1	.70	.49	.445	.410	.310	.220	.030	0.0	0.0	0.0	.85
15.0	13.0	10.0	8.0	5.5	3.3	2.0	1.1	.70	.49	.445	.400	.300	.200	0.0	0.0	0.0	0.0	.90

Free discharge from the low-level outlet is

$$CQFREE = COQL * CAREA * (2g)^{.5} * (EL - ELEVL)^{.5} \qquad (3.82)$$

where CQFREE is the conduit discharge for unsubmerged outlet, COQL is the discharge coefficient, CAREA is the conduit cross-sectional area, EL is the reservoir water surface elevation, and ELEVL is the center elevation of the conduit outlet. Tailwater elevation is interpolated from the tailwater rating table and the corrected conduit flow is computed from

$$CQCOND = COQL - CAREA * (2g)^{.5} * (EL - ZXTWEL)^{.5} \qquad (3.83)$$

where CQCOND is the conduit discharge corrected for submergence, and ZXTWEL is the conduit tailwater elevation. ZXTWEL and CQCOND are recomputed until the change in CQCOND is less than 0.1 percent.

3.6.6 Average-Lag

The Straddle-Stagger (Progressive Average-Lag) Method (Corps of Engineers, 1960) routes by lagging flows LAG time intervals then averaging NSTDL flows.

$$Q(I) = QIN(1) \qquad I \leq LAG \quad \ldots\ldots\ldots\ldots \quad (3.84)$$

$$Q(I) = QIN(I-LAG) \qquad I > LAG \quad \ldots\ldots\ldots\ldots \quad (3.85)$$

$$QOUT(I) = \sum_{L = I - \frac{NSTDL}{2}}^{I + \frac{NSTDL}{2}} \frac{Q(L)}{NSTDL} \quad \ldots\ldots\ldots\ldots \quad (3.86)$$

where LAG is the number of time intervals to lag inflow hydrograph, NSTDL is the number of ordinates to average to compute the outflow, QIN is the inflow hydrograph ordinate, Q is the lagged hydrograph ordinate, and QOUT is the outflow hydrograph ordinate.

The Tatum (Successive Average-Lag) Method (Corps of Engineers, 1960) computes the outflow hydrograph as an average of the current and previous inflow ordinates.

$$Q(I) = (QIN(I) + QIN(I-1))/2 \quad \ldots\ldots\ldots\ldots \quad (3.87)$$

where QIN is the inflow hydrograph ordinate, and Q is the routed hydrograph ordinate. This averaging is repeated NSTPS times to produce the outflow hydrograph.

3.6.7 Kinematic Wave

Kinematic wave routing was described in detail in section 3.4. The channel routing computation can be utilized independently of the other elements of the subbasin runoff. In this case, an upstream inflow is routed through a reach (independent of lateral inflows) using the previously described numerical methods. The kinematic wave method in HEC-1 does not allow for explicit separation of main channel and overbank areas. The cross-sectional geometry is limited to the shapes shown in Fig. 3.6. Theoretically a flood wave routed by the kinematic wave technique through these channel sections is translated, but does not attenuate (although a degree of attenuation is introduced by the finite difference solution). Consequently, the kinematic wave routing technique is most appropriate in channels where flood wave attenuation is not significant, as is typically the case in urban areas. Otherwise, flood wave attenuation can be modeled empirically by using the storage routing methods, modified Puls or working R and D.

3.7 Diversions

Flow diversions may be simulated by linear interpolation from input tables of inflow versus diverted flow. The inflow DINFLO(I) corresponds to an amount of flow DIVFLO(I) to be diverted to a designated point in or out of the river basin. The diverted hydrograph can be retrieved and routed and combined with other flows anywhere in the system network downstream of the point of diversion or to a parallel drainage system. A diversion is illustrated in the first example problem, Section 12.1.

3.8 Pumping Plants

Pumping plants may be simulated for interior drainage problems where runoff ponds in low areas or behind levees, flood walls, etc. Multiple pumps may be used, each with different on and off elevations. Pumps are simulated using the level-pool reservoir routing option described in section 3.6.5. The program checks the reservoir stage at the beginning of each time period. If the stage exceeds the "pump-on" elevation the pump is turned on and the pump output is included as an additional outflow term in the routing equation. When the reservoir stage drops below a "pump-off" elevation, the pump is turned off. Several pumps with different on and off elevations may be used.

Each pump discharges at a constant rate. It is either on or off. There is no variation of discharge with head. The average discharge for a time period is set to the pump capacity, so it is assumed that the pump turned on immediately after the end of the previous period.

Pumped flow may be retrieved at any point downstream of the pump location in the same manner as a diverted hydrograph.

Section 4

PARAMETER CALIBRATION

Calibration and verification are essential parts of the modeling process. Rough estimates for the parameters in the HEC-1 model can be obtained from the description of the methods in Section 3; however, the model should be calibrated to observed flood data whenever possible. HEC-1 provides a powerful optimization technique for the estimation of some of the parameters when gaged precipitation and runoff data are available. By using this technique and regionalizing the results, rainfall-runoff parameters for ungaged areas can also be estimated (HEC, 1981). Examples of the use of the optimization option are given in Tests 4 and 5. A summary of the HEC's experience with automatic calibration of rainfall-runoff models is given by Ford et al. (1980).

4.1 Unit Hydrograph and Loss Rate Parameters

4.1.1 Optimization Methodology

The parameter calibration option has the capability to automatically determine a set of unit hydrograph and loss rate parameters that "best" reconstitute an observed runoff hydrograph for a subbasin. The data which must be provided to the model are: basin average precipitation; basin area; starting flow and base flow parameters STRTQ, QRCSN and RTIOR; and the outflow hydrograph. Means for estimating these data and their use in the model are described in Section 3. Unit hydrograph and loss rate parameters can be determined individually or in combination. Parameters that are not to be determined from the optimization process must be estimated and provided to the model. Initial estimates of the parameters to be determined can be input by the user or chosen by the program's optimization procedure.

The runoff parameters that can be determined in the calibration are the unit hydrograph parameters of the Snyder, Clark and SCS methods and the loss rate parameters of the exponential, Holtan, SCS, and initial/constant methods. The melt rate and threshold melt temperature can also be optimized for snow hydrology studies. If the Snyder method is employed, the Clark coefficients will be determined and converted to the Snyder parameters.

The "best" reconstitution is considered to be that which minimizes an objective function, STDER. The objective function is the square root of the weighted squared difference between the observed hydrograph and the computed hydrograph. Presumably, this difference will be a minimum for the optimal parameter estimates. STDER is depicted in Fig. 4.1 and computed as follows.

$$STDER = \left[\sum_{i=1}^{n} (QOBS_i - QCOMP_i)^2 * WT_i/n \right]^{1/2} \quad (4.1)$$

where $QCOMP_i$ is the runoff hydrograph ordinate for time period i computed by HEC-1, $QOBS_i$ is the observed runoff hydrograph ordinate i, n is the total number of hydrograph ordinates, and WT_i is the weight for the hydrograph ordinate i computed from the following equation.

$$WT_i = (QOBS_i + QAVE)/(2 * QAVE) \qquad (4.2)$$

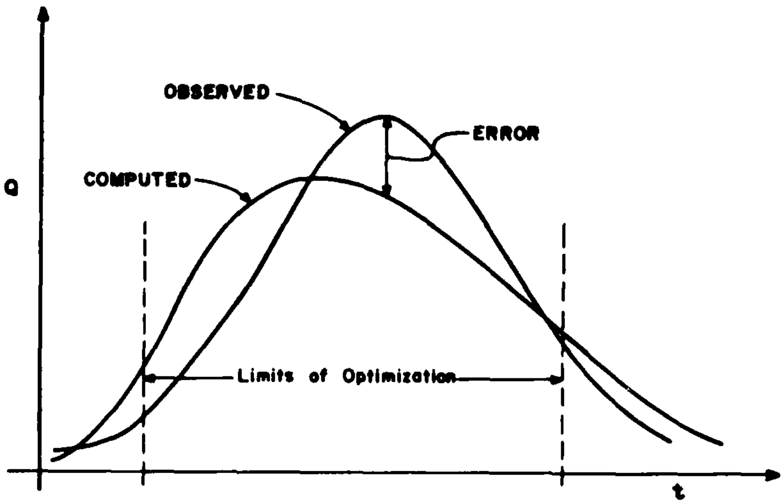


Figure 4.1 Error Calculation for Hydrologic Optimization

where QAVE is the average observed discharge. This weighting function emphasizes accurate reproduction of peak flows rather than low flows by biasing the objective function. Any errors for computed discharges that exceed the average discharge will be weighted more heavily, and hence the optimization scheme should focus on reduction of these errors.

The minimum of the objective function is found by employing the univariate search technique (Ford et al., 1980). The univariate search method computes values of the objective function for various values of the optimization parameters. The values of the parameters are systematically altered until STDER is minimized.

The range of feasible values of the parameters is bounded because of physical limitations on the values that the various unit hydrograph, loss rate, and snowmelt parameters may have, and also because of numerical limitations imposed by the mathematical functions. In addition to bounds on the maximum and minimum values of certain parameters, the interaction of some parameters is also restricted because of physical or numerical limitations. These constraints are summarized in Table 4.1. The constraints shown here are limited to those imposed explicitly by the program. Additional constraints may be appropriate in certain circumstances; however, these must be imposed externally to the program when the user must decide whether to accept, modify, or reject a given parameter set, based on engineering judgment.

The optimization procedure does not guarantee that a "global" optimum (or a global minimum of the objective function) will be found for the runoff parameter; a local minimum of the objective function might be found by the procedure. To help assess the results of the optimization, HEC-1 provides graphical and statistical comparisons of the observed and computed hydrographs. From this, the user can then judge the accuracy of the optimization result. It is possible that the computed hydrograph will not meet with the criteria

TABLE 4.1

Constraints on Unit Graph and Loss Rate Parameters

Clark Unit Graph Parameters:

$TC \geq 1.03\Delta t$
$R \geq .52$
Δt = Computation Interval

Loss Rate Parameters

Exponential	SCS
ERAIN ≤ 1.0	0 ≤ CN ≤ 100
RTIOL ≥ 1.0	

Snowmelt

RTIOK ≥ 1.0
- 1.11°C ≤ FRZTP ≤ 3.33°C

Uniform	Holtan
STRTL ≥ 0	FC ≥ 0
CNSTL ≥ 0	GIA ≥ 1.0
	BEXP ≥ 0

established by the user. An improvement in the reconstitution might be affected by specifying different starting values for the parameters to be optimized. This can be accomplished by varying the starting values in a number of optimization runs in order to better sample the objective function and find a global optimum.

4.1.2 Analysis of Optimization Results

The computed output resulting from an optimization run describes some of the initial and intermediate computations performed to obtain optimal precipitation-runoff parameters. It is instructive to relate the optimization algorithm to the example output shown in Table 4.2 (see Section 12.4, for the complete example application of this parameter calibration). The algorithm proceeds as follows:

1. Initial values are assigned for all parameters. These values may be assigned by the user or program-assigned default values, Table 4.3, may be used. In the example output, four parameters are optimized: unit hydrograph parameters TC and R, and exponential loss infiltration parameters STRKR and DLTKR (ERAIN and RTIOL are constant). In this case, initial values were chosen by the user, STRKR = .20, etc. Note that the unit hydrograph parameters TC, R are displayed as the sum (TC+R) and ratio R/(TC+R) which are adjusted by the program during the optimization process.

TABLE 4.2

HEC-1 Unit Hydrograph and Loss Rate Optimization Output

INITIAL ESTIMATES FOR OPTIMIZATION VARIABLES

TC+R	R/(TC+R)	STRKR	DLTKR	RTIOL	ERAIN
6.16	0.50	0.20	0.50	1.00	0.50

INTERMEDIATE VALUES OF OPTIMIZATION VARIABLES
(*INDICATES CHANGE FROM PREVIOUS VALUE)
(+INDICATES VARIABLE WAS NOT CHANGED)

OBJECTIVE FUNCTION	TC+R	R/(TC+R)	STRKR	DLTKR	RTIOL	ERAIN
VOL. ADJ.	6.156	0.500	0.448*	1.119*	1.000	0.500
3.4957E+02	6.895*	0.500	0.448	1.119	1.000	0.500
3.4713E+02	6.895	0.522*	0.448	1.119	1.000	0.500
3.4450E+02	6.895	0.522	0.437*	1.119	1.000	0.500
3.3939E+02	6.895	0.522	0.437	0.984*	1.000	0.500
3.3928E+02	6.920*	0.522	0.437	0.984	1.000	0.500
3.3592E+02	6.920	0.547*	0.437	0.984	1.000	0.500
3.3518E+02	6.920	0.547	0.443*	0.984	1.000	0.500
3.2855E+02	6.920	0.547	0.443	0.814*	1.000	0.500
3.2712E+02	7.016*	0.547	0.443	0.814	1.000	0.500
3.2702E+02	7.016	0.551*	0.443	0.814	1.000	0.500
3.2473E+02	7.016	0.551	0.452*	0.814	1.000	0.500
3.1128E+02	7.016	0.551	0.452	0.542*	1.000	0.500
3.1012E+02	7.101*	0.551	0.452	0.542	1.000	0.500
3.1012E+02	7.101	0.551*	0.452	0.542	1.000	0.500
3.0577E+02	7.101	0.551	0.465*	0.542	1.000	0.500
2.9360E+02	7.101	0.551	0.465	0.362*	1.000	0.500
2.8841E+02	7.101	0.551	0.465	0.241*	1.000	0.500
2.8635E+02	7.101	0.551	0.465	0.161*	1.000	0.500
2.8187E+02	7.101	0.551	0.478*	0.161	1.000	0.500
2.8183E+02	7.101	0.551	0.477*	0.161	1.000	0.500
2.8134E+02	7.046*	0.551	0.477	0.161	1.000	0.500
VOL. ADJ.	7.046	0.551	0.487*	0.164*	1.000	0.500

OPTIMIZATION RESULTS

CLARK UNITGRAPH PARAMETERS
TC 3.16
R 3.88

SNYDER STANDARD UNITGRAPH PARAMETERS
TP 2.99
CP 0.52

LAG FROM CENTER OF MASS OF EXCESS
TO CENTER OF MASS OF UNITGRAPH 5.36

UNITGRAPH PEAK 4332.
TIME OF PEAK 3.00

EXPONENTIAL LOSS RATE PARAMETERS
STRKR 0.49
DLTKR 0.16
RTIOL 1.00
ERAIN 0.50

EQUIVALENT UNIFORM LOSS RATE 0.444

COMPARISON OF COMPUTED AND OBSERVED HYDROGRAPHS

STATISTICS BASED ON OPTIMIZATION REGION
(ORDINATES 1 THROUGH 61)

	SUM OF FLOWS	EQUIV DEPTH	MEAN FLOW	TIME TO CENTER OF MASS	LAG C.M. TO C.M.	PEAK FLOW	TIME OF PEAK
PRECIPITATION EXCESS		0.937		4.13			
COMPUTED HYDROGRAPH	84787.	0.867	1390.	8.51	4.38	3621.	7.25
OBSERVED HYDROGRAPH	84787.	0.867	1390.	8.16	4.03	3540.	7.25
DIFFERENCE	0.	0.000	0.	0.35	0.35	81.	0.00
PERCENT DIFFERENCE	0.00				8.68	2.28	

STANDARD ERROR 270. AVERAGE ABSOLUTE ERROR 208.
OBJECTIVE FUNCTION 284. AVERAGE PERCENT ABSOLUTE ERROR 27.27

TABLE 4.3

HEC-1 Default Initial Estimates for Unit Hydrograph and Loss Rate Parameters

	Parameter	Initial Value
Unit Graph		
Clark	TC+R	$(TAREA)^{1/2}$
	R/(TC+R)	0.5
Loss Rates		
Exponential	COEF	0.07
	STRKR	0.2
	STRKS	0.2
	RTIOK	2.0
	ERAIN	0.5
	FRZTP	0.0
	DLTKR	0.5
	RTIOL	2.0
Initial & Uniform	STRTL	1.0
	CNSTL	0.1
Holtan	FC	0.01
	GIA	0.5
	SA	1.0
	BEXP	1.4
Curve Number	STRTL	1.08
	CRVNBR	65

TAREA = Drainage area, in square miles

2. The response of the river basin as simulated with the initial parameter estimates and the initial value of the objective function is calculated. The volume of the simulated hydrograph is adjusted to within one percent of the observed hydrograph if the option to adjust infiltration parameters has been selected. This is demonstrated by the asterisked (*) values of STRKR (= .448*) and DLTKR (= 1.119*) in the example output. The asterisk (*) denotes which variable was changed and its "optimum" value. The value of the objective function at this point equals 3.4957×10^2.

3. In the order shown in Tables 4.2 and 4.3, each parameter to be estimated is decreased by one percent and then by two percent, the system response is evaluated, and the objective function calculated for each change, respectively. This gives three separate system evaluations at

equally-spaced values of the paramenter with all other parameters held constant. The "best" value of the parameter is then estimated using Newton's method. This is demonstrated in the example by the asterisked values of each of the optimization variables (e.g., TC+R = 6.895*, R/(TC+R) = .522*, etc.). A parameter which does not improve the objective function under this procedure is maintained at its original value. This is indicated by a plus (+) in place of an asterisk (*) in the computed output; this circumstance does not occur in the example.

4. Step 3 is repeated four times. This results in adjustments to all four of the optimization parameters, four separate times. In this example, the resulting final values of the variables are: TC+R = 7.101*, R/(TC+R) = .551*, STRKR = .465*, DLTKR = .362*.

5. Step 3 is then repeated for the parameter that most improved the value of the objective function in its last change. This is continued until no single change in any parameter yields a reduction of the objective function of more than one percent. In the example this leads to changes to STRKR and DLTKR.

6. One more complete search of all parameters is made. This leads to a change in TC+R = 7.046*, leading to a final minimum objective function value of 2.8134×10^2.

7. A final adustment ot the infiltration parameters is made to adjust the computed hydrograph volume to within one percent of the observed hydrograph volume. Note that this leads to a small change in the objective function from optimal.

The final results of the optimization are also summarized in Table 4.2, TC = 3.16, R = 3.88, etc. Additional information is displayed comparing computed and observed hydrograph statistics, which are defined as follows:

Standard Error =	the root mean squared sum of the difference between observed and computed hydrographs.
Objective Function =	the weighted root mean squared sum of the difference between observed and computed hydrographs.
Average Absolute Error =	the average of the absolute value of the differences between observed and computed hydrographs.
Average Percent Absolute Error =	the average of absolute value of percent difference between computed and observed hydrograph ordinates.

The definition of the remaining statistics in Table 4.2 is self evident. As can be seen from the final statistics, the optimization results are very acceptable in this case.

4.1.3 Application of the Calibration Capability (from Ford et al., 1980)

Due to the varying quantity and form of data available for precipitation-runoff analysis, the exact sequence of steps in application of the automatic calibration capability of HEC-1 varies from study to study. An often-used strategy employs the following steps when using the complete exponential loss rate equation:

1. For each storm selected, determine the base flow and recession parameters that are event dependent. These are not included in the set of parameters that can be estimated automatically. These parameters are the recession flow for antecedent runoff (STRTQ), the discharge at which recession flow begins (QRCSN), and the recession coefficient that is the ratio of flow at some time to the flow one hour later (RTIOR).

2. For each storm at each gage, determine the optimal estimates of all unknown unit hydrograph and loss rate parameters using automatic calibration.

3. If ERAIN is to be estimated, select a regional value of ERAIN, based on analysis of the results of Step 2 for all storms for the representative gages.

4. Using the optimization scheme, estimate the unknown parameters with ERAIN now fixed at the selected value. Select an appropriate regional value of RTIOL if RTIOL is unknown. If the temporal and spatial distribution of precipitation is not well defined, an initial loss, followed by a uniform loss rate may be appropriate. (In this case, ERAIN = 0 and RTIOL = 1; or the initial and uniform loss rate parameters may be used.) If these values are used, as they often are in studies accomplished at HEC, Steps 2, 3, and 4 are omitted.

5. With ERAIN and RTIOL fixed, estimate the remaining unknown parameters using the optimization scheme. Select a value of STRKR for each storm being used for calibration. If parameter values for adjacent basins have been determined, check the selected value for regional consistency.

6. With ERAIN, RTIOL, and STRKR fixed, use the parameter estimation algorithm to compute all remaining unknown parameters. DLTKR can be generalized and fixed if desired at this point, although this parameter is considered to be relatively event-dependent.
7. Using the calibration capability of HEC-1, determine values of TC+R and R/(TC+R). Select appropriate values of TC+R for each gage. In order to determine TC and R, an average value of R/(TC+R) is typically selected for the region.

8. Once all parameters have been selected, the values should be verified by simulating the response of the gaged basins to other events not included in the calibration process.

4.2 Routing Parameters

HEC-1 may also be used to automatically derive routing criteria for certain hydrologic routing techniques. Criteria can be derived for the Tatum, straddle-stagger and Muskingum routing methods only.

Inputs to this method are observed inflow and outflow hydrographs and a pattern local inflow hydrograph for the river reach. The pattern hydrograph is used to compensate for the difference between observed inflow and outflow hydrographs. The assumed pattern hydrograph can have a significant effect on the optimized routing criteria.

Observed hydrographs are reconstituted to minimize the squared sum of the deviations between the observed hydrograph and the reconstituted hydrograph. The procedure used is essentially the same as in the unit hydrograph and loss rate parameters case.

Section 5

MULTIPLAN-MULTIFLOOD ANALYSIS

The multiplan-multiflood simulation option allows a user to investigate a series of floods for a number of different characterizations (plans) of the watershed in a single computer run. The advantage in this option is that multiple storms and flood control projects can be simulated efficiently and the results can be compared with a minimum of effort by the user.

The multiflood simulation allows the user to analyze several different floods in the same computer run. The multifloods are computed as ratios of a base event (e.g., .5, 1.0, 1.5, etc.) which may be either precipitation or runoff. The ratio hydrographs are computed for every component of the river basin. In the case of rainfall, each ordinate of the input base-event hyetograph is multiplied by a ratio and a stream network rainfall-runoff simulation carried out for each ratio. This is done for every ratio of the base event. In the case of runoff ratios, the ratios are applied to the computed or direct-input hydrograph and no rainfall-runoff calculations are made for individual ratios.

The multiplan option allows a user to conveniently modify a basin model to reflect desired flood control projects and changes in the basin's runoff response characteristics. This is useful when, for example, a comparison of flood control options or the effects of urbanization are being analyzed. The user designates PLAN 1 as the existing river basin model, and then modifies the existing plan data to reflect basin changes (such as reservoirs, channel improvements, or changes in land use) in PLANS 2, 3, etc.

If the basin's rainfall-runoff response characteristics are modified in one of the plans, then precipitation ratios and not runoff ratios must be used. Otherwise, ratios of hydrographs should be used. The program performs a stream network analysis, or multiflood analysis, for each plan, Fig. 5.1. The results of the analysis provide flood hydrograph data for each plan and each ratio of the base event. The summary of the results at the end of the program output provides the user with a convenient method for comparing the differences between plans and the differences between different flood ratios for the same plan.

The input conventions for the use of this option are described in the input description. Section 10 gives specific examples on the use of data set update techniques for the multiplan option. Example problems 9 and 10, Section 12, illustrate the use of this HEC-1 option.

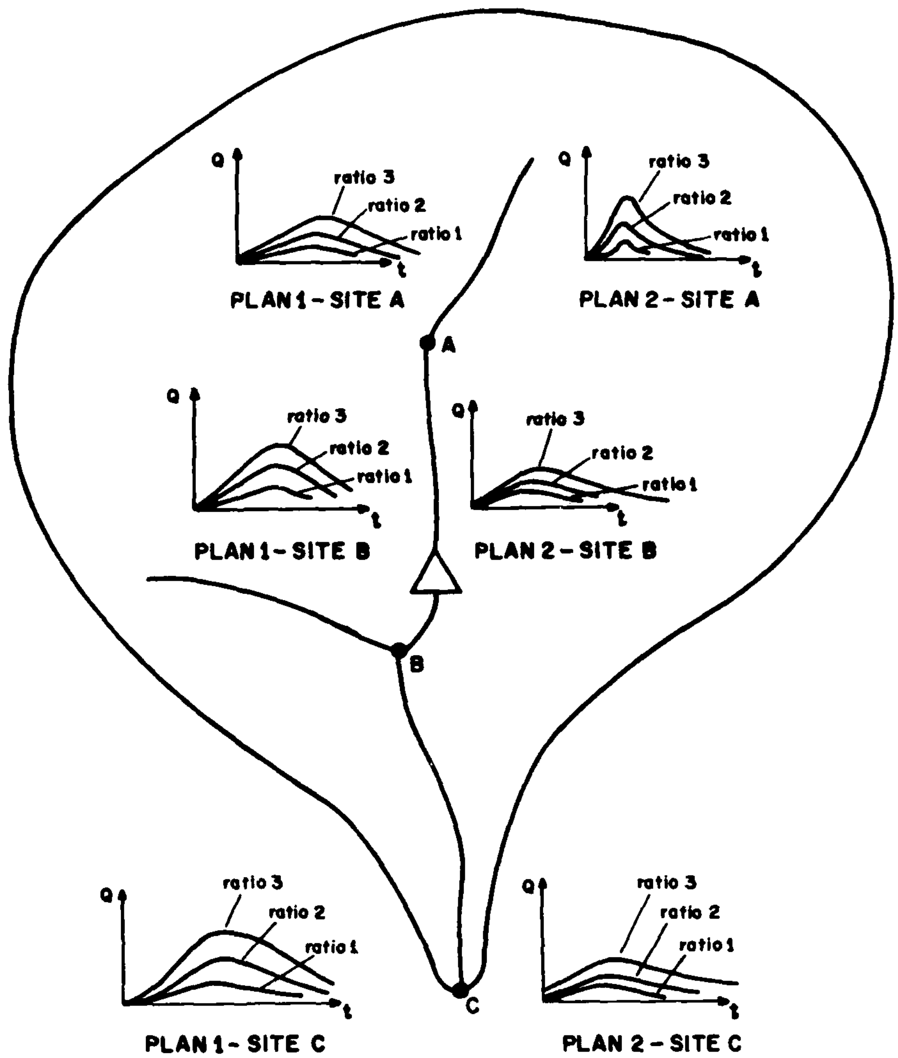


Figure 5.1 Multiflood and Multiplan Hydrographs

Section 6

DAM SAFETY ANALYSIS

The dam safety analysis capability was added to the HEC-1 model to assist in studies required for the National Non-Federal Dam Safety Inspection Program. This option uses simplified hydraulic techniques to estimate the potential for and consequences of dam overtopping or structural failures on downstream areas in a river basin. Subsequent paragraphs describe dam overtopping analysis, dam-break model formulation, the methodology used to simulate dam failures, and the limitations of the method. An example of dam overtopping analysis with HEC-1 is given in example problem 7, Section 12. Example problem 8 simulates dam failures.

6.1 Model Formulation

The reservoir component (described in Section 2) is employed in a stream network model to simulate a dam failure. In this case, the procedure for developing the stream network model is essentially the same as in precipitation-runoff analysis. However, the model emphasis is likely to be different. Most of the modeling effort is spent in characterizing the inflows to the dam under investigation, specifying the characteristics of the dam failure, and routing the dam failure hydrograph to a desired location in the river basin. Lateral inflows to the stream below the dam are usually small compared to the flows resulting from the dam failure and thus of less importance.

6.2 Dam Safety Analysis Methodology

The dam safety simulation differs from the previously described reservoir routing in that the elevation-outflow relation is computed by determining the flow over the top of the dam (dam overtopping) and/or through the dam breach (dam break) as well as through other reservoir outlet works. The elevation-outflow characteristics are then combined with the level-pool storage routing (see Section 3) to simulate a dam failure.

6.2.1 Dam Overtopping (Level Crest)

The discharge over the top of the dam is computed by the weir flow equation

$$Q_{od} = COQW * DAMWID * h_1^{EXPD} \quad \ldots\ldots\ldots\ldots \quad (6.1)$$

Where h_1 is the depth of water over the top of dam, COQW is the weir discharge coefficient, DAMWID is the effective width of top-of-dam weir overflow, and EXPD is the exponent of head. These variables are illustrated in Fig. 6.1. The top-of-dam weir crest length, DAMWID, must not include the spillway. Spillway discharges continue to be computed by the spillway equation (see Section 3) even as the water surface elevation exceeds the top of the dam. The weir flow for dam overtopping is added to the spillway and low level-outlet discharges.

6.2.2 Dam Overtopping (Non-Level Crest)

Critical flow over a non-level dam crest is computed from crest length

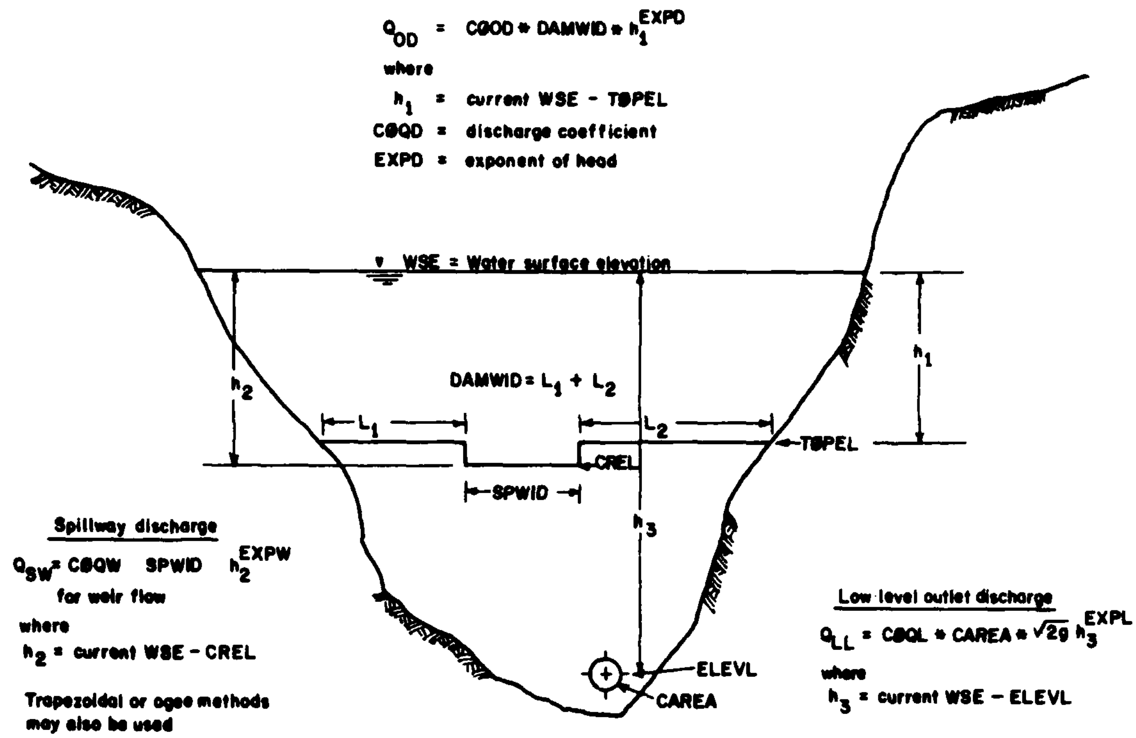


Figure 6.1 Spillway Adequacy and Dam Overtopping Variables in HEC-1

and elevation data. A dam crest such as shown in Fig. 6.2a is transformed (for use by the program) to an equivalent section shown in Fig. 6.2b. This crest is divided into rectangular and trapezoidal sections and the flow is computed through each section.

For a rectangular section (Fig. 6.2c), critical depth, d_c, is

$$d_c = 2/3 * H_m \quad \text{(6.2)}$$

where H_m is the available specific energy which is taken to be the depth of the water above the bottom of the section.

For a trapezoidal section (Fig. 6.2d), the critical depth is

$$d_c = 2/3 * (H_m + 1/4 * \Delta y) \quad \text{(6.3)}$$

where Δy is the change in elevation across the section (ELVW(I+1) - ELVW(I)). Flow area, A, is computed as $T{*}d_c$ for rectangular sections and as $1/2\ T(2d_c - \Delta y)$ for trapezoidal sections, where T is top width (WIDTH(I+1) - WIDTH(I)).

The flow through the section is computed from

$$Q = \frac{(A^3 * g)^{1/2}}{T} \quad \text{(6.4)}$$

where g is acceleration due to gravity. The total flow over the top of dam is

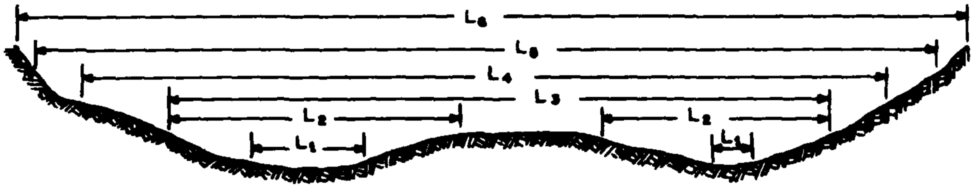


Figure 6.2a Non-Level Dam Crest

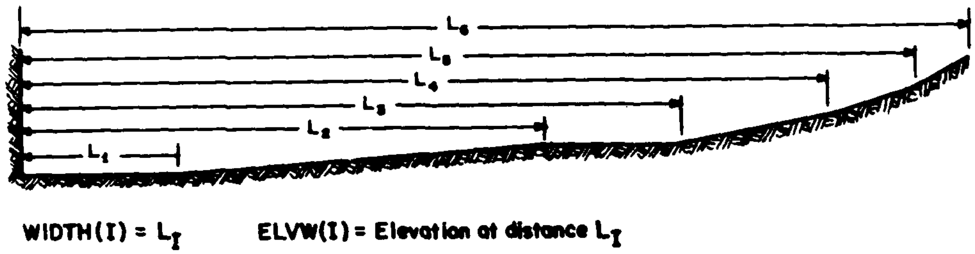


Figure 6.2b Equivalent Sections

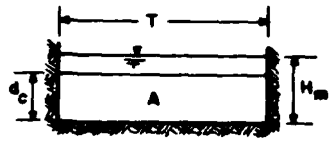


Figure 6.2c Rectangular Section

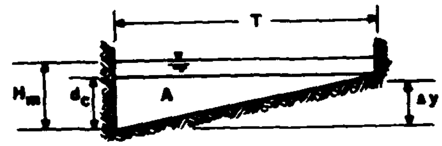


Figure 6.2d Trapezoidal Section

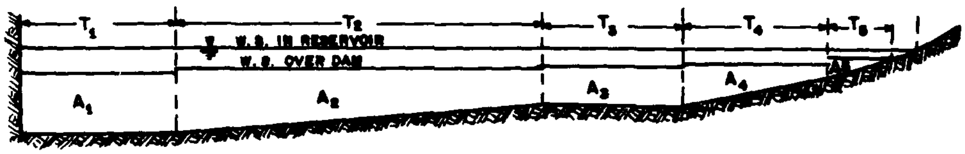


Figure 6.2e Flow Computations for Sections

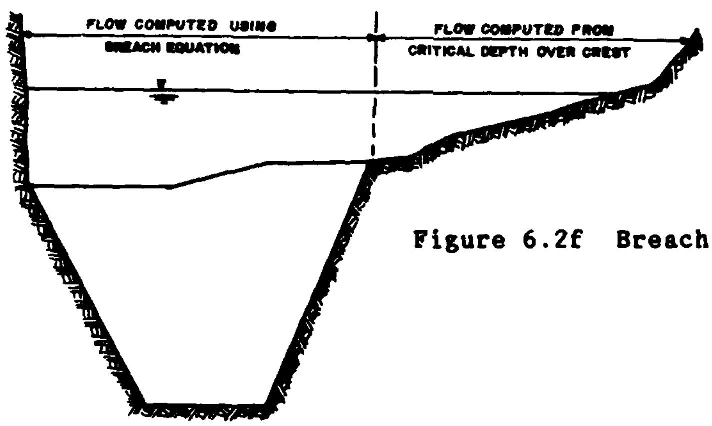


Figure 6.2f Breach Analysis

Figure 6.2 Non-Level Dam Crest

then the sum of flows through each section (Fig. 6.2e). When a dam is being breached the width of the breach is subtracted from the crest length beginning at the lowest portion of the dam (Fig. 6.2f).

6.2.3 Dam Breaks

Dam breaks are simulated using the methodology proposed by Fread (National Weather Service, 1979) with the exception that no reduction in the breach discharge is made for submergence caused by downstream flow controls. Structural failures are modeled by assuming certain geometrical shapes for the dam breach. The variables used in the analysis, as well as the dam breach shapes available in the program, are shown in Fig. 6.3.

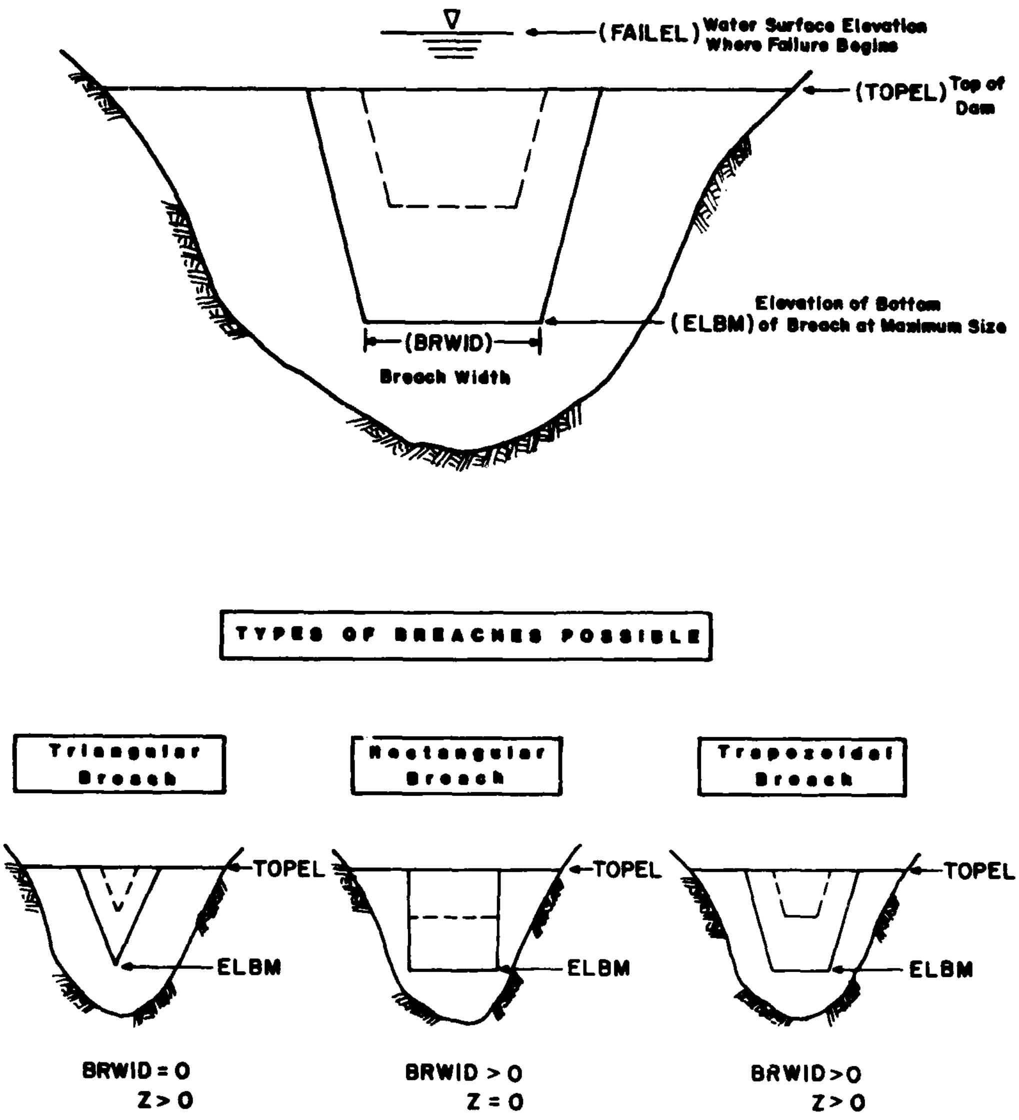


Figure 6.3 HEC-1 Dam-Breach Parameters

Flow Q through a dam breach is computed as

$$Q = C1 * BRWID * (WSEL - BREL)^{1.5} + C2 * (WSEL - BREL)^{2.5} \quad . . . . .(6.5)$$

where WSEL is the reservoir water surface elevation, BREL is the elevation at base of breach, BRWID is the breach width, C1 is the broad-crested rectangular weir coefficient (3.08), and C2 is the V-notch weir coefficient (2.44Z) with side slope Z, horizontal to vertical.

The breach is initiated when the water surface in the reservoir reaches a given elevation (FAILEL). The breach begins at the top of the dam and expands linearly to the bottom elevation of the breach (ELBM) and to its full width in a given time (TFAIL). Note that the top-of-dam elevation must be specified to fully determine the breach geometry.

The failure duration (TFAIL) is divided into 50 computation intervals. These short intervals are used to minimize routing errors during the period of rapidly changing flows when the breach is forming. Downstream routing methods in HEC-1 use a time interval which is usually greater than the time interval used during breach development. Errors may be introduced into the downstream routing of the failure hydrograph if the HEC-1 standard time is too large compared to the duration of the breach. That is, if the HEC-1 time interval is larger than the breach duration, the entire breach hydrograph may occur within a single HEC-1 time interval. Because HEC-1 computes and displays only end-of-period discharges, the peaks occurring within a time interval are not known.

This potential problem of loss of volume and peak is apparent in the program output which shows the short interal failure hydrograph and the location of the regular HEC-1 time intervals. It is important to be sure that the breach hydrograph is adequately described by the HEC-1 end-of-period intervals or else the downstream routings will be erroneous.

6.3 Limitations

The dam-break simulation assumes that the dam-break hydrograph will not be affected by tailwater constraints i.e., no correction for submergence of the weir outflows is made. Also, the reservoir pool remains level. Also, HEC-1 hydrologic routing methods are assumed appropriate for the dynamic flood wave. Under the appropriate conditions, these assumptions will be approximately true and the analysis will give answers which are sufficiently accurate for the purpose of the study. However, care should be taken in interpreting the results of the dam-break analysis. If a higher order of accuracy is needed, then an unsteady flow model, such as the National Weather Service's DAMBRK (1979), should be used.

Section 7

PRECIPITATION
DEPTH-AREA RELATIONSHIP SIMULATION

One of the more difficult problems of hydrologic evaluation is that of determining the effect that a project on a remote tributary has on floods at a downstream location. A similar problem is that of deriving flood hydrographs, such as for standard project floods or 100-year exceedence interval floods, at a series of locations throughout a complex river basin. Both problems could require the successive evaluation of many storm centerings upstream of each location of interest.

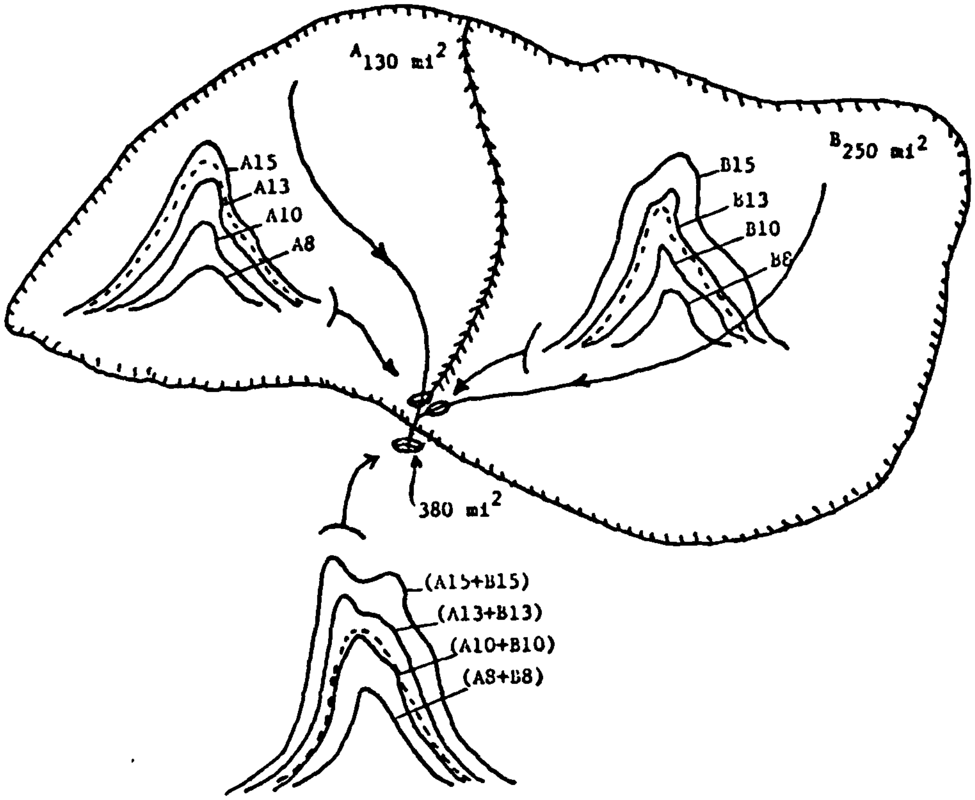
Precipitation must be distributed throughout the basin in such a manner that the runoff generated by each subbasin tributary to the location of interest is consistent with the runoff contributed by the other subbasins, including the subbasin on which a project may be located. Consistency between successive downstream hydrographs can be maintained by generating each from rainfall quantities that correspond to a specific subbasin size and a specific precipitation depth-drainage area relationship. The precipitation depth-drainage area relationship should correspond to the desired runoff event to be evaluated (e.g. standard project flood).

7.1 General Concept

The average depth of precipitation over a tributary area for a storm generally decreases with the size of contributing area. Thus, it is ordinarily necessary to recompute a decreasingly consistent flood quantity contributed by each subbasin to successive downstream points. In order to avoid the proliferation of hydrographs that would ensue, the depth area calculation of HEC-1 makes use of a number of hydrographs (termed "index hydrographs") computed from a range of precipitation depths throughout the river basin complex. The index hydrographs are computed from a set of precipitation depth-drainage area (index area) values, a time distribution of rainfall pattern, and appropriate loss rate and unit hydrograph parameters. Fig. 7.1 is a schematic of a basin for which consistent hydrographs are desired for subbasins A, B, and the stream confluence of A and B. The precipitation depth-drainage area relationship is tabulated on the figure.

The computation procedure is identical for subbasins A and B. Four index runoff hydrographs for each subbasin are computed for precipitation quantities of 15, 13, 10 and 8 inches (for the subbasin's tributary area) and are labeled A15, A13, etc., and B15, B13, etc. The consistent hydrograph is that which corresponds to the appropriate precipitation depth for the subbasin's drainage area. The consistent hydrographs are determined by interpolating between the two index hydrographs bracketing the subbasin's drainage area and are shown dashed on the figure.

The consistent hydrograph for the confluence of A and B must be representative of runoff contributed by both upstream tributary areas A and B. The sum of the two consistent hydrographs would not be representative of both areas combined because the runoff volume would not be consistent with the precipitation depth-drainage area relationship. As shown on the figure, the index hydrographs for the confluence are the sum of the index hydrographs



Precipitation Depth-Drainage Area Function

Area - mi^2	Precip.- In.
100	15
200	13
500	10
1000	8

Legend

- ⊖ Desired location for consistent hydrograph
- Stream channel
- Drainage boundary
- $^A130$ mi^2 etc. - Subarea label and drainage area

Figure 7.1 Two-Subbasin Precipitation Depth-Area Simulation from subbasins A and B and are labeled (A15 + B15), (A13 + B13), etc., to so indicate. The consistent hydrograph for the confluence of A and B is then determined by interpolating between the two combined index hydrographs that bracket the sum of drainage areas A and B, as shown on the Fig.7.1.

The depth-area procedure of generating index hydrographs, interpolating, adding them to other index hydrographs and interpolating, routing and interpolating, is repeated throughout a river basin for as many locations as are desired. Fig. 7.2 shows the precipitation depth-area calculation procedure for all locations in a complex river basin.

7.2 Interpolation Formula

An interpolation formula is applied to discharge ordinates for the two index hydrographs corresponding to areas which bracket the tributary drainage area. The interpolation is based on the index area and the actual tributary area.

The formula may be deduced from the following:

(1) The runoff transformation used (unit hydrograph) is a linear process.

(2) Precipitation depth varies approximately in proportion to the logarithm of the index drainage area.

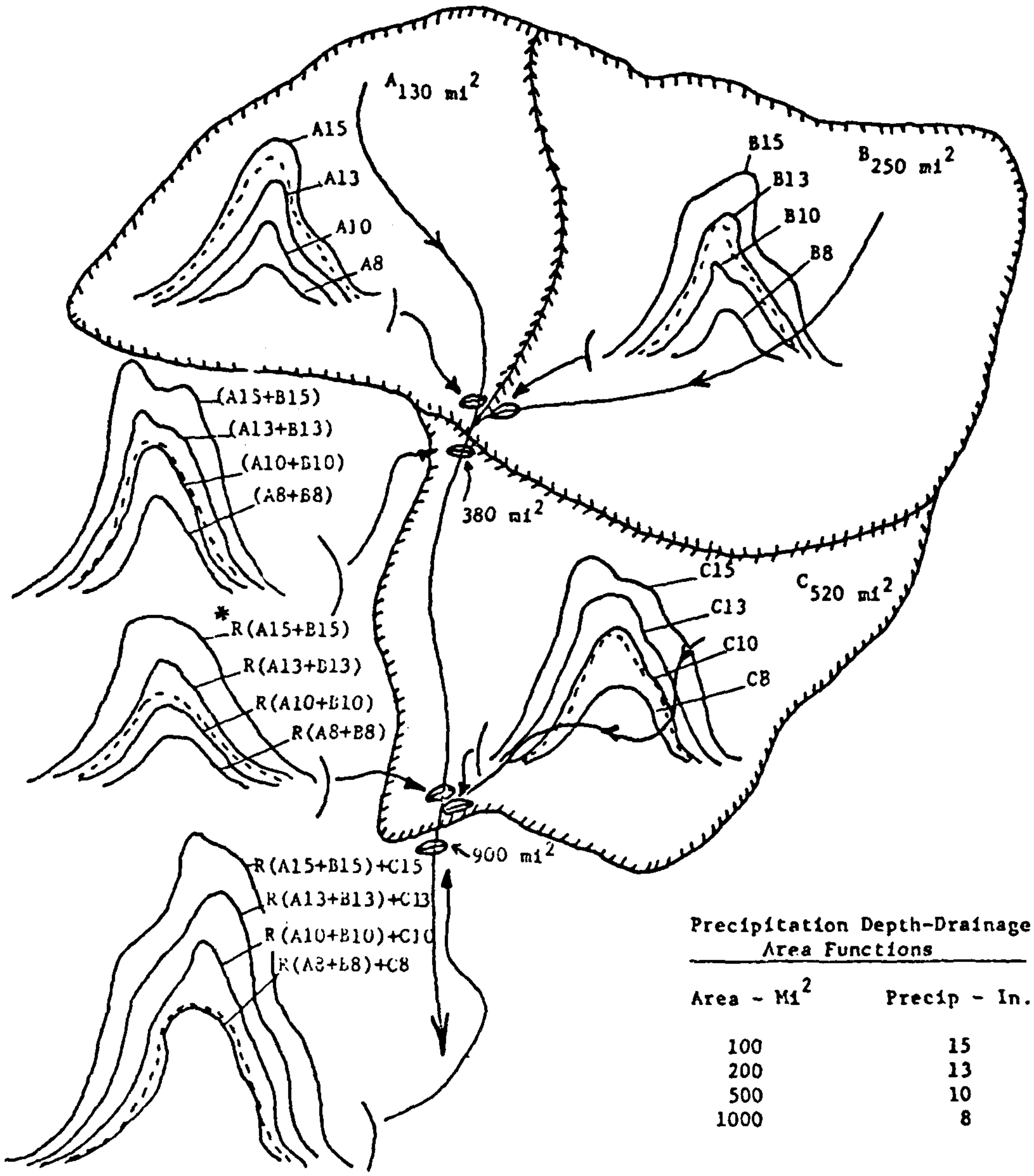
The interpolation formula can thus be derived assuming a linear discharge-log drainage area relationship as follows:

$$Q = Q1 * (\log \frac{A2}{Ax} / \log \frac{A2}{A1}) + (Q2 * \log \frac{Ax}{A1} / \log \frac{A2}{A1}) \quad . \; . \; . \; . \; . \; . \; . \; . \quad (7.1)$$

where Q is the instantaneous flow of the consistent hydrograph, Ax is the tributary area for stream location, A1 is the next smaller index area, A2 is the next larger index area, Q1 is the instantaneous flow for index hydrograph 1, Q2 is the instantaneous flow for index hydrograph 2.

The interpolation formula would be exact if the loss function applied was uniform and if the precipitation depth-drainage area relationship was in fact a straight line on semilogarithmic paper. Because the interpolation formula is not exact, the computer program insures that the peak of the interpolated hydrographs below all confluences are not smaller than any of the interpolated hydrographs above the confluence.

Operation of HEC-1 for the depth-area computation requires that the basin be modeled (Section 2) and that the desired precipitation depth- drainage area relationship be defined by up to five pairs of values that include the range of tributary areas to be encountered. A different temporal pattern may be specified for each depth-area point. Successive runs of the depth-area feature with and without a proposed project will provide a balanced evaluation of that project on downstream flood hydrographs. A single run will provide a set of hydrographs at all locations within the basin that conform consistently with the precipitation depth-drainage area function.



Precipitation Depth-Drainage Area Functions

Area - Mi^2	Precip - In.
100	15
200	13
500	10
1000	8

Legend

- * Routed
- ⊖ Desired location for consistent hydrograph
- Stream channel
- Drainage Boundary
- $A_{130\ mi^2}$ etc. - Subarea label and drainage area

Figure 7.2 Multi-Subbasin Precipitation Depth-Area Simulation

Section 8

FLOOD DAMAGE ANALYSIS

Flood loss mitigation planning requires the ability to rationally assess the economic consequences of flood inundation damage. The flood damage analysis option provides the capability to assess flood inundation damage and determine flood damage reduction benefits provided by alternative flood loss mitigation measures. The subsequent sections discuss the basic concepts and methodologies employed in performing a flood damage analysis. Example problem 11, Section 12, shows the input data and output for a flood damage analysis.

8.1 Basic Principle

The damage reduction accrued due to the implementation of a flood loss mitigation plan is determined by computing the difference between damage values occurring in a river basin with and without the measures. Damage is assumed to be only a function of peak discharge or stage and does not depend on the duration of flooding. Total damage is determined by summing the damage computed for individual damage reaches within the river basin. The damage in each reach is calculated as the sum of damage for individual land use categories (e.g. agricultural, commercial, industrial, etc.).

HEC-1 computes expected annual damage (EAD) as the integral of the damage-exceedence frequency curve. EAD is the average-year damage that can be expected to occur in the reach over an extended period of time.

The basic technique used in the EAD analysis is to form the damage frequency curve by combining damage versus flow (stage) and flow (stage) versus frequency relations which are characteristic of the area that the damage reach represents. The damage versus flow (stage) relation ascribes a dollar damage that occurs in an area to a level of flood flow. The flow (stage) versus exceedence frequency relation ascribes an exceedence frequency to the magnitude of flood flow. By combining this information, the damage versus frequency curve and, hence, the EAD for a reach can be determined.

Consequently, the EAD is the measure of flood damage occurring in a river basin. By comparing river basin EAD with and without flood loss mitigation measures, damage reduction benefits are computed.

8.2 Model Formulation

In the flood damage analysis, the conceptual model of the river basin developed for a multiplan-multiflood analysis (example problems 9 and 10, Section 12) is extended to include damage computations. Damage reaches are designated by providing economic data, consisting of flow (stage) versus frequency and flow (stage) versus damage data, for each damage reach in the multiplan-multiflood model.

In the extended multiplan-multiflood analysis, PLAN 1 represents the base condition. Subsequent plans represent alternative flood loss mitigation plans. The difference between the EAD computed for PLAN 1 and subsequent plans is the damage reduction accrued by the flood loss mitigation measure(s).

The development of the conceptual model for the flood damage analysis is based on the interrelated requirements for the stream network and damage calculations. This relationship is shown on Fig. 8.1 where subbasins, routing reaches, and damage reaches are delineated for an example river basin. The definition of the subbasins and routing reaches for the stream network calculations is determined in part by criteria outlined in Section 2, and in part by the requirements of the damage calculations.

The damage reaches in each area of interest are determined by isolating river reaches which have consistent flood profiles. (Consistent flood profiles occur when the stage profile along the reach is of similar shape for a range of flood frequencies. For example, similar profiles are indicated when the difference between the stages due to the 10- and 20-year flood is approximately the same throughout the entire reach.) Data used in the damage calculation are developed for an index location within each damage reach.

Note that the damage reach may encompass parts of a number of routing reaches. The flows used in the damage calculation are based on the outflows from the most downstream of these routing reaches. The flows combined with damage data for the index location result in the appropriate damage for the entire damage reach.

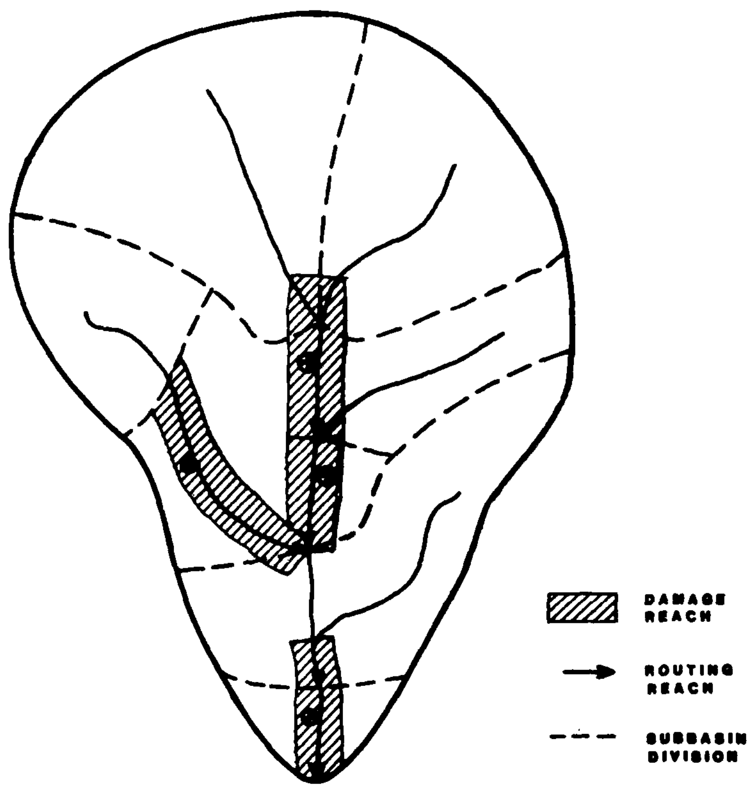


Figure 8.1 Flood-Damage Reduction Model

8.3 Damage Reach Data

The input data for damage computations follow the multiplan-multiflood stream network data in the input data set as shown in test example 11 and can be supplied in a number of forms.

Damage data can be provided as stage-damage or flow-damage tables. These data can be provided for a number of different damage categories for each reach.

Frequency data can be provided as stage-frequency or flow-frequency tables. In the case that the damage data are given in terms of flows and frequency data in terms of stages (or vice versa), a rating curve for the reach must be provided to relate stages and flows.

Damage reach location information may be specified in order to summarize damage in a river basin. Two locational descriptors (e.g., river and county names) are provided for each damage reach. A damage summary table is developed in which damage is summed and cross tabulated by the rivers and counties (or any other locational descriptors) in which they occurred.

8.4 Flood Damage Computation Methodology

There are two basic computations in a flood damage analysis: exceedence frequency curve modification and EAD calculation. Structural flood control measures (e.g., reservoirs and channel improvements) affect the flow-frequency relationship. Nonstructural measures (e.g., flood proofing and warning) do not usually have much impact on the flood-frequency relationship but do modify the flow (stage) damage relationship.

8.4.1 Frequency Curve Modification

The flow-exceedence frequency data provided for damage reaches refer to PLAN 1 or the base plan of the multiplan-multiflood model. Implementation of structural flood control measures or changes in watershed response will change this exceedence frequency relation. HEC-1 computes modified frequency relationships using the following methodology.

1) A multiflood analysis is performed for PLAN 1 to establish the frequency of the peak discharge of each ratio of the pattern event. The peak-flow frequency for each ratio of the pattern event is interpolated from the input flow-frequency data tables for a damage reach. Since the flow-frequency data are generally highly non-linear, the interpolation is done with a cubic spline fit of the data as shown in Fig. 8.2.

   A stage frequency curve is established in essentially the same manner as for flows if stage-frequency data are specified for a damage reach. However, since the stage-frequency data are generally more uniform than the flow-frequency data, a linear interpolation scheme is used to determine frequencies for peak stage of each ratio of the multiflood.

2) A multiflood simulation is performed for the flood control plans. The peak discharges (stages) are computed at each damage reach for

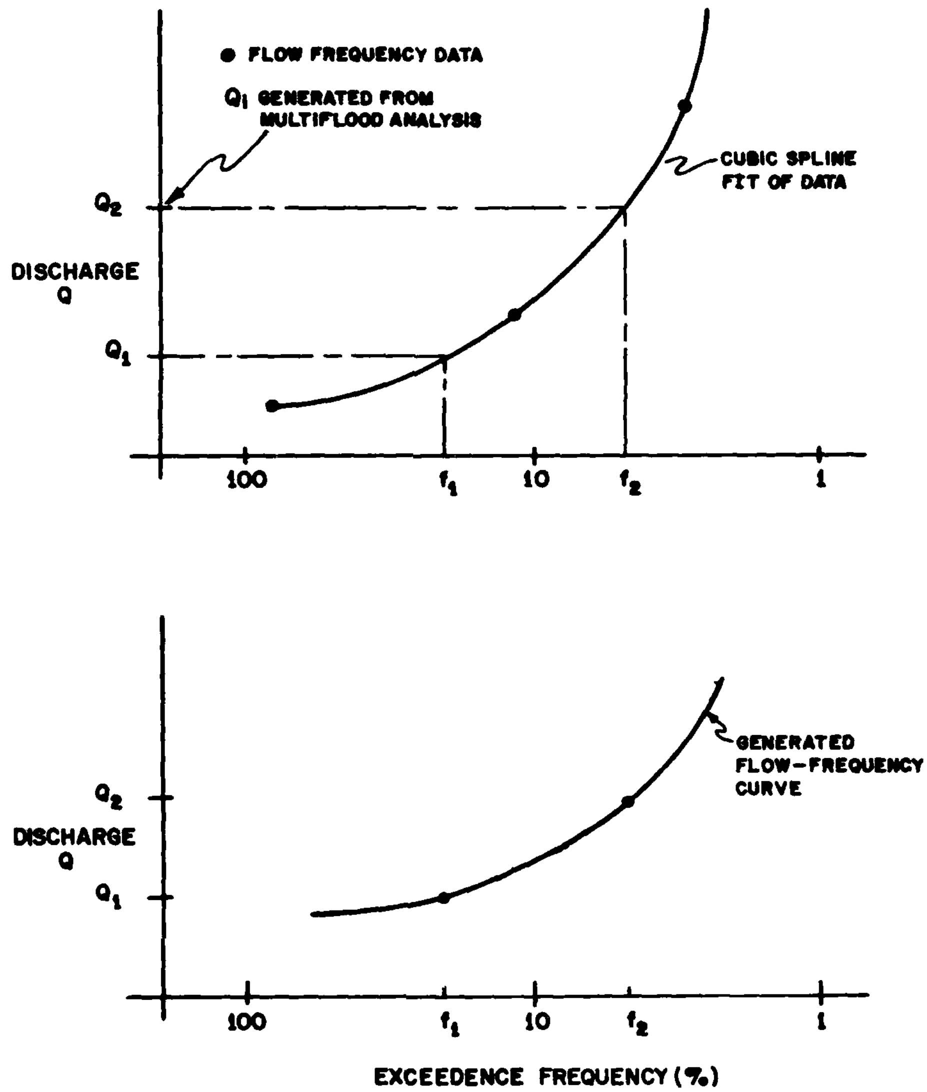
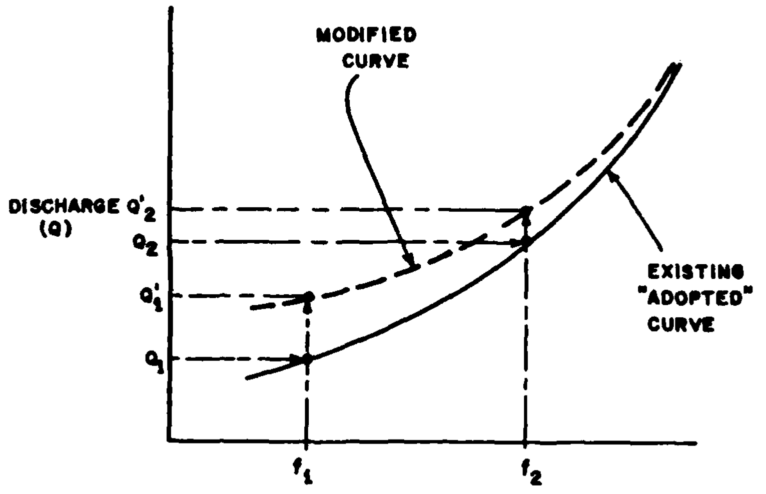


Figure 8.2 Flow Frequency Curve

each ratio of the design event. It is assumed that the frequency of each ratio remains the same as computed for the base case in (1) above; and only the peak flows associated with each ratio change for different plans. In this manner, the modified flow-frequency curve is computed for all ratios as shown in Fig. 8.3. Thus, for example, the peak flow of RATIO 3 of PLAN 2 has the same frequency as the peak flow of RATIO 3 of PLAN 1. The assumption inherent in this procedure is that the event ratio-frequency relation is not affected by basin configuration. Care should be taken in interpreting the results of the model when this assumption is not warranted.

8.4.2 Expected Annual Damage (EAD) Calculation

EAD is calculated by combining the flow-frequency curve and the



Q_i = PEAK DISCHARGE FOR DESIGN STORM i

f_i = FREQUENCY OF Q_i FROM GIVEN CURVE

Q'_i PEAK DISCHARGE FROM DESIGN STORM i UNDER MODIFIED WATERSHED CONDITION

Figure 8.3 Flow-Frequency-Curve Modification

flow-damage data for each PLAN and damage reach (HEC, 1979a) using the following methodology.

1) The flow-frequency curve is used in conjunction with the flow-damage data to produce a damage-frequency curve as shown in Fig. 8.4 The frequency interval between each pair of RATIOS is divided into ten equal increments. A cubic spline fit procedure is used to define the flow-frequency curve and interpolate the value of the flows for each of the ten frequency increments. Damage for each flow, and hence, the corresponding frequency, is found from the damage-flow data by linear interpolation, thus defining the damage frequency curve.

   In the case that stages are used, the procedure is the same except that the stages for generated frequencies are determined using a linear interpolation procedure. If stages are specified for the damage data and flows for the frequency data (or vice versa), a rating curve is used to relate the stages and flows before determining the appropriate damage.

2) The damage-frequency curve, at its extreme points, must include a zero damage (and corresponding frequency) and a zero exceedence frequency (and corresponding damage). The program does not extrapolate to zero damage. Consequently, a simulated peak flow in the multiflood analysis must be small enough to correspond to zero damage in the flow-damage table. Otherwise, an error in the expected annual damage calculation will be introduced. A zero exceedence frequency event cannot be specified in the program, even if one could be defined. However, the program does extrapolate to the zero exceedence frequency

as shown in Fig. 8.4. This extrapolation will not severely affect the accuracy of the result if the peak flows generated result in a relatively small exceedence frequency.

3) The integral of the damage-frequency curve is the EAD for the reach. This area is computed using a three point Gaussian Quadrature formula.

4) If more than one damage category is specified for a reach, the above steps are repeated for each category. The EAD is summed for all the categories to produce the EAD for the reach.

The damage reduction accrued due to the employment of a flood loss mitigation plan is equal to the difference between the PLAN 1 EAD and the flood control EAD. The model performs this computation for all plans in the multiplan-multiflood analysis.

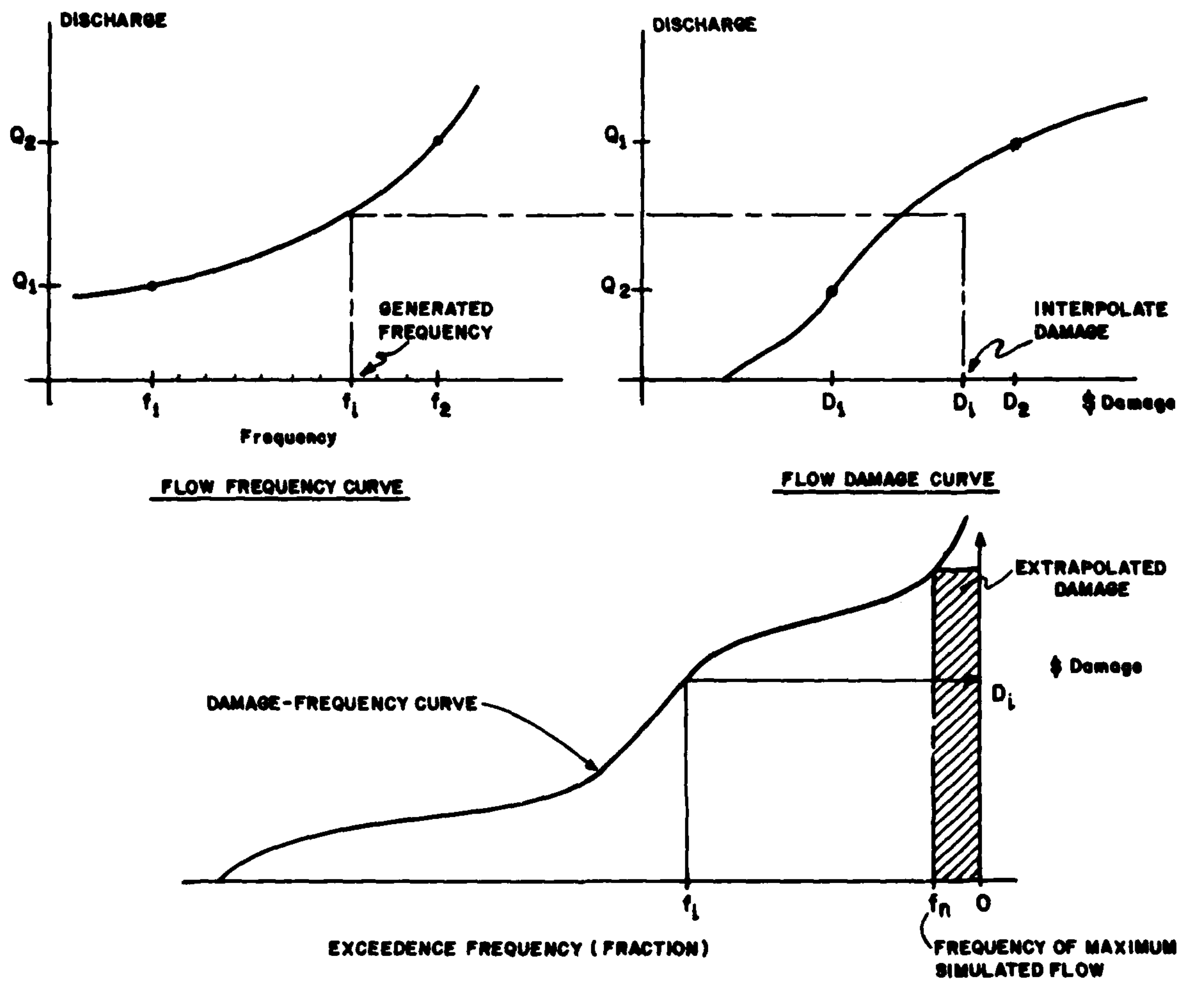


Figure 8.4 Damage Frequency Curve

Section 9

FLOOD CONTROL SYSTEM OPTIMIZATION

The flood control system optimization option is used to determine optimal sizes for the flood loss mitigation measures in a river basin flood control plan (Davis, 1974). The subsequent sections discuss the formulation of an optimization model, the measures (components) that can be optimized, data requirements, and the optimization methodology used. Example problem 12, Section 12, illustrates the application of this capability.

9.1 Optimization Model Formulation

The flood control system optimization capability is an extension of the flood damage analysis described in Section 8. The optimization model utilizes a two-plan damage analysis: PLAN 1 is the base condition of the existing river basin and PLAN 2 is the flood control plan being optimized. Data on the costs of various sizes of flood control projects are required, otherwise the formulation of the optimization model is essentially the same as in the flood damage model case. The flood control components that can be optimized as part of the flood control system are as follows:

Reservoir Component. The storage of an uncontrolled spillway-type reservoir is optimized by determining the elevation of the reservoir spillway, thus defining the point at which the reservoir begins to spill. The low-level outlet characteristics of the reservoir are fixed by input.

Diversion Component. Flow diversions, such as described for the stream network simulation, may have their channel capacity optimized. The diverted flow may be returned to another branch of the stream network or simply lost from the system.

Pumping Plant Component. Pumping plants may be located virtually anywhere in a stream network and their capacity may be optimized. The pumped water may be returned to another branch of the stream network or simply lost from the system.

Local Protection Project. A local protection project can be used to model a channel improvement or a levee. This component can only be used in conjunction with the damage analysis of a reach. Consequently, the optimization data are included in the economic data portion of the simulation input data set and are described in the economic input data description section. The local protection project analysis requires capacity and cost data together with pattern damage tables for maximum and minimum sizes of the project. Damage functions are interpolated for project sizes between these maximum and minimum design values. The difference between the channel improvement and the levee option is specified in the pattern damage tables. The channel improvement damage tables represent a reduction in the damage function specified for PLAN 1. On the other hand, the damage pattern tables for the levee indicate zero damage for flows below the design capacity and preserves the existing flow-damage relationships for flows exceeding the design capacity. Consequently, the pattern damage functions are equal to the existing damage functions for all non-zero damage values.

Uniform Level of Protection. A flood control plan may require that, as part of the flood control system, levees (local protection projects) provide the same level or a uniform level of protection at a number of locations (damage reaches). In this instance, the level of protection refers to the flood exceedence frequency at which the capacity of the project is surpassed. The flood control system optimization option can be used to determine the uniform level of protection that, in conjunction with the structural flood control components, leads to the maximum net flood loss reduction benefits in the river basin.

9.2 Data Requirements

The flood control component optimization model requires data as described for the flood damage model plus information about the capital and operating costs of the projects and about the objective function for the flood control scheme. The data for the various types of flood control components are essentially the same and may be separated into cost and capacity data, and optimization criteria as follows.

Cost and Capacity Data. Two types of data are required to calculate the total annual cost of a flood control component. First, capacity versus capital cost tables are required to determine the capital cost for any capacity of the flood control component. A capital recovery factor is also required so that equivalent annual costs for the capital investments can be computed. Second, operation and maintenance costs are computed as a proportion of the capital cost. For pumping plants, average annual power costs for various pump capacities are required. Pump operation costs are computed in proportion to the volume pumped. Capital and operating costs for non-optimized components of the system may also be considered.

Optimization Criteria. The optimization methodology operates on maximum net benefit and/or flow targets criteria. Maximum net benefits are computed using the cost and flood damage data previously described. Desired streamflow limitations may also be specified at any point downstream of a flood control project. These streamflow limitations, referred to as "flow targets" are specified as the flow (stage) which is desired to occur with a given exceedence frequency. For example, it may be desired to have the 5% flood at a particular location be 5,000 cfs. The input data for flow targets are the discharge or stage and the exceedence frequency.

9.3 Optimization Methodology

9.3.1 General Procedure

The model determines an optimal flood control system by minimizing a system objective function. The system objective function is the sum of flood control system total annual cost and the expected annual damage occurring in the basin. If flow targets are specified, then the previous sum is multiplied by a penalty factor which increases the objective function proportionately to deviations from the target. Note that the minimization of the objective function leads to the maximization of the net benefits accrued due to the employment of the flood loss mitigation measures. Net benefits are equal to the difference between the EAD occurring in PLAN 1 and the sum of the system costs and EAD occurring in PLAN 2.

The optimization procedure can be generally described as follows:

(1) An initial system configuration is analyzed by the program based on capacities specified by the user. The model performs a stream network simulation and expected annual damage calculation for the base condition, PLAN 1, without the proposed flood control measures. The base condition need only be simulated once because it will not change and serves as the reference point for computation of net benefits accruing to the proposed flood control plan. The stream network and expected annual damage calculations for the initial sizes of the proposed flood control system are then performed and the initial value of the objective function is determined. The program computes and displays the net benefit that is accrued due to the employment of the initial flood control system.

(2) The model then uses the univariate search procedure to find a minimum value for the objective function. (The optimization algorithm is the same as used for parameter optimization, Section 4.) The procedure finds a minimum by systematically altering flood control component capacities in order to calculate various values of the system objective function. Each time a flood control system capacity is changed, stream network calculation and EAD calculations are performed giving a value for the system objective function.

(3) Once the optimization procedure is completed, the costs, damage and net benefits accrued to the optimized system are computed and displayed.

An important point to note is that the optimization procedure does not guarantee a global minimum for the objective function. Local minimum points may be found by the procedure. This can be tested by trying different initial capacities for the flood control system optimization run. If the optimal system found each time is the same, then there is strong evidence that the minimum found is global. The optimization results and the steps in the optimization process should be reviewed carefully to see that they are reasonable. Other component sizes not analyzed by the search procedure should also be analyzed to see if better results can be obtained.

9.3.2 Computation Equations

The system objective function STDER is calculated as follows:

$$STDER = (TANCST + ANDMG) * (ODEV + CONST) \quad (9.1)$$

where TANCST is the flood control system total annual cost, ANDMG is the river basin expected annual damage, ODEV is the sum of the weighted deviations from the target flow or stage, and CONST is a term representing the importance of the target penalty (default value equal to 1.0). As CONST increases, the target penalty has less importance in determining STDER.

The total annual cost TANCST is computed by the following formula:

$$TANCST = ANFCST + ANOMPR + FDCNT + FAN \quad (9.2)$$

where ANFCST is the sum of the equivalent annual capital costs for the flood control components, ANOMPR is the sum of the annual operation, maintenance, power and replacement costs for the flood control components, FDCNT is the equivalent annual capital cost for non-optimized components, and FAN is the annual operation, maintenance, power and replacement cost for non-optimized components.

The annualized capital and operation and maintenance costs are computed as follows.

ANFCST = (CAPCST * CRF) for all projects. . . . . (9.3)

ANOMPR = (CAPCST * ANCSTF) for all projects . . . . (9.4)

FDCNT = FCAP * CRF . . . . (9.5)

FAN = FCAP * ANCSTF. . . . . (9.6)

where CAPCST is the capital cost of a flood control project, CRF is the capital recovery factor for a specified project life and interest rate, and FCAP is the total capital cost of the non-optimized components of the system. FDCNT may be computed as shown above or the equivalent annual capital cost may be specified as direct input.

The expected annual damage, ANDMG, is calculated as described in Section 8.

The target penalty is a sum of weighted deviations from the conditions specified at designated reaches where damage is being calculated. The penalty at a single reach is a function of the deviation DEV from the target.

DEV = TRGT - TMP . . . . (9.7)

where TRGT is the target flow specified by the user for a given exceedence frequency, and TMP is the computed flow for the given exceedence frequency with the flood control projects in operation, i.e., PLAN 2. The exceedence frequency specified for the target penalty is used to interpolate a value of TMP from the PLAN 2 flow-frequency curve computed for a reach. The interpolation is accomplished by using the cubic-spline fit procedure.

The penalty, PEN, for deviations from the target conditions are calculated for stages as:

$PEN = (DEV/ANORM)^4$ . . . . (9.8)

and for flows:

$PEN = (DEV/(ANORM * TRGT))^4$ . . . . (9.9)

where ANORM is a normalizing factor (default value of 0.1).

The sum of the penalties for all reaches is equal to the deviation penalty ODEV in equation 9.1. The factors CONST (equation 9.1) and ANORM can be adjusted by the user (ANORM should be greater than or equal to .02) until satisfactory compliance with the target constraints are met by the optimization procedure. The default values for these parameters should suffice for most purposes.

Section 10

INPUT DATA OVERVIEW

This section describes: the general organization of the input data, special features for specifying data, and groupings of data to accomplish specific simulation options. A detailed descripiton of the individual input data records and their contents is given in the Appendix A: Input Description.

10.1 Organization of Input Data

There are two general types of data records for HEC-1: input control and river basin simulation data. The input control records tell the program the format of the river basin data as well as controlling certain diagnostic output. All input control records begin with an asterisk (*) in column one follwed by a command. These input controls are discussed in the next subsection and a detailed explanation is given in Appendix A.

The river basin simulation data are all identified by a unique two-character alphabetic code in columns one and two of each record. These codes serve two functions: they identify the data to be read from the record; and they activate various simulation options. The first character of the code identifies the general category and the second character identifies a specific type of data within a category. An overview of these data categories and codes is shown in Table 10.1. The flood damage data, beginning with the EC record is placed at the end of the river basin simulation data. These data are not all labeled as E records because the record code and format were taken from the Expected Annual Flood Damage (HEC, 1979) program. Thus these same data records may be used directly in both programs.

The river basin simulation data records are structured by the user to reflect the topology of the basin. The sequence of the input data prescribes how the river basin is simulated. There are three general subdivisions of these data as shown in Table 10.2: job control; hydrology and hydraulics; and economics. Example input data for a simple river basin are shown in Fig. 10.1. The data model of a river basin can be thought of as a series of building blocks, each block beginning with a KK record. The data following each KK record identifies the type of operation to be performed, e.g., BA signifies subbasin runoff and R_ signifies a routing. Section 12 gives examples of input data structures to accomplish various program options.

10.2 Special Features for Input Data

10.2.1 Input Control

There are six input control commands: *FREE, *FIX, *LIST, *NOLIST, *MESSAGE, and *DIAGRAM. Data can be input to the HEC-1 model in a fixed and/or free format as noted in the Input Data Description. The traditional HEC fixed-format input structure (ten 8-column fields) is the default option of the program. The program now provides the capability to enter data in a free format. All records following a *FREE record in the data will be considered as being in free format. Free format data fields are separated by commas or one or more spaces, and successive commas represent blank fields. The fixed format can be returned to at any point in the data set by providing a *FIX record. The *FIX will be in control until another *FREE record is encountered, etc.

TABLE 10.1

HEC-1 Input Data Identification Scheme

Data Category	Record Identification	Description of Data
Job Initialization	ID	Job IDentification
	IT	Job Time Control
	IM	Metric Units
	IO	General Output Controls
	IN	Time Control for INput Data Arrays
Variable Output Summary	VS	Stations to be summarized
	VV	Variables to be summarized
Optimization	OU	Unit Graph and Loss Rate Controls
	OR	Routing Controls
	OS	Flood Control System Optimization
	OO	System Optimization Objective Function
Job Type	JP	Multi-Plan Data
	JR	Multi-Ratio Data
	JD	Depth-Area Data
Job Step Control	KK	Stream Station Identification
	KM	Alphanumeric Message Record
	KO	Output Control for This Station
	KF	Format for Punched Output
	KP	Plan Number
Hydrograph Transformation	HC	Combine Hydrographs
	HQ/HS	Stage/Discharge Rating Curve
	HL	Local flow computation option
	HB	Hydrograph Balance Option
Hydrograph Data	QO	Observed Hydrograph
	QI	Direct Input Hydrograph
	QS	Stage Hydrograph
	QP	Pattern Hydrograph
Basin Data	BA	Basin Area
	BF	Base Flow Characteristics
	BR	Retrieve Runoff Data from ATODTA File
	BI	Input Hydrograph from Prior Job
Precipitation Data	PB	Basin-Average Total Precipitation
	PI	Incremental Precipitation Time Series
	PC	Cumulative Precipitation Time Series
	PG	Gage Storm Total Precipitation
	PI/PC	Incremental/Cumulative Precipitation Time Series for Recording Gage
	PR	Recording Gages to be Weighted

TABLE 10.1: HEC-1 Input Data Identification Scheme (Cont'd)

Data Category	Record Identification	Description of Data
Precipitation Data (Cont'd)	PT	Storm Total Gages to be Weighted
	PW	Weightings for Precipitation Gages
	PH	Hypothetical Storm's Return Period
	PM	Probable Maximum Precipitation Option
	PS	Standard Project Precipitation Option
Loss Rate Data	LE	HEC's Exponential Rainfall Loss Rate Function
	LM	HEC's Exponential SnowMelt Function
	LU	Initial and Uniform Rates
	LS	SCS Curve Number
	LH	Holtan's Function
Unitgraph Data	UI	Direct Input Unitgraph
	UC	Clark Unitgraph
	US	Snyder Unitgraph
	UD	SCS Dimensionless Unitgraph
	UA	Time-Area Data
	UK	Kinematic Overland
	RK	Kinematic Wave Channel (collector, main)
Melt Data	MA	Zone Area and Snow Content Data
	MC	Melt Coefficient
	MD	Dewpoint Data
	MS	Solar Radiation Data
	MT	Temperature Data
	MW	Wind Data
Routing Data	RN	No Routing for Current Plan
	RL	Channel Loss Rates
	RT	STraddle/Stagger Parameters
	RM	Muskingum Parameters
	RS	Storage Routing Option, follow with SV and SQ records if Modified Puls is used
	RC	Channel Characteristics for Normal Depth Storage Routing
	RX	Cross Section X Coordinates
	RY	Cross Section Y Coordinates
	RK	Kinematic Wave Channel
Storage Routing Data	SL	Low Level Outlet Characteristics
	ST	Top of Dam Characteristics
	SW	Width/Elevation for Non-Level Top of Dam
	SE	Geometry
	SS	Spillway Characteristics
	SG	OGee or Trapezoidal Spillway Option
	SQ	Discharge/Elevation Tailwater Rating
	SE	Curve for SG record

TABLE 10.1: HEC-1 Input Data Identification Scheme (Cont'd)

Data Category	Record Identification	Description of Data
Storage Routing Data (Cont.)	SV	Reservoir Volume
	SQ	Discharge,
	SA	Surface Area, and
	SE	Water Surface Elevation Data
	SB	Dam Breach Characteristics
	SO	Optimization Parameters
	SD	Cost $ Function Corresponding to SV Data
Diversion Data	DR	Retrieve Diverted Flow
	DT	Flow Diversion Characteristics
	DI	Variable Diversion Q as Function of
	DQ	Inflow
	DO	Diversion Size Optimization Data
	DD	Cost $ Function for Diversion
Pumping Withdrawal Data	WP	Pump Characteristics
	WO	Pump Size Optimization Data
	WC	Capacity Function for Pump
	WD	Cost $ Function for Pump
	WR	Pump flow retrieval
Flood Damage Data	EC	Identifies Flood Damage Option
	CN	Damage Category Names
	PN	Plan Names
	WN	Watershed Name
	TN	Township Name
	WT	Watershed and Township Location
	FR	Frequency Data
	QF	Discharges for FR data
for each	SF	Stages for Rating Curve with QS
damage	QS	Discharges for SQ data
reach	SD	Stages for Damage Data, DG
	QD	Discharges for Damage Data, DG
	DG	Damage Data
	EP	End of Plan Identifier
End of Job	ZZ	Required to end job

A preprocessor in the program converts free-format data to the standard 8-character field structure and prints the reformatted data. This "echo print" may be turned off and on with *NOLIST and *LIST records.

Messages, notes, explanations of data, etc., can be inserted anywhere in the data set by using the *MESSAGE record. These records are printed with the *LIST option but are not shown on any further output.

TABLE 10.2

Subdivisions of Simulation Data

Job Control	Hydrology & Hydraulics	Economics & End of Job
I_, Job Initialization	K_, Job step control	E_, etc., Economics, data
V_, Variable Output Summary	H_, Hydrograph transformation	ZZ, End of job
O_, Optimization	Q_, Hydrograph data	
J_, Job Type	B_, Basin data	
	P_, Precipitation data	
	L_, Loss (infiltration) data	
	U_, Unitgraph data	
	M_, Melt data	
	R_, Routing data	
	S_, Storage data	
	D_, Diversion data	
	W_, Pump Withdrawal data	

The stream network structure can be portrayed diagramatically by using the *DIAGRAM record at the beginning of the data set. This option causes the program to search the input data set for KK records and determine the job step computation associated with each KK record group. A flow chart of the stream network simulation as recognized from the KK-record sequences is printed. The user should verify that this flow chart conforms to the intended network of subbasins and routing reaches.

10.2.2 Time Series Input

The IN record allows the user to enter time-series data, either hyetographs or hydrographs, at time steps other than the computation interval specified on the IT record. This option is convenient when entering data generated by another program or in a separate HEC-1 simulation. Note that if direct input unit hydrograph ordinates is used (UI record), they must be at the same time step as the simulation computation interval and cannot be input with the IN record.

10.2.3 Data Repetition Conventions

In many instances, certain physical characteristics are the same for a number of subbasins in the stream network model (for instance, infiltration characteristics). Further, in a multiplan analysis, much of the PLAN 1 subbasin data remains unchanged in subsequent plans. The HEC-1 program input conventions make it unnecessary to repeat much of this information in the data set.

Data groups for subbasin runoff simulation which need not be repeated (if they are the same as input for the previous subbasin) are shown in Table 10.3. HEC-1 automatically uses the previous subbasin's input data for these data types unless new data are provided for the current subbasin. The source of the data used as identified by the input record number is printed in the left hand margin. If a zero is printed as the input record number, this means no data records have been provided, up to that point, which contain the required information. Great care should be taken to verify that the input data used was so intended. No data are repeatable for routing reaches.

TABLE 10.3

Data Repetition Options

Data Types which are Automatically Repeated	Record Identification
Rainfall	P
Infiltration	L
Base Flow	BF
Snowmelt	M
*Unit Hydrograph	US, UC, UD
*Kinematic Wave	** UK, RK

* Not recommended
** Only if all records remain unchanged

In the multiplan analysis, data may be supplied for a number of plans for the same subbasin. Data need not be repeated for each plan by following two conventions:

(1) Plans not specified in the data set by a KP record are assumed to be the same as the first plan in the KK record group. (Data for a particular plan follows a KP record in the data set.)

(2) Data specified subsequent to a KP record are considered to update previous plan data. If no data follows a KP record, then the indicated plan will be considered to be equivalent to the immediately preceding plan in the data set. See example problem 10 for an application of this program input convention.

10.3 Hydrologic/Hydraulic Simulation Options

The HEC-1 program has a number of alternative methods available for simulating some aspects of the hydrologic/hydraulic processes (as referred to in the center column of Table 10.2). The different methods were also noted in the several data types available for one data category. For example, loss rates may be calculated by any of four different methods: exponential, initial/constant, SCS, or Holtan. The general sequence of model building operations was shown in Fig. 10.1.

There are a number of methods available for specifying rainfall hyetographs in the stream network computation as described in Section 3 and Table 10.4. Historical gage data can be input to the subbasin runoff computation as shown in Fig. 10.2 The gage data consists of PG records for nonrecording gages and PG and PI or PC records for recording gages. These data are usually grouped toward the beginning of the data set before the first KK-record runoff computation. Within each KK-record group, the (PR, PW) and (PT, PW) records are used to specify which gages and corresponding weightings are to be used for computation of that subbasin's average precipitation. <u>Note that a recording gage can be used as both a storm total and a recording gage station</u>. This is indicated by using gage WEST of PT and PW records in Fig. 10.2. If the storm total value is not specified on the PG record for the recording station (as is the case for the Fig. 10.2 example), the program sums the incremental values on the PI records to compute that value.

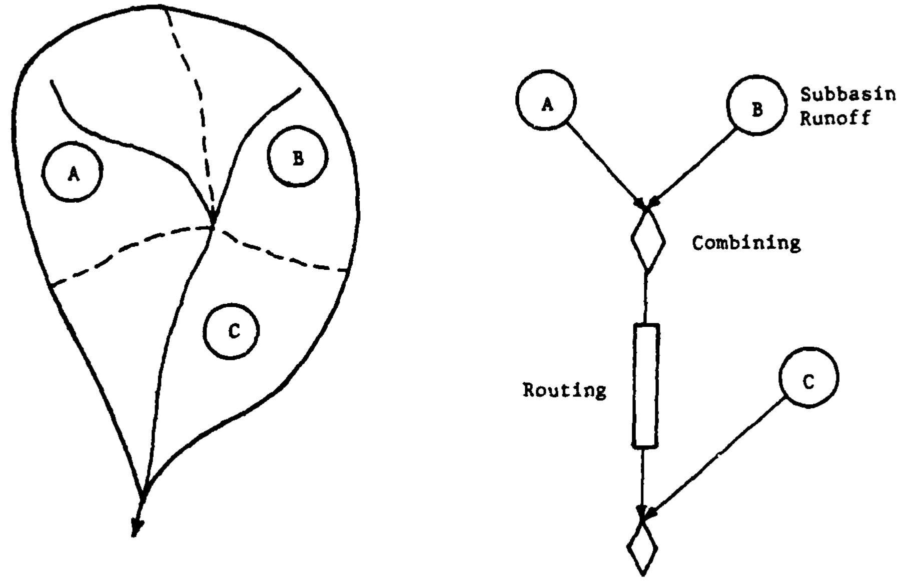
In order to facilitate the selection of data for the various simulation options, the following set of tables have been prepared.

Table 10.4	Precipitation Data Input Options
Table 10.5	Hydrograph Derivation Input Options
Table 10.6	Hydrograph Optimization Input Data Options
Table 10.7	Channel and Reservoir Routing Input Data Options
Table 10.8	Spillway Routing, Dam Overtopping and Dam Failure Input Data Options
Table 10.9	Net Benefit Analysis Input Data
Table 10.10	Flood Control Project Optimization Input Data Options
Table 10.11	Hydrograph Transformation, Comparison and I/O

These tables identify alternative methods for inputting data and simulating basin hydrology, hydraulics and flood damage. The example test problems in Section 12 further illustrate the input data structures for the various capabilities of HEC-1.

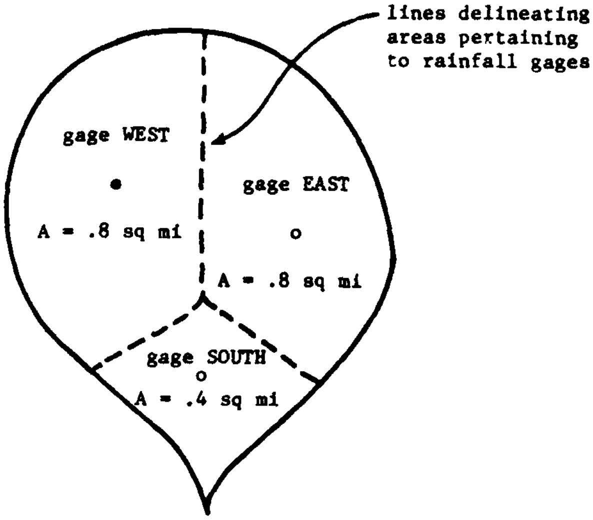
<u>10.4 Input Data Retrieval from the HEC Data Storage System (DSS)</u>

The HEC Data Storage System , DSS (HEC, 1984), may be used to supply certain catchment characteristics and time-series data to the HEC-1 input data set. Those data are runoff parameters stored by program HYDPAR (Corps of Engineers, 1978), cumulative and incremental precipitation (PC and PI data), and streamflows (QI and QO data). The input connections used to retrieve data are given in the overview of HEC-1 usage with DSS in Appendix B. Access to DSS is limited to HEC-supported computers, and requires a special version of HEC-1 and associated DSS software.



	Card ID	Description
	ID	Title
	IT	Time interval and beginning time
	IØ	Output control option for whole job
	KK	Subbasin A
Runoff	BA	Area
from	BF	Base flow
Subbasin	P_	Select one precipitation method, use IN if necessary
A	L_	Select one loss rate method
	U_	Select one rainfall excess transformation method
	KK	
Subbasin B	BA	Similar to above for Subbasin A
runoff	BF	
	P_,L_,U_	
	KK	Station name
Combine	KM	Combine runoff from A and B (message option)
A + B	HC	Indicate 2 hydrographs are to be combined
Route	KK	Station name
(A+B)	RL	Channel loss optional
to C	R_	Select one routing method
	KK	
Subbasin C	BA	Similar to above for Subbasin A
runoff	BF	
	P_,L_,U_	
Combine	KK	Station name
Routed (A+B) with C	HC	Indicate 2 hydrographs are to be combined
	KK	
	IN	Compare computed and observed flows
	QØ	
	ZZ	End

Figure 10.1 Example Input Data Organization for a River Basin



Symbols

● - Recording gage

o - Nonrecording gage

Total Rainfall

EAST - 4.8"

WEST - 3.5"

SOUTH - 4.2"

DATA INPUT

	Card ID	Data			
	ID				
	IT				
Rainfall gage data	PG	EAST	4.8		
	PG	SOUTH	4.2		
	PG	WEST			
	PI	.02	.05	etc.	recording gage readings for storm
	⋮				
	KK	3-gage basin			
	BA	2.0			
Gage weightings for basin-average total	PT	WEST	EAST	SOUTH	
	PW	.4	.4	.2	
Gage weightings for basin-average recorder	PR	WEST			
	PW	1			
	L_				
	U_				

Figure 10.2 Precipitation Gage Data for Subbasin-Average Computation

TABLE 10.4

Precipitation Data Input Options

Type of Storm Data	Record Identification
Basin-Average Storm Depth and Time Series	PB and/or (PI or PC)
Recording and Nonrecording Gages	PG for all nonrecording gages PG and (PI or PC) for all recording gages PR, PW, PT, PW for each subbasin
Synthetic Storm from Depth-Duration data	PH
Probable Maximum Storm	PM
Standard Project Storm	PS
Depth-Area with Synthetic Storm	JD, PH, or PI/PC

TABLE 10.5

Hydrograph Input or Computation Options

	Hydrograph Derivation Options and Records			
Type of Data	Input Hydrograph	SAM*	Unit Graph	Kinematic Wave
Inflows or Precipitation	QI	P_, M_	P_, M_	P_, M_
Basin Area	BA	BR	BA	BA
Base Flow	-	-	BF	BF
Loss Rate			LE, LM, LU, LS, or LH	LE, LM, LU, LS or LH
Overland Flow Routing			UI, UC, US, UA or UD	UK, RK

*Spatial data management and analysis files

TABLE 10.6

Runoff and Routing Optimization Input Data Options

Type of Data	Runoff Optimization	Routing Optimization
Optimization Control	OU	OR
Basin Characteristics	BA, L_, U_, and BF	
Pattern Hydrograph		QP
Observed Data	P_, M_, QO	QI, QO

TABLE 10.7

Channel and Reservoir Routing Methods Input Data Options
(without spillway and overtopping analysis)

		Modified Puls		
Type of Data	Muskingum	Given Storage Outflow	Normal-Depth Storage Outflow	Kinematic Wave
Routing Control	RM	RS	RS	RK
Storage Discharge Relationships	--	SV/SQ*	--	--
Rating-Curve	--	SQ/SE*	--	--
Channel Hydraulic Characteristics	--	--	RC, RX, RY	RK

* These data may be computed from options listed in Table 10.8

TABLE 10.8

Spillway Routing, Dam Overtopping, and Dam Failure
Input Data Options

	Type of Spillway Analysis			
Type of Data	Given Rating Curve	Weir Coefficients	Trapezoid	Ogee
Routing control	RS	RS, SS	RS, SG	RS, SG
Rating curve input	SQ, SE	--	--	--
Reservoir Area-Storage-Elevation	SA or SV, SE	SA or SV, SE	SA or SV, SE	SA or SV, SE
Spillway and low level outlet specs	SS (first field only)	SS, SL	SS	SS
Trapezoidal and Ogee specs and tailwater	--	--	SG, SQ, SE	SG, SQ, SE
Dam overtopping data	ST** SW, SE***	ST** SW, SE	ST** SW, SE	ST** SW, SE
Dam failure data	SB*	SB*	SB*	SB*

* Required with ST record for dam-break simulations
**Required to obtain special summary printout for spillway adequacy and dam overtopping (ID only)
*** The SW, SE are used for non-level top of dam. The discharges computed with this option are added to discharges computed with the above options.

TABLE 10.9

Flood Damage Analysis Input Data Options

Type of Data	Record Identification
Economic Analysis delimiter	EC
Damage Reach ID	KK
Damage Category	CN, WN*, PN*, TN*
Flow Frequency and Flow Damage Data	FR, QF, DG, QD, or FR, QF, SQ, QS, DG, SQ
Stage Frequency and Stage Damage Data	FR, SR, DG, SD or FR, SF, SQ, QS, DG, QD

* Optional records

TABLE 10.10

Flood Control Project Optimization
Input Data Options

Type of Data	Stream Network Data: Pump	Stream Network Data: Reservoir	Stream Network Data: Diversion	Economic Data: Local Protection Project
Optimization		OS		
Target Penalty		OO		
Discount Factor + Size Constraint	WO	SO	DO	LO
Cost	WC, WD	SD*	DC, DD	LC, LD
Damage Pattern				DU, DL
Degree of Protection				DP

* Used with SE, SA or SV records for storage routing

Table 10.11

Hydrograph Transformation, Comparisons and I/O

	Transformation	Comparison	I/O
Combination	HC		
Adjust hydrograph ordinates	BA or HB		
Local Flow	HL, QO		
Compute Stage	*HQ, HE		
Compare with observations		QO or HL	
Punch			*KO, KF
Read or Write from Scratch Files			*KO or BI

* The use of these options must be in combination with some other hydrograph computation

Section 11

PROGRAM OUTPUT

A large variety and degree of detail in the printer output are available from HEC-1. This section describes the output in terms of input data feedback, intermediate simulation results, summary results, and error messages. The degree of detail of virtually all of the program output can be controlled by the user.

Several of the summary outputs are printed from scratch files generated during the simulation. If the user desires to save these scratch files for use in other jobs (say, for a plotting device), their location can be found in the definition of Input/Output Fortran logical units in Table 13.1 of Section 13.

11.1 Input Data Feedback

The input data file for each job are read and copied to a working file. As the data are copied to the working file they are converted from free format to fixed format (see Section 10.2.1) and a sequence number is assigned to each line. The reformatted data are printed so the user can see the data which are going into the main part of the program.

If a *DIAGRAM record is included in the input set, HEC-1 will plot a diagram of the stream network. The program scans the record identification codes to produce this diagram. B_ records (indicating subbasin runoff) cause a new branch to be added to the diagram. R_ records cause a 'V' to be printed indicating a routing reach. HC records cause a number of branches to be combined indicating a confluence of rivers. DT and DR cause right and left arrows to be printed showing diversion hydrographs leaving and returning to the network, respectively. The stream network diagram also shows how HEC-1 stores hydrographs in the computer memory. As a new branch is added to the diagram a new hydrograph is added to storage. Moving down the page, each hydrograph replaces in the computer memory the one printed above it. Diversion hydrographs are stored on a separate file.

11.2 Intermediate Simulation Results

The data used in each hydrograph computation (KK-record group) can be printed as well as the computed hydrograph, rainfall, storage, etc. as applicable. This output can be controlled by the IO record in general or overridden by the KO record for this specific KK-record group. The KK-record group of data which the program will use in its calculations are printed prior to the calculations. The sources of these data are indicated by the record identification code and line number printed on the left side of the page. The line numbers are keyed to the input data listing printed at the beginning of the job. The line number '0' indicates that no data were provided and default values are being used. Great care should be taken to verify that the intended data are being used in the calculation.

Hydrographs may be printed in tabular form and/or graphed (printer plot) with the date, time, and sequence number for each ordinate. For runoff calculations, rainfall, losses, and excesses are included in the table and plot. For snowmelt calculations, separate values of loss and excess are printed for rainfall and snowmelt. For storage routings, storage and stage (if stage data are given) are printed/plotted along with discharge.

For optimization jobs (unit graph and loss rate, routing, or flood control project sizing), the program prints values for the variables and objective function for each iteration of the process. This output should be carefully reviewed to understand why changes are being made in the variables and to verify (using engineering judgment and comparison with similar results) that the results are reasonable.

11.3 Summary Results

The program produces hydrologic and economic summaries of the computations throughout the river basin. Users can also design their own special summaries using the VS and VV data. The standard program hydrologic summary shows the peak flow (stage) and accumulated drainage area for every hydrograph computation (KK-record group) in the simulation. The summaries may also include peak flows for each plan and ratio in multiplan-multiflood analysis or the peak flows for various durations in the basic stream network analysis. Flood damage summary data show the flood damages and damage reduction benefits (also costs for project optimization) for each damage reach and for the river basin. The river basin damage reduction results may also be summarized by two locational descriptors (say river name and county name) if desired.

11.4 Output to HEC Data Storage System (DSS)

The HEC Data Storage System, DSS (HEC, 1984), may be used to save HEC-1 output information for use in another HEC-1 simualtion or by other HEC computer programs. Time-series data, streamflow or stage, as well as paired-function data, flow-frequency curves, can be output to DSS. The means by which this data can be stored is given in the overview of HEC-1 usage with DSS in Appendix B. Access to DSS is limited to HEC-supported computers, and requires a special version of HEC-1 and DSS software.

11.5 Error Messages

Table 11.1 lists error messages (in capital letters) which HEC-1 will print along with an explanation of the message. Some errors will not cause the program to stop execution, so the user should always check the output for possible errors or warnings. The array dimensions listed in Table 11.1 are those used by HEC-1 on a mainframe computer.

The computer operating system may also print error messages. When an error occurs, the user should first ascertain if it is generated by HEC-1 or by the system. If it is generated by HEC-1, i.e., in the format given in Table 11.1, that table should be referred to and the indicated actions taken. If the error is system generated, the computer center user service and/or the in-house computer systems personnel should be contacted to ascertain the meaning of the error. These errors may be due to incorrectly input or read data or errors in HEC-1 or the computer system. If these system errors cannot be resolved in-house or if there is an error in the HEC-1 program, the HEC should be contacted.

TABLE 11.1

HEC-1 Error Messages

Error No.	Message	Subroutine
1	INVALID RECORD IDENTIFICATION CODE, OR RECORD OUT OF SEQUENCE. Program does not recognize the record identification code in colums 1 and 2. Some records must be read in a designated sequence. Refer to input description and section 10 of users manual. Program allows up to 30 input errors before terminating.	INPUT
2	NUMBER OF ORDINATES CANNOT EXCEED xxx. Number of ordinates, NQ, on IT record must be reduced to the stated limit.	OUTPUT
3	(NPLAN*NTRIO) CANNOT EXCEED xxx AND (NPLAN*NTRIO*NQ) CANNOT EXCEED xxx. Number of plans, ratios, or hydrograph ordinates must be reduced to stated limit.	OUTPUT
4	NO HYDROGRAPH AVAILABLE TO ROUTE. No hydrograph has been given to initiate network diagram.	PREVU
5	TOO MANY HYDROGRAPHS. COMBINE MORE OFTEN. Space for stream network diagram is limited, so maximum number of branches is limited to 9.	PREVU
6	TRIED TO COMBINE MORE HYDROGRAPHS THAN AVAILABLE. Network diagram has fewer branches than are to be combined at this point.	PREVU
7	DIMENSION EXCEEDED ON RECORD NO. nn **xx RECORD **. Too many values were read from given record. Check input description.	ECONO
8	xx RECORD ENCOUNTERED WHEN yy RECORD WAS EXPECTED FOLLOWING RECORD NO. nnn. Record No. nnn indicated that the next record would be a yy record, but an xx record was read instead. A record may be missing or out of sequence.	ECONO
9	QF OR SF RECORD MISSING. New flow- or stage-frequency data are required for each damage reach.	ECONO
10	QD OR SD RECORD MISSING. New flow- or stage-damage data are required for each damage reach.	ECONO
11	SQ RECORD MUST PRECEDE QS RECORD. See input description.	ECONO
12	SQ AND/OR QS MISSING. A stage-flow curve is required to convert flows to stages or vice versa.	ECONO
13	FIRST PLAN AT EACH STATION MUST BE PLAN 1. (EP-RECORD MAY BE MISSING). Damage calculations assume that Plan 1 is the existing condition. Frequencies are given for Plan 1 and flows for the other plans produced by the same ratio are assumed to have the same frequencies. See section 8 of users manual.	ECONO
14	PEAK FLOW/STAGE DATA FOR LOCATION xxxxx NOT FOUND. Station name on KK record is not the same as station name used in hydrologic calculations. When an SF record is used, peak stages must have been calculated in the hydrologic portion of HEC-1	ECONO

TABLE 11.1:
HEC-1 Error Messages (Cont'd)

Error No.	Message	Subroutine
15	INSUFFICIENT DATA FOR STORAGE ROUTING. May also indicate redundant data. Storage routing requires storage and outflow data. With some options stages are required. See input description.	RESOUT
16	ARRAY ON RECORD NO. nnn (xx) EXCEEDS DIMENSION OF KK. Attempted to read more data from xx record than was dimensioned in program.	REDARY
17	NUMBER OF PUMPS EXCEEDS nn. Attempted to read more pump data than dimensioned. For multiplan runs, number of pumps can be reset to zero by reading a blank WP record.	INPUT
18	NO TOTAL-STORM STATION WEIGHTS. Weighting factors are required to average total storm precipitation.	BASIN
19	NO RECORDING STATION WEIGHTS. Weighting factors are required to average temporal distribution of precipitation.	BASIN
20	PRECIPITATION STATION xxxxx NOT FOUND. Station name given on PR or PT record does not match names given on PG records.	BASIN
21	TIME INTERVAL TOO SMALL FOR DURATION OF PMS OR SPS. Standard project storm has a duration of 96 hours. Probable maximum storm duration varies from 24 to 96 hours, depending on given data. The given combination of time interval and storm duration causes the number of ordinates to exceed the program dimensions. Use a larger time interval or shorter storm.	BASIN
22	NO PREVIOUS DIVERSION HYDROGRAPHS HAVE BEEN SAVED. Attempted to retrieve a diversion hydrograph before the diversion has been computed.	DIVERT
23	DIVERSION HYDROGRAPH NOT FOUND FOR STATION xxxxx. Station name on DR record does not match names given on previous DT records.	DIVERT
24	INITIAL VALUES OF TC AND R. For optimization run, given values of TC and R on UC record must both be positive or both negative.	INVAR
25	STATION xxxxx NOT FOUND ON UNIT nn. Station name on BI record does not match names of hydrographs stored on unit nn.	READQ
26	SPILLWAY CREST IS ABOVE MAXIMUM RESERVOIR ELEVATION. Program cannot compute spillway discharge. Maximum reservoir elevation is assumed to be highest stage given with storage data.	RESOUT
27	VARIABLE NUMBER (nn) EXCEEDS SIZE OF VAR ARRAY. Variable numbers given on DO, SO, WO, and LO records must be in the range 1-10.	SETOPT
28	HYDROGRAPH STACK FULL. COMBINE MORE OFTEN. Storage space for hydrographs is full. Required storage can be reduced by using more combining points in the stream network.	STACK
29	ONLY ONE DATA POINT FOR INTERPOLATION. Program cannot interpolate from one piece of data. More ratios or frequencies are required for damage calculations.	AKIMAI

TABLE 11.1:
HEC-1 Error Messages (Cont'd)

Error No.	Message	Subroutine
30	X VALUES ARE NOT UNIQUE AND/OR INCREASING FOR CUBIC SPLINE INTERPOLATION. The cubic spline interpolation routine requires that the independent variable be unique and monotonically increasing, i.e., X_j X_{j-1} for all j.	AKIMA
31	xx RECORD MUST FOLLOW yy RECORD (INPUT LINE NO. nn). An xx record was expected to be after the yy record. See input description for xx and yy records. nn is sequence number of yy record.	INPUT
32	NUMBER OF STORAGE VALUES AND NUMBER OF OUTFLOW VALUES ARE NOT EQUAL. Number of values given on SA or SV records must be the same as the number of flows on the SQ record unless elevations (SE record) are given for both storage and outflow. The number of values is determined by the last non-zero value on the record.	RESOUT
33	PLAN NUMBER (nn) ON KP-RECORD (NO. ii) IS GREATER THAN NUMBER OF PLANS (mm) DECLARED ON JP-RECORD. Number of plans for this run is declared on JP record. Plan number must be a positive integer less or than equal to value on JP record.	INPUT
34	HYDROGRAPH STACK IS EMPTY. Attempted to combine more hydrographs than have been saved (HC record), or attempted to route an upstream hydrograph when no hydrographs have been saved (e.g., RK record with "yes" option in kinematic wave runoff). Use *DIAGRAM record to check stream network.	STACK
35	PLAN NUMBER nn (ON KP-RECORD NO. iii) HAS ALREADY BEEN COMPUTED FOR STATION xxxxxxxxx. Duplicate plan numbers may not be used within a KK record segment of the input set. The plan number is set to 1 when a KK record is read. Only K_ or I record may be present between the KK record and a KP record for plan number 1. This does not preclude the first KP record from being for anyother plan (see input description for KP record).	INPUT
36	ACCUMULATED AREA IS ZERO. ENTER AREA FOR COMBINED HYDROGRAPH IN FIELD 2 OF HC-RECORD. Basin area for a combined hydrograph was calculated as zero. This will result in an error when computing an interpolated hydrograph for the depth-area option (JD-Record). Basin area to be used to calculate the interpolated hydrograph should be entered in Field 2 of the HC Record.	MANE2
37	OPERATION CANNOT BE DETERMINED FROM RECORDS IN KK-RECORD GROUP BEGINNING WITH RECORD NO. XXX. The records specified in a KK-record group were not complete and it is likely that data needs to be specified on additional records.	HEC1

Section 12

EXAMPLE PROBLEMS

This section contains several problems which serve as illustrative examples of various capabilities of HEC-1. The first three example problems illustrate the most basic river basin modeling capabilities. Following these, specialized capabilities of HEC-1 are added to the basic model. The last four examples (9, 10, 11 and 12) are a sequence of steps necessary to perform multiflood, multiplan, flood damage, and flood control project optimization analyses.

12.1 Example Problem #1: Stream Network Model

A stream network model was developed for the Red River watershed shown in Fig. 12.1. The development of this type of model for a watershed is basic to the use of the HEC-1 program. The example demonstrates the following features of the program:

a. Data input conventions.
b. Rainfall specification by non-recording gage, recording gage and gage weighting data.
c. Calculation of runoff hydrographs utilizing loss rate, base flow and unit graph data.
d. Flood hydrograph routing by the channel storage method.
e. Reservoir routing using the spillway and low-level outlet options.
f. Channel bifurcations (man-made or natural) using the diversion option.
g. Input of time-series data at time increments different than the computational time step.

Tables 12.1a-12.1c display data for the watershed model; note that the data record identifiers used to input each type of data are also indicated in the tables. Important points to note about the stream network model data are as follows:

(a) Both recording and non-recording gage stations can be used as total-storm stations for a subbasin as specified on the PT, PW cards. (The total depth associated with incremental or cumulative rainfall data is automatically calculated for each recording gage.) In this example, gage 400 is used only for the temporal pattern. The subbasin storm pattern is calculated as a weighted average of the recording gage storm patterns indicated on the PR, PW cards.

(b) The various unit hydrograph options available can be used with any of the loss rate options. The data in the appropriate HEC-1 format and the results of the computer simulation are displayed in the Table 12.1d computer output.

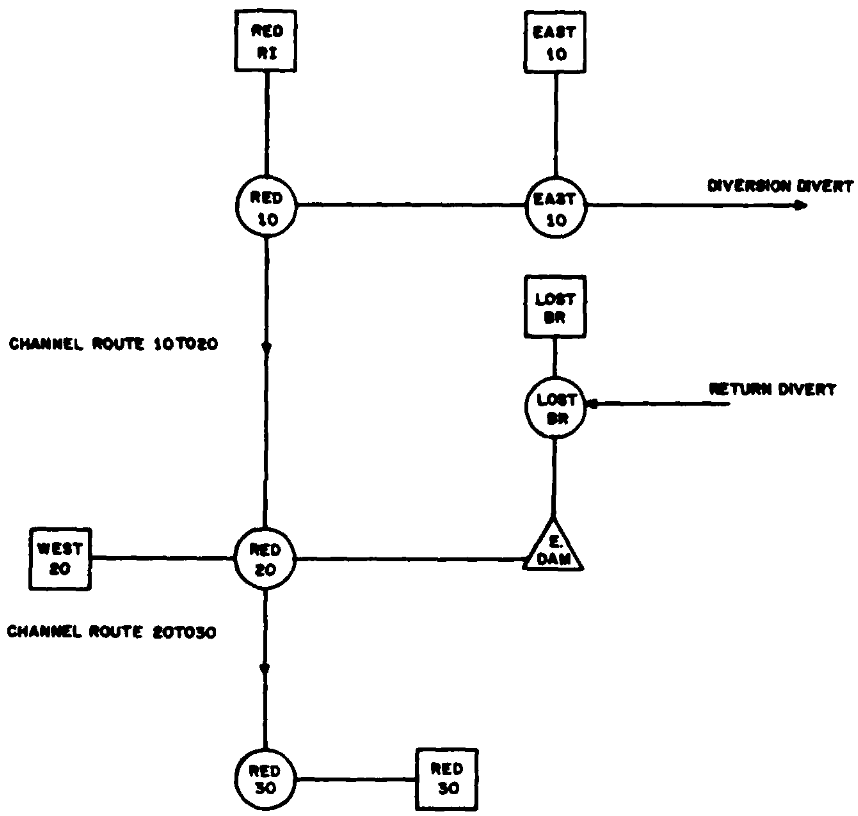


Figure 12.1 Stream Network Model Schematic

TABLE 12.1a

Red River Watershed: Rainfall and Observed Hydrograph Data

Rainfall Data	Record Identifier
Total Storm Data:	PG
Gage # — Storm Depth	
60 — 4.68 inches	
61 — 4.65	
62 — 4.85	
63 — 4.90	
64 — 5.10	
Hourly Precipitation Data: Starting Time: 7:15 AM, Date: June 12, 1968	IN
Station #: 400	PG
Hourly incremental rainfall: .04, .35, .01, .03, .73, .21, .02, .01, .03, .01	PI
Observed Hydrograph Data:	
Station RED30	KK
Observed flow beginning at same time simulation starts, see input data listing. IN card is required preceding the flow data because the data tabulation interval is different than the previous IN card for rainfall.	IN, QO

TABLE 12.1b

SUBBASIN PHYSICAL PARAMETERS (Test 1)

SUBBASIN NAME (KK CARD)	BASIN AREA (SQ MI) (BA CARD)	PRECIPITATION GAGE WEIGHTS (PT, PW CARD) GAGE #	WT.	LOSS RATE (METHOD)	LOSS RATE (CARD)	UNIT GRAPH (METHOD)	UNIT GRAPH (CARD)	BASE FLOW PARAMETERS (BF CARD) STRTQ	QRCSN	RTIOR
RED RI	.82	400 60 61	1 .75 .25	SCS CN=80	LS	SCS LAG=1.47	UD	10.0	-2.5	1.2
EAST10	.66	400 61 62 63	1 .6 .3 .1	EXPON. STRKR=0.6 DLTKR=1.0 RTIOR=1.0 ERAIN=0.0	LE	SNYDER TP=1.3 CP=0.8	US	10.0	-.25	1.2
LOSTBR	.36	400 62 63	1 .5 .5	UNIFORM STRTL=0.3 CNSTL=.04	LU	CLARK TC=0.8 R=1.2	UC	10.0	-.25	1.2
WES120	.80	400 63 64	1 .6 .4	HOLTAN GIA=0.4 SA=0.3 EXP=1.4 FC=.04	LH	SCS LAG=.94	UD	10.0	-.25	1.2
RED30	.19	400 64 63	1 .65 .35	SCS CN=79	LS	SCS LAG=1.04	UD	10.0	-.25	1.2

TABLE 12.1c

Channel Storage Routing And Diversion Data

CHANNEL STORAGE ROUTING											RECORD IDENTIFIER
Reach: 10to20											KK
VOLUME-OUTFLOW DATA											RS
VOLUME:	0	18	36	54	84	110	138	174	228	444	SV
OUTFLOW:	0	500	1000	1500	2150	2600	3000	3450	4000	6000	SQ
Reach: 20to30											KK
VOLUME-OUTFLOW DATA											RS
VOLUME:	0	17	42	67	100	184	274	386	620		SV
OUTFLOW:	0	500	1000	1500	2000	3000	4000	5000	7000		SQ

RESERVOIR ROUTING DATA						RECORD IDENTIFIER
Reservoir: E.DAM						KK
Initial WSEL: 851.2						RS
LOW LEVEL OUTLET						SL
Invert elevation = 851.2 m.s.l.						
Cross-sectional area = 12 sq.ft.						
Discharge coefficient = .6						
Head exponent = .5						
SPILLWAY						SS
Crest elevation = 856 m.s.l.						
Width = 60 feet						
Weir coefficient = 2.7						
Head exponent = 1.5						
VOLUME-ELEVATION DATA						
VOLUME:	21	100	205	325	955	SV
ELEVATION:	850	851.5	853.3	856.5	858.0	SE

DIVERSION DATA						RECORD IDENTIFIER
Location: EAST10						KK
DIVERSION DESIGNATION						DT
Diverted flows labeled: DIVERT						
DIVERTED FLOW DATA						
CHANNEL INFLOW:	0	100	300	600	900	DT
DIVERTED FLOW:	0	25	100	180	270	DQ

TABLE 12.1d

Example Problem #1: Input and Output

```
X     X  XXXXXXX   XXXXX          X
X     X  X        X     X        XX
X     X  X        X               X
XXXXXXX  XXXX     X       XXXXX   X
X     X  X        X               X
X     X  X        X     X         X
X     X  XXXXXXX   XXXXX         XXX
```

THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THE VERSION RELEASED 31JAN85
CONTAINS NEW OPTIONS ON RL AND BA RECORDS, AND ADDS THE HL RECORD. SEE JANUARY 1985 INPUT
DESCRIPTION FOR NEW DEFINITIONS.

```
                                          HEC-1 INPUT                                    PAGE  1

LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1           ID        EXAMPLE PROBLEM NO. 1
  2           ID        STREAM NETWORK MODEL
              *DIAGRAM
  3           IT      15 12JUN68     715      58
  4           IO       5
  5           PG      60    4.68
  6           PG      61    4.65
  7           PG      62    4.85
  8           PG      63    4.90
  9           PG      64    5.10
 10           PG     400       0
 11           IN      60 12JUN68     715
 12           PI     .04     .35     .01     .03     .73     .21     .02     .01     .03     .01

 13           KK   RED RI
 14           KO       4
 15           KM        SCS RUNOFF COMPUTATION
 16           BA     .82
 17           BF    10.0    -.25     1.2
 18           PR     400
 19           PW       1
 20           PT      60      61
 21           PW     .75     .25
 22           LS              80
 23           UD    1.47

 24           KK  EAST10
 25           KO       4
 26           KM        SNYDER UNIT GRAPH COMPUTATION-EXPONENTIAL LOSS RATE
 27           BA     .66
 28           BF    10.0    -.25     1.2
 29           PR     400
 30           PW       1
 31           PT      61      62      63
 32           PW      .6      .3      .1
 33           LE      .6     1.0     1.0       0
 34           US     1.3      .8

 35           KK  EAST10
 36           KM        DIVERT FLOW TO LOSTRR
 37           DT  DIVERT
 38           DI       0     100     300     600     900
 39           DQ       0      25     100     180     270

 40           KK   RED10
 41           KM        COMBINE HYDROGRAPHS FROM SUBBASINS EAST10 AND RED RI
 42           HC       2

 43           KK  10TO20
 44           KO       4
 45           KM        ROUTE FLOWS FROM STATION RED10 TO RED 20
 46           RS       1    FLOW      -1
 47           SV       0      18      36      54      84     110     138     174     228     444
 48           SQ       0     500    1000    1500    2150    2600    3000    3450    4000    6000
```

```
LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  49          KK  LOSTBR
  50          KM       RETRIEVE DIVERSION FROM EAST10
  51          DR  DIVERT

  52          KK  LOSTBR
  53          KM       CLARK UNIT GRAPH COMPUTATION-INITIAL AND UNIFORM LOSS RATES
  54          BA     .36
  55          BF    10.0    -.25     1.2
  56          PR     400
  57          PW       1
  58          PT      62      63
  59          PW      .5      .5
  60          LU      .3     .04
  61          UC     .80     1.2

  62          KK  LOSTBR
  63          KM       COMBINE RUNOFF FROM LOSTBR WITH DIVERTED FLOW
  64          HC       2

  65          KK   E.DAM
  66          KM       ROUTE FLOWS THROUGH DAM
  67          RS       1    ELEV   851.2
  68          SV      21     100     205     325     955
  69          SE     850   851.5   853.3   856.5   858.0
  70          SL   851.2      12      .6      .5
  71          SS     856      60     2.7     1.5

  72          KK  WEST20
  73          KM       SCS RUNOFF COMPUTATION-HOLTAN LOSS RATE
  74          KO       1       2
  75          BA     .80
  76          BF    10.0    -.25     1.2
  77          PR     400
  78          PW       1
  79          PT      63      64
  80          PW      .6      .4
  81          LH     .04      .4      .3     1.4
  82          UD     .94

  83          KK   RED20
  84          KM       COMBINE RUNOFF FROM WEST20,OUTFLOW FROM E.DAM AND REACH 1020
  85          HC       3

  86          KK  20TO30
  87          KM       ROUTE FLOWS FROM RED20 TO RED30
  88          RS       1    FLOW      -1
  89          SV       0      17      42      67     100     184     274     386     620
  90          SQ       0     500    1000    1500    2000    3000    4000    5000    7000

  91          KK   RED30
  92          KM       RUNOFF BY THE SCS METHOD
  93          BA     .19
  94          BF    10.0    -.25     1.2
  95          PR     400
  96          PW       1
  97          PT      64      63
  98          PW     .65     .35
  99          LS              79
 100          UD    1.03

 101          KK   RED30
 102          KM       COMBINE RUNOFF FROM RED30 AND OUTFLOW FROM REACH 20TO30
 103          HC       2

 104          KK    GAGE
 105          KO       1
 106          KM       COMPARE COMPUTED AND OBSERVED HYDROGRAPHS AT RED30
 107          IN      15 12JUN68     715
 108          QO      10      13      16      20      25      30      51      92     159     241
 109          QO     332     399     412     393     348     291     255     229     235     321
 110          QO     472     705     921    1120    1255    1345    1373    1314    1228    1122
 111          QO     996     900     817     742     668     614     549     500     444     409
 112          QO     388     372     359     348     338     328     321     310     300     291
 113          QO     282     274     267     277     252     240     231     224
 114          ZZ
```

```
                SCHEMATIC DIAGRAM OF STREAM NETWORK
INPUT
 LINE      (V) ROUTING          (--->) DIVERSION
  NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED FLOW

  13       RED RI
                .
                .
  24            .      EAST10
                .           .
                .           .
  37            .           .--------> DIVERT
  35            .      EAST10
                .           .
                .           .
  40        RED10.............
                V
                V
  43       10TO20
                .
                .
  51            .           .<-------  DIVERT
  49            .      LOSTBR
                .           .
                .           .
  52            .           .      LOSTBR
                .           .           .
                .           .           .
  62            .      LOSTBR............
                .           V
                .           V
  65            .       E.DAM
                .           .
                .           .
  72            .           .      WEST20
                .           .           .
                .           .           .
  83        RED20.........................
                V
                V
  86       20TO30
                .
                .
  91            .       RED30
                .           .
                .           .
 101        RED30.............
```

```
****************************************                              ****************************************
*                                      *                              *                                      *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                              *   U.S. ARMY CORPS OF ENGINEERS       *
*            FEBRUARY 1981             *                              *   THE HYDROLOGIC ENGINEERING CENTER  *
*          REVISED 14 JUN 85           *                              *        609 SECOND STREET             *
*                                      *                              *      DAVIS, CALIFORNIA 95616         *
*   RUN DATE  2 JUL 85    TIME  13:45:17 *                            *  (916) 440-3285 OR (FTS) 448-3285    *
*                                      *                              *                                      *
****************************************                              ****************************************


                              EXAMPLE PROBLEM NO. 1
                              STREAM NETWORK MODEL

  4 IO        OUTPUT CONTROL VARIABLES
                   IPRNT          5  PRINT CONTROL
                   IPLOT          0  PLOT CONTROL
                   QSCAL          0.  HYDROGRAPH PLOT SCALE
                    DMSG        YES  PRINT DIAGNOSTIC MESSAGES

    IT        HYDROGRAPH TIME DATA
                    NMIN         15  MINUTES IN COMPUTATION INTERVAL
                   IDATE    12JUN68  STARTING DATE
                   ITIME       0715  STARTING TIME
                      NQ         58  NUMBER OF HYDROGRAPH ORDINATES
                  NDDATE    12JUN68  ENDING DATE
                  NDTIME       2130  ENDING TIME

                 COMPUTATION INTERVAL    0.25 HOURS
                      TOTAL TIME BASE   14.25 HOURS

         ENGLISH UNITS
              DRAINAGE AREA          SQUARE MILES
              PRECIPITATION DEPTH    INCHES
              LENGTH, ELEVATION      FEET
              FLOW                   CUBIC FEET PER SECOND
              STORAGE VOLUME         ACRE-FEET
              SURFACE AREA           ACRES
              TEMPERATURE            DEGREES FAHRENHEIT

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** **

         **************
         *            *
 13 KK   *   RED RI   *
         *            *
         **************

 14 KO        OUTPUT CONTROL VARIABLES
                   IPRNT          4  PRINT CONTROL
                   IPLOT          0  PLOT CONTROL
                   QSCAL          0.  HYDROGRAPH PLOT SCALE
                             SCS RUNOFF COMPUTATION

              SUBBASIN RUNOFF DATA

 16 BA        SUBBASIN CHARACTERISTICS
                   TAREA       0.82  SUBBASIN AREA
```

```
17 BF          BASE FLOW CHARACTERISTICS
                     STRTQ        10.00  INITIAL FLOW
                     QRCSN        -0.25  BEGIN BASE FLOW RECESSION
                     RTIOR      1.20000  RECESSION CONSTANT

               PRECIPITATION DATA

20 PT           TOTAL STORM STATIONS        60        61
21 PW                        WEIGHTS      0.75      0.25

18 PR             RECORDING STATIONS       400
19 PW                        WEIGHTS      1.00

22 LS          SCS LOSS RATE
                     STRTL         0.50  INITIAL ABSTRACTION
                    CRVNBR        80.00  CURVE NUMBER
                     RTIMP         0.00  PERCENT IMPERVIOUS AREA

23 UD          SCS DIMENSIONLESS UNITGRAPH
                      TLAG         1.47  LAG

                                                     ***

             PRECIPITATION STATION DATA

                  STATION     TOTAL    AVG. ANNUAL     WEIGHT
                       60      4.68          0.00        0.75
                       61      4.65          0.00        0.25

               TEMPORAL DISTRIBUTIONS

               STATION      400,  WEIGHT =   1.00
                    0.01      0.01      0.01      0.01      0.09      0.09      0.09      0.09      0.00      0.00
                    0.00      0.00      0.01      0.01      0.01      0.01      0.18      0.18      0.18      0.18
                    0.05      0.05      0.05      0.05      0.00      0.00      0.00      0.01      0.00      0.00
                    0.00      0.00      0.01      0.01      0.01      0.01      0.00      0.00      0.00      0.00

                                                   UNIT HYDROGRAPH
                                              31 END-OF-PERIOD ORDINATES
             17.       51.      105.      175.      226.      247.      246.      222.      191.      149.
            110.       85.       66.       52.       40.       31.       24.       19.       14.       11.
              9.        7.        5.        4.        3.        3.        2.        2.        1.        1.
              0.


*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** **


           **************
           *            *
24 KK      *   EAST10   *
           *            *
           **************

25 KO          OUTPUT CONTROL VARIABLES
                     IPRNT            4  PRINT CONTROL
                     IPLOT            0  PLOT CONTROL
                     QSCAL           0.  HYDROGRAPH PLOT SCALE
                               SNYDER UNIT GRAPH COMPUTATION-EXPONENTIAL LOSS RATE

             SUBBASIN RUNOFF DATA

27 BA          SUBBASIN CHARACTERISTICS
                     TAREA         0.66  SUBBASIN AREA
```

```
28 BF          BASE FLOW CHARACTERISTICS
                     STRTQ         10.00  INITIAL FLOW
                     QRCSN         -0.25  BEGIN BASE FLOW RECESSION
                     RTIOR       1.20000  RECESSION CONSTANT

               PRECIPITATION DATA

31 PT           TOTAL STORM STATIONS        61        62        63
32 PW                        WEIGHTS      0.60      0.30      0.10

29 PR             RECORDING STATIONS       400
30 PW                        WEIGHTS      1.00

33 LE          EXPONENTIAL LOSS RATE
                     STRKR          0.60  INITIAL VALUE OF LOSS COEFFICIENT
                     DLTKR          1.00  INITIAL LOSS
                     RTIOL          1.00  LOSS COEFFICIENT RECESSION CONSTANT
                     ERAIN          0.00  EXPONENT OF PRECIPITATION
                     RTIMP          0.00  PERCENT IMPERVIOUS AREA

34 US          SNYDER UNITGRAPH
                        TP          1.30  LAG
                        CP          0.80  PEAKING COEFFICIENT

               SYNTHETIC ACCUMULATED-AREA VS. TIME CURVE WILL BE USED

                                                         ***

             PRECIPITATION STATION DATA

                    STATION     TOTAL    AVG. ANNUAL    WEIGHT
                         61      4.65         0.00        0.60
                         62      4.85         0.00        0.30
                         63      4.90         0.00        0.10

               TEMPORAL DISTRIBUTIONS

               STATION      400,  WEIGHT =   1.00
                    0.01      0.01      0.01      0.01      0.09      0.09      0.09      0.09      0.00      0.00
                    0.00      0.00      0.01      0.01      0.01      0.01      0.18      0.18      0.18      0.18
                    0.05      0.05      0.05      0.05      0.00      0.00      0.00      0.01      0.00      0.00
                    0.00      0.00      0.01      0.01      0.01      0.01      0.00      0.00      0.00      0.00

                                               UNIT HYDROGRAPH PARAMETERS
                                          CLARK    TC=  1.81 HR,       R=  0.55 HR
                                         SNYDER    TP=  1.29 HR,      CP=  0.79

                                                    UNIT HYDROGRAPH
                                               16 END-OF-PERIOD ORDINATES
             23.       79.      146.      210.      252.      261.      238.      181.      116.       73.
             46.       29.       18.       12.        7.        5.


*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***


           **************
           *            *
43 KK      *   10TO20   *
           *            *
           **************

44 KO          OUTPUT CONTROL VARIABLES
                     IPRNT             4  PRINT CONTROL
```

```
                    IPLOT          0  PLOT CONTROL
                    QSCAL          0.  HYDROGRAPH PLOT SCALE
                               ROUTE FLOWS FROM STATION RED10 TO RED 20

                HYDROGRAPH ROUTING DATA

 46 RS            STORAGE ROUTING
                    NSTPS           1  NUMBER OF SUBREACHES
                     ITYP        FLOW  TYPE OF INITIAL CONDITION
                   RSVRIC       -1.00  INITIAL CONDITION
                        X        0.00 WORKING R AND D COEFFICIENT

 47 SV              STORAGE       0.0      18.0      36.0      54.0      84.0     110.0     138.0     174.0     228.0     444.0

 48 SQ            DISCHARGE        0.      500.     1000.     1500.     2150.     2600.     3000.     3450.     4000.     6000.

                                                  ***

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

             **************
             *            *
 72 KK       *   WEST20   *
             *            *
             **************

 74 KO            OUTPUT CONTROL VARIABLES
                    IPRNT           1  PRINT CONTROL
                    IPLOT           2  PLOT CONTROL
                    QSCAL          0.  HYDROGRAPH PLOT SCALE

                SUBBASIN RUNOFF DATA

 75 BA            SUBBASIN CHARACTERISTICS
                    TAREA        0.80  SUBBASIN AREA

 76 BF            BASE FLOW CHARACTERISTICS
                    STRTQ       10.00  INITIAL FLOW
                    QRCSN       -0.25  BEGIN BASE FLOW RECESSION
                    RTIOR     1.20000  RECESSION CONSTANT

                  PRECIPITATION DATA

 79 PT             TOTAL STORM STATIONS        63        64
 80 PW                          WEIGHTS      0.60      0.40

 77 PR               RECORDING STATIONS       400
 78 PW                          WEIGHTS      1.00

 81 LH            HOLTAN LOSS RATE
                       FC        0.04  DEEP PERCOLATION RATE
                      GIA        0.40  COEFFICIENT OF SA
                       SA        0.30  DEPTH OF AVAILABLE STORAGE
                     BEXP        1.40  EXPONENT OF SA
                    RTIMP        0.00  PERCENT IMPERVIOUS AREA

 82 UD            SCS DIMENSIONLESS UNITGRAPH
                     TLAG        0.94  LAG

                                                  ***
```

PRECIPITATION STATION DATA

STATION	TOTAL	AVG. ANNUAL	WEIGHT
63	4.90	0.00	0.60
64	5.10	0.00	0.40

TEMPORAL DISTRIBUTIONS

STATION 400, WEIGHT = 1.00

0.01	0.01	0.01	0.01	0.09	0.09	0.09	0.09	0.00	0.00
0.00	0.00	0.01	0.01	0.01	0.01	0.18	0.18	0.18	0.18
0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.01	0.00	0.00
0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00

UNIT HYDROGRAPH
21 END-OF-PERIOD ORDINATES

48.	153.	299.	361.	343.	280.	188.	125.	87.	59.
40.	27.	19.	13.	9.	6.	4.	3.	2.	1.
0.									

****

HYDROGRAPH AT STATION WEST20

****

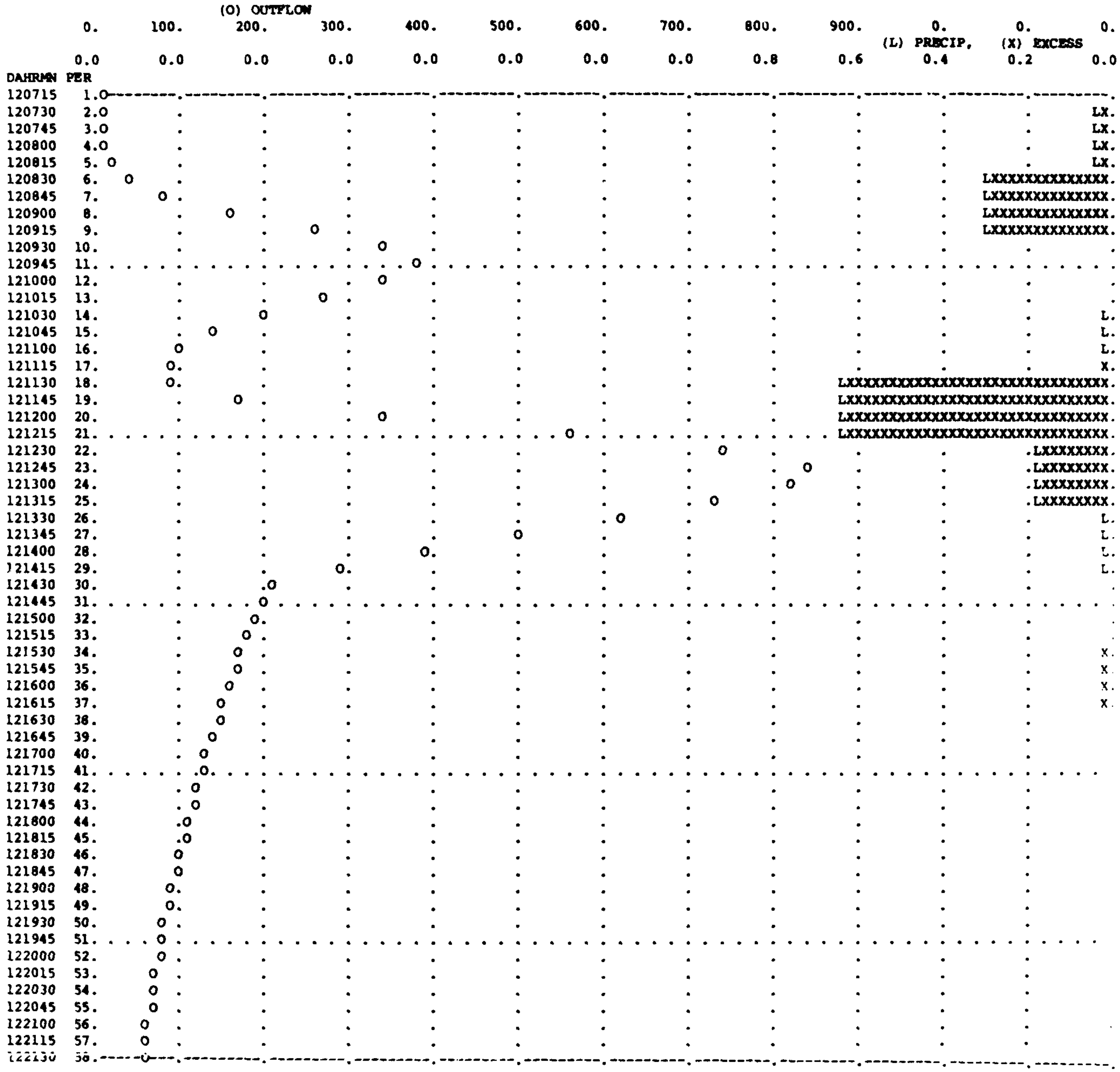
DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	*	DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q
12	JUN	0715	1	0.00	0.00	0.00	10.	*	12	JUN	1430	30	0.01	0.01	0.00	211.
12	JUN	0730	2	0.03	0.02	0.01	10.	*	12	JUN	1445	31	0.01	0.01	0.00	200.
12	JUN	0745	3	0.03	0.02	0.01	11.	*	12	JUN	1500	32	0.01	0.01	0.00	192.
12	JUN	0800	4	0.03	0.02	0.01	15.	*	12	JUN	1515	33	0.01	0.01	0.00	183.
12	JUN	0815	5	0.03	0.02	0.01	19.	*	12	JUN	1530	34	0.03	0.01	0.01	175.
12	JUN	0830	6	0.30	0.02	0.28	36.	*	12	JUN	1545	35	0.03	0.01	0.01	167.
12	JUN	0845	7	0.30	0.02	0.28	81.	*	12	JUN	1600	36	0.03	0.01	0.01	160.
12	JUN	0900	8	0.30	0.02	0.28	164.	*	12	JUN	1615	37	0.03	0.01	0.01	152.
12	JUN	0915	9	0.30	0.02	0.29	263.	*	12	JUN	1630	38	0.01	0.01	0.00	146.
12	JUN	0930	10	0.01	0.01	0.00	344.	*	12	JUN	1645	39	0.01	0.01	0.00	139.
12	JUN	0945	11	0.01	0.01	0.00	377.	*	12	JUN	1700	40	0.01	0.01	0.00	133.
12	JUN	1000	12	0.01	0.01	0.00	343.	*	12	JUN	1715	41	0.01	0.01	0.00	127.
12	JUN	1015	13	0.01	0.01	0.00	275.	*	12	JUN	1730	42	0.00	0.00	0.00	121.
12	JUN	1030	14	0.03	0.02	0.01	201.	*	12	JUN	1745	43	0.00	0.00	0.00	115.
12	JUN	1045	15	0.03	0.02	0.01	139.	*	12	JUN	1800	44	0.00	0.00	0.00	111.
12	JUN	1100	16	0.03	0.02	0.01	99.	*	12	JUN	1815	45	0.00	0.00	0.00	106.
12	JUN	1115	17	0.03	0.02	0.01	91.	*	12	JUN	1830	46	0.00	0.00	0.00	101.
12	JUN	1130	18	0.63	0.02	0.62	87.	*	12	JUN	1845	47	0.00	0.00	0.00	97.
12	JUN	1145	19	0.63	0.01	0.62	168.	*	12	JUN	1900	48	0.00	0.00	0.00	[illegible]
12	JUN	1200	20	0.63	0.01	0.62	343.	*	12	JUN	1915	49	0.00	0.00	0.00	[illegible]
12	JUN	1215	21	0.63	0.01	0.62	556.	*	12	JUN	1930	50	0.00	0.00	0.00	[illegible]
12	JUN	1230	22	0.18	0.01	0.17	740.	*	12	JUN	1945	51	0.00	0.00	0.00	[illegible]
12	JUN	1245	23	0.18	0.01	0.17	839.	*	12	JUN	2000	52	0.00	0.00	0.00	77
12	JUN	1300	24	0.18	0.01	0.17	817.	*	12	JUN	2015	53	0.00	0.00	0.00	74.
12	JUN	1315	25	0.18	0.01	0.17	729.	*	12	JUN	2030	54	0.00	0.00	0.00	70.
12	JUN	1330	26	0.02	0.02	0.00	619.	*	12	JUN	2045	55	0.00	0.00	0.00	67.
12	JUN	1345	27	0.02	0.01	0.01	503.	*	12	JUN	2100	56	0.00	0.00	0.00	64.
12	JUN	1400	28	0.02	0.01	0.01	393.	*	12	JUN	2115	57	0.00	0.00	0.00	61.
12	JUN	1415	29	0.02	0.01	0.01	294.	*	12	JUN	2130	58	0.00	0.00	0.00	59.
								*				SUM	4.98	0.55	4.43	

****

PEAK FLOW	TIME		MAXIMUM AVERAGE FLOW			
(CFS)	(HR)		6-HR	24-HR	72-HR	14.25-HR
839.	5.50	(CFS)	367.	210.	210.	210.
		(INCHES)	4.265	5.803	5.803	5.803
		(AC-FT)	182.	248.	248.	248.

CUMULATIVE AREA = 0.80 SQ MI

STATION WEST20



```
104 KK       *    GAGE  *

105 KO          OUTPUT CONTROL VARIABLES
                     IPRNT             1  PRINT CONTROL
                     IPLOT             0  PLOT CONTROL
                     QSCAL            0.  HYDROGRAPH PLOT SCALE
                               COMPARE COMPUTED AND OBSERVED HYDROGRAPHS AT RED30

107 IN          TIME DATA FOR INPUT TIME SERIES
                     JXMIN            15  TIME INTERVAL IN MINUTES
                    JXDATE       12JUN68  STARTING DATE
                    JXTIME           715  STARTING TIME
```

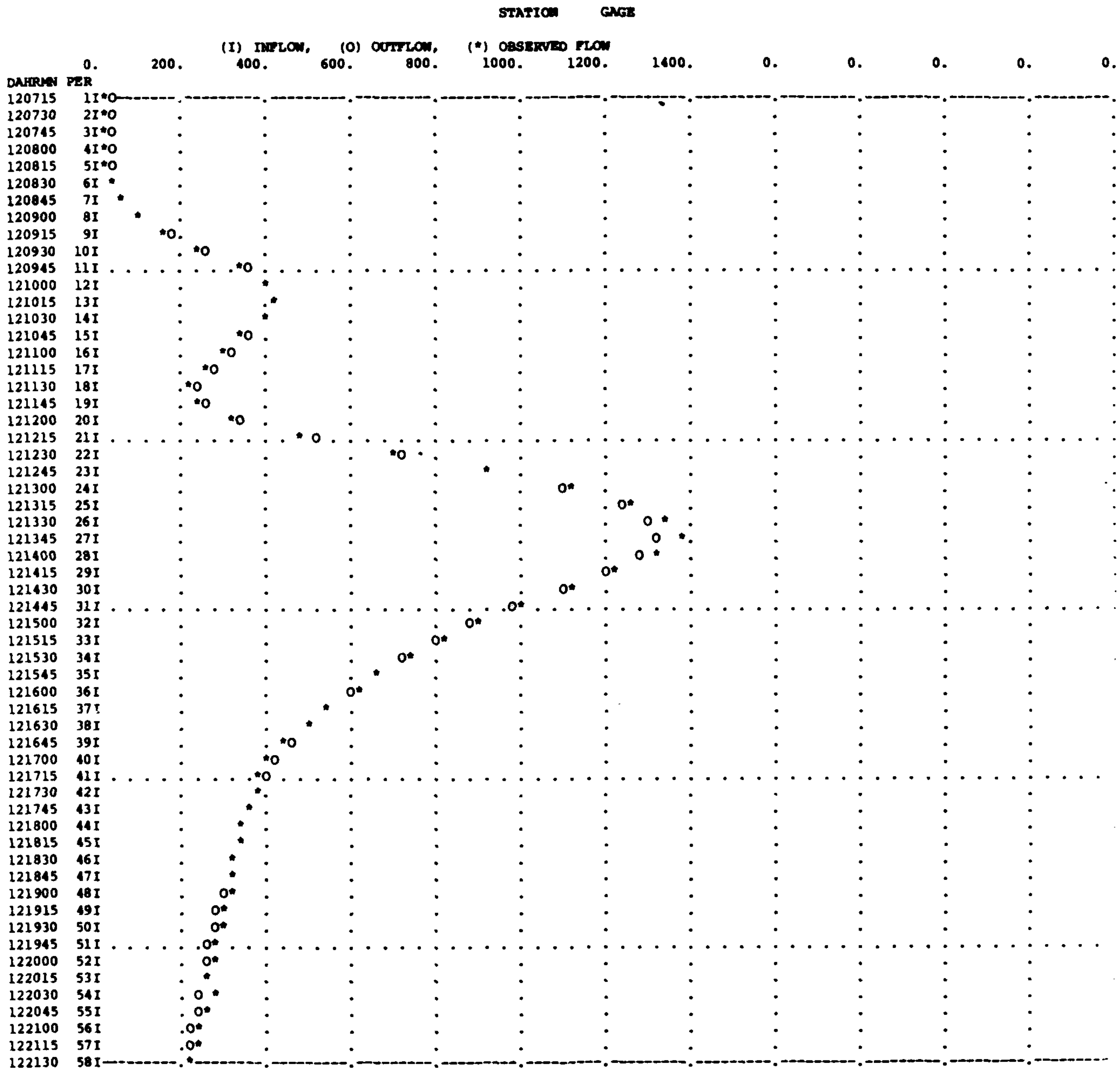
COMPARISON OF COMPUTED AND OBSERVED HYDROGRAPHS

	SUM OF FLOWS	EQUIV DEPTH	MEAN FLOW	TIME TO CENTER OF MASS	LAG C.M. TO C.M.	PEAK FLOW	TIME OF PEAK
COMPUTED HYDROGRAPH	27067.	3.705	467.	7.63	7.63	1331.	6.50
OBSERVED HYDROGRAPH	26768.	3.664	462.	7.75	7.75	1373.	6.50
DIFFERENCE	299.	0.041	5.	-0.12	-0.12	-42.	0.00
PERCENT DIFFERENCE	1.12				-1.59	-3.09	

STANDARD ERROR	21.	AVERAGE ABSOLUTE ERROR	18.
OBJECTIVE FUNCTION	22.	AVERAGE PERCENT ABSOLUTE ERROR	18.56

HYDROGRAPH AT STATION GAGE

DA	MON	HRMN	ORD	COMP Q	OBS Q	RESIDUL	DA	MON	HRMN	ORD	COMP Q	OBS Q	RESIDUL	DA	MON	HRMN	ORD	COMP Q	OBS Q	RESIDUL
12	JUN	0715	1	38.	10.	28.	12	JUN	1215	21	536.	472.	64.	12	JUN	1715	41	401.	388.	13.
12	JUN	0730	2	37.	13.	24.	12	JUN	1230	22	731.	705.	26.	12	JUN	1730	42	382.	372.	10.
12	JUN	0745	3	37.	16.	21.	12	JUN	1245	23	937.	921.	16.	12	JUN	1745	43	365.	359.	6.
12	JUN	0800	4	38.	20.	18.	12	JUN	1300	24	1119.	1120.	-1.	12	JUN	1800	44	350.	348.	2.
12	JUN	0815	5	40.	25.	15.	12	JUN	1315	25	1249.	1255.	-6.	12	JUN	1815	45	336.	338.	-2.
12	JUN	0830	6	46.	30.	16.	12	JUN	1330	26	1318.	1345.	-27.	12	JUN	1830	46	324.	328.	-4.
12	JUN	0845	7	64.	51.	13.	12	JUN	1345	27	1331.	1373.	-42.	12	JUN	1845	47	312.	321.	-9.
12	JUN	0900	8	106.	92.	14.	12	JUN	1400	28	1290.	1314.	-24.	12	JUN	1900	48	301.	310.	-9.
12	JUN	0915	9	178.	159.	19.	12	JUN	1415	29	1210.	1228.	-18.	12	JUN	1915	49	290.	300.	-10.
12	JUN	0930	10	270.	241.	29.	12	JUN	1430	30	1100.	1122.	-22.	12	JUN	1930	50	280.	291.	-11.
12	JUN	0945	11	359.	332.	27.	12	JUN	1445	31	987.	996.	-9.	12	JUN	1945	51	270.	282.	-12.
12	JUN	1000	12	418.	399.	19.	12	JUN	1500	32	890.	900.	-10.	12	JUN	2000	52	261.	274.	-13.
12	JUN	1015	13	435.	412.	23.	12	JUN	1515	33	806.	817.	-11.	12	JUN	2015	53	252.	267.	-15.
12	JUN	1030	14	417.	393.	24.	12	JUN	1530	34	731.	742.	-11.	12	JUN	2030	54	243.	277.	-34.
12	JUN	1045	15	378.	348.	30.	12	JUN	1545	35	662.	668.	-6.	12	JUN	2045	55	235.	252.	-17.
12	JUN	1100	16	330.	291.	39.	12	JUN	1600	36	602.	614.	-12.	12	JUN	2100	56	227.	240.	-13.
12	JUN	1115	17	289.	255.	34.	12	JUN	1615	37	551.	549.	2.	12	JUN	2115	57	220.	231.	-11.
12	JUN	1130	18	261.	229.	32.	12	JUN	1630	38	502.	500.	2.	12	JUN	2130	58	213.	224.	-11.
12	JUN	1145	19	270.	235.	35.	12	JUN	1645	39	458.	444.	14.							
12	JUN	1200	20	358.	321.	37.	12	JUN	1700	40	426.	409.	17.							


STATION GAGE
(I) INFLOW, (O) OUTFLOW, (*) OBSERVED FLOW
0. 200. 400. 600. 800. 1000. 1200. 1400. 0. 0. 0. 0. 0.
DAHRMN PER
120715 1I
120730 2I
120745 3I
120800 4I
120815 5I
120830 6I
120845 7I
120900 8I
120915 9I
120930 10I
120945 11I
121000 12I
121015 13I
121030 14I
121045 15I
121100 16I
121115 17I
121130 18I
121145 19I
121200 20I
121215 21I
121230 22I
121245 23I
121300 24I
121315 25I
121330 26I
121345 27I
121400 28I
121415 29I
121430 30I
121445 31I
121500 32I
121515 33I
121530 34I
121545 35I
121600 36I
121615 37I
121630 38I
121645 39I
121700 40I
121715 41I
121730 42I
121745 43I
121800 44I
121815 45I
121830 46I
121845 47I
121900 48I
121915 49I
121930 50I
121945 51I
122000 52I
122015 53I
122030 54I
122045 55I
122100 56I
122115 57I
122130 58I

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
HYDROGRAPH AT	RED RI	460.	6.25	221.	116.	116.	0.82		
HYDROGRAPH AT	EAST10	442.	5.75	174.	100.	100.	0.66		
DIVERSION TO	DIVERT	138.	5.75	52.	29.	29.	0.66		
HYDROGRAPH AT	EAST10	304.	5.75	122.	71.	71.	0.66		
2 COMBINED AT	RED10	740.	6.00	341.	188.	188.	1.48		
ROUTED TO	10TO20	667.	6.50	339.	186.	186.	1.48		
HYDROGRAPH AT	LOSTBR	138.	5.75	52.	29.	29.	0.00		
HYDROGRAPH AT	LOSTBR	309.	5.50	149.	85.	85.	0.36		
2 COMBINED AT	LOSTBR	436.	5.50	200.	114.	114.	0.36		
ROUTED TO	E.DAM	68.	10.00	67.	47.	47.	0.36	852.69	10.00
HYDROGRAPH AT	WEST20	839.	5.50	367.	210.	210.	0,80		
3 COMBINED AT	RED20	1378.	6.00	733.	444.	444.	2.64		
ROUTED TO	20TO30	1224.	6.50	729.	439.	439.	2.64		
HYDROGRAPH AT	RED30	143.	5.75	61.	34.	34.	0.19		
2 COMBINED AT	RED30	1331.	6.50	789.	473.	473.	2.83		

12.2 Example Problem #2: Kinematic Wave Watershed Model

The use of the kinematic wave option is demonstrated in the development of a model for the Smith River Watershed. A schematic diagram of the watershed model is shown in Fig. 12.2.

The input data for the watershed are displayed in Tables 12.2a - 12.2c. The HEC-1 data model for the basin is shown in Table 12.2d. There are a number of important points to note about the data:

(1) Each subbasin has data for two overland flow elements (only one is required) which is specified on the UK card. The two elements represent separately the impervious and pervious areas of a subbasin.

(2) Collector channel and main channel data are specified on the RK card for each subbasin. As many as two collector channels can be specified for each subbasin, however, only one collector channel was used in this example.

(3) The infiltration data is specified only once, on the LS card, for subbasin sub 1. The infiltration data on this card is assumed to apply for all subsequent runoff computations by program input convention.

The simulation results are displayed in Table 12.2d following the input listing.

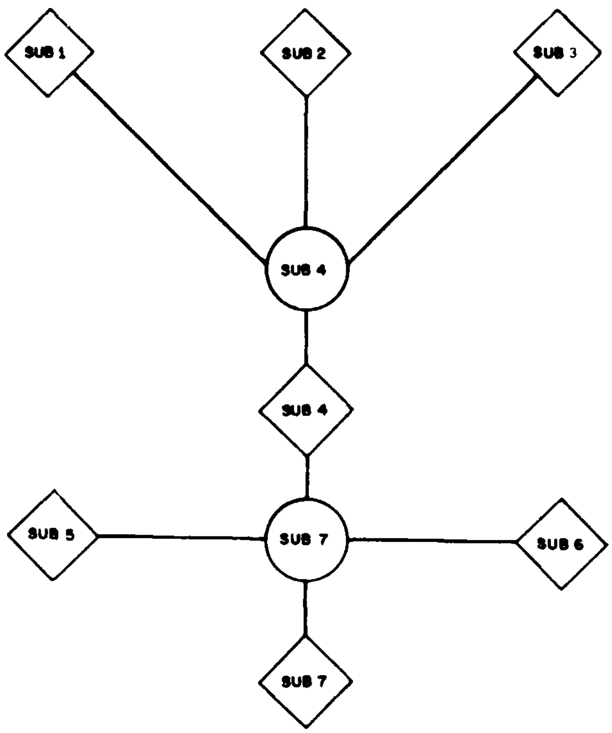


Figure 12.2 Kinematic Wave Model Schematic

TABLE 12.2a

Subbasin Characteristics

SUBBASIN DATA	OVERLAND FLOW PLANE DATA (UK RECORD) O.F. LENGTH (ft.)	O.F. SLOPE (ft/ft)	MANNING N	% SUBBASIN AREA	DRAIN AREA (sq. mi.)	LOSS RATE (LS RECORD) SCS CURVE NUMBER
SUB 1						
Imp Catchment	100	.03	.24	15	1.43	98
Perv Catchment	190	.02	.35	85		85
SUB 2						
Imp Catchment	100	.05	.24	15	.67	98
Perv Catchment	190	.03	.35	85		85
SUB 3						
Imp Catchment	100	.05	.24	15	.56	98
Perv Catchment	190	.03	.35	85		85
SUB 4						
Imp Catchment	100	.03	.24	15	1.83	98
Perv Catchment	190	.015	.35	85		85
SUB 5						
Imp Catchment	100	.05	.24	20	.67	98
Perv Catchment	220	.028	.35	80		85
SUB 6						
Imp Catchment	100	.03	.24	20	1.43	98
Perv Catchment	200	.02	.35	80		85
SUB 7						
Imp Catchment	100	.06	.24	15	.96	98
Perv Catchment	190	.03	.35	85		85

TABLE 12.2b

CHANNEL DATA (Test 2)
(RK RECORD)

SUBBASIN	LENGTH (ft)	SLOPE (ft/ft)	MANNING N	AREA (sq mi)	SHAPE	WIDTH (ft)	SIDE SLOPE (ft/ft)	UPSTREAM INFLOW
SUB 1								
COLLECTOR CHANNEL	2000	.008	.02	.45	TRAP	0	1	—
MAIN CHANNEL	13500	.004	.08		TRAP	2	2	no
SUB 2								
COLLECTOR CHANNEL	2400	.01	.02	.39	TRAP	0	1	—
MAIN CHANNEL	6500	.008	.08	—	TRAP	2	2	no
SUB 3								
COLLECTOR CHANNEL	1600	.019	.02	.35	TRAP	0	1	
MAIN CHANNEL	6500	.012	.08	—	TRAP	2	2	
SUB 4								
COLLECTOR CHANNEL	2500	.01	.02	.79	TRAP	0	1	—
MAIN CHANNEL	12000	.007	.05	—	TRAP	50	2	yes
SUB 5								
COLLECTOR CHANNEL	2000	.013	.02	.42	TRAP	0	1	—
MAIN CHANNEL	8000	.01	.05	—	TRAP	8	3	no
SUB 6								
COLLECTOR CHANNEL	2200	.011	.02	.55	TRAP	0	1	—
MAIN CHANNEL	14000	.005	.09	—	TRAP	2	2	no
SUB 7								
COLLECTOR CHANNEL	2100	.024	.02	.74	TRAP	0	1	—
MAIN CHANNEL	7000	.011	.05		TRAP	50	3	yes

TABLE 12.2c

Precipitation Data

NON RECORDING GAGE DATA		RECORD IDENFIFIERS
GAGE #	DEPTH (in)	PG
1	1.96	
2	1.68	
3	2.73	
4	2.56	
5	2.52	

SUBBASIN GAGE WEIGHTS — PR, PT, PW

SUBBASIN	RECORDING		TOTAL	
	GAGE #	WT.	GAGE #	WT.
SUB 1	10	1	1	.75
			3	.25
SUB 2	10	1	1	.75
			2	.25
SUB 3	20	1	2	1
SUB 4	40	1	2	.05
			3	.40
			4	.50
			5	.05
SUB 5	40	1	2	.2
			4	.8
SUB 6	40	1	4	1
SUB 7	50	1	5	1

TABLE 12.2d

Example Problem #2: Input and Output

HEC-1 INPUT PAGE 1

LINE	ID	1	2	3	4	5	6	7	8	9	10
1	ID	EXAMPLE PROBLEM NO. 2									
2	ID	KINEMATIC WAVE WATERSHED MODEL									
3	IT	15			60						
4	IO	5									
5	PG	1	1.96								
6	PG	2	1.68								
7	PG	3	2.73								
8	PG	4	2.56								
9	PG	4	2.56								
10	PG	5	2.52								
11	PG	10									
12	PI	.00	.01	.00	.00	0.	0.	0.	0.	.01	.01
13	PI	.01	.01	.01	.01	.01	.01	.03	.03	.03	.03
14	PI	.08	.08	.08	.08	.23	.15	.05	.02	.08	.22
15	PI	.23	.20	.09	.01	.02	.05	.01	.01	0.	0.
16	PI	0.	0.	0.	0.	0.	0.	0.	0.	.01	.01
17	PI	.00	.01	.01	.01	.00	.01	0.	0.	0.	0.
18	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
19	PI	0.	0.								
20	PG	20									
21	PI	.01	.01	.01	.01	.01	.01	0.	0.	.01	.01
22	PI	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
23	PI	.02	.02	.02	.02	.01	.02	.01	.01	.01	.20
24	PI	.72	.33	.05	.02	.04	.02	.01	.01	.01	.01
25	PI	.01	.01	.01	.01	.01	.01	.00	.01	.01	.00
26	PI	.01	.01	.00	.01	.00	.01	0.	0.	0.	0.
27	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
28	PI	0.	0.								
29	PG	30									
30	PI	.02	.02	.02	.02	.03	.03	.00	0.	.00	.00
31	PI	.00	.00	.00	.00	.00	.00	.06	.06	.06	.06
32	PI	.15	.15	.15	.15	.20	.04	.01	.15	.28	.28
33	PI	.33	.31	.01	.06	.04	.02	0.	0.	.01	.01
34	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
35	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
36	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
37	PI	0.	0.								
38	PG	40	0.								
39	PI	.04	.04	0.	0.	.03	.03	.00	0.	.01	.01
40	PI	.01	.01	.01	.01	.01	.01	.03	.03	.03	.03
41	PI	.15	.15	.15	.15	.13	.02	.01	.04	.08	.17
42	PI	.37	.40	.30	.03	.02	.03	.01	.01	0.	0.
43	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
44	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
45	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
46	PI	0.	0.								
47	PG	50									
48	PI	0.	0.	.03	.03	0.	0.	.01	.01	.01	.01
49	PI	.01	.01	.01	.01	.01	.01	.04	.04	.04	.04
50	PI	.11	.11	.11	.11	.15	.04	.02	.04	.06	.16
51	PI	.28	.45	.41	.04	.02	.03	0.	0.	.03	.02
52	PI	.00	.01	.00	.00	0.	0.	0.	0.	0.	0.
53	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
54	PI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
55	PI	0.	0.								
56	KK	SUB1									
57	KM	RUNOFF FROM SUBBASIN 1									
58	KO	1									
59	PR	10									
60	PW	1									
61	PT	1	3								
62	PW	.75	.25								
63	BA	1.43									
64	LS		98			85					
65	UK	100	.03	.24	15						
66	UK	190	.02	.35	85						
67	RK	2000	.008	.02	.45	TRAP	0	1			
68	RK	13500	.004	.08		TRAP	2	2			

```
LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  69          KK    SUB2
  70          KM         RUNOFF FROM SUBBASIN 2
  71          PR      10
  72          PW       1
  73          PT       1       2
  74          PW     .75     .25
  75          BA     .67
  76          UK     100     .05     .24      15
  77          UK     190     .03     .35      85
  78          RK    2400     .01     .02     .39    TRAP       0       1
  79          RK    6500    .008     .08            TRAP       2       2

  80          KK    SUB3
  81          KM         RUNOFF FROM SUBBASIN 3
  82          BA     .56
  83          PR      20
  84          PW       1
  85          PT       2
  86          PW       1
  87          UK     100     .05     .24      15
  88          UK     190     .03     .35      85
  89          RK    1600    .019     .02     .35    TRAP       0       1
  90          RK    6500    .012     .08            TRAP       2       2

  91          KK    SUB4
  92          KM         COMBINE RUNOFF FROM SUB1, SUB2 AND SUB3
  93          HC       3

  94          KK    SUB4
  95          KM         RUNOFF FROM SUBBASIN 4
  96          PR      40
  97          PW       1
  98          PT       2       3       4       5
  99          PW     .05     .40     .50     .05
 100          BA    1.83
 101          UK     100     .03     .24      15
 102          UK     190    .015     .35      85
 103          RK    2500     .01     .02     .79    TRAP       0       1
 104          RK   12000    .007     .05            TRAP      50       2     YES

 105          KK    SUB5
 106          KM         RUNOFF FROM SUBBASIN 5
 107          PR      40
 108          PW       1
 109          PT       2       4
 110          PW      .2      .8
 111          BA     .67
 112          UK     100     .05     .24      20
 113          UK     220    .028     .35      80
 114          RK    2000    .013     .02     .42    TRAP       0       1
 115          RK    8000     .01     .05            TRAP       8       3

 116          KK    SUB6
 117          KM         RUNOFF FROM SUBBASIN 6
 118          PR      40
 119          PW       1
 120          PT       4
 121          PW       1
 122          BA    1.43
 123          UK     100     .03     .24      20
 124          UK     200     .02     .35      80
 125          RK    2200    .011     .02     .55    TRAP       0       1
 126          RK   14000    .005     .09            TRAP       2       2

 127          KK    SUB7
 128          KM         COMBINE RUNOFF FROM SUB4, SUB5, AND SUB6
 129          HC       3

 130          KK    SUB7
 131          KM         RUNOFF FROM SUB7 AND UPSTREAM INFLOW
 132          PR      50
 133          PW       1
 134          PT       5
 135          PW       1
 136          BA     .96
 137          UK     100     .06     .24      15
 138          UK     190     .03     .35      85
 139          RK    2100    .024    .020     .74    TRAP       0       1
 140          RK    7000    .011    .050            TRAP      50       3     YES
 141          ZZ
```

```
****************************************                    ****************************************
*                                      *                    *                                      *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                    *   U.S. ARMY CORPS OF ENGINEERS       *
*          FEBRUARY 1981               *                    * THE HYDROLOGIC ENGINEERING CENTER    *
*        REVISED 14 JUN 85             *                    *      609 SECOND STREET               *
*                                      *                    *    DAVIS, CALIFORNIA 95616           *
* RUN DATE  2 JUL 85    TIME  13:45:17 *                    * (916) 440-3285 OR (FTS) 448-3285     *
*                                      *                    *                                      *
****************************************                    ****************************************


                         EXAMPLE PROBLEM NO. 2
                         KINEMATIC WAVE WATERSHED MODEL

  4 IO        OUTPUT CONTROL VARIABLES
                    IPRNT           5  PRINT CONTROL
                    IPLOT           0  PLOT CONTROL
                    QSCAL          0.  HYDROGRAPH PLOT SCALE
                     DMSG         YES  PRINT DIAGNOSTIC MESSAGES

    IT        HYDROGRAPH TIME DATA
                     NMIN          15  MINUTES IN COMPUTATION INTERVAL
                    IDATE      1    0  STARTING DATE
                    ITIME        0000  STARTING TIME
                       NQ          60  NUMBER OF HYDROGRAPH ORDINATES
                   NDDATE      1    0  ENDING DATE
                   NDTIME        1445  ENDING TIME

               COMPUTATION INTERVAL    0.25 HOURS
                    TOTAL TIME BASE   14.75 HOURS

         ENGLISH UNITS
             DRAINAGE AREA          SQUARE MILES
             PRECIPITATION DEPTH    INCHES
             LENGTH, ELEVATION      FEET
             FLOW                   CUBIC FEET PER SECOND
             STORAGE VOLUME         ACRE-FEET
             SURFACE AREA           ACRES
             TEMPERATURE            DEGREES FAHRENHEIT


*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

          **************
          *            *
 56 KK    *    SUB1    *
          *            *
          **************

 58 KO        OUTPUT CONTROL VARIABLES
                    IPRNT           1  PRINT CONTROL
                    IPLOT           0  PLOT CONTROL
                    QSCAL          0.  HYDROGRAPH PLOT SCALE

             SUBBASIN RUNOFF DATA

 63 BA        SUBBASIN CHARACTERISTICS
                    TAREA        1.43  SUBBASIN AREA
```

```
                    PRECIPITATION DATA

61 PT          TOTAL STORM STATIONS        1         3
62 PW                       WEIGHTS     0.75      0.25

59 PR            RECORDING STATIONS       10
60 PW                       WEIGHTS     1.00

64 LS          SCS LOSS RATE
                  STRTL          0.04  INITIAL ABSTRACTION
                 CRVNBR         98.00  CURVE NUMBER
                  RTIMP          0.00  PERCENT IMPERVIOUS AREA

                LOSS RATE VARIABLES FOR SECOND OVERLAND FLOW ELEMENT
                  STRTL          0.35  INITIAL ABSTRACTION
                 CRVNBR         85.00  CURVE NUMBER
                  RTIMP          0.00  PERCENT IMPERVIOUS AREA

               KINEMATIC WAVE
65 UK           OVERLAND-FLOW ELEMENT NO. 1
                      L          100.  OVERLAND FLOW LENGTH
                      S        0.0300  SLOPE
                      N         0.240  ROUGHNESS COEFFICIENT
                     PA          15.0  PERCENT OF SUBBASIN
66 UK           OVERLAND-FLOW ELEMENT NO. 2
                      L          190.  OVERLAND FLOW LENGTH
                      S        0.0200  SLOPE
                      N         0.350  ROUGHNESS COEFFICIENT
                     PA          85.0  PERCENT OF SUBBASIN
67 RK           COLLECTOR CHANNEL
                      L         2000.  CHANNEL LENGTH
                      S        0.0080  SLOPE
                      N         0.020  CHANNEL ROUGHNESS COEFFICIENT
                     CA          0.45  CONTRIBUTING AREA
                  SHAPE          TRAP  CHANNEL SHAPE
                     WD          0.00  BOTTOM WIDTH OR DIAMETER
                      Z          1.00  SIDE SLOPE
68 RK           MAIN CHANNEL
                      L        13500.  CHANNEL LENGTH
                      S        0.0040  SLOPE
                      N         0.080  CHANNEL ROUGHNESS COEFFICIENT
                     CA          1.43  CONTRIBUTING AREA
                  SHAPE          TRAP  CHANNEL SHAPE
                     WD          2.00  BOTTOM WIDTH OR DIAMETER
                      Z          2.00  SIDE SLOPE
                 RUPSTQ            NO  ROUTE UPSTREAM HYDROGRAPH

                                                             ***
```

PRECIPITATION STATION DATA

STATION	TOTAL	AVG. ANNUAL	WEIGHT
1	1.96	0.00	0.75
3	2.73	0.00	0.25

TEMPORAL DISTRIBUTIONS

STATION 10, WEIGHT = 1.00

0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.03
0.08	0.08	0.08	0.08	0.23	0.15	0.05	0.02	0.08	0.22
0.23	0.20	0.09	0.01	0.02	0.05	0.01	0.01	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
0.00	0.01	0.01	0.01	0.00	0.01				

COMPUTED KINEMATIC PARAMETERS

ELEMENT	ALPHA	M	DT (MIN)	DX (FT)
1	1.0753	1.667	15.00	50.00
2	0.6021	1.667	15.00	95.00
3	3.3366	1.333	15.00	1000.00
4	0.5115	1.351	15.00	6750.00

HYDROGRAPH AT STATION SUB1

DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q
1		0000	1	0.00	0.00	0.00	0.	1		0730	31	0.24	0.09	0.15	127.
1		0015	2	0.00	0.00	0.00	0.	1		0745	32	0.25	0.08	0.17	202.
1		0030	3	0.01	0.01	0.00	0.	1		0800	33	0.22	0.06	0.16	305.
1		0045	4	0.00	0.00	0.00	0.	1		0815	34	0.10	0.02	0.08	367.
1		0100	5	0.00	0.00	0.00	0.	1		0830	35	0.01	0.00	0.01	352.
1		0115	6	0.00	0.00	0.00	0.	1		0845	36	0.02	0.01	0.02	299.
1		0130	7	0.00	0.00	0.00	0.	1		0900	37	0.05	0.01	0.04	247.
1		0145	8	0.00	0.00	0.00	0.	1		0915	38	0.01	0.00	0.01	204.
1		0200	9	0.00	0.00	0.00	0.	1		0930	39	0.01	0.00	0.01	170.
1		0215	10	0.01	0.01	0.00	0.	1		0945	40	0.00	0.00	0.00	139.
1		0230	11	0.01	0.01	0.00	0.	1		1000	41	0.00	0.00	0.00	114.
1		0245	12	0.01	0.01	0.00	0.	1		1015	42	0.00	0.00	0.00	93.
1		0300	13	0.01	0.01	0.00	0.	1		1030	43	0.00	0.00	0.00	76.
1		0315	14	0.01	0.01	0.00	0.	1		1045	44	0.00	0.00	0.00	63.
1		0330	15	0.01	0.01	0.00	0.	1		1100	45	0.00	0.00	0.00	53.
1		0345	16	0.01	0.01	0.00	0.	1		1115	46	0.00	0.00	0.00	44.
1		0400	17	0.01	0.01	0.00	0.	1		1130	47	0.00	0.00	0.00	37.
1		0415	18	0.03	0.03	0.00	0.	1		1145	48	0.00	0.00	0.00	32.
1		0430	19	0.03	0.03	0.00	0.	1		1200	49	0.00	0.00	0.00	27.
1		0445	20	0.03	0.03	0.00	0.	1		1215	50	0.01	0.00	0.01	24.
1		0500	21	0.03	0.03	0.00	1.	1		1230	51	0.01	0.00	0.01	21.
1		0515	22	0.09	0.08	0.01	1.	1		1245	52	0.00	0.00	0.00	20.
1		0530	23	0.09	0.08	0.01	3.	1		1300	53	0.01	0.00	0.01	18.
1		0545	24	0.09	0.07	0.02	6.	1		1315	54	0.01	0.00	0.01	18.
1		0600	25	0.09	0.06	0.03	10.	1		1330	55	0.01	0.00	0.01	17.
1		0615	26	0.25	0.15	0.10	18.	1		1345	56	0.00	0.00	0.00	17.
1		0630	27	0.16	0.08	0.08	42.	1		1400	57	0.01	0.00	0.01	17.
1		0645	28	0.05	0.02	0.03	71.	1		1415	58	0.00	0.00	0.00	17.
1		0700	29	0.02	0.01	0.01	88.	1		1430	59	0.00	0.00	0.00	17.
1		0715	30	0.09	0.04	0.05	98.	1		1445	60	0.00	0.00	0.00	16.
											SUM	2.15	1.09	1.06	

TOTAL RAINFALL = 2.15, TOTAL LOSS = 1.09, TOTAL EXCESS = 1.06

K FLOW (FS)	TIME (HR)		6-HR	24-HR	72-HR	14.75-HR
			MAXIMUM AVERAGE FLOW			
367.	8.25	(CFS)	136.	59.	59.	59.
		(INCHES)	0.886	0.944	0.944	0.944
		(AC-FT)	68.	72.	72.	72.

CUMULATIVE AREA = 1.43 SQ MI

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
HYDROGRAPH AT	SUB1	367.	8.25	136.	59.	59.	1.43		
HYDROGRAPH AT	SUB2	207.	8.25	54.	23.	23.	0.67		
HYDROGRAPH AT	SUB3	230.	8.25	37.	16.	16.	0.56		
3 COMBINED AT	SUB4	804.	8.25	226.	98.	98.	2.66		
HYDROGRAPH AT	SUB4	1674.	8.50	477.	205.	205.	4.49		
HYDROGRAPH AT	SUB5	427.	8.25	87.	37.	37.	0.67		
HYDROGRAPH AT	SUB6	628.	8.50	196.	84.	84.	1.43		
3 COMBINED AT	SUB7	2663.	8.25	757.	325.	325.	6.59		
HYDROGRAPH AT	SUB7	3158.	8.50	887.	380.	380.	7.55		

*** NORMAL END OF HEC-1 ***

12.3 Example Problem #3: Snowmelt Runoff Simulation

This example demonstrates the degree-day method of deriving a runoff hydrograph due to snowmelt. The example basin configuration and data are shown in Fig. 12.3 and Table 12.3a. The general procedure used in this case is as follows:

(1) Determine total precipitation based on melt coefficients, initial available snowpack, rainfall and temperature data.
(2) Compute excess from exponential loss equations.
(3) Use the SCS unit hydrograph to route the excess to the basin outlet.

The input data and results of the analysis are displayed in the computer printout in Table 12.3b.

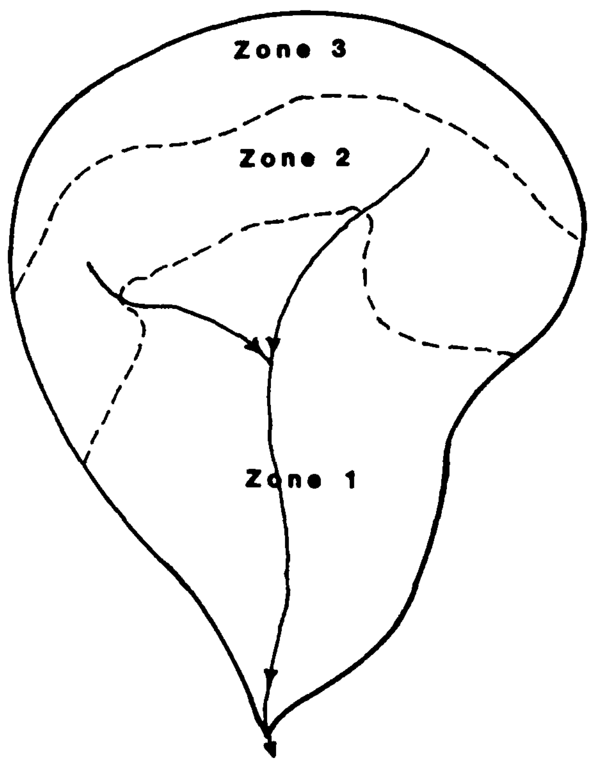


Figure 12.3 Snowmelt Basin

TABLE 12.3a

Snowmelt Data

INFILTRATION	CARDS
Rainfall - Exponential Loss Rate	LE
STRKR = 0.24 DLTKR = 0.00 RTIOL = 1.00 ERAIN = 0.70	
Snowmelt - Exponential Loss Rate	LM
STRKS = 0.24 RTIOK = 1.00	
UNIT HYDROGRAPH	UC
TC = 46 R = 183	
ZONE DATA	NA

ZONE	AREA (sq miles)	SNOWPACK (in water)
1	1,000	7.5
2	500	6.2
3	370	8.4

MELT COEFFICIENTS	MC
TLAPS = 3.3 COEF = .08 FRZTP = 33	

TABLE 12.3b

Example Problem #3: Input and Output

```
                                       HEC-1 INPUT                                              PAGE

        LINE         ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

           1         ID        EXAMPLE PROBLEM NO. 3
           2         ID        SNOWMELT RUNOFF SIMULATION
*** FREE ***
           3         IT     720 04APR75    0800      90
           4         IO       0       2
           5         IN    1440 04APR75    0800
           6         PG     100
           7         PI       0       0       0       0       0       0    0.26    0.04     0.0     0.0
           8         PI     .01      .0       0       0       0       0       0      .2     .67     .36
           9         PI     .01     .02      .3     .07     .09     .04       0       0       0     .01
          10         PI     .02       0       0       0     .02     .03     .58     .56       0       0
          11         PI     .32     .27       0     .48     .46     .21       0     .07     .01     .06

          12         KK       7
          13         KM    ,MINNESOTA RIVER BASIN
          14         BA    1870
          15         BF       8    1500  1.0022
          16         PT     100
          17         PW     1.0
          18         PR     100
          19         PW     1.0
          20         UC      46     183
          21         LE     .24       0     1.0      .7
          22         LM     .24     1.0
                     * ******************** ZONE1 DATA (LOWEST ZONE)
          23         MA    1000     7.5
```

```
                * ******************** DATA FOR ZONES AT HIGHER ELEVATIONS (1000 FT INCREMENTS)
     24         MA    500     6.2
     25         MA    370     8.4
     26         MC    3.3     .08      33
     27         IN   1440 04APR75    0800
     28         MT     18      30      35      31      27      22      32      14       0       2
     29         MT     17      37      28      37      38      34      37      48      51      47
     30         MT     42      45      55      60      54      53      52      47      45      50
     31         MT     55      51      50      49      50      60      55      50      41      46
     32         MT     54      57      57      54      64      65      63      58      52      47
     33         ZZ
```

```
****************************************                     ****************************************
                                       *                     *                                      *
 FLOOD HYDROGRAPH PACKAGE  (HEC-1)     *                     *     U.S. ARMY CORPS OF ENGINEERS     *
            FEBRUARY 1981              *                     *  THE HYDROLOGIC ENGINEERING CENTER   *
          REVISED 18 JUN 81            *                     *         609 SECOND STREET            *
                                       *                     *       DAVIS, CALIFORNIA 95616        *
 RUN DATE 24 JUN 81    TIME   9:09:07  *                     *  (916) 440-3285 OR (FTS) 448-3285    *
                                       *                     *                                      *
****************************************                     ****************************************


                          EXAMPLE PROBLEM NO. 3
                          SNOWMELT RUNOFF SIMULATION

  4 IO         OUTPUT CONTROL VARIABLES
                      IPRNT            0  PRINT CONTROL
                      IPLOT            2  PLOT CONTROL
                      QSCAL           0.  HYDROGRAPH PLOT SCALE
                       DMSG          YES  PRINT DIAGNOSTIC MESSAGES

  5 IN         TIME DATA FOR INPUT TIME SERIES
                      JXMIN         1440  TIME INTERVAL IN MINUTES
                      JXDATE      4APR75  STARTING DATE
                      JXTIME         800  STARTING TIME

    IT         HYDROGRAPH TIME DATA
                       NMIN          720  MINUTES IN COMPUTATION INTERVAL
                      IDATE       4APR75  STARTING DATE
                      ITIME         0800  STARTING TIME
                         NQ           90  NUMBER OF HYDROGRAPH ORDINATES
                     NDDATE      18MAY75  ENDING DATE
                     NDTIME         2000  ENDING TIME

                 COMPUTATION INTERVAL   12.00 HOURS
                      TOTAL TIME BASE 1068.00 HOURS

         ENGLISH UNITS
              DRAINAGE AREA          SQUARE MILES
              PRECIPITATION DEPTH    INCHES
              LENGTH, ELEVATION      FEET
              FLOW                   CUBIC FEET PER SECOND
              STORAGE VOLUME         ACRE-FEET
              SURFACE AREA           ACRES
              TEMPERATURE            DEGREES FAHRENHEIT


*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

           **************
           *            *
 12 KK     *       7    *
           *            *
           **************
                     ,MINNESOTA RIVER BASIN

 27 IN         TIME DATA FOR INPUT TIME SERIES
                      JXMIN         1440  TIME INTERVAL IN MINUTES
                      JXDATE      4APR75  STARTING DATE
                      JXTIME         800  STARTING TIME
```

```
SUBBASIN RUNOFF DATA

14 BA        SUBBASIN CHARACTERISTICS
                   TAREA      1870.00  SUBBASIN AREA

15 BF        BASE FLOW CHARACTERISTICS
                   STRTQ         8.00  INITIAL FLOW
                   QRCSN      1500.00  BEGIN BASE FLOW RECESSION
                   RTIOR      1.00220  RECESSION CONSTANT

             PRECIPITATION DATA

16 PT          TOTAL STORM STATIONS       100
17 PW                       WEIGHTS      1.00

18 PR           RECORDING STATIONS       100
19 PW                       WEIGHTS      1.00

   MC        SNOWMELT DATA
                   TLAPS         3.30  TEMPERATURE LAPSE RATE
                    COEF         0.08  SNOWMELT COEFFICIENT
                   FRZTP        33.00  MELT TEMPERATURE

   MA          ELEVATION ZONE DATA
                 ZONE   AREA   SNOWPACK   ANNUAL PRECIP
                    1  1000.       7.50         0.00
                    2   500.       6.20         0.00
                    3   370.       8.40         0.00

   MT          TEMPERATURE DATA
```

18.0	24.0	30.0	32.5	35.0	33.0	31.0	29.0	27.0	24.5
22.0	27.0	32.0	23.0	14.0	7.0	0.0	1.0	2.0	9.5
17.0	27.0	37.0	32.5	28.0	32.5	37.0	37.5	38.0	36.0
34.0	35.5	37.0	42.5	48.0	49.5	51.0	49.0	47.0	44.5
42.0	43.5	45.0	50.0	55.0	57.5	60.0	57.0	54.0	53.5
53.0	52.5	52.0	49.5	47.0	46.0	45.0	47.5	50.0	52.5
55.0	53.0	51.0	50.5	50.0	49.5	49.0	49.5	50.0	55.0
60.0	57.5	55.0	52.5	50.0	45.5	41.0	43.5	46.0	50.0
54.0	55.5	57.0	57.0	57.0	55.5	54.0	59.0	64.0	64.5

```
21 LE        EXPONENTIAL LOSS RATE
                   STRKR         0.24  INITIAL VALUE OF LOSS COEFFICIENT
                   DLTKR         0.00  INITIAL LOSS
                   RTIOL         1.00  LOSS COEFFICIENT RECESSION CONSTANT
                   ERAIN         0.70  EXPONENT OF PRECIPITATION
                   RTIMP         0.00  PERCENT IMPERVIOUS AREA

   LM        MELTWATER LOSS RATE
                   STRKS         0.24  INITIAL VALUE OF LOSS COEFFICIENT
                   RTIOK         1.00  LOSS COEFFICIENT RECESSION CONSTANT

20 UC        CLARK UNITGRAPH
                      TC        46.00  TIME OF CONCENTRATION
                       R       183.00  STORAGE COEFFICIENT

             SYNTHETIC ACCUMULATED-AREA VS. TIME CURVE WILL BE USED

                                                  ***

           PRECIPITATION STATION DATA

                 STATION     TOTAL     AVG. ANNUAL     WEIGHT
                     100      4.59          0.00        1.00

             TEMPORAL DISTRIBUTIONS


             STATION      100,  WEIGHT =   1.00
```

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.13	0.13	0.02	0.02	0.00	0.00	0.00	0.00
0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.10	0.10	0.33	0.34	0.18	0.18
0.00	0.01	0.01	0.01	0.15	0.15	0.03	0.04	0.04	0.05
0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
0.01	0.02	0.29	0.29	0.28	0.28	0.00	0.00	0.00	0.00
0.16	0.16	0.13	0.14	0.00	0.00	0.24	0.24	0.23	

```
                              UNIT HYDROGRAPH PARAMETERS
                          CLARK    TC= 46.00 HR,      R=183.00 HR
                         SNYDER    TP= 49.11 HR,      CP=  0.23
```

UNIT HYDROGRAPH
83 END-OF-PERIOD ORDINATES

602.	2263.	4252.	5476.	5586.	5231.	4899.	4588.	4296.	4024.
3768.	3529.	3305.	3095.	2899.	2715.	2542.	2381.	2230.	2088.
1955.	1831.	1715.	1606.	1504.	1409.	1319.	1235.	1157.	1084.
1015.	950.	890.	833.	781.	731.	685.	641.	600.	562.
527.	493.	462.	433.	405.	379.	355.	333.	312.	292.
273.	256.	240.	224.	210.	197.	184.	173.	162.	151.
142.	133.	124.	116.	109.	102.	96.	90.	84.	79.
74.	69.	65.	60.	57.	53.	50.	46.	44.	41.
38.	36.	33.							

****

HYDROGRAPH AT STATION 7

****

DA MON HRMN	ORD	PRECIP	TEMP	SNOMELT	SNOLOSS	SNOEXCS	RAIN	RAINLOS	RAINEXS	SNO+RAIN	LOSS	EXCESS	COMP Q
4 APR 0800	1	0.00	18.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.
4 APR 2000	2	0.00	24.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.

Note: Lines 3-32 not shown

DA MON HRMN	ORD	PRECIP	TEMP	SNOMELT	SNOLOSS	SNOEXCS	RAIN	RAINLOS	RAINEXS	SNO+RAIN	LOSS	EXCESS	COMP Q
20 APR 0800	33	0.00	37.0	0.05	0.05	0.00	0.00	0.00	0.00	0.05	0.05	0.00	43.
20 APR 2000	34	0.00	42.5	0.23	0.17	0.06	0.00	0.00	0.00	0.23	0.17	0.06	74.
21 APR 0800	35	0.00	48.0	0.45	0.29	0.16	0.00	0.00	0.00	0.45	0.29	0.16	260.
21 APR 2000	36	0.10	49.5	0.51	0.30	0.21	0.10	0.06	0.04	0.61	0.36	0.25	786.
22 APR 0800	37	0.10	51.0	0.57	0.32	0.24	0.10	0.06	0.04	0.67	0.38	0.29	1761.
22 APR 2000	38	0.33	49.0	0.49	0.26	0.23	0.33	0.18	0.15	0.82	0.44	0.38	3167.
23 APR 0800	39	0.34	47.0	0.41	0.22	0.18	0.33	0.19	0.15	0.74	0.41	0.33	4875.
23 APR 2000	40	0.18	44.5	0.31	0.19	0.12	0.18	0.11	0.07	0.49	0.30	0.18	6597.
24 APR 0800	41	0.18	42.0	0.21	0.14	0.07	0.14	0.09	0.05	0.35	0.23	0.12	7970.
24 APR 2000	42	0.00	43.5	0.27	0.19	0.07	0.00	0.00	0.00	0.27	0.20	0.07	8773.
25 APR 0800	43	0.01	45.0	0.33	0.23	0.10	0.01	0.00	0.00	0.33	0.23	0.10	9083.
25 APR 2000	44	0.01	50.0	0.53	0.32	0.21	0.01	0.01	0.00	0.54	0.33	0.21	9223.
26 APR 0800	45	0.01	55.0	0.73	0.40	0.32	0.01	0.01	0.00	0.74	0.41	0.33	9573.
26 APR 2000	46	0.15	57.5	0.83	0.42	0.41	0.15	0.08	0.07	0.98	0.50	0.48	10446.
27 APR 0800	47	0.15	60.0	0.50	0.27	0.22	0.15	0.09	0.06	0.65	0.36	0.28	11831.
27 APR 2000	48	0.03	57.0	0.23	0.14	0.09	0.03	0.03	0.01	0.26	0.17	0.09	13230.
28 APR 0800	49	0.04	54.0	0.10	0.06	0.04	0.04	0.03	0.00	0.14	0.09	0.04	14047.
28 APR 2000	50	0.04	53.5	0.10	0.06	0.04	0.04	0.04	0.00	0.14	0.10	0.04	14095.
29 APR 0800	51	0.05	53.0	0.09	0.06	0.04	0.05	0.04	0.00	0.14	0.10	0.04	13655.
29 APR 2000	52	0.02	52.5	0.09	0.06	0.03	0.02	0.02	0.00	0.11	0.08	0.03	13069.
30 APR 0800	53	0.02	52.0	0.09	0.05	0.03	0.02	0.02	0.00	0.11	0.07	0.03	12481.
30 APR 2000	54	0.00	49.5	0.07	0.05	0.02	0.00	0.00	0.00	0.07	0.05	0.02	11904.
1 MAY 0800	55	0.00	47.0	0.05	0.04	0.01	0.00	0.00	0.00	0.05	0.04	0.01	11323.
1 MAY 2000	56	0.00	46.0	0.04	0.03	0.01	0.00	0.00	0.00	0.04	0.03	0.01	10729.
2 MAY 0800	57	0.00	45.0	0.03	0.03	0.00	0.00	0.00	0.00	0.03	0.03	0.00	10124.
2 MAY 2000	58	0.00	47.5	0.05	0.04	0.01	0.00	0.00	0.00	0.05	0.04	0.01	9530.
3 MAY 0800	59	0.00	50.0	0.07	0.05	0.02	0.00	0.00	0.00	0.07	0.05	0.02	8978.
3 MAY 2000	60	0.00	52.5	0.03	0.02	0.00	0.00	0.00	0.00	0.03	0.03	0.00	8478.
4 MAY 0800	61	0.01	55.0	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	8007.
4 MAY 2000	62	0.01	53.0	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	7541.
5 MAY 0800	63	0.01	51.0	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	7075.
5 MAY 2000	64	0.00	50.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6626.
6 MAY 0800	65	0.00	50.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6206.
6 MAY 2000	66	0.00	49.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5812.
7 MAY 0800	67	0.00	49.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5443.
7 MAY 2000	68	0.00	49.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5097.
8 MAY 0800	69	0.00	50.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4774.

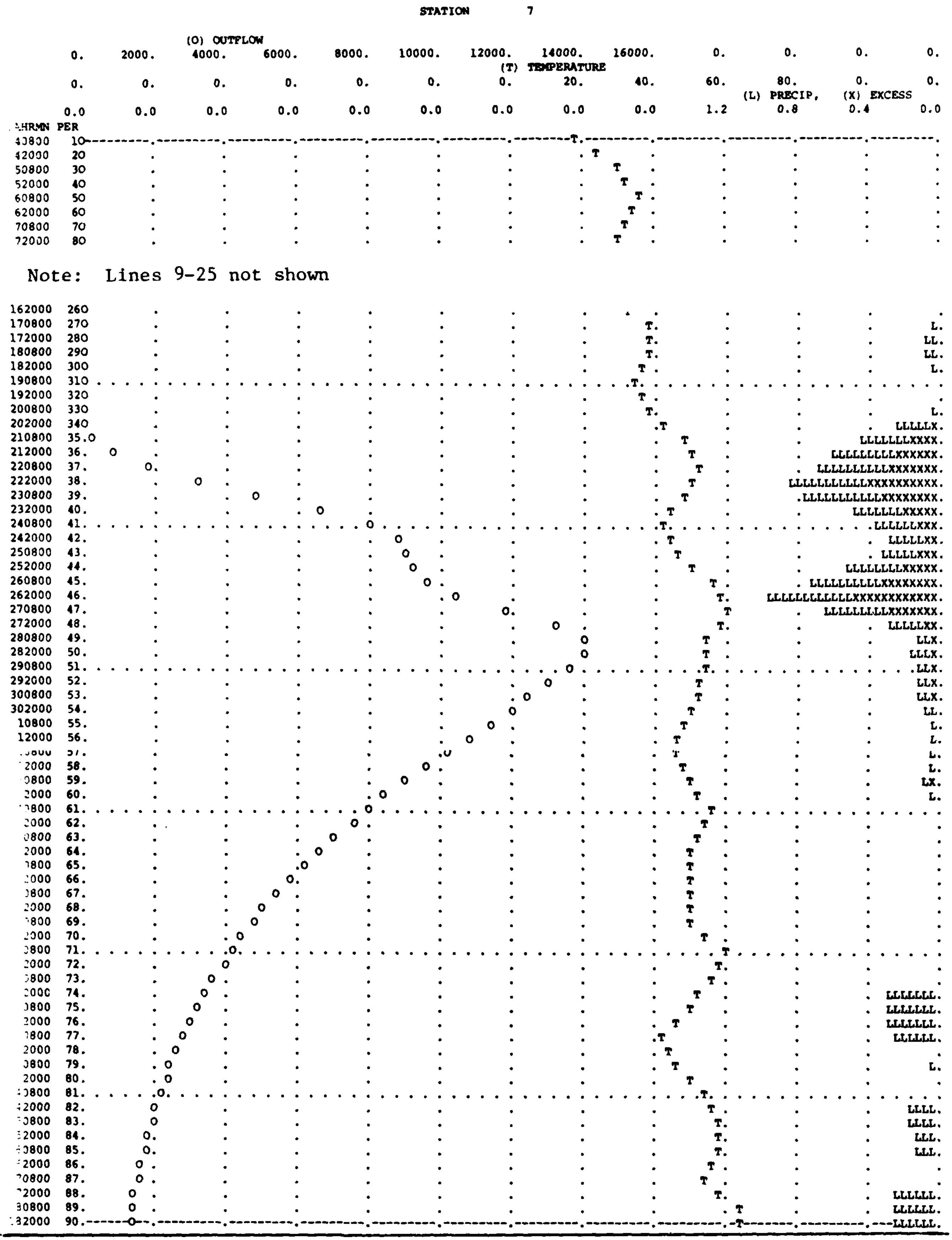
Note: Lines 70-88 not shown

DA MON HRMN	ORD	PRECIP	TEMP	SNOMELT	SNOLOSS	SNOEXCS	RAIN	RAINLOS	RAINEXS	SNO+RAIN	LOSS	EXCESS	COMP Q
18 MAY 0800	89	0.24	64.0	0.00	0.00	0.00	0.24	0.24	0.00	0.24	0.24	0.00	1424.
18 MAY 2000	90	0.23	64.5	0.00	0.00	0.00	0.23	0.23	0.00	0.23	0.23	0.00	1387.

****

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 10-DAY	30-DAY	90-DAY	44.5-DAY
14095.	588.00	(CFS)	10928.	5759.	3884.	3884.
		(INCHES)	2.173	3.436	3.438	3.438
		(AC-FT)	216756.	342675.	342854.	342854.

CUMULATIVE AREA = 1870.00 SQ MI


STATION 7
(O) OUTFLOW
0. 2000. 4000. 6000. 8000. 10000. 12000. 14000. 16000. 0. 0. 0. 0.
(T) TEMPERATURE
0. 0. 0. 0. 0. 0. 0. 20. 40. 60. 80. 0. 0.
(L) PRECIP, (X) EXCESS
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.2 0.8 0.4 0.0
DAHRMN PER
Note: Lines 9-25 not shown

12.4 Example Problem #4: Unit Graph and Loss Rate Parameter Optimization

This example demonstrates the optimization of Clark Unit Hydrograph parameters TC and R, and the loss rate parameters for the HEC-1 exponential loss function. Note that unit graph and loss rate parameters can be fixed at a desired value; in this example, the exponential loss rate parameter ERAIN was fixed at 0.7, leaving the remaining loss rate and unit graph parameters to be optimized. The example input data in the appropriate HEC-1 format and the optimization results are shown in Table 12.4.

TABLE 12.4

Example Problem #4: Input and Output

```
                                      HEC-1 INPUT                                         PAGE 1

LINE       ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1        ID        EXAMPLE TEST NO. 4
  2        ID        UNIT GRAPH AND LOSS RATE OPTIMIZATION
  3        IT      15 67AUG27    1145      61
  4        IO       1       2
  5        OU
  6        PG  467042    2.39    1.00
  7        PG     100
  8        PI     .00     .00     .03     .06     .45     .42     .29     .14     .08     .04
  9        PI     .03     .02     .02     .02     .01     .01     .01     .01     .01     .02
 10        PI     .01     .01     .02     .01     .01     .01     .01     .01     .01     .00
 11        PI     .01     .01     .00     .00     .01     .02     .01     .01     .01     .00
 12        PI     .01     .01     .01     .01     .00     .00     .00     .01     .00     .00
 13        PG     300
 14        PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
 15        PI     .00     .00     .00     .10     .45    1.45     .73     .02     .80     .50
 16        PI     .25     .05     .00     .00     .00     .00     .00     .00     .00     .00
 17        PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
 18        PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
 19        PG    5000
 20        PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
 21        PI     .00     .00     .00     .00     .00     .00     .00     .00     .00     .00
 22        PI     .00     .00     .00     .00     .00     .00     .00     .00     .04     .23
 23        PI     .39     .18     .56     .00     .00     .00     .19     .08     .20     .20
 24        PI     .11     .03     .00     .00     .00     .00     .00     .00     .00     .00

 25        KK  467042
 26        QO      57      57      59      61      63      65      67      69      71      73
 27        QO     130     250     370     520     720     920    1170    1470    1720    1900
 28        QO    2060    2250    2400    2570    2720    2860    3090    3390    3540    3520
 29        QO    3480    3330    3290    3230    3100    2900    2720    2520    2270    2050
 30        QO    1800    1570    1430    1300    1200    1100     980     890     800     745
 31        QO     690     650     610     570     540     510     490     475     460     445
 32        QO     430       0       0       0       0       0       0       0       0       0
 33        PT  467042
 34        PW    1.00  0.      0.      0.      0.
 35        PR     100     300    5000       0       0
 36        PW     .45     .45     .10  0.      0.
 37        BA   37.90  0.
 38        BF     57.    -.25  1.3195
 39        UC   -1.00   -1.00
 40        LE     -1.     -1.      1.      .5
 41        ZZ
```

```
******************************************                                    ****************************************
*                                        *                                    *                                      *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)    *                                    *     U.S. ARMY CORPS OF ENGINEERS     *
*           FEBRUARY 1981                *                                    *  THE HYDROLOGIC ENGINEERING CENTER   *
*         REVISED 14 JUN 85              *                                    *          609 SECOND STREET           *
*                                        *                                    *       DAVIS, CALIFORNIA 95616        *
*  RUN DATE  2 JUL 85    TIME  13:45:17  *                                    *  (916) 440-3285 OR (FTS) 448-3285    *
*                                        *                                    *                                      *
******************************************                                    ****************************************


                              EXAMPLE TEST NO. 4
                              UNIT GRAPH AND LOSS RATE OPTIMIZATION

  4 IO          OUTPUT CONTROL VARIABLES
                     IPRNT            1  PRINT CONTROL
                     IPLOT            2  PLOT CONTROL
                     QSCAL           0.  HYDROGRAPH PLOT SCALE
                      DMSG          YES  PRINT DIAGNOSTIC MESSAGES

    IT          HYDROGRAPH TIME DATA
                      NMIN           15  MINUTES IN COMPUTATION INTERVAL
                     IDATE      67AUG27  STARTING DATE
                     ITIME         1145  STARTING TIME
                        NQ           61  NUMBER OF HYDROGRAPH ORDINATES
                    NDDATE       2SEP27  ENDING DATE
                    NDTIME         0245  ENDING TIME

                COMPUTATION INTERVAL   0.25 HOURS
                     TOTAL TIME BASE  15.00 HOURS

        ENGLISH UNITS
            DRAINAGE AREA          SQUARE MILES
            PRECIPITATION DEPTH    INCHES
            LENGTH, ELEVATION      FEET
            FLOW                   CUBIC FEET PER SECOND
            STORAGE VOLUME         ACRE-FEET
            SURFACE AREA           ACRES
            TEMPERATURE            DEGREES FAHRENHEIT

    OU          OPTIMIZATION OF UNITGRAPH AND LOSS RATE PARAMETERS
                     IFORD            1  FIRST ORDINATE OF OPTIMIZATION REGION
                     ILORD           61  LAST ORDINATE OF OPTIMIZATION REGION

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

            **************
            *            *
 25 KK      *   467042   *
            *            *
            **************

              SUBBASIN RUNOFF DATA

 37 BA          SUBBASIN CHARACTERISTICS
                     TAREA        37.90  SUBBASIN AREA

 38 BF          BASE FLOW CHARACTERISTICS
                     STRTQ        57.00  INITIAL FLOW
```

QRCSN -0.25 BEGIN BASE FLOW RECESSION
RTIOR 1.31950 RECESSION CONSTANT

PRECIPITATION DATA

33 PT	TOTAL STORM STATIONS	467042					
34 PW	WEIGHTS	1.00					
35 PR	RECORDING STATIONS	100	300	5000	0	0
36 PW	WEIGHTS	0.45	0.45	0.10	0.00	0.00

40 LE EXPONENTIAL LOSS RATE

STRKR	-1.00	INITIAL VALUE OF LOSS COEFFICIENT
DLTKR	-1.00	INITIAL LOSS
RTIOL	1.00	LOSS COEFFICIENT RECESSION CONSTANT
ERAIN	0.50	EXPONENT OF PRECIPITATION
RTIMP	0.00	PERCENT IMPERVIOUS AREA

39 UC CLARK UNITGRAPH

TC	-1.00	TIME OF CONCENTRATION
R	-1.00	STORAGE COEFFICIENT

SYNTHETIC ACCUMULATED-AREA VS. TIME CURVE WILL BE USED

***

PRECIPITATION STATION DATA

STATION	TOTAL	AVG. ANNUAL	WEIGHT
467042	2.39	1.00	1.00

TEMPORAL DISTRIBUTIONS

STATION 100, WEIGHT = 0.45

0.00	0.00	0.03	0.06	0.45	0.42	0.29	0.14	0.08	0.04
0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02
0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00
0.01	0.01	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.00
0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01		

STATION 300, WEIGHT = 0.45

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.10	0.45	1.45	0.73	0.02	0.80	0.50
0.25	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

STATION 5000, WEIGHT = 0.10

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.23
0.39	0.18	0.56	0.00	0.00	0.00	0.19	0.08	0.20	0.20
0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00		

INITIAL ESTIMATES FOR OPTIMIZATION VARIABLES

TC+R	R/(TC+R)	STRKR	DLTKR	RTIOL	ERAIN
6.16	0.50	0.20	0.50	1.00	0.50

INTERMEDIATE VALUES OF OPTIMIZATION VARIABLES
(*INDICATES CHANGE FROM PREVIOUS VALUE)
(+INDICATES VARIABLE WAS NOT CHANGED)

OBJECTIVE FUNCTION	TC+R	R/(TC+R)	STRKR	DLTKR	RTIOL	ERAIN
VOL. ADJ.	6.156	0.500	0.448*	1.119*	1.000	0.500
3.4957E+02	6.895*	0.500	0.448	1.119	1.000	0.500
3.4713E+02	6.895	0.522*	0.448	1.119	1.000	0.500
3.4450E+02	6.895	0.522	0.437*	1.119	1.000	0.500
3.3939E+02	6.895	0.522	0.437	0.984*	1.000	0.500
3.3928E+02	6.920*	0.522	0.437	0.984	1.000	0.500
3.3592E+02	6.920	0.547*	0.437	0.984	1.000	0.500
3.3518E+02	6.920	0.547	0.443*	0.984	1.000	0.500
3.2855E+02	6.920	0.547	0.443	0.814*	1.000	0.500
3.2712E+02	7.016*	0.547	0.443	0.814	1.000	0.500
3.2702E+02	7.016	0.551*	0.443	0.814	1.000	0.500
3.2473E+02	7.016	0.551	0.452*	0.814	1.000	0.500
3.1128E+02	7.016	0.551	0.452	0.542*	1.000	0.500

3.1012E+02	7.101*	0.551	0.452	0.542	1.000	0.500
3.1012E+02	7.101	0.551*	0.452	0.542	1.000	0.500
3.0577E+02	7.101	0.551	0.465*	0.542	1.000	0.500
2.9360E+02	7.101	0.551	0.465	0.362*	1.000	0.500
2.8841E+02	7.101	0.551	0.465	0.241*	1.000	0.500
2.8635E+02	7.101	0.551	0.465	0.161*	1.000	0.500
2.8187E+02	7.101	0.551	0.478*	0.161	1.000	0.500
2.8183E+02	7.101	0.551	0.477*	0.161	1.000	0.500
2.8134E+02	7.046*	0.551	0.477	0.161	1.000	0.500
VOL. ADJ.	7.046	0.551	0.4[illegible]*	0.164*	1.000	0.500

OPTIMIZATION RESULTS

CLARK UNITGRAPH PARAMETERS
- TC 3.16
- R 3.88

SNYDER STANDARD UNITGRAPH PARAMETERS
- TP 2.99
- CP 0.52

LAG FROM CENTER OF MASS OF EXCESS TO CENTER OF MASS OF UNITGRAPH 5.36

UNITGRAPH PEAK 4332.
TIME OF PEAK 3.00

EXPONENTIAL LOSS RATE PARAMETERS
- STRKR 0.49
- DLTKR 0.16
- RTIOL 1.00
- ERAIN 0.50

EQUIVALENT UNIFORM LOSS RATE 0.444

COMPARISON OF COMPUTED AND OBSERVED HYDROGRAPHS

STATISTICS BASED ON OPTIMIZATION REGION
(ORDINATES 1 THROUGH 61)

	SUM OF FLOWS	EQUIV DEPTH	MEAN FLOW	TIME TO CENTER OF MASS	LAG C.M. TO C.M.	PEAK FLOW	TIME OF PEAK
PRECIPITATION EXCESS		0.937		4.13			
COMPUTED HYDROGRAPH	84787.	0.867	1390.	8.51	4.38	3621.	7.25
OBSERVED HYDROGRAPH	84787.	0.867	1390.	8.16	4.03	3540.	7.25
DIFFERENCE	0.	0.000	0.	0.35	0.35	81.	0.00
PERCENT DIFFERENCE	0.00				8.68	2.28	

STANDARD ERROR 270.
OBJECTIVE FUNCTION 284.
AVERAGE ABSOLUTE ERROR 208.
AVERAGE PERCENT ABSOLUTE ERROR 27.27

UNIT HYDROGRAPH
89 END-OF-PERIOD ORDINATES

96.	361.	741.	1191.	1690.	2227.	2779.	3285.	3700.	4017.
4232.	4332.	4265.	4050.	3797.	3560.	3338.	3130.	2935.	2752.
2580.	2419.	2268.	2127.	1994.	1870.	1753.	1644.	1541.	1445.
1355.	1270.	1191.	1117.	1047.	982.	920.	863.	809.	759.
711.	667.	625.	586.	550.	515.	483.	453.	425.	398.
374.	350.	328.	308.	289.	271.	254.	238.	223.	209.
196.	184.	172.	162.	152.	142.	133.	125.	117.	110.
103.	97.	91.	85.	80.	75.	70.	66.	62.	58.
54.	51.	48.	45.	42.	39.	37.	34.	32.	

****

HYDROGRAPH AT STATION 467042

****

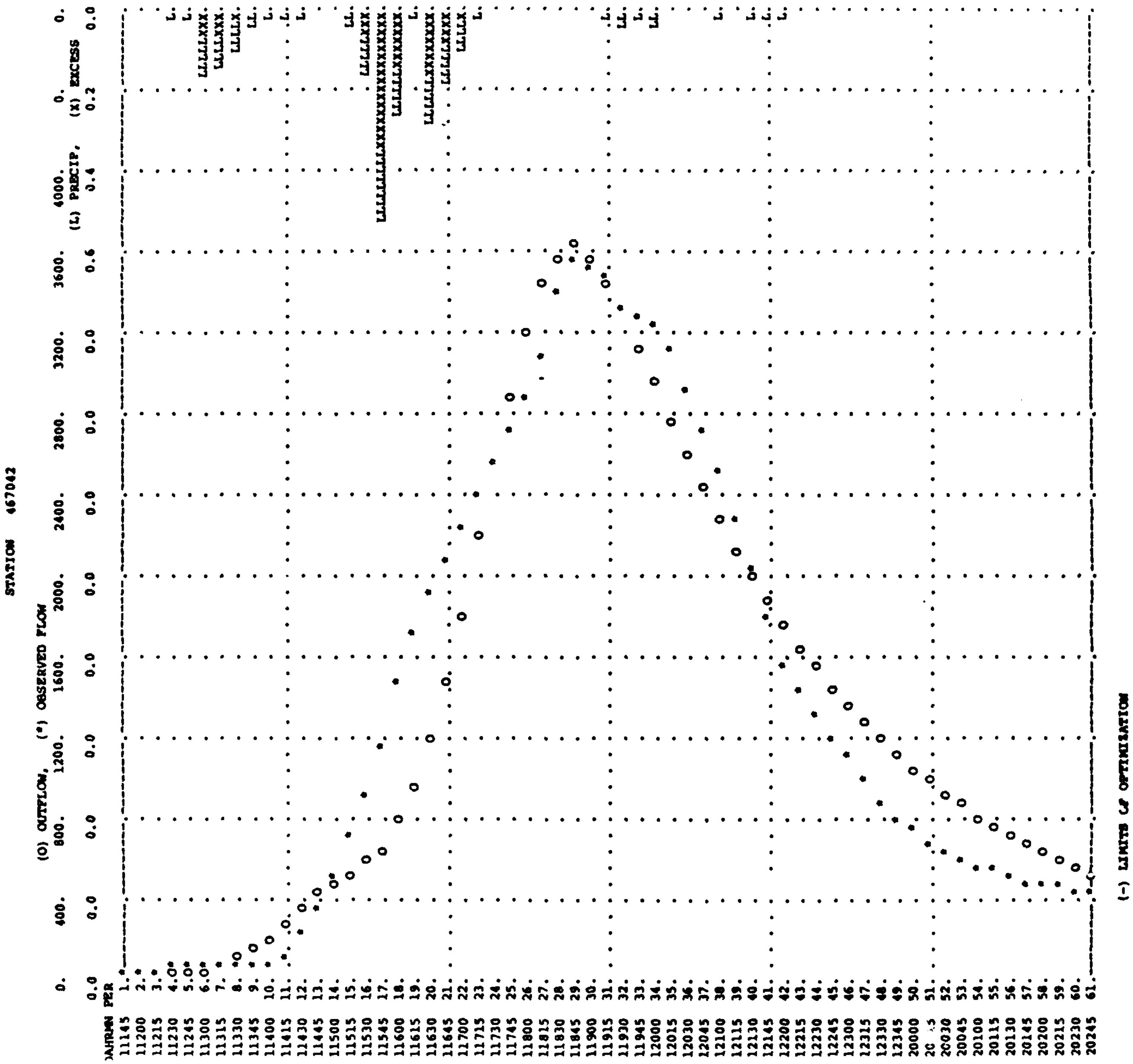
DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	OBS Q
1	SEP	1145	1	0.00	0.00	0.00	57.	57.
1	SEP	1200	2	0.00	0.00	0.00	53.	57.
1	SEP	1215	3	0.00	0.00	0.00	50.	59.
1	SEP	1230	4	0.01	0.01	0.00	46.	61.
1	SEP	1245	5	0.02	0.02	0.00	43.	63.
1	SEP	1300	6	0.16	0.10	0.06	46.	65.
1	SEP	1315	7	0.15	0.09	0.05	64.	67.
1	SEP	1330	8	0.10	0.08	0.02	100.	69.
1	SEP	1345	9	0.05	0.05	0.00	151.	71.
1	SEP	1400	10	0.03	0.03	0.00	212.	73.
1	SEP	1415	11	0.01	0.01	0.00	280.	130.
1	SEP	1430	12	0.01	0.01	0.00	352.	250.
1	SEP	1445	13	0.01	0.01	0.00	423.	370.
1	SEP	1500	14	0.01	0.01	0.00	487.	520.
1	SEP	1515	15	0.04	0.04	0.00	539.	720.
1	SEP	1530	16	0.16	0.10	0.06	584.	920.
1	SEP	1545	17	0.52	0.18	0.34	658.	1170.
1	SEP	1600	18	0.26	0.12	0.14	792.	1470.
1	SEP	1615	19	0.01	0.01	0.00	973.	1720.
1	SEP	1630	20	0.29	0.13	0.16	1198.	1900.
1	SEP	1645	21	0.18	0.10	0.08	1481.	2060.
1	SEP	1700	22	0.09	0.07	0.02	1818.	2250.
1	SEP	1715	23	0.02	0.02	0.00	2189.	2400.
1	SEP	1730	24	0.01	0.01	0.00	2557.	2570.
1	SEP	1745	25	0.00	0.00	0.00	2894.	2720.
1	SEP	1800	26	0.00	0.00	0.00	3187.	2860.
1	SEP	1815	27	0.00	0.00	0.00	3420.	3090.
1	SEP	1830	28	0.00	0.00	0.00	3573.	3390.
1	SEP	1845	29	0.00	0.00	0.00	3621.	3540.
1	SEP	1900	30	0.01	0.01	0.00	3568.	3520.
1	SEP	1915	31	0.02	0.02	0.00	3457.	3480.

DA	MON	HRMN	ORD	RAIN	LOSS	EXCESS	COMP Q	OBS
1	SEP	1930	32	0.03	0.03	0.00	3311.	333[illegible]
1	SEP	1945	33	0.02	0.02	0.00	3135.	329[illegible]
1	SEP	2000	34	0.04	0.04	0.00	2947.	323[illegible]
1	SEP	2015	35	0.00	0.00	0.00	2764.	310[illegible]
1	SEP	2030	36	0.00	0.00	0.00	2592.	290[illegible]
1	SEP	2045	37	0.01	0.01	0.00	2430.	272[illegible]
1	SEP	2100	38	0.02	0.02	0.00	2278.	252[illegible]
1	SEP	2115	39	0.01	0.01	0.00	2136.	227[illegible]
1	SEP	2130	40	0.02	0.02	0.00	2003.	205[illegible]
1	SEP	2145	41	0.02	0.02	0.00	1878.	180[illegible]
1	SEP	2200	42	0.01	0.01	0.00	1761.	157[illegible]
1	SEP	2215	43	0.01	0.01	0.00	1651.	143[illegible]
1	SEP	2230	44	0.00	0.00	0.00	1548.	130[illegible]
1	SEP	2245	45	0.00	0.00	0.00	1451.	120[illegible]
1	SEP	2300	46	0.00	0.00	0.00	1361.	110[illegible]
1	SEP	2315	47	0.00	0.00	0.00	1276.	98[illegible]
1	SEP	2330	48	0.00	0.00	0.00	1196.	89[illegible]
1	SEP	2345	49	0.00	0.00	0.00	1122.	80[illegible]
2	SEP	0000	50	0.00	0.00	0.00	1052.	74[illegible]
2	SEP	0015	51	0.00	0.00	0.00	986.	69[illegible]
2	SEP	0030	52	0.00	0.00	0.00	925.	65[illegible]
2	SEP	0045	53	0.00	0.00	0.00	867.	61[illegible]
2	SEP	0100	54	0.00	0.00	0.00	813.	570.
2	SEP	0115	55	0.00	0.00	0.00	762.	540.
2	SEP	0130	56	0.00	0.00	0.00	714.	510.
2	SEP	0145	57	0.00	0.00	0.00	670.	490.
2	SEP	0200	58	0.00	0.00	0.00	628.	475.
2	SEP	0215	59	0.00	0.00	0.00	589.	460.
2	SEP	0230	60	0.00	0.00	0.00	552.	445.
2	SEP	0245	61	0.00	0.00	0.00	518.	430.
		SUM		2.39	1.45	0.94		

****

PEAK FLOW	TIME		MAXIMUM AVERAGE FLOW			
(CFS)	(HR)		6-HR	24-HR	72-HR	15.00-HR
3621.	7.00	(CFS)	2591.	1408.	1408.	1408.
		(INCHES)	0.636	0.864	0.864	0.864
		(AC-FT)	1285.	1746.	1746.	1746.

CUMULATIVE AREA = 37.90 SQ MI



** STATION 467042 ** DRAINAGE AREA = 37.90

..DATE...	.......PERCENT ERROR......				.... O P T I M I Z A T I O N				R E S U L T S						
DA MON YR	AVG	VOL	LAG	PEAK	TC	R	TC+R	R/(TC+R)	TP	CP	QP	STRKR	DLTKR	RTIOL	ERAIN
67 AUG 27	27.3	0.0	8.7	2.3	3.16	3.88	7.05	0.55	2.99	0.52	111.	0.49	0.16	1.00	0.50

*** NORMAL END OF JOB ***

12.5 Example Problem #5: Routing Parameter Optimization

Input data requirements for the routing parameter optimization are observed inflow and outflow hydrographs and a pattern lateral inflow hydrograph for the routing reach. The routing parameters optimized in this example are the Muskingum K and X, and the number of subreaches, NSTEPS. The example input data and optimization results are shown in Table 12.5.

TABLE 12.5

Example Problem #5: Input and Output

```
                                        HEC-1 INPUT                                                    PAGE  1

LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1          ID        EXAMPLE PROBLEM NO. 5
   2          ID        STREAMFLOW ROUTING OPTIMIZATION
   3          ID        MUSKINGUM METHOD
   4          IT     720  600000       0      16
   5          IO       1       2
   6          OR       2

   7          KK       1
   8          QF    2000    2000    7000   11700   16500   24000   29100   28400   23800   19400
   9          QF   15300   11200    8200    6400    5200    4600       0       0       0       0
  10          QI    2200    2200   14500   28400   31800   29700   25300   20400   16300   12600
  11          QI    9300    6700    5000    4100    3600    2400       0       0       0       0
  12          QO    2000    2000    7000   11700   16500   24000   29100   28400   23800   19400
  13          QO   15300   11200    8200    6400    5200    4600       0       0       0       0
  14          RL      0.      0.
  15          RM      -1   -1.00   -1.00
  16          ZZ


                              EXAMPLE PROBLEM NO. 5
                              STREAMFLOW ROUTING OPTIMIZATION
                              MUSKINGUM METHOD

    5 IO          OUTPUT CONTROL VARIABLES
                        IPRNT          1  PRINT CONTROL
                        IPLOT          2  PLOT CONTROL
                        QSCAL         0.  HYDROGRAPH PLOT SCALE
                         DMSG        YES  PRINT DIAGNOSTIC MESSAGES

      IT          HYDROGRAPH TIME DATA
                         NMIN        720  MINUTES IN COMPUTATION INTERVAL
                        IDATE     6000 0  STARTING DATE
                        ITIME       0000  STARTING TIME
                           NQ         16  NUMBER OF HYDROGRAPH ORDINATES
                       NDDATE    13    0  ENDING DATE
                       NDTIME       1200  ENDING TIME

                    COMPUTATION INTERVAL   12.00 HOURS
                         TOTAL TIME BASE  180.00 HOURS

           ENGLISH UNITS
              DRAINAGE AREA            SQUARE MILES
              PRECIPITATION DEPTH      INCHES
              LENGTH, ELEVATION        FEET
              FLOW                     CUBIC FEET PER SECOND
              STORAGE VOLUME           ACRE-FEET
              SURFACE AREA             ACRES
              TEMPERATURE              DEGREES FAHRENHEIT

      OR          OPTIMIZATION OF ROUTING PARAMETERS
                        IFORD          2  FIRST ORDINATE OF OPTIMIZATION REGION
                        ILORD         16  LAST ORDINATE OF OPTIMIZATION REGION
```

```
                  **************
                  *            *
 7 KK             *      1     *
                  *            *
                  **************

                    HYDROGRAPH ROUTING DATA

 14 RL                ROUTING LOSSES
                          QLOSS          0.00  INITIAL LOSS
                          CLOSS          0.00  ADDITIONAL FRACTION LOST

 15 RM                MUSKINGUM ROUTING
                          NSTPS            -1  NUMBER OF SUBREACHES
                          AMSKK         -1.00  MUSKINGUM K
                              X         -1.00  MUSKINGUM X
                                                                    ***

                                                     INITIAL ESTIMATES FOR OPTIMIZATION VARIABLES
                        AMSKK          X
                        12.00        0.20

                                                     INTERMEDIATE VALUES OF OPTIMIZATION VARIABLES
                                                       (*INDICATES CHANGE FROM PREVIOUS VALUE)
                                                       (+INDICATES VARIABLE WAS NOT CHANGED)
 OBJECTIVE
 FUNCTION               AMSKK          X
                 NUMBER OF ROUTING STEPS =  1
   2194.2               18.000*      0.200
   2157.1               18.000       0.137*

   1791.6               23.109*      0.137
   1744.8               23.109       0.206*

   1730.9               22.344*      0.206
   1728.7               22.344       0.194*

   1728.7               22.300*      0.194
   1728.7               22.300       0.193*


   1728.7               22.296*      0.193
                 NUMBER OF ROUTING STEPS =  2
   2113.6               18.000*      0.200
   1979.9               18.000       0.133*

   1804.4               25.063*      0.133
   1778.3               25.063       0.089*

   1648.8               19.146*      0.089
   1617.3               19.146       0.059*

   1397.3               22.641*      0.059
   1394.8               22.641       0.040*

   1348.3               21.535*      0.040
   1348.1               21.592*      0.040

   1348.1               21.592*      0.040




                 NUMBER OF ROUTING STEPS =  3
   2270.1               18.000*      0.200
   2129.9               18.000       0.133*

   2006.4               25.214*      0.133
   1944.1               25.214       0.089*

   1782.5               19.111*      0.089
   1732.2               19.111       0.059*

   1507.2               22.987*      0.059
   1482.3               22.987       0.040*

   1404.0               21.566*      0.040
   1403.4               21.680*      0.040
   1385.8               21.680       0.026*
   1374.9               21.680       0.018*

   1374.8               21.650*      0.018
                 NUMBER OF ROUTING STEPS =  2
   2113.6               18.000*      0.200
   1979.9               18.000       0.133*

   1804.4               25.063*      0.133
   1778.3               25.063       0.089*

   1648.8               19.146*      0.089
   1617.3               19.146       0.059*

   1397.3               22.641*      0.059
   1394.8               22.641       0.040*

   1348.3               21.535*      0.040
   1348.1               21.592*      0.040

   1348.1               21.592*      0.040
```

DERIVED COEFFICIENTS

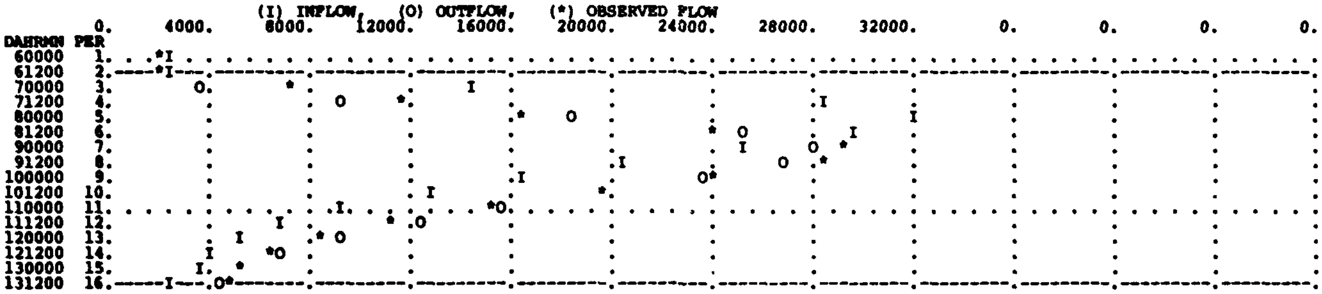
NSTPS	NSTDL	LAG	AMSKK	X	TSK
2	0	0	21.61	0.04	0.00

DAY MON	HRMN	ORD	INFLOW	LOCAL	OUTFLOW	ACTUAL
6	0000	1	2200.	3.	2203.	2000.
6	1200	2	2200.	3.	2203.	2000.
7	0000	3	14500.	10.	3634.	7000.
7	1200	4	28400.	16.	9296.	11700.
8	0000	5	31800.	23.	18224.	16500.
8	1200	6	29700.	34.	25405.	24000.
9	0000	7	25300.	41.	28062.	29100.
9	1200	8	20400.	40.	26900.	28400.
10	0000	9	16300.	33.	23623.	23800.
10	1200	10	12600.	27.	19673.	19400.
11	0000	11	9300.	21.	15791.	15300.
11	1200	12	6700.	16.	12242.	11200.
12	0000	13	5000.	11.	9222.	8200.
12	1200	14	4100.	9.	6901.	6400.
13	0000	15	3600.	7.	5316.	5200.
13	1200	16	2400.	6.	4223.	4600.
		SUM	214500.	300.	212915.	214800.

STATION 1

STATION 1

(I) INFLOW, (O) OUTFLOW, (*) OBSERVED FLOW



(-) LIMITS OF OPTIMIZATION

12.6 Example Problem #6: Precipitation Depth-Area Simulation

In this example, runoff in the river basin shown in Figure 12.4 is to be simulated using the precipitation depth-area relationship given in Table 12.6a. The storm pattern, to be used for all drainage basin sizes in this case, is also shown in Table 12.6a.

All subbasin system hydrographs are routed and combined as in a stream network computation. However, the resulting hydrograph at any control point is interpolated from the system hydrographs based on the cumulative area to that point. The listing of the input data deck and the resulting depth-area simulation is shown in Table 12.6b.

TABLE 12.6a

Depth-Area Simulation Data

RAINFALL DATA		CARD(S)
TRANSPOSITION AREA (sq mi)	STORM DEPTH (in)	JD
1000	9.08	
3000	8.93	
5000	8.70	
7000	8.57	
9000	8.43	

Please see data input listing for pattern hyetograph (PI cards)

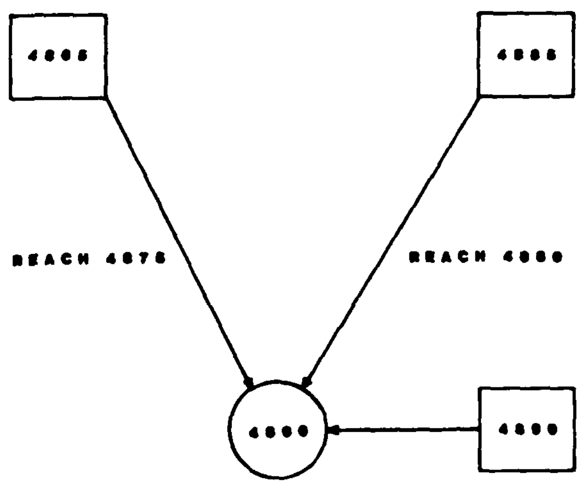


Figure 12.4 Precipitation Depth-Area Analysis Basin

TABLE 12.6b

Example Problem #6: Input and Output

```
                                          HEC-1 INPUT                                                   PAGE  1

LINE           ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1            ID           EXAMPLE PROBLEM NO. 6
  2            ID          PRECIPITATION DEPTH-AREA SIMULATION
  3            ID          FOR A RIVER BASIN
  4            ID                                 AND INTERPOLATION ROUTINE
  5            IT     120       0       0      97
  6            IO       5
  7            JD    9.08 1000.00
  8            PI  0.      0.      0.       .0014   .0015   .0048   .0092   .0048   .0048   .0063
  9            PI   .0131   .0141   .0189   .0237   .0189   .0141   .0092   .0048   .0029   .0015
 10            PI   .0029  0.      0.      0.       .0087   .0175   .0175   .0175   .0039   .0087
 11            PI  0.      0.       .0140  0.       .0097   .0184  0.      0.       .0310  0.
 12            PI  0.       .0209   .0179   .0155   .0155   .0058   .0131   .0155   .0063   .0097
 13            PI   .0087   .0126   .0175   .0146   .0121   .0141   .0141   .0136   .0126   .0155
 14            PI   .0170   .0233   .0209   .0276   .0340   .0660   .0209   .0184   .0170   .0155
 15            PI   .0146   .0126   .0073   .0107   .0049   .0073   .0034   .0024  0.      0.
 16            PI   .0107  0.       .0107   .0310   .0048   .0281   .0141   .0048   .0039   .0087
 17            PI  0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
 18            JD    8.93 3000.00
 19            JD    8.70 5000.00
 20            JD    8.57 7000.00
 21            JD    8.43 9000.00

 22            KK    4865
 23            KO       3
 24            BA   3503.      0.
 25            LE     .40      0.    4.00     .70      0.
 26            UC   12.30    8.60
 27            BF   1200.   3000.  1.0132

 28            KK    4890
 29            RL      0.      0.
 30            RT      24               0

 31            KK    4885
 32            BA   1750.      0.
 33            LE     .33      0.    4.00     .70      0.
 34            UC    6.60    4.60
 35            BF    280.    700.  1.0147

 36            KK    4890
 37            RL      0.      0.
 38            RT      12       2       0

 39            KK    4890
 40            BA   3296.      0.
 41            LE     .39      0.    4.00     .70      0.
 42            UC   13.20    9.20
 43            BF    400.   1000.  1.0147

 44            KK    4890
 45            HC       3
 46            ZZ


                      EXAMPLE PROBLEM NO. 6
                      PRECIPITATION DEPTH-AREA SIMULATION
                      FOR A RIVER BASIN
                                  AND INTERPOLATION ROUTINE

 6 IO         OUTPUT CONTROL VARIABLES
                   IPRNT           5  PRINT CONTROL
                   IPLOT           0  PLOT CONTROL
                   QSCAL          0.  HYDROGRAPH PLOT SCALE
                   DMSG          YES  PRINT DIAGNOSTIC MESSAGES

   IT         HYDROGRAPH TIME DATA
                    NMIN         120  MINUTES IN COMPUTATION INTERVAL
                   IDATE      1    0  STARTING DATE
                   ITIME        0000  STARTING TIME
                      NQ          97  NUMBER OF HYDROGRAPH ORDINATES
                  NDDATE      9    0  ENDING DATE
                  NDTIME        0000  ENDING TIME

                COMPUTATION INTERVAL    2.00 HOURS
                     TOTAL TIME BASE  192.00 HOURS

       ENGLISH UNITS
            DRAINAGE AREA           SQUARE MILES
            PRECIPITATION DEPTH     INCHES
            LENGTH, ELEVATION       FEET
            FLOW                    CUBIC FEET PER SECOND
            STORAGE VOLUME          ACRE-FEET
            SURFACE AREA            ACRES
            TEMPERATURE             DEGREES FAHRENHEIT

 7 JD         INDEX STORM NO. 1
                    STRM        9.08  PRECIPITATION DEPTH
                    TRDA     1000.00  TRANSPOSITION DRAINAGE AREA

 8 PI           PRECIPITATION PATTERN
                   0.00     0.00     0.00     0.00     0.00     0.00     0.01     0.00     0.00     0.01
                   0.01     0.01     0.02     0.02     0.02     0.01     0.01     0.00     0.00     0.00
                   0.00     0.00     0.00     0.00     0.01     0.02     0.02     0.02     0.00     0.01
                   0.00     0.00     0.01     0.00     0.01     0.02     0.00     0.00     0.03     0.00
                   0.00     0.02     0.02     0.02     0.02     0.01     0.01     0.02     0.01     0.01
                   0.01     0.01     0.02     0.01     0.01     0.01     0.01     0.01     0.01     0.02
                   0.02     0.02     0.02     0.03     0.03     0.07     0.02     0.02     0.02     0.02
                   0.01     0.01     0.01     0.01     0.00     0.01     0.00     0.00     0.00     0.00
                   0.01     0.00     0.01     0.03     0.00     0.03     0.01     0.00     0.00     0.01
```

```
18 JD         INDEX STORM NO. 2
                   STRM        8.93  PRECIPITATION DEPTH
                   TRDA     3000.00  TRANSPOSITION DRAINAGE AREA

 0 PI           PRECIPITATION PATTERN
                 0.00       0.00       0.00       0.00       0.00       0.00       0.01       0.00       0.00       0.01
                 0.01       0.01       0.02       0.02       0.02       0.01       0.01       0.00       0.00       0.00
                 0.00       0.00       0.00       0.00       0.01       0.02       0.02       0.02       0.00       0.01
                 0.00       0.00       0.01       0.00       0.01       0.02       0.00       0.00       0.03       0.00
                 0.00       0.02       0.02       0.02       0.02       0.01       0.01       0.02       0.01       0.01
                 0.01       0.01       0.02       0.01       0.01       0.01       0.01       0.01       0.01       0.02
                 0.02       0.02       0.02       0.03       0.03       0.07       0.02       0.02       0.02       0.02
                 0.01       0.01       0.01       0.01       0.00       0.01       0.00       0.00       0.00       0.00
                 0.01       0.00       0.01       0.03       0.00       0.03       0.01       0.00       0.00       0.01

19 JD         INDEX STORM NO. 3
                   STRM        8.70  PRECIPITATION DEPTH
                   TRDA     5000.00  TRANSPOSITION DRAINAGE AREA

 0 PI           PRECIPITATION PATTERN
                 0.00       0.00       0.00       0.00       0.00       0.00       0.01       0.00       0.00       0.01
                 0.01       0.01       0.02       0.02       0.02       0.01       0.01       0.00       0.00       0.00
                 0.00       0.00       0.00       0.00       0.01       0.02       0.02       0.02       0.00       0.01
                 0.00       0.00       0.01       0.00       0.01       0.02       0.00       0.00       0.03       0.00
                 0.00       0.02       0.02       0.02       0.02       0.01       0.01       0.02       0.01       0.01
                 0.01       0.01       0.02       0.01       0.01       0.01       0.01       0.01       0.01       0.02
                 0.02       0.02       0.02       0.03       0.03       0.07       0.02       0.02       0.02       0.02
                 0.01       0.01       0.01       0.01       0.00       0.01       0.00       0.00       0.00       0.00
                 0.01       0.00       0.01       0.03       0.00       0.03       0.01       0.00       0.00       0.01

20 JD         INDEX STORM NO. 4
                   STRM        8.57  PRECIPITATION DEPTH
                   TRDA     7000.00  TRANSPOSITION DRAINAGE AREA

 0 PI           PRECIPITATION PATTERN
                 0.00       0.00       0.00       0.00       0.00       0.00       0.01       0.00       0.00       0.01
                 0.01       0.01       0.02       0.02       0.02       0.01       0.01       0.00       0.00       0.00
                 0.00       0.00       0.00       0.00       0.01       0.02       0.02       0.02       0.00       0.01
                 0.00       0.00       0.01       0.00       0.01       0.02       0.00       0.00       0.03       0.00
                 0.00       0.02       0.02       0.02       0.02       0.01       0.01       0.02       0.01       0.01
                 0.01       0.01       0.02       0.01       0.01       0.01       0.01       0.01       0.01       0.02
                 0.02       0.02       0.02       0.03       0.03       0.07       0.02       0.02       0.02       0.02
                 0.01       0.01       0.01       0.01       0.00       0.01       0.00       0.00       0.00       0.00
                 0.01       0.00       0.01       0.03       0.00       0.03       0.01       0.00       0.00       0.01

21 JD         INDEX STORM NO. 5
                   STRM        8.43  PRECIPITATION DEPTH
                   TRDA     9000.00  TRANSPOSITION DRAINAGE AREA

 0 PI           PRECIPITATION PATTERN
                 0.00       0.00       0.00       0.00       0.00       0.00       0.01       0.00       0.00       0.01
                 0.01       0.01       0.02       0.02       0.02       0.01       0.01       0.00       0.00       0.00
                 0.00       0.00       0.00       0.00       0.01       0.02       0.02       0.02       0.00       0.01
                 0.00       0.00       0.01       0.00       0.01       0.02       0.00       0.00       0.03       0.00
                 0.00       0.02       0.02       0.02       0.02       0.01       0.01       0.02       0.01       0.01
                 0.01       0.01       0.02       0.01       0.01       0.01       0.01       0.01       0.01       0.02
                 0.02       0.02       0.02       0.03       0.03       0.07       0.02       0.02       0.02       0.02
                 0.01       0.01       0.01       0.01       0.00       0.01       0.00       0.00       0.00       0.00
                 0.01       0.00       0.01       0.03       0.00       0.03       0.01       0.00       0.00       0.01

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

            **************
            *            *
22 KK       *    4865    *
            *            *
            **************

23 KO         OUTPUT CONTROL VARIABLES
                   IPRNT          3  PRINT CONTROL
                   IPLOT          0  PLOT CONTROL
                   QSCAL         0.  HYDROGRAPH PLOT SCALE

           SUBBASIN RUNOFF DATA

24 BA         SUBBASIN CHARACTERISTICS
                   TAREA    3503.00  SUBBASIN AREA

27 BF         BASE FLOW CHARACTERISTICS
                   STRTQ    1200.00  INITIAL FLOW
                   QRCSN    3000.00  BEGIN BASE FLOW RECESSION
                   RTIOR    1.01320  RECESSION CONSTANT

25 LE         EXPONENTIAL LOSS RATE
                   STRKR       0.40  INITIAL VALUE OF LOSS COEFFICIENT
                   DLTKR       0.00  INITIAL LOSS
                   RTIOL       4.00  LOSS COEFFICIENT RECESSION CONSTANT
                   ERAIN       0.70  EXPONENT OF PRECIPITATION
                   RTIMP       0.00  PERCENT IMPERVIOUS AREA

26 UC         CLARK UNITGRAPH
                      TC      12.30  TIME OF CONCENTRATION
                       R       8.60  STORAGE COEFFICIENT

              SYNTHETIC ACCUMULATED-AREA VS. TIME CURVE WILL BE USED

                                                            .***

                                                       UNIT HYDROGRAPH PARAMETERS
                                                CLARK   TC= 12.30 HR,        R=  8.60 HR
                                               SNYDER   TP= 10.29 HR,       CP=  0.65

                                                              UNIT HYDROGRAPH
                                                       27 END-OF-PERIOD ORDINATES
         10918.     39523.     77100.    113480.    137385.    142547.    126313.    100632.     79667.     63070.
         49930.     39528.     31293.     24774.     19613.     15527.     12292.      9731.      7704.      6099.
          4828.      3822.      3026.      2396.      1897.      1501.      1189.

   ***             ***             ***             ***             ***
```

HYDROGRAPH AT STATION 4865
TRANSPOSITION AREA 1000.0 SQ MI

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 6-HR	24-HR	72-HR	192.00-HR
158251.	140.00	(CFS)	155074.	124589.	78467.	42735.
		(INCHES)	0.412	1.323	2.499	3.630
		(AC-FT)	76896.	247119.	466913.	678114.

CUMULATIVE AREA = 3503.00 SQ MI

*** *** *** *** ***

HYDROGRAPH AT STATION 4865
TRANSPOSITION AREA 3000.0 SQ MI

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 6-HR	24-HR	72-HR	192.00-HR
154475.	140.00	(CFS)	151369.	121524.	76450.	41543.
		(INCHES)	0.402	1.290	2.435	3.528
		(AC-FT)	75059.	241039.	454908.	659196.

CUMULATIVE AREA = 3503.00 SQ MI

*** *** *** *** ***

HYDROGRAPH AT STATION 4865
TRANSPOSITION AREA 5000.0 SQ MI

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 6-HR	24-HR	72-HR	192.00-HR
148710.	140.00	(CFS)	145712.	116845.	73371.	39726.
		(INCHES)	0.387	1.241	2.337	3.374
		(AC-FT)	72254.	231759.	436588.	630363.

CUMULATIVE AREA = 3503.00 SQ MI

*** *** *** *** ***

HYDROGRAPH AT STATION 4865
TRANSPOSITION AREA 7000.0 SQ MI

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 6-HR	24-HR	72-HR	192.00-HR
145464.	140.00	(CFS)	142527.	114212.	71639.	38705.
		(INCHES)	0.378	1.213	2.282	3.287
		(AC-FT)	70675.	226536.	426282.	614162.

CUMULATIVE AREA = 3503.00 SQ MI

*** *** *** *** ***

HYDROGRAPH AT STATION 4865
TRANSPOSITION AREA 9000.0 SQ MI

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 6-HR	24-HR	72-HR	192.00-HR
141980.	140.00	(CFS)	139109.	111386.	69780.	37611.
		(INCHES)	0.369	1.183	2.223	3.194
		(AC-FT)	68979.	220930.	415223.	596796.

CUMULATIVE AREA = 3503.00 SQ MI

*** *** *** *** ***

INTERPOLATED HYDROGRAPH AT 4865

PEAK FLOW (CFS)	TIME (HR)		MAXIMUM AVERAGE FLOW 6-HR	24-HR	72-HR	192.00-HR
152726.	140.00	(CFS)	149653.	120104.	75516.	40992.
		(INCHES)	0.397	1.275	2.405	3.482
		(AC-FT)	74208.	238223.	449349.	650447.

CUMULATIVE AREA = 3503.00 SQ MI

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
HYDROGRAPH AT	4865	152726.	140.00	149653.	120104.	75516.	3503.00		
ROUTED TO	4890	134678.	166.00	132570.	114463.	72205.	3503.00		
HYDROGRAPH AT	4885	112011.	136.00	103306.	72302.	43669.	1750.00		
ROUTED TO	4890	93847.	148.00	91223.	70648.	43403.	1750.00		
HYDROGRAPH AT	4890	142090.	142.00	138339.	113338.	72159.	3296.00		
3 COMBINED AT	4890	249934.	146.00	247715.	227713.	172326.	8549.00		

12.7 Example Problem #7: Dam Safety Analysis

Two examples of dam analysis are included in these example problems: Test 7 illustrates evaluations of overtopping of the dam, and Test 8 shows the analysis of the downstream consequences resulting from various assumed dam breaches. The desired hydrologic analysis includes evaluations of overtopping the dam and of various types of structural failures. Figure 12.5 illustrates the schematic of the Bear Creek system and associated hydrologic data. Table 12.7a gives pertinent reservoir data.

Problem Description

Test 7 analyzes the overtopping potential of the Bear Creek Dam. Ratios of the PMF were generated and routed through the reservoir to determine the event (expressed as percent of the PMF) that would overtop the structure. The general procedure used in the analysis was:

- Develop the PMP for area above the reservoir from input index rainfall parameters.
- Determine average basin loss rates and probable maximum rainfall excess.
- Develop a unit hydrograph using the Snyder method.
- Generate the runoff hydrograph and add base flow to get probable maximum inflow hydrograph to the reservoir.
- Apply ratios to the PMF to obtain a series of proportional inflow hydrographs.
- Develop reservoir storage-outflow functions from elevation-area relationship and characteristics of reservoir outlet works and dam.
- Route hydrographs through the reservoir and determine the ratio of the PMP that overtops the dam.

The input data and output from the HEC-1 program are shown in Table 12.7b.

Discussion of Results

The last page of the HEC-1 output (Table 12.7b) provides a "SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION *DAM*" which illustrates the potential of the dam to overtop as a ratio of the PMF. Also, data on duration of overtopping and maximum water surface elevations, for use in determining possible dam failure due to erosion are shown. Interpolation of the information provided in that summary indicates that a flood of about thirty percent of the PMF would overtop the dam.

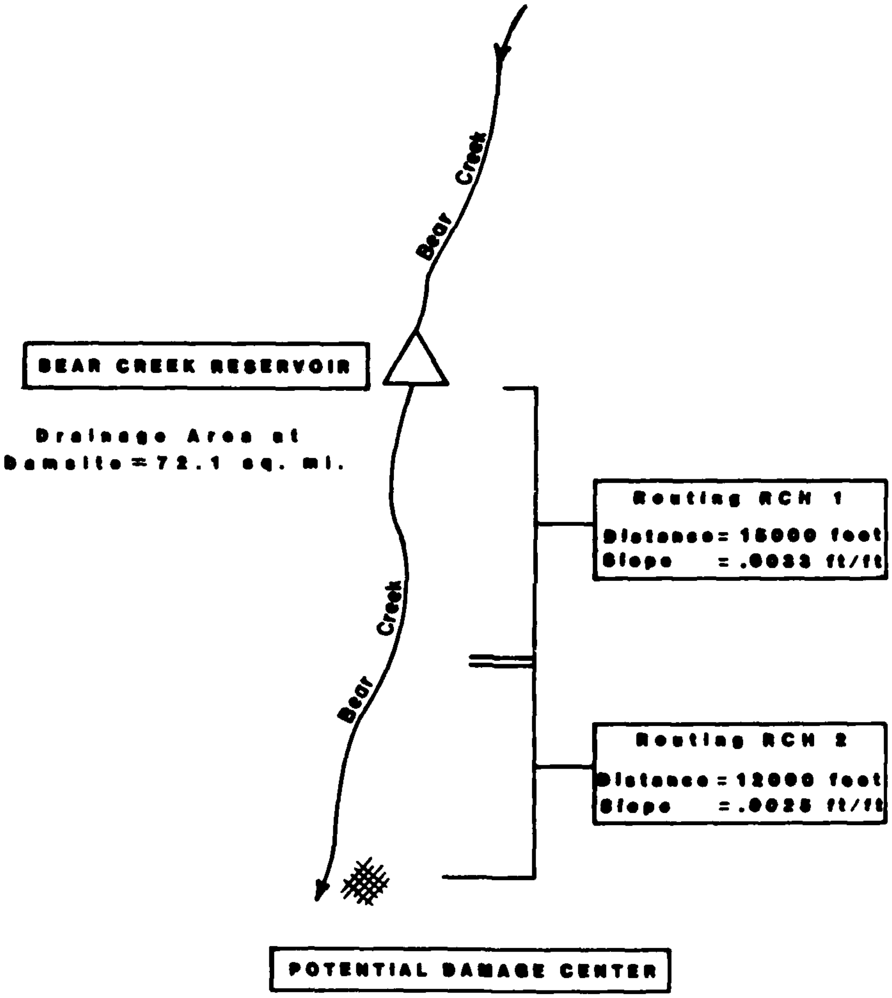


Figure 12.5 Schematic of Bear Creek Basin

TABLE 12.7a

Reservoir Data

RECORD IDENTIFIER

Outflow characteristics of the Bear Creek Reservoir:

Low level outlet — SL

- Diameter = 4 feet
- Coefficient of discharge = .7
- Downstream centerline elevation of outlet = 380.0 m.s.l.
- Exponent of head = .5

Spillway — SS

- Crest elevation = 420.0 m.s.l.
- Length = 200 feet
- Weir coefficient = 3.1
- Exponent of head = 1.5

Dam — ST

- Crest elevation = 432.0 m.s.l.
- Length = 900 feet
- Weir coefficient = 3.1
- Exponent of head = 1.5

Reservoir elevation-area relationship — SE, SA

Elevation (m.s.l.)	Area (acres)
340	0
380	100
410	250
420	300
424	320
428	350
432	380
436	410
440	450
444	500

TABLE 12.7b

Example Problem #7: Input and Output

```
                                        HEC-1 INPUT                                                          PAGE  1

   LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

      1          ID        EXAMPLE PROBLEM NO. 7
      2          ID        DAM SAFETY ANALYSIS
      3          ID               ANALYSIS OF DAM OVERTOPPING USING RATIOS OF PMF
*** FREE ***
      4          IT      15       0       0     121
      5          IO       5
      6          JR    FLOW     .20     .35     .50     .65     .80     1.0

      7          KK  INFLOW  INFLOW TO BEAR CREEK RESERVOIR
      8          BA    72.1
      9          BF    -1.0    -.05     2.0
     10          PM      25       0       0              82      97     110
     11          LU     1.0     .04
     12          US     4.8     .60

     13          KK     DAM     BEAR CREEK DAM
     14          RS       1    STOR   10000
     15          SA       0     100     250     300     320     350     380     410     450     500
     16          SE     340     380     410     420     424     428     432     436     440     444
     17          SS     420     200     3.1     1.5
     18          SL     380    12.6      .7      .5
     19          ST     432     900     3.1     1.5

     20          KK    RCH1
     21          KM      ROUTE OUTFLOW FROM RESERVOIR THROUGH FIRST CHANNEL REACH DOWNSTREAM
     22          RS       1    STOR      -1
     23          RC     .04     .05     .04   15000   .0033     312
     24          RX       0     500    1400    1425    1450    1475    2500    3000
     25          RY     400     350     290     280     280     290     350     400
     26          ZZ
```

```
*****************************************                                  ****************************************
*                                       *                                  *                                      *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                  *     U.S. ARMY CORPS OF ENGINEERS     *
*             FEBRUARY 1981             *                                  *  THE HYDROLOGIC ENGINEERING CENTER   *
*          REVISED 14 JUN 85            *                                  *          609 SECOND STREET           *
*                                       *                                  *       DAVIS, CALIFORNIA 95616        *
*  RUN DATE  2 JUL 85    TIME  13:45:17 *                                  *   (916) 440-3285 OR (FTS) 448-3285   *
*                                       *                                  *                                      *
*****************************************                                  ****************************************
```

```
                              EXAMPLE PROBLEM NO. 7
                              DAM SAFETY ANALYSIS
                                     ANALYSIS OF DAM OVERTOPPING USING RATIOS OF PMF

  5 IO          OUTPUT CONTROL VARIABLES
                      IPRNT          5  PRINT CONTROL
                      IPLOT          0  PLOT CONTROL
                      QSCAL         0.  HYDROGRAPH PLOT SCALE
                       DMSG        YES  PRINT DIAGNOSTIC MESSAGES

    IT          HYDROGRAPH TIME DATA
                       NMIN         15  MINUTES IN COMPUTATION INTERVAL
                      IDATE      1   0  STARTING DATE
                      ITIME       0000  STARTING TIME
                         NQ        121  NUMBER OF HYDROGRAPH ORDINATES
                     NDDATE      2   0  ENDING DATE
                     NDTIME       0600  ENDING TIME

                 COMPUTATION INTERVAL    0.25 HOURS
                      TOTAL TIME BASE   30.00 HOURS

        ENGLISH UNITS
             DRAINAGE AREA            SQUARE MILES
             PRECIPITATION DEPTH      INCHES
             LENGTH, ELEVATION        FEET
             FLOW                     CUBIC FEET PER SECOND
             STORAGE VOLUME           ACRE-FEET
             SURFACE AREA             ACRES
             TEMPERATURE              DEGREES FAHRENHEIT

    JP          MULTI-PLAN OPTION
                     NPLAN           1  NUMBER OF PLANS

    JR          MULTI-RATIO OPTION
                  RATIOS OF RUNOFF
                 0.20     0.35     0.50     0.65     0.80     1.00
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIO 1 0.20	RATIO 2 0.35	RATIO 3 0.50	RATIO 4 0.65	RATIO 5 0.80	RATIO 6 1.00
HYDROGRAPH AT										
+	INFLOW	72.10	1	FLOW	19032.	33305.	47579.	61853.	76126.	95158.
				TIME	20.25	20.25	20.25	20.25	20.25	20.25
ROUTED TO										
+	DAM	72.10	1	FLOW	17040.	31622.	46856.	61272.	75545.	94537.
				TIME	21.50	21.00	20.75	20.50	20.50	20.50
			** PEAK STAGES IN FEET **							
			1	STAGE	428.93	432.90	434.60	435.90	437.03	438.39
				TIME	21.50	21.00	20.75	20.50	20.50	20.50
ROUTED TO										
+	RCH1	72.10	1	FLOW	16886.	31224.	46515.	60842.	75115.	94074.
				TIME	22.00	21.50	21.00	20.75	20.75	20.75
			** PEAK STAGES IN FEET **							
			1	STAGE	298.11	301.71	304.37	306.39	308.10	310.07
				TIME	22.00	21.50	21.00	20.75	20.75	20.75

SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION DAM

PLAN 1		INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
	ELEVATION	422.71	420.00	432.00
	STORAGE	9991.	9161.	13200.
	OUTFLOW	3225.	447.	26283.

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
0.20	428.93	0.00	12070.	17051.	0.00	21.50	0.00
0.35	432.90	0.90	13546.	31655.	3.50	21.00	0.00
0.50	434.61	2.61	14215.	46866.	7.25	20.75	0.00
0.65	435.90	3.90	14737.	61284.	9.50	20.50	0.00
0.80	437.03	5.03	15206.	75558.	11.25	20.50	0.00
1.00	438.39	6.39	15789.	94548.	12.75	20.50	0.00

*** NORMAL END OF HEC-1 ***

12.8 Example Problem #8: Dam Failure Analysis

Test 8 involves evaluation of the downstream hydrologic-hydraulic consequences in the Bear Creek system (Fig. 12.5) resulting from different assumed structural failures of the dam (Table 12.7a). The test uses the multiplan capability of the program to evaluate five different types of dam breaches in a single computer run. The user designed output option was also used in this test. The computation sequence performed by the program was:

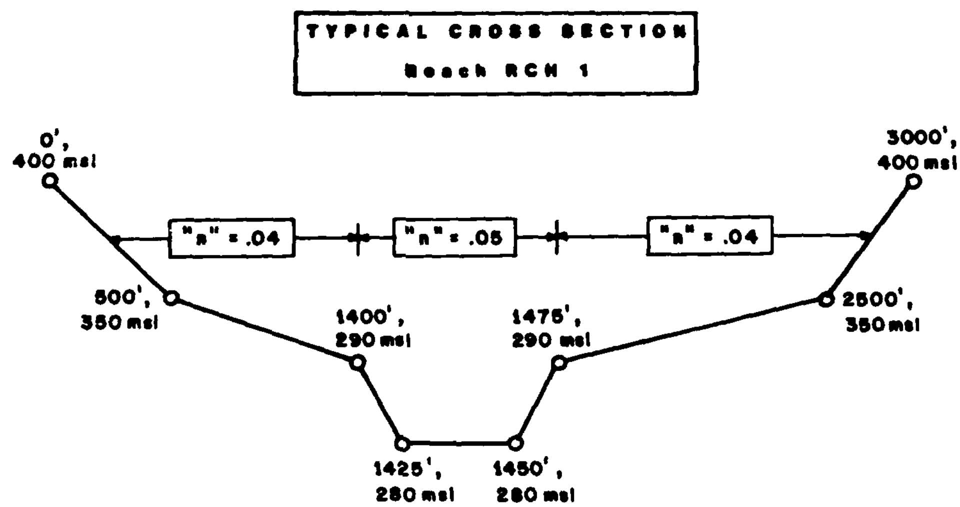
- Compute the PMF inflow hydrograph for the reservoir.
- Route the hydrograph through the reservoir. The outflow hydrograph is based on the specified breach criteria and normal releases of the outlet works.
- Route hydrographs through channel reaches RCH 1 and RCH 2 using the cross-sectional data shown in Fig. 12.6.

A summary of the HEC-1 results are shown in Table 12.8a. The input format and computation results for this test are shown in Table 12.8b.

Discussion of Results

The failure analysis performed provides insight into the sensitivity of various breach dimensions on downstream water surface elevations. The downstream peak discharges and corresponding stages are given in Table 12.8a. The HEC-1 summary output, Table 12.8b, contains these results (input and output listing as well as line printer plots of the breach hydrographs).

The plots illustrate how well the hydrograph depicted by normal time steps represents the breach hydrograph generated using smaller time steps. PLAN 1 has a volume gain of 2330 acre-feet from the peak portion of the hydrograph indicating that a smaller time step should be used. The plot for PLAN 3 indicates that the peak flow from the dam occurs after the breach is fully formed. Characterization of the outflow hydrograph and peak discharge will depend on the specified time step as in a standard storage routing.



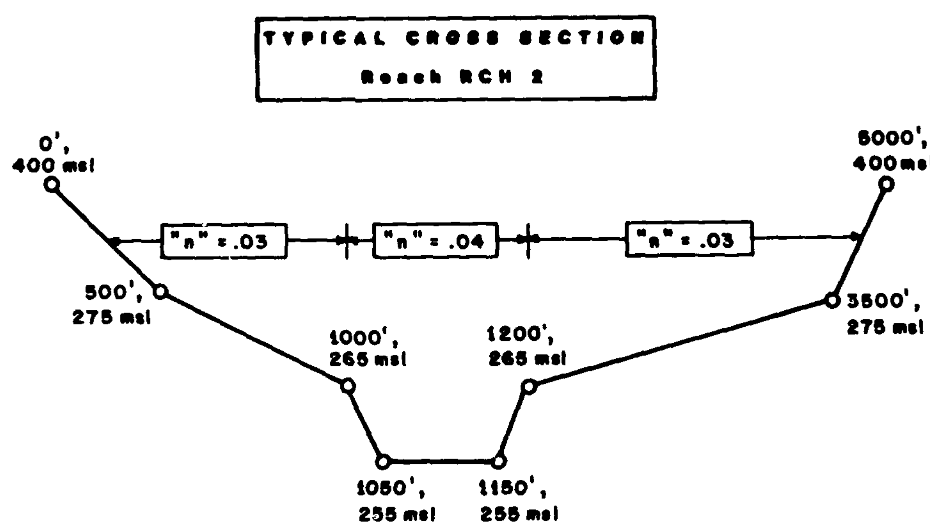


Figure 12.6 Bear Creek Downstream Cross Sections

TABLE 12.8a

Dam Failure Analysis Results

Plan No. and Breach Criteria	Reservoir Peak Q	Reservoir Peak W.S. El.	RCH1 Peak Q	RCH1 Peak W.S. El.	RCH2 Peak Q	RCH2 Peak W.S. El.
Plan 1 fail time = 15 min. total dam	1,244,000	433.5	610,000	334.1	422,000	280.7
Plan 2 fail time = 3 hrs. total dam	209,000	434.1	197,000	317.7	184,000	276.0
Plan 3 fail time = 3 hrs breach depth = 50 ft. b.w. = 50 ft. s.s. = 2:1	135,000	435.4	127,000	312.9	122,000	274.2
Plan 4 fail time = 3 hrs breach depth = 70 ft. b.w. = 200 ft. s.s. = 2:1	180,000	434.6	175,000	316.3	171,000	275.6
Plan 5 fail time = 10 hrs breach depth = 70 ft. b.w. = 200 ft. s.s. = 2:1	109,000	436.6	109,000	311.4	108,000	273.7

TABLE 12.8b

Example Problem #8: Input and Output

```
                                   HEC-1 INPUT                                          PAGE  1

   LINE         ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

                ID        EXAMPLE PROBLEM NO. 8
                ID        DAM FAILURE ANALYSIS
*** FIX ***
                IT      15                      140
                IO       4
                JP       5
                VS    RCH1    RCH1    RCH1    RCH1    RCH2    RCH2    RCH2    RCH2
                VV    2.11    2.51    7.11    7.51    2.11    2.51    7.11    7.51

                KK      IN          BEAR CREEK RESERVOIR
                KM      CALCULATION OF INFLOW TO BEAR CREEK RESERVOIR
                BA    72.1
                PM      25       0       0       0      82      97     110
                LU      1.     .04
                US     4.8     .60
                BF      -1    -.05   1.319

                KK     OUT          BEAR CREEK DAM
                KM        ROUTED FLOWS THROUGH BEAR CREEK RESERVOIR
                KO       1
                KP       1
                RS       1    ELEV     420
                SA       0     100     250     300     320     350     380     410     450     500
                SE     340     380     410     420     424     428     432     436     440     444
                SS     420     200     3.1     1.5
                ST     432     900     3.1     1.5
                SL     380    12.6      .7      .5
                SB     340     900       0     .25     433
                KP       2
                SB     340     900       0       3     433
                KP       3
                KO       5
                SB     382      50       2       3     433
                KP       4
                SB     362     200       2       3     433
                KP       5
                SB     362     200       2      10     433
```

```
35          KK    RCH1
36          KO      5
37          KM        CHANNEL ROUTING    REACH 2-3
38          RS      1     STOR       0
39          RC    .04      .05     .04   15000   .0033    335
40          RX      0      500    1400    1425    1450   1475   2500   3000
41          RY    400      350     290     280     280    290    350    400

42          KK    RCH2
43          KO      5
44          KM        CHANNEL ROUTING    REACH 3-4
45          RS      1     STOR       0
46          RC    .03      .04     .03   12000   .0025    280
47          RX      0      500    1000    1050    1150   1200   3500   5000
48          RY    400      275     265     255     255    265    275    400
49          ZZ
```

```
****************************************                ****************************************
*                                      *                *                                      *
*  FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                *   U.S. ARMY CORPS OF ENGINEERS       *
*          FEBRUARY 1981               *                * THE HYDROLOGIC ENGINEERING CENTER    *
*        REVISED 14 JUN 85             *                *       609 SECOND STREET              *
*                                      *                *     DAVIS, CALIFORNIA 95616          *
* RUN DATE  2 JUL 85    TIME  13:45:17 *                * (916) 440-3285 OR (FTS) 448-3285     *
*                                      *                *                                      *
****************************************                ****************************************
```

```
                         EXAMPLE PROBLEM NO. 8
                         DAM FAILURE ANALYSIS

 4 IO          OUTPUT CONTROL VARIABLES
                    IPRNT          4  PRINT CONTROL
                    IPLOT          0  PLOT CONTROL
                    QSCAL          0.  HYDROGRAPH PLOT SCALE
                     DMSG        YES  PRINT DIAGNOSTIC MESSAGES

   IT          HYDROGRAPH TIME DATA
                     NMIN         15  MINUTES IN COMPUTATION INTERVAL
                    IDATE     1    0  STARTING DATE
                    ITIME       0000  STARTING TIME
                       NQ        140  NUMBER OF HYDROGRAPH ORDINATES
                   NDDATE     2    0  ENDING DATE
                   NDTIME       1045  ENDING TIME

               COMPUTATION INTERVAL    0.25 HOURS
                    TOTAL TIME BASE   34.75 HOURS

         ENGLISH UNITS
              DRAINAGE AREA           SQUARE MILES
              PRECIPITATION DEPTH     INCHES
              LENGTH, ELEVATION       FEET
              FLOW                    CUBIC FEET PER SECOND
              STORAGE VOLUME          ACRE-FEET
              SURFACE AREA            ACRES
              TEMPERATURE             DEGREES FAHRENHEIT

               USER-DEFINED OUTPUT SPECIFICATIONS

      TABLE 1
   VS      STATION      RCH1      RCH1      RCH1      RCH1      RCH2      RCH2      RCH2      RCH2
   VV VARIABLE CODE     2.11      2.51      7.11      7.51      2.11      2.51      7.11      7.51      0.00      0.00

   JP          MULTI-PLAN OPTION
                    NPLAN          5  NUMBER OF PLANS

   JR          MULTI-RATIO OPTION
                  RATIOS OF RUNOFF
                 1.00
```

```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

            **************
            *            *
   8 KK     *     IN     *              BEAR CREEK RESERVOIR
            *            *
            **************
```

```
**************
                    CALCULATION OF INFLOW TO BEAR CREEK RESERVOIR

          SUBBASIN RUNOFF DATA

10 BA          SUBBASIN CHARACTERISTICS
                    TAREA       72.10  SUBBASIN AREA

14 BF          BASE FLOW CHARACTERISTICS
                    STRTQ       72.10  INITIAL FLOW
                    QRCSN       -0.05  BEGIN BASE FLOW RECESSION
                    RTIOR     1.31900  RECESSION CONSTANT

               PRECIPITATION DATA

11 PM          PROBABLE MAXIMUM STORM
                      PMS       25.00  INDEX PRECIPITATION
                    TRSPC        0.86  TRANSPOSITION COEFFICIENT
                    TRSDA       72.10  TRANSPOSITION AREA
                      SWD          NO  USE SWD DISTRIBUTION

                  PERCENT OF INDEX PRECIPITATION OCCURRING IN GIVEN TIME
                     6-HR   12-HR   24-HR   48-HR   72-HR   96-HR
                     82.0    97.0   110.0     0.0     0.0     0.0

12 LU          UNIFORM LOSS RATE
                    STRTL        1.00  INITIAL LOSS
                    CNSTL        0.04  UNIFORM LOSS RATE
                    RTIMP        0.00  PERCENT IMPERVIOUS AREA

13 US          SNYDER UNITGRAPH
                       TP        4.80  LAG
                       CP        0.60  PEAKING COEFFICIENT

               SYNTHETIC ACCUMULATED-AREA VS. TIME CURVE WILL BE USED

                                                         ***

                                       UNIT HYDROGRAPH PARAMETERS
                                   CLARK    TC=  5.16 HR,        R=  4.88 HR
                                  SNYDER    TP=  4.80 HR,       CP=  0.60

                                            UNIT HYDROGRAPH
                                       115 END-OF-PERIOD ORDINATES
        70.      265.      547.      883.     1259.     1667.     2099.     2552.     3020.     3501.
      3984.     4437.     4834.     5174.     5457.     5683.     5851.     5958.     [illegible]     5963.
      5810.     5554.     5277.     5013.     4762.     4524.     4298.     4083.     3879.     3685.
      3501.     3326.     3160.     3002.     2851.     2709.     2574.     2445.     2323.     2207.
      2096.     1991.     1892.     1797.     1707.     1622.     1541.     1464.     1391.     1321.
      1255.     1192.     1133.     1076.     1022.      971.      923.      877.      833.      791.
       752.      714.      678.      644.      612.      582.      552.      525.      499.      474.
       450.      428.      406.      386.      367.      348.      331.      314.      299.      284.
       269.      256.      243.      231.      219.      209.      198.      188.      179.      170.
       161.      153.      146.      138.      131.      125.      119.      113.      107.      102.
        97.       92.       87.       83.       79.       75.       71.       67.       64.       61.
        58.       55.       52.       50.       47.

***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***

          PLAN  2 INPUT DATA FOR STATION        IN ARE SAME AS FOR PLAN  1

***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***

          PLAN  3 INPUT DATA FOR STATION        IN ARE SAME AS FOR PLAN  1

**     ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***

          PLAN  4 INPUT DATA FOR STATION        IN ARE SAME AS FOR PLAN  1

**     ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***

          PLAN  5 INPUT DATA FOR STATION        IN ARE SAME AS FOR PLAN  1

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** **
```

```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

            **************
            *            *
  15 KK     *    OUT     *              BEAR CREEK DAM
            *            *
            **************

  17 KO          OUTPUT CONTROL VARIABLES
                      IPRNT          1  PRINT CONTROL
                      IPLOT          0  PLOT CONTROL
                      QSCAL         0.  HYDROGRAPH PLOT SCALE

***      ***      ***      ***      ***      ***      ***      ***      ***      ***      ***      ***      ***      ***      ***      ***      ***

  18 KP        PLAN  1 FOR STATION      OUT                 BEAR CREEK DAM

               HYDROGRAPH ROUTING DATA

  19 RS          STORAGE ROUTING
                      NSTPS           1  NUMBER OF SUBREACHES
                      ITYP         ELEV  TYPE OF INITIAL CONDITION
                    RSVRIC       420.00  INITIAL CONDITION
                         X         0.00  WORKING R AND D COEFFICIENT

  20 SA                AREA         0.0     100.0     250.0     300.0     320.0     350.0     380.0     410.0     450.0     500.0

  21 SE           ELEVATION      340.00    380.00    410.00    420.00    424.00    428.00    432.00    436.00    440.00    444.00

  24 SL          LOW-LEVEL OUTLET
                      ELEVL      380.00  ELEVATION AT CENTER OF OUTLET
                      CAREA       12.60  CROSS-SECTIONAL AREA
                       COQL        0.70  COEFFICIENT
                       EXPL        0.50  EXPONENT OF HEAD

  22 SS          SPILLWAY
                       CREL      420.00  SPILLWAY CREST ELEVATION
                      SPWID      200.00  SPILLWAY WIDTH
                       COQW        3.10  WEIR COEFFICIENT
                       EXPW        1.50  EXPONENT OF HEAD

  23 ST          TOP OF DAM
                      TOPEL      432.00  ELEVATION AT TOP OF DAM
                     DAMWID      900.00  DAM WIDTH
                       COQD        3.10  WEIR COEFFICIENT
                       EXPD        1.50  EXPONENT OF HEAD

  25 SB          BREACH DATA
                       ELBM      340.00  ELEVATION AT BOTTOM OF BREACH
                      BRWID      900.00  WIDTH OF BREACH BOTTOM
                          Z        0.00  BREACH SIDE SLOPE
                      TFAIL        0.25  TIME FOR BREACH TO DEVELOP
                     FAILEL      433.00  W.S. ELEVATION TO TRIGGER FAILURE
                                                  ***
```

COMPUTED STORAGE-ELEVATION DATA

STORAGE	0.00	1333.33	6414.47	9160.68	10400.46	11740.01	13199.60	14779.22	16498.60	18397.72
ELEVATION	340.00	380.00	410.00	420.00	424.00	428.00	432.00	436.00	440.00	444.00

COMPUTED OUTFLOW-ELEVATION DATA

(EXCLUDING FLOW OVER DAM)

OUTFLOW	0.00	0.00	102.19	114.85	131.09	152.68	182.78	227.66	301.76	447.38
ELEVATION	340.00	380.00	382.09	382.64	383.43	384.66	386.68	390.36	398.20	420.00
OUTFLOW	524.09	1044.57	2444.54	5159.65	9625.53	16277.80	25552.06	37883.90	53708.92	73462.72
ELEVATION	420.25	420.97	422.17	423.85	426.01	428.65	431.77	435.37	439.45	444.00

COMPUTED STORAGE-OUTFLOW-ELEVATION DATA

(INCLUDING FLOW OVER DAM)

STORAGE	0.00	1333.33	1550.59	1610.64	1700.12	1842.50	2091.06	2590.89	3870.13	6414.47
OUTFLOW	0.00	0.00	102.19	114.85	131.09	152.68	182.78	227.66	301.76	387.44
ELEVATION	340.00	380.00	382.09	382.64	383.43	384.66	386.68	390.36	398.20	410.00
STORAGE	9160.68	9234.42	9453.83	9824.07	10353.84	10400.46	11060.17	11740.01	11970.54	13113.30
OUTFLOW	447.38	524.09	1044.57	2444.54	5159.65	5429.21	9625.53	14519.08	16277.80	25552.06
ELEVATION	420.00	420.25	420.97	422.17	423.85	424.00	426.01	428.00	428.65	431.77
STORAGE	13199.60	14522.21	14779.22	16250.56	16498.60	18397.72				
OUTFLOW	26283.01	55139.86	62529.34	110388.65	119132.92	189440.84				
ELEVATION	432.00	435.37	436.00	439.45	440.00	444.00				

BEGIN DAM FAILURE AT 16.75 HOURS

HYDROGRAPH AT STATION OUT
PLAN 1, RATIO = 1.00

DA	MON	HRMN	ORD	OUTFLOW	STORAGE	STAGE
1		0000	1	447.	9160.7	420.0
1		0015	2	447.	9152.9	420.0
1		0030	3	447.	9145.0	419.9
1		0045	4	447.	9137.0	419.9
1		0100	5	447.	9128.9	419.9
1		0115	6	447.	9120.8	419.9
1		0130	7	446.	9112.6	419.8
1		0145	8	446.	9104.3	419.8
1		0200	9	446.	9096.0	419.8
1		0215	10	446.	9087.6	419.8
1		0230	11	446.	9079.2	419.7
1		0245	12	446.	9070.7	419.7
1		0300	13	446.	9062.1	419.7
1		0315	14	445.	9053.6	419.6
1		0330	15	445.	9044.9	419.6
1		0345	16	445.	9036.3	419.6
1		0400	17	445.	9027.6	419.6
1		0415	18	445.	9018.9	419.5
1		0430	19	445.	9010.1	419.5
1		0445	20	444.	9001.4	419.5
1		0500	21	444.	8992.6	419.4
1		0515	22	444.	8983.8	419.4
1		0530	23	444.	8974.9	419.4
1		0545	24	444.	8966.2	419.3
1		0600	25	444.	8957.6	419.3
1		0615	26	443.	8949.5	419.3
1		0630	27	443.	8942.4	419.3
1		0645	28	443.	8937.0	419.2
1		0700	29	443.	8934.1	419.2
1		0715	30	443.	8934.7	419.2
1		0730	31	443.	8939.9	419.3
1		0745	32	443.	8950.7	419.3
1		0800	33	444.	8968.3	419.4
1		0815	34	444.	8994.0	419.4
1		0830	35	445.	9028.8	419.6
1		0845	36	446.	9074.0	419.7
1		0900	37	447.	9130.9	419.9
1		0915	38	477.	9199.9	420.1
1		0930	39	605.	9280.2	420.4
1		0945	40	813.	9371.2	420.7
1		1000	41	1099.	9471.7	421.0
1		1015	42	1464.	9580.5	421.4
1		1030	43	1904.	9696.1	421.8
1		1045	44	2414.	9817.2	422.2
1		1100	45	2987.	9942.1	422.6
1		1115	46	3615.	10069.2	423.0
1		1130	47	4286.	10197.0	423.4

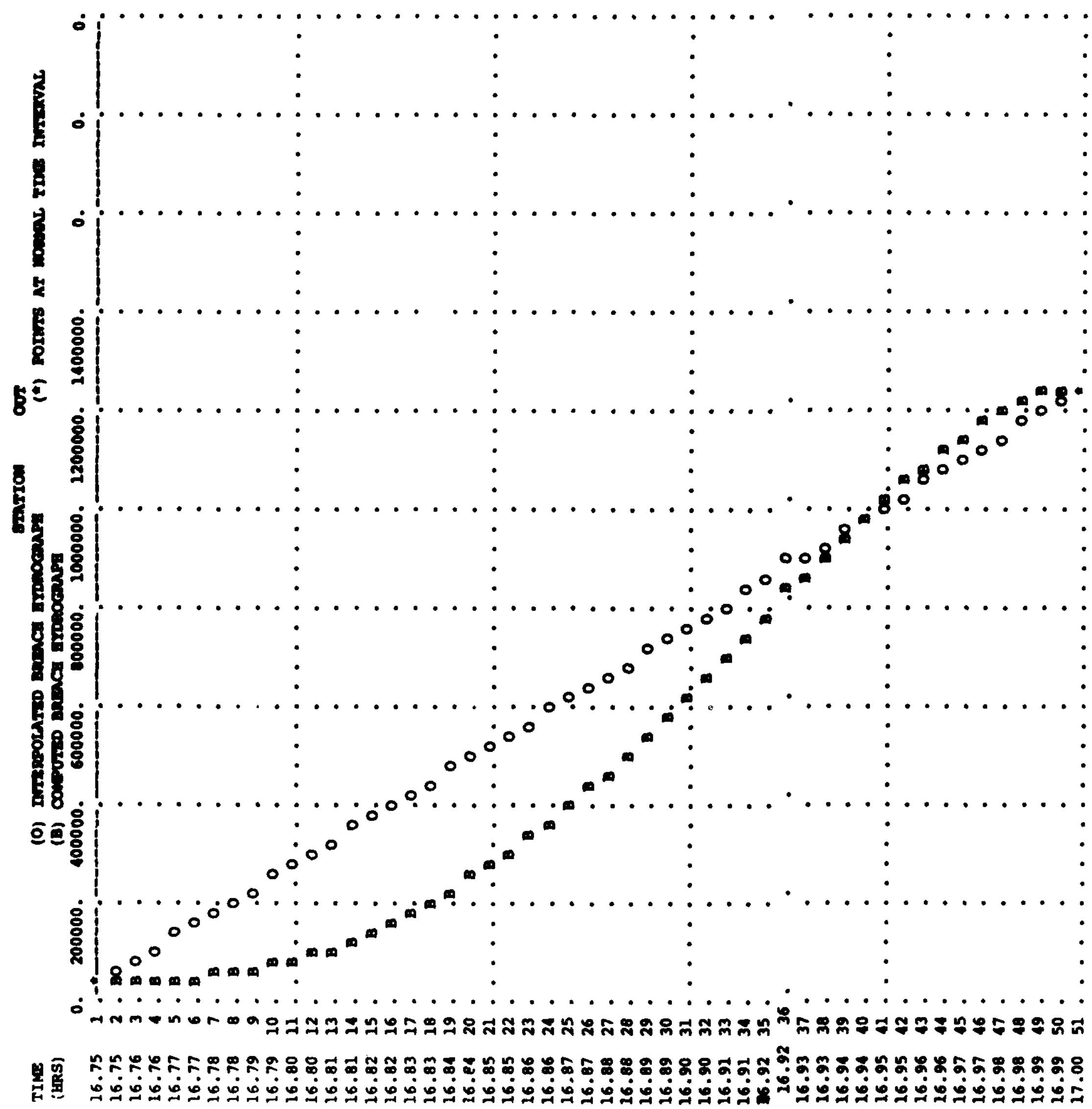
DA	MON	HRMN	ORD	OUTFLOW	STORAGE	STAGE
1		1145	48	4989.	10324.0	423.8
1		1200	49	5714.	10449.0	424.2
1		1215	50	6450.	10571.1	424.5
1		1230	51	7193.	10690.5	424.9
1		1245	52	7945.	10808.0	425.3
1		1300	53	8712.	10924.6	425.6
1		1315	54	9501.	11041.9	426.0
1		1330	55	10323.	11161.4	426.3
1		1345	56	11190.	11285.0	426.7
1		1400	57	12117.	11414.6	427.1
1		1415	58	13119.	11552.0	427.5
1		1430	59	14211.	11699.1	427.9
1		1445	60	15413.	11858.0	428.3
1		1500	61	16742.	12030.5	428.8
1		1515	62	18213.	12218.0	429.3
1		1530	63	19842.	12422.0	429.9
1		1545	64	21666.	12646.6	430.5
1		1600	65	23747.	12898.3	431.2
1		1615	66	26139.	13182.6	432.0
1		1630	67	30485.	13482.9	432.7
1		1645	68	36297.	13773.4	433.5
1		1700	69	1244166.	3946.2	398.6
1		1715	70	59117.	9.5	347.7
1		1730	71	63945.	11.1	348.1
1		1745	72	68727.	12.8	348.5
1		1800	73	73426.	14.6	348.9
1		1815	74	77934.	16.5	349.2
1		1830	75	82065.	18.3	349.6
1		1845	76	85687.	19.9	349.8
1		1900	77	88762.	21.4	350.1
1		1915	78	91263.	22.6	350.3
1		1930	79	93164.	23.5	350.4
1		1945	80	94455.	24.2	350.5
1		2000	81	95125.	24.5	350.6
1		2015	82	95158.	24.6	350.6
1		2030	83	94495.	24.2	350.5
1		2045	84	93048.	23.5	350.4
1		2100	85	90939.	22.4	350.2
1		2115	86	88476.	21.2	350.1
1		2130	87	85827.	20.0	349.9
1		2145	88	83040.	18.7	349.6
1		2200	89	80149.	17.4	349.4
1		2215	90	77196.	16.2	349.2
1		2230	91	74218.	14.9	348.9
1		2245	92	71248.	13.8	348.7
1		2300	93	68317.	12.7	348.5
1		2315	94	65471.	11.6	348.2

DA	MON	HRMN	ORD	OUTFLOW	STORAGE	STAGE
1		2330	95	62753.	10.7	348.0
1		2345	96	60170.	9.8	347.8
2		0000	97	57713.	9.0	347.6
2		0015	98	55366.	8.3	347.4
2		0030	99	53120.	7.7	347.2
2		0045	100	50964.	7.0	347.0
2		0100	101	48891.	6.5	346.8
2		0115	102	46894.	6.0	346.6
2		0130	103	44966.	5.5	346.4
2		0145	104	43101.	5.0	346.2
2		0200	105	41294.	4.6	346.1
2		0215	106	39539.	4.2	345.9
2		0230	107	37833.	3.9	345.7
2		0245	108	36173.	3.5	345.5
2		0300	109	34559.	3.2	345.4
2		0315	110	32991.	3.0	345.2
2		0330	111	31469.	2.7	345.1
2		0345	112	29993.	2.4	344.9
2		0400	113	28564.	2.2	344.7
2		0415	114	27182.	2.0	344.6
2		0430	115	25849.	1.8	344.4
2		0445	116	24567.	1.6	344.3
2		0500	117	23341.	1.5	344.1
2		0515	118	22174.	1.3	344.0
2		0530	119	21065.	1.2	343.9
2		0545	120	20011.	1.1	343.7
2		0600	121	19011.	1.0	343.6
2		0615	122	18060.	0.9	343.5
2		0630	123	17157.	0.8	343.4
2		0645	124	16299.	0.7	343.3
2		0700	125	15484.	0.7	343.1
2		0715	126	14710.	0.6	343.0
2		0730	127	13974.	0.5	342.9
2		0745	128	13275.	0.5	342.8
2		0800	129	12612.	0.4	342.7
2		0815	130	11981.	0.4	342.7
2		0830	131	11382.	0.4	342.6
2		0845	132	10813.	0.3	342.5
2		0900	133	10272.	0.3	342.4
2		0915	134	9759.	0.3	342.3
2		0930	135	9271.	0.2	342.2
2		0945	136	8807.	0.2	342.2
2		1000	137	8367.	0.2	342.1
2		1015	138	7948.	0.2	342.0
2		1030	139	7549.	0.2	342.0
2		1045	140	7170.	0.1	341.9

PEAK OUTFLOW IS 1244166. AT TIME 17.00 HOURS

THE DAM BREACH HYDROGRAPH WAS DEVELOPED USING A TIME INTERVAL OF 0.005 HOURS DURING BREACH FORMATION.
DOWNSTREAM CALCULATIONS WILL USE A TIME INTERVAL OF 0.250 HOURS.
THIS TABLE COMPARES THE HYDROGRAPH FOR DOWNSTREAM CALCULATIONS WITH THE COMPUTED BREACH HYDROGRAPH.
INTERMEDIATE FLOWS ARE INTERPOLATED FROM END-OF-PERIOD VALUES.

TIME (HOURS)	TIME FROM BEGINNING OF BREACH (HOURS)	INTERPOLATED BREACH HYDROGRAPH (CFS)	-	COMPUTED BREACH HYDROGRAPH (CFS)	=	ERROR (CFS)	ACCUMULATED ERROR (CFS)	ACCUMULATED ERROR (AC-FT)
16.750	0.000	36297.		36297.		0.	0.	0.
16.755	0.005	60454.		36651.		23803.	23803.	10.
16.760	0.010	84612.		37634.		46978.	70781.	29.
16.765	0.015	108769.		39427.		69342.	140123.	58.
16.770	0.020	132927.		42174.		90753.	230876.	95.
16.775	0.025	157084.		45994.		111090.	341967.	141.
16.780	0.030	181241.		50991.		130251.	472217.	195.
16.785	0.035	205399.		57253.		148146.	620363.	256.
16.790	0.040	229556.		64858.		164698.	785062.	324.
16.795	0.045	253713.		73874.		179840.	964901.	399.
16.800	0.050	277871.		84359.		193512.	1158414.	479.
16.805	0.055	302028.		96362.		205666.	1364080.	564.
16.810	0.060	326186.		109922.		216263.	1580343.	653.
16.815	0.065	350343.		125075.		225266.	1805611.	746.
16.820	0.070	374500.		141848.		232653.	2038264.	842.
16.825	0.075	398658.		160258.		238400.	2276663.	941.
16.830	0.080	422815.		180320.		242495.	2519158.	1041.
16.835	0.085	446973.		202040.		244932.	2764091.	1142.
16.840	0.090	471130.		225421.		245709.	3009800.	1244.
16.845	0.095	495287.		250461.		244826.	3254626.	1345.
16.850	0.100	519445.		277167.		242277.	3496903.	1445.
16.855	0.105	543602.		305594.		238008.	3734911.	1543.
16.860	0.110	567759.		335715.		232044.	3966955.	1639.
16.865	0.115	591917.		367271.		224646.	4191601.	1732.
16.870	0.120	616074.		400189.		215885.	4407486.	1821.
16.875	0.125	640232.		434384.		205847.	4613333.	1906.
16.880	0.130	664389.		469763.		194626.	4807959.	1987.
16.885	0.135	688546.		506221.		182325.	4990284.	2062.
16.890	0.140	712704.		543644.		169060.	5159344.	2132.
16.895	0.145	736861.		581904.		154957.	5314301.	2196.
16.900	0.150	761019.		620868.		140151.	5454452.	2254.
16.905	0.155	785176.		660381.		124795.	5579246.	2305.
16.910	0.160	809333.		700283.		109051.	5688297.	2351.
16.915	0.165	833491.		740403.		93088.	5781385.	2389.
16.920	0.170	857648.		780562.		77086.	5858470.	2421.
16.925	0.175	881805.		820583.		61222.	5919693.	2446.
16.930	0.180	905963.		860405.		45558.	5965250.	2465.
16.935	0.185	930120.		899949.		30171.	5995422.	2477.
16.940	0.190	954278.		939176.		15102.	6010524.	2484.
16.945	0.195	978435.		978312.		123.	6010647.	2484.
16.950	0.200	1002592.		1016305.		-13713.	5996934.	2478.
16.955	0.205	1026750.		1052711.		-25961.	5970973.	2467.
16.960	0.210	1050907.		1087237.		-36329.	5934643.	2452.
16.965	0.215	1075065.		1119566.		-44502.	5890142.	2434.
16.970	0.220	1099222.		1149390.		-50168.	5839974.	2413.
16.975	0.225	1123379.		1176368.		-52989.	5786985.	2391.
16.980	0.230	1147537.		1199788.		-52251.	5734734.	2370.
16.985	0.235	1171694.		1218913.		-47219.	5687514.	2350.
16.990	0.240	1195851.		1233145.		-37293.	5650221.	2335.
16.995	0.245	1220009.		1241813.		-21804.	5628417.	2326.
17.000	0.250	1244166.		1244166.		-0.	5628417.	2326.



PEAK FLOW (CFS)	TIME (HR)		6-HR	MAXIMUM AVERAGE FLOW 24-HR	72-HR	34.75-HR
1244166.	17.00	(CFS)	130590.	50608.	35124.	35124.
		(INCHES)	16.840	26.104	26.232	26.232
		(AC-FT)	64755.	100380.	100872.	100872.

PEAK STORAGE (AC-FT)	TIME (HR)	6-HR	MAXIMUM AVERAGE STORAGE 24-HR	72-HR	34.75-HR
13796.	16.78	11444.	7054.	4873.	4873.

PEAK STAGE (FEET)	TIME (HR)	6-HR	MAXIMUM AVERAGE STAGE 24-HR	72-HR	34.75-HR
433.54	16.78	427.05	401.28	383.63	383.63

CUMULATIVE AREA = 72.10 SQ MI

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26 KP          PLAN  2 FOR STATION      OUT                          BEAR CREEK DAM

27 KO             OUTPUT CONTROL VARIABLES
                        IPRNT            1  PRINT CONTROL
                        IPLOT            0  PLOT CONTROL
                        QSCAL           0.  HYDROGRAPH PLOT SCALE

               HYDROGRAPH ROUTING DATA

19 RS             STORAGE ROUTING
                        NSTPS            1  NUMBER OF SUBREACHES
                        ITYP          ELEV  TYPE OF INITIAL CONDITION
                        RSVRIC      420.00  INITIAL CONDITION
                        X             0.00  WORKING R AND D COEFFICIENT

20 SA                   AREA           0.0     100.0     250.0     300.0     320.0     350.0     380.0     410.0     450.0     500.0

21 SE             ELEVATION         340.00    380.00    410.00    420.00    424.00    428.00    432.00    436.00    440.00    444.00

24 SL             LOW-LEVEL OUTLET
                        ELEVL       380.00  ELEVATION AT CENTER OF OUTLET
                        CAREA        12.60  CROSS-SECTIONAL AREA
                        COQL          0.70  COEFFICIENT
                        EXPL          0.50  EXPONENT OF HEAD

22 SS             SPILLWAY
                        CREL        420.00  SPILLWAY CREST ELEVATION
                        SPWID       200.00  SPILLWAY WIDTH
                        COQW          3.10  WEIR COEFFICIENT
                        EXPW          1.50  EXPONENT OF HEAD

23 ST             TOP OF DAM
                        TOPEL       432.00  ELEVATION AT TOP OF DAM
                        DAMWID      900.00  DAM WIDTH
                        COQD          3.10  WEIR COEFFICIENT
                        EXPD          1.50  EXPONENT OF HEAD

28 SB             BREACH DATA
                        ELBM        340.00  ELEVATION AT BOTTOM OF BREACH
                        BRWID       900.00  WIDTH OF BREACH BOTTOM
                        Z             0.00  BREACH SIDE SLOPE
                        TFAIL         3.00  TIME FOR BREACH TO DEVELOP
                        FAILEL      433.00  W.S. ELEVATION TO TRIGGER FAILURE
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COMPUTED STORAGE-ELEVATION DATA

STORAGE	0.00	1333.33	6414.47	9160.68	10400.46	11740.01	13199.60	14779.22	16498.60	18397.72
ELEVATION	340.00	380.00	410.00	420.00	424.00	428.00	432.00	436.00	440.00	444.00

COMPUTED OUTFLOW-ELEVATION DATA

OUTFLOW	0.00	0.00	102.19	114.85	131.09	152.68	182.78	227.66	301.76	447.38
ELEVATION	340.00	380.00	382.09	382.64	383.43	384.66	386.68	390.36	398.20	420.00
OUTFLOW	524.09	1044.57	2444.54	5159.65	9625.53	16277.80	25552.06	37883.89	53708.91	73462.71
ELEVATION	420.25	420.97	422.17	423.85	426.01	428.65	431.77	435.37	439.45	444.00

COMPUTED STORAGE-OUTFLOW-ELEVATION DATA

STORAGE	0.00	1333.33	1550.59	1610.64	1700.12	1842.50	2091.06	2590.89	3870.13	9160.68
OUTFLOW	0.00	0.00	102.19	114.85	131.09	152.68	182.78	227.66	301.76	447.38
ELEVATION	340.00	380.00	382.09	382.64	383.43	384.66	386.68	390.36	398.20	420.00
STORAGE	9234.42	9453.83	9824.07	10353.84	11060.17	11970.54	13113.30	14522.20	16250.56	18397.72
OUTFLOW	524.09	1044.57	2444.54	5159.65	9625.53	16277.80	25552.06	37883.89	53708.91	73462.71
ELEVATION	420.25	420.97	422.17	423.85	426.01	428.65	431.77	435.37	439.45	444.00

BEGIN DAM FAILURE AT 16.75 HOURS

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HYDROGRAPH AT STATION   OUT
PLAN 2,   RATIO =   1.00

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DA	MON	HRMN	ORD	OUTFLOW	STORAGE	STAGE	*	DA	MON	HRMN	ORD	OUTFLOW	STORAGE	STAGE	*	DA	MON	HRMN	ORD	OUTFLOW	STORAGE	STAGE
1		0000	1	447.	9160.7	420.0	*	1		1145	48	4989.	10324.0	423.8	*	1		2330	95	62759.	10.7	348.0
1		0015	2	447.	9152.9	420.0	*	1		1200	49	5714.	10449.0	424.2	*	1		2345	96	60177.	9.8	347.8
1		0030	3	447.	9145.0	419.9	*	1		1215	50	6450.	10571.1	424.5	*	2		0000	97	57723.	9.0	347.6
1		0045	4	447.	9137.0	419.9	*	1		1230	51	7193.	10690.5	424.9	*	2		0015	98	55388.	8.3	347.4
1		0100	5	447.	9128.9	419.9	*	1		1245	52	7945.	10808.0	425.3	*	2		0030	99	53158.	7.7	347.2
1		0115	6	447.	9120.8	419.9	*	1		1300	53	8712.	10924.6	425.6	*	2		0045	100	51023.	7.1	347.0
1		0130	7	446.	9112.6	419.8	*	1		1315	54	9501.	11041.9	426.0	*	2		0100	101	48972.	6.5	346.8
1		0145	8	446.	9104.3	419.8	*	1		1330	55	10323.	11161.4	426.3	*	2		0115	102	46999.	6.0	346.6
1		0200	9	446.	9096.0	419.8	*	1		1345	56	11190.	11285.0	426.7	*	2		0130	103	45097.	5.5	346.4
1		0215	10	446.	9087.6	419.8	*	1		1400	57	12117.	11414.6	427.1	*	2		0145	104	43259.	5.1	346.2

1	0230	11	446.	9079.2	419.7	*	1	1415	58	13119.	11552.0	427.5	*	2	0200	105	41479.	4.7	346.1
1	0245	12	446.	9070.7	419.7	*	1	1430	59	14211.	11699.1	427.9	*	2	0215	106	39753.	4.3	345.9
1	0300	13	446.	9062.1	419.7	*	1	1445	60	15413.	11858.0	428.3	*	2	0230	107	38076.	3.9	345.7
1	0315	14	445.	9053.6	419.6	*	1	1500	61	16742.	12030.5	428.8	*	2	0245	108	36443.	3.6	345.6
1	0330	15	445.	9044.9	419.6	*	1	1515	62	18213.	12218.0	429.3	*	2	0300	109	34853.	3.3	345.4
1	0345	16	445.	9036.3	419.6	*	1	1530	63	19842.	12422.0	429.9	*	2	0315	110	33305.	3.0	345.2
1	0400	17	445.	9027.6	419.6	*	1	1545	64	21666.	12646.6	430.5	*	2	0330	111	31800.	2.7	345.1
1	0415	18	445.	9018.9	419.5	*	1	1600	65	23747.	12898.3	431.2	*	2	0345	112	30338.	2.5	344.9
1	0430	19	445.	9010.1	419.5	*	1	1615	66	26139.	13182.6	432.0	*	2	0400	113	28919.	2.3	344.8
1	0445	20	444.	9001.4	419.5	*	1	1630	67	30485.	13482.9	432.7	*	2	0415	114	27544.	2.1	344.6
1	0500	21	444.	8992.6	419.4	*	1	1645	68	36297.	13773.4	433.5	*	2	0430	115	26213.	1.9	344.5
1	0515	22	444.	8983.8	419.4	*	1	1700	69	47771.	13997.9	434.1	*	2	0445	116	24929.	1.7	344.3
1	0530	23	444.	8974.9	419.4	*	1	1715	70	72262.	13951.6	433.9	*	2	0500	117	23694.	1.5	344.2
1	0545	24	444.	8966.2	419.3	*	1	1730	71	107456.	13385.3	432.5	*	2	0515	118	22511.	1.4	344.0
1	0600	25	444.	8957.6	419.3	*	1	1745	72	151386.	12082.6	429.0	*	2	0530	119	21386.	1.2	343.9
1	0615	26	443.	8949.5	419.3	*	1	1800	73	185889.	10046.0	422.9	*	2	0545	120	20316.	1.1	343.8
1	0630	27	443.	8942.4	419.3	*	1	1815	74	208217.	7513.2	414.2	*	2	0600	121	19300.	1.0	343.6
1	0645	28	443.	8937.0	419.2	*	1	1830	75	202406.	4879.2	403.3	*	2	0615	122	18335.	0.9	343.5
1	0700	29	443.	8934.1	419.2	*	1	1845	76	172793.	2721.1	391.2	*	2	0630	123	17419.	0.8	343.4
1	0715	30	443.	8934.7	419.2	*	1	1900	77	141211.	1298.4	379.6	*	2	0645	124	16548.	0.7	343.3
1	0730	31	443.	8939.9	419.3	*	1	1915	78	117067.	509.6	369.0	*	2	0700	125	15720.	0.7	343.2
1	0745	32	443.	8950.7	419.3	*	1	1930	79	103749.	155.0	359.5	*	2	0715	126	14934.	0.6	343.1
1	0800	33	444.	8968.3	419.4	*	1	1945	80	97536.	25.8	350.7	*	2	0730	127	14188.	0.5	343.0
1	0815	34	444.	8994.0	419.4	*	1	2000	81	95630.	24.8	350.6	*	2	0745	128	13478.	0.5	342.9
1	0830	35	445.	9028.8	419.6	*	1	2015	82	95238.	24.6	350.6	*	2	0800	129	12805.	0.4	342.8
1	0845	36	446.	9074.0	419.7	*	1	2030	83	94506.	24.2	350.5	*	2	0815	130	12164.	0.4	342.7
1	0900	37	447.	9130.9	419.9	*	1	2045	84	93048.	23.5	350.4	*	2	0830	131	11556.	0.4	342.6
1	0915	38	477.	9199.9	420.1	*	1	2100	85	90939.	22.4	350.2	*	2	0845	132	10979.	0.3	342.5
1	0930	39	605.	9280.2	420.4	*	1	2115	86	88478.	21.2	350.1	*	2	0900	133	10430.	0.3	342.4
1	0945	40	813.	9371.2	420.7	*	1	2130	87	85830.	20.0	349.9	*	2	0915	134	9908.	0.3	342.3
1	1000	41	1099.	9471.7	421.0	*	1	2145	88	83044.	18.7	349.6	*	2	0930	135	9413.	0.2	342.3
1	1015	42	1464.	9580.5	421.4	*	1	2200	89	80154.	17.4	349.4	*	2	0945	136	8942.	0.2	342.2
1	1030	43	1904.	9696.1	421.8	*	1	2215	90	77201.	16.2	349.2	*	2	1000	137	8495.	0.2	342.1
1	1045	44	2414.	9817.2	422.2	*	1	2230	91	74224.	14.9	349.0	*	2	1015	138	8070.	0.2	342.0
1	1100	45	2987.	9942.1	422.6	*	1	2245	92	71254.	13.8	348.7	*	2	1030	139	7665.	0.2	342.0
1	1115	46	3615.	10069.2	423.0	*	1	2300	93	68323.	12.7	348.5	*	2	1045	140	7280.	0.1	341.9
1	1130	47	4286.	10197.0	423.4	*	1	2315	94	65478.	11.6	348.2	*						
						*							*						

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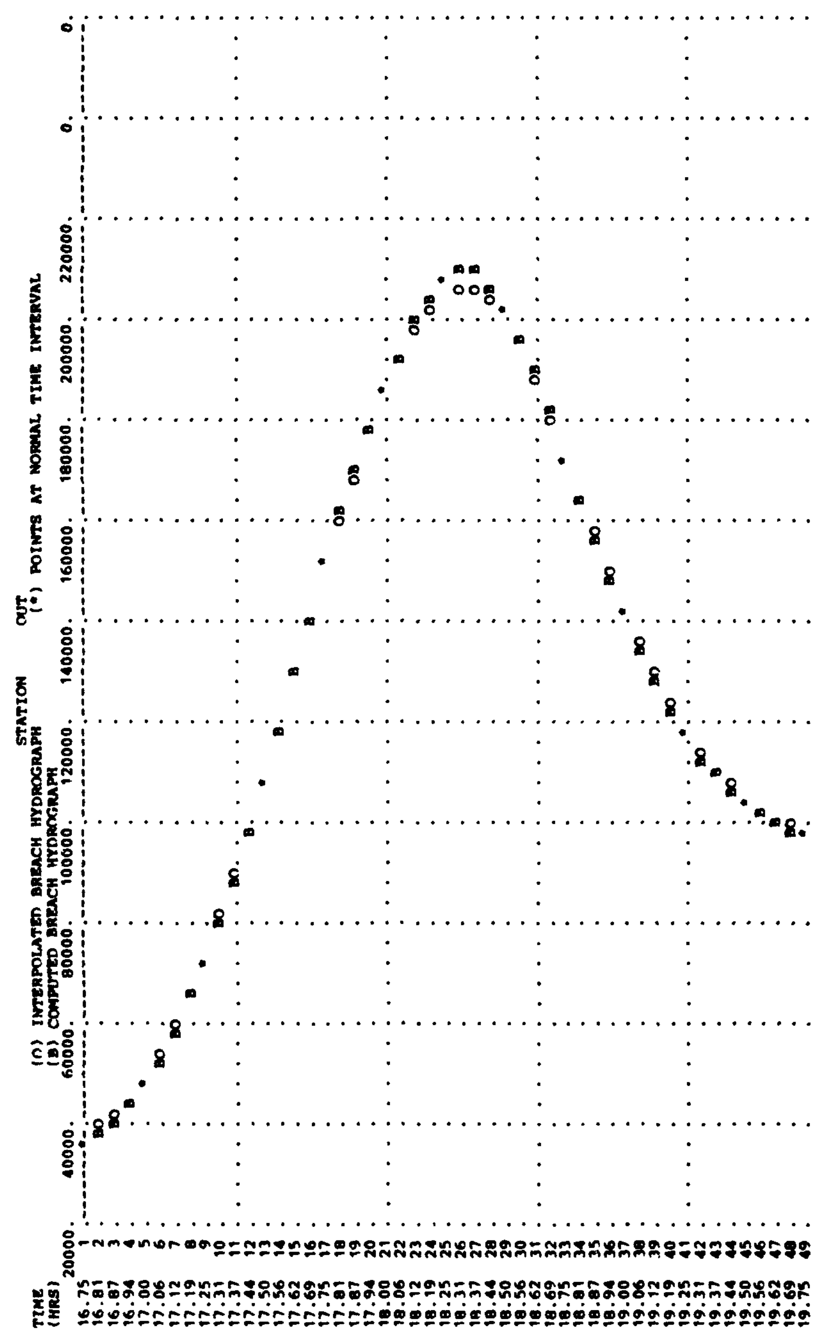
PEAK OUTFLOW IS 209653. AT TIME 18.31 HOURS

THE DAM BREACH HYDROGRAPH WAS DEVELOPED USING A TIME INTERVAL OF 0.062 HOURS DURING BREACH FORMATION.
DOWNSTREAM CALCULATIONS WILL USE A TIME INTERVAL OF 0.250 HOURS.
THIS TABLE COMPARES THE HYDROGRAPH FOR DOWNSTREAM CALCULATIONS WITH THE COMPUTED BREACH HYDROGRAPH.
INTERMEDIATE FLOWS ARE INTERPOLATED FROM END-OF-PERIOD VALUES.

TIME (HOURS)	TIME FROM BEGINNING OF BREACH (HOURS)	INTERPOLATED BREACH HYDROGRAPH (CFS)	-	COMPUTED BREACH HYDROGRAPH (CFS)	=	ERROR (CFS)	ACCUMULATED ERROR (CFS)	ACCUMULATED ERROR (AC-FT)
16.750	0.000	36297.		36297.		0.	0.	0.
16.812	0.062	39166.		38048.		1118.	1118.	6.
16.875	0.125	42034.		40472.		1562.	2679.	14.
16.937	0.187	44903.		43696.		1207.	3886.	20.
17.000	0.250	47771.		47771.		0.	3886.	20.
17.062	0.312	53894.		52702.		1192.	5078.	26.
17.125	0.375	60017.		58462.		1555.	6633.	34.
17.187	0.437	66140.		65002.		1138.	7771.	40.
17.250	0.500	72262.		72262.		0.	7771.	40.
17.312	0.562	81061.		80184.		877.	8648.	45.
17.375	0.625	89859.		88715.		1145.	9793.	51.
17.437	0.697	98658.		97776.		882.	10675.	55.
17.500	0.750	107456.		107456.		0.	10675.	55.
17.562	0.812	118439.		118188.		250.	10925.	56.
17.625	0.875	129421.		129608.		-187.	10737.	55.
17.687	0.937	140403.		140743.		-339.	10398.	54.
17.750	1.000	151386.		151386.		0.	10398.	54.
17.812	1.062	160012.		161352.		-1341.	9057.	47.
17.875	1.125	168638.		170479.		-1842.	7216.	37.
17.937	1.187	177263.		178654.		-1391.	5825.	30.
18.000	1.250	185889.		185889.		0.	5825.	30.
18.062	1.312	191471.		192515.		-1044.	4781.	25.
18.125	1.375	197053.		199351.		-2297.	2484.	13.
18.187	1.437	202635.		204801.		-2166.	318.	2.
18.250	1.500	208217.		208217.		0.	318.	2.
18.312	1.562	206764.		209653.		-2889.	-2572.	-13.
18.375	1.625	205311.		209209.		-3898.	-6469.	-33.
18.437	1.687	203859.		206750.		-2892.	-9361.	-48.
18.500	1.750	202406.		202406.		0.	-9361.	-48.
18.562	1.812	195002.		196467.		-1464.	-10825.	-56.
18.625	1.875	187599.		189281.		-1682.	-12507.	-65.
18.687	1.937	180196.		181252.		-1056.	-13563.	-70.
18.750	2.000	172793.		172793.		0.	-13563.	-70.
18.812	2.062	164897.		164269.		628.	-12935.	-67.
18.875	2.125	157002.		155998.		1003.	-11931.	-62.
18.937	2.187	149106.		148258.		848.	-11083.	-57.
19.000	2.250	141211.		141211.		0.	-11083.	-57.
19.062	2.312	135175.		134593.		582.	-10501.	-54.
19.125	2.375	129139.		128118.		1021.	-9480.	-49.
19.187	2.437	123103.		122196.		907.	-8573.	-44.
19.250	2.500	117067.		117067.		0.	-8573.	-44.
19.312	2.562	113738.		112738.		999.	-7574.	-39.
19.375	2.625	110408.		109118.		1290.	-6284.	-32.
19.437	2.687	107078.		106155.		923.	-5361.	-28.
19.500	2.750	103749.		103749.		0.	-5361.	-28.
19.562	2.812	102196.		101708.		487.	-4874.	-25.
19.625	2.875	100643.		99966.		677.	-4197.	-22.
19.687	2.937	99089.		98598.		492.	-3705.	-19.
19.750	3.000	97536.		97536.		0.	-3705.	-19.



PEAK FLOW	TIME		MAXIMUM AVERAGE FLOW			
(CFS)	(HR)		6-HR	24-HR	72-HR	34.75-HR
		(CFS)				
208217.	18.25		110602.	45347.	31490.	31490.
		(INCHES)	14.262	23.390	23.518	23.518
		(AC-FT)	54844.	89944.	90436.	90436.

PEAK STORAGE	TIME	MAXIMUM AVERAGE STORAGE			
(AC-FT)	(HR)	6-HR	24-HR	72-HR	34.75-HR
14025.	17.12	12055.	7850.	5423.	5423.

PEAK STAGE	TIME	MAXIMUM AVERAGE STAGE			
(FEET)	(HR)	6-HR	24-HR	72-HR	34.75-HR
434.13	17.12	428.79	407.31	387.79	387.79

CUMULATIVE AREA = 72.10 SQ MI

*** *** *** *** *** *** *** *** *** *** ***

(Note: RCH1 and RCH2 output omitted)

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

RATIOS APPLIED TO FLOWS

OPERATION	STATION	AREA	PLAN		RATIO 1 1.00
HYDROGRAPH AT	IN	72.10	1	FLOW	95158.
				TIME	20.25
			2	FLOW	95158.
				TIME	20.25
			3	FLOW	95158.
				TIME	20.25
			4	FLOW	95158.
				TIME	20.25
			5	FLOW	95158.
				TIME	20.25
ROUTED TO	OUT	72.10	1	FLOW	1244166.
				TIME	17.00
			2	FLOW	208217.
				TIME	18.25
			3	FLOW	135679.
				TIME	19.75
			4	FLOW	179533.
				TIME	19.50
			5	FLOW	109207.
				TIME	21.75
			** PEAK STAGES IN FEET **		
			1	STAGE	433.54
				TIME	16.78
			2	STAGE	434.13
				TIME	17.12
			3	STAGE	435.35
				TIME	17.94
			4	STAGE	434.61
				TIME	17.37
			5	STAGE	436.63
				TIME	19.00
ROUTED TO	RCH1	72.10	1	FLOW	610857.
				TIME	17.25
			2	FLOW	197055.
				TIME	18.50
			3	FLOW	127387.
				TIME	20.00
			4	FLOW	175177.
				TIME	19.75
			5	FLOW	108707.
				TIME	22.00
			** PEAK STAGES IN FEET **		
			1	STAGE	334.07
				TIME	17.25
			2	STAGE	317.71
				TIME	18.50
			3	STAGE	312.91
				TIME	20.00
			4	STAGE	316.30
				TIME	19.75
			5	STAGE	311.39
				TIME	22.00
ROUTED TO	RCH2	72.10	1	FLOW	422100.
				TIME	17.25
			2	FLOW	184431.
				TIME	18.75
			3	FLOW	122201.
				TIME	20.25
			4	FLOW	170547.
				TIME	19.75
			5	FLOW	108251.
				TIME	22.25
			** PEAK STAGES IN FEET **		
			1	STAGE	280.63
				TIME	17.25
			2	STAGE	275.97
				TIME	18.75
			3	STAGE	274.18
				TIME	20.25
			4	STAGE	275.61
				TIME	19.75
			5	STAGE	273.67
				TIME	22.25

SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION OUT

PLAN 1 ....

	INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
ELEVATION	420.00	420.00	432.00
STORAGE	9161.	9161.	13200.
OUTFLOW	447.	447.	26283.

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
1.00	433.54	1.54	13796.	1244166.	0.60	17.00	16.75

PLAN 2 ....

	INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
ELEVATION	420.00	420.00	432.00
STORAGE	9161.	9161.	13200.
OUTFLOW	447.	447.	26283.

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
1.00	434.13	2.13	14025.	209653.	1.25	18.31	16.75

PLAN 3 ....

	INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
ELEVATION	420.00	420.00	432.00
STORAGE	9161.	9161.	13200.
OUTFLOW	447.	447.	26283.

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
1.00	435.35	3.35	14516.	135679.	3.00	19.75	16.75

PLAN 4 ....

	INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
ELEVATION	420.00	420.00	432.00
STORAGE	9161.	9161.	13200.
OUTFLOW	447.	447.	26283.

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
1.00	434.61	2.61	14218.	180309.	1.87	19.37	16.75

93

PLAN 5 ....

	INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
ELEVATION	420.00	420.00	432.00
STORAGE	9161.	9161.	13200.
OUTFLOW	447.	447.	26283.

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
1.00	436.63	4.63	15040.	109207.	5.00	21.75	16.75

1TABLE 1			STATION	RCH1	RCH1	RCH1	RCH1	RCH2	RCH2	RCH2	RCH2
				FLOW	FLOW	STAGE	STAGE	FLOW	FLOW	STAGE	STAGE
			PLAN	1	5	1	5	1	5	1	5
			RATIO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
PER	DAY	MON	HRMN								
1	1		0000	0.00	0.00	280.00	280.00	0.00	0.00	255.00	255.00
2	1		0015	73.46	73.46	280.76	280.76	5.47	5.47	255.02	255.02
3	1		0030	134.83	134.83	281.40	281.40	20.17	20.17	255.09	255.09
4	1		0045	186.10	186.10	281.94	281.94	41.06	41.06	255.18	255.18

########## LINES 5-67 OF TABLE DELETED ##########

PER	DAY	MON	HRMN	RCH1 FLOW 1	RCH1 FLOW 5	RCH1 STAGE 1	RCH1 STAGE 5	RCH2 FLOW 1	RCH2 FLOW 5	RCH2 STAGE 1	RCH2 STAGE 5
68	1		1645	29240.53	29240.53	301.20	301.20	23238.22	23238.22	268.06	268.06
69	1		1700	444993.64	34257.42	328.80	302.22	126295.76	26641.93	274.33	268.49
70	1		1715	610856.69	39968.23	334.07	303.32	422099.99	30879.24	280.63	268.98
71	1		1730	191962.67	46376.13	317.39	304.29	405333.93	35919.22	280.33	269.54
72	1		1745	109731.29	52690.26	311.48	305.24	207893.99	41900.66	276.51	270.03
73	1		1800	86194.68	58962.31	309.27	306.16	135232.29	48019.02	274.66	270.53
74	1		1815	79963.23	65445.61	308.62	306.92	107021.76	54491.94	273.62	270.98
75	1		1830	79983.95	71517.89	308.62	307.63	92937.04	61133.02	273.02	271.38
76	1		1845	82216.45	77240.11	308.89	308.30	86915.12	67420.99	272.74	271.76
77	1		1900	85233.80	82577.57	309.18	308.93	85292.23	73362.75	272.67	272.11
78	1		1915	88143.51	87761.17	309.46	309.42	86002.65	79369.30	272.70	272.39
79	1		1930	90621.69	92248.82	309.69	309.84	87722.18	84780.14	272.78	272.64
80	1		1945	92562.79	96109.30	309.87	310.20	89691.05	89561.79	272.87	272.86
81	1		2000	93918.85	99371.66	310.00	310.51	91496.97	93722.65	272.95	273.06
82	1		2015	94663.18	102046.72	310.07	310.76	92918.42	97277.01	273.02	273.22
83	1		2030	94762.51	104143.41	310.08	310.96	93831.33	100236.91	273.06	273.36
84	1		2045	94159.00	105672.08	310.02	311.10	94151.55	102679.02	273.08	273.46
85	1		2100	92840.47	106595.89	309.90	311.19	93819.94	104547.86	273.06	273.53
86	1		2115	90933.00	107051.59	309.72	311.23	92836.43	105778.92	273.02	273.58
87	1		2130	88630.57	107639.85	309.50	311.29	91282.40	106626.42	272.94	273.61
88	1		2145	86075.02	108417.92	309.26	311.36	89283.24	107385.03	272.85	273.64
89	1		2200	83346.91	108707.48	309.00	311.39	86957.12	108022.05	272.74	273.66
90	1		2215	80630.44	108182.78	308.70	311.34	84429.45	108250.90	272.63	273.67
91	1		2230	77806.19	106917.19	308.37	311.22	81778.32	107871.77	272.50	273.65
92	1		2245	74896.29	105126.79	308.03	311.05	79017.33	106871.19	272.38	273.62
93	1		2300	71963.07	103155.94	307.68	310.87	76174.65	105394.59	272.24	273.56
94	1		2315	69055.46	101552.70	307.34	310.72	73292.42	103750.06	272.11	273.50
95	1		2330	66219.81	100143.05	307.01	310.58	70599.08	102180.23	271.95	273.44
96	1		2345	63490.32	98221.21	306.69	310.40	67872.35	100618.78	271.79	273.38
97	2		0000	60882.14	95610.83	306.39	310.16	65173.10	98735.03	271.63	273.29
98	2		0015	58396.80	92394.08	306.09	309.85	62546.24	96327.36	271.47	273.18
99	2		0030	56162.39	88681.82	305.77	309.51	60046.12	93382.03	271.32	273.04
100	2		0045	53979.22	84603.38	305.44	309.12	57684.30	89953.39	271.18	272.88

########## LINES 101-124 OF TABLE DELETED ##########

PER	DAY	MON	HRMN	RCH1 FLOW 1	RCH1 FLOW 5	RCH1 STAGE 1	RCH1 STAGE 5	RCH2 FLOW 1	RCH2 FLOW 5	RCH2 STAGE 1	RCH2 STAGE 5
125	2		0700	17234.57	18132.50	298.13	298.39	19302.40	20286.18	267.35	267.53
126	2		0715	16374.46	17229.65	297.89	298.13	18359.13	19302.42	267.18	267.35
127	2		0730	15556.60	16370.82	297.65	297.89	17455.23	18357.52	267.02	267.18
128	2		0745	14779.22	15554.40	297.43	297.65	16591.47	17453.13	266.87	267.02
129	2		0800	14093.57	14778.59	297.15	297.43	15757.18	16589.63	266.64	266.87
130	2		0815	13439.12	14094.50	296.86	297.15	14982.55	15756.06	266.41	266.64
131	2		0830	12797.01	13441.65	296.57	296.86	14257.08	14982.53	266.20	266.41
132	2		0845	12174.88	12801.22	296.30	296.58	13567.93	14258.38	266.00	266.20
133	2		0900	11576.66	12180.84	296.03	296.30	12909.51	13570.71	265.81	266.00
134	2		0915	11004.08	11584.40	295.78	296.04	12279.51	12913.87	265.62	265.81
135	2		0930	10457.59	11013.59	295.53	295.78	11583.02	12285.53	265.36	265.63
136	2		0945	9936.92	10468.86	295.30	295.54	10856.00	11593.43	265.02	265.36
137	2		1000	9441.39	9949.93	295.08	295.31	10243.84	10867.32	264.74	265.03
138	2		1015	8969.93	9456.04	294.87	295.09	9699.18	10256.47	264.48	264.74
139	2		1030	8521.30	8986.14	294.67	294.88	9198.91	9713.28	264.25	264.49
140	2		1045	8094.50	8539.10	294.48	294.68	8737.39	9214.53	263.99	264.26
			MAX	610856.69	108707.48	334.07	311.39	422099.99	108250.90	280.63	273.67
			MIN	0.00	0.00	280.00	280.00	0.00	0.00	255.00	255.00
			AVE	34828.23	31008.91	296.18	296.19	34706.26	30882.19	264.74	264.72

*** NORMAL END OF HEC-1 ***

12.9 Example Problem #9: Multiflood Analysis

12.9.1 Introduction to Example Problems 9, 10, 11 and 12

The next four problems demonstrate the multiflood, multiplan, flood damage and flood control system optimization analysis capabilities of HEC-1. The watershed being analyzed has been experiencing severe flooding problems. To evaluate flood control measures proposed to mitigate existing problems, the HEC-1 model is to be employed. Problem 9 describes the use of the HEC-1 multiflood analysis capabilities in evaluating flooding potential of the subject watershed. Problem 10 continues the analysis begun in problem 9 by utilizing the HEC-1 multiplan-multiflood analysis capabilities to investigate various flood control scenarios for the watershed. In problem 11, the flood loss reduction benefits of proposed flood control measures are evaluated by adding flood damage data to the watershed model developed in problems 9 and 10. Problem 12 utilizes the HEC-1 optimization scheme to determine the optimal size of one of the flood control systems proposed in problem 11.

The Rockbed Watershed is the location of a small but expanding community. A diagram of the watershed is given in Fig. 12.7. In the past, the area has experienced flooding in the low land area near the Black Water estuary. This flooding has generally been caused by the ponding at the 48" culvert, which drains runoff from the watershed through a protective embankment into the estuary. Recently, however, flooding in the area has had more serious consequences due to the residential and commercial development in the low lands. In addition, urbanization in the upper reaches of the watershed has caused increases in storm water runoff which further impacts on the flooding problems in the low land areas.

12.9.2 Multiflood Analysis

The hydrologic-hydraulic analysis of the Rockbed watershed with HEC-1 will focus on the two special problem areas shown in Fig. 12.7, flood damage areas in reaches RCH1 and RCH2. The hydrologic effects of a series of floods on these damage reaches will be determined by using the multiflood analysis capabilities of HEC-1. In this example, ratios of a design flood will be used to simulate the effects of a number of different events at the damage centers. The ratios are taken of the flow (see JR card) and not of the precipitation because the rainfall-runoff response is assumed to be the same for current and future conditions.

The input data and program output are shown in Table 12.9a. In this case, the runoff from the design flood is input directly; these data would have been obtained from previous rainfall-runoff simulations. The RCH1 channel routing data are for the modified Puls method in which previous water surface profile studies have determined the storage-outflow characteristics of the reach. The RCH2 routing is from the ponding area, through the levee culvert, and into the main river. Two important points should be made about the input and output for this example:

(1) The multiflood analysis data deck differs from a stream network data deck by the addition of a JR card (see problem 1 for an example of a stream network analysis).

(2) The resulting peak flows and stages for each ratio of the design flood are displayed in the summary output at the end of the exhibited printout.

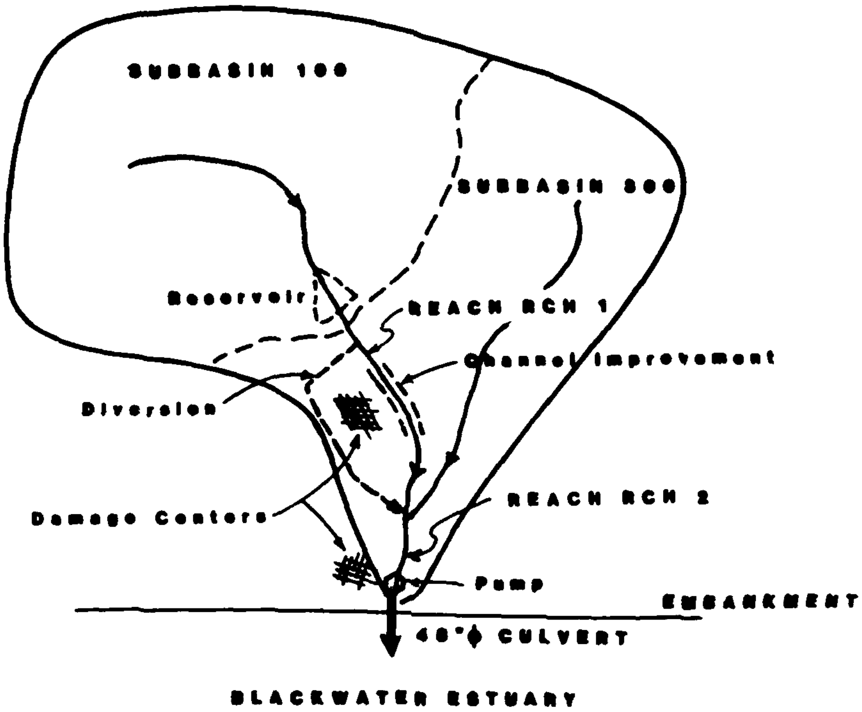


Figure 12.7a Rockbed Basin and Potential Flood Control Projects

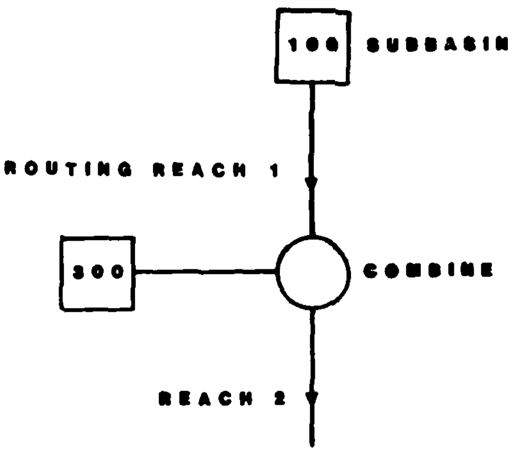


Figure 12.7b Rockbed Basin Schematic for Multiflood Analysis

Figure 12.7 Rockbed River Basin

TABLE 12.9

Example Problem #9: Input and Output

```
                                    HEC-1 INPUT                                              PAGE  1

LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

  1           ID        EXAMPLE PROBLEM NO. 9
  2           ID        MULTIFLOOD ANALYSIS
  3           ID        ROCKBED WATERSHED
              *DIAGRAM
  4           IT      60       0       0     130
  5           IO       4
              * ***************************     MULTIFLOOD RATIOS
  6           JR    FLOW     .11     .26     .45     .65     .86    1.00    1.20    1.40    1.50

  7           KK     100
  8           KM        DESIGN FLOOD FOR SUBBASIN 100
  9           BA    35.1
 10           QI      24      24      24      26      33      50      86     189     376     516
 11           QI     594     657     710     760     801     839     910    1044    1287    1921
 12           QI    2995    3953    4599    5077    5363    5374    5099    4603    3980    3325
 13           QI    2719    2200    1844    1540    1251     994     777     605     471     365
 14           QI     281       0       0       0       0       0       0       0       0       0

 15           KK    RCH1
 16           KM        LOCATION OF EXISTING FLOOD HAZARD
 17           RS       1    STOR     -1.      0.
 18           SV      0.     50.    475.    940.   2135.   3080.      0.      0.      0.      0.
 19           SQ      0.    200.   1020.   2050.   6100.  10250.      0.      0.      0.      0.

 20           KK     300
 21           KM        RUNOFF FROM SUBBASIN 300
 22           BA    49.1
 23           QI      32      32      32      35      44      67     114     252     501     688
 24           QI     789     877     940    1013    1068    1119    1214    1392    1717    2561
 25           QI    3993    4273    6139    6727    7163    7179    6789    6137    5308    4433
 26           QI    3622    2930    2458    2053    1665    1325    1032     806     628     487
 27           QI     374

 28           KK     300
 29           KM        COMBINED UPSTREAM INFLOWS
 30           HC       2

 31           KK    RCH2
 32           KM        DAMAGE CENTER LOCATED IN THIS REACH, LOWLAND FLOODING
 33           RS       1    STOR     -1.      0.
 34           SV      0.    400.  30000.  35000.  40000.
 35           SE     840     845     855     857     859
 36           SQ       0    1250    1500    1800    2000
 37           ZZ
```

```
                      SCHEMATIC DIAGRAM OF STREAM NETWORK
INPUT
 LINE        (V) ROUTING            (--->) DIVERSION
  NO.        (.) CONNECTOR          (<---) RETURN OF DIVERTED FLOW

   7           100
                V
                V
  15          RCH1
                .
                .
  20            .         300
                .           .
                .           .
  28           300............
                V
                V
  31          RCH2

(***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

```
                              EXAMPLE PROBLEM NO. 9
                              MULTIFLOOD ANALYSIS
                              ROCKBED WATERSHED

 IO           OUTPUT CONTROL VARIABLES
                    IPRNT           4  PRINT CONTROL
                    IPLOT           0  PLOT CONTROL
                    QSCAL          0.  HYDROGRAPH PLOT SCALE
                     DMSG         YES  PRINT DIAGNOSTIC MESSAGES

 IT           HYDROGRAPH TIME DATA
                     NMIN          60  MINUTES IN COMPUTATION INTERVAL
                    IDATE      1    0  STARTING DATE
                    ITIME        0000  STARTING TIME
                       NQ         130  NUMBER OF HYDROGRAPH ORDINATES
                   NDDATE      6    0  ENDING DATE
                   NDTIME        0900  ENDING TIME

                COMPUTATION INTERVAL    1.00 HOURS
                     TOTAL TIME BASE  129.00 HOURS

      ENGLISH UNITS
           DRAINAGE AREA           SQUARE MILES
           PRECIPITATION DEPTH     INCHES
           LENGTH, ELEVATION       FEET
           FLOW                    CUBIC FEET PER SECOND
           STORAGE VOLUME          ACRE-FEET
           SURFACE AREA            ACRES
           TEMPERATURE             DEGREES FAHRENHEIT

 JP           MULTI-PLAN OPTION
                    NPLAN           1  NUMBER OF PLANS

 JR           MULTI-RATIO OPTION
                   RATIOS OF RUNOFF
                 0.11      0.26      0.45      0.65      0.86      1.00      1.20      1.40      1.50


 *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

          **************
          *            *
 7 KK     *      100   *
          *            *
          **************
                              DESIGN FLOOD FOR SUBBASIN 100

           SUBBASIN RUNOFF DATA

 9 BA         SUBBASIN CHARACTERISTICS
                    TAREA       35.10  SUBBASIN AREA

                                                   ***


 *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

          **************
          *            *
 KK       *     RCH1   *
          *            *
          **************
                              LOCATION OF EXISTING FLOOD HAZARD

           HYDROGRAPH ROUTING DATA

 RS           STORAGE ROUTING
                    NSTPS           1  NUMBER OF SUBREACHES
                     ITYP        STOR  TYPE OF INITIAL CONDITION
                   RSVRIC       -1.00  INITIAL CONDITION
                        X        0.00  WORKING R AND D COEFFICIENT

 SV             STORAGE          0.       50.0     475.0     940.0    2135.0    3080.0

 SQ           DISCHARGE          0.       200.     1020.     2050.     6100.    10250.
                                                   ***


 *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
              ***************
              *             *
   20 KK      *     300     *
              *             *
              ***************
                                   RUNOFF FROM SUBBASIN 300

                 SUBBASIN RUNOFF DATA

   22 BA           SUBBASIN CHARACTERISTICS
                         TAREA       49.10  SUBBASIN AREA

                                                                ***

 *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              ***************
              *             *
   28 KK      *     300     *
              *             *
              ***************
                                   COMBINED UPSTREAM INFLOWS

   30 HC           HYDROGRAPH COMBINATION
                         ICOMP            2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                                ***

 *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              ***************
              *             *
      KK      *    RCH2     *
              *             *
              ***************
                                   DAMAGE CENTER LOCATED IN THIS REACH, LOWLAND FLOODING

                 HYDROGRAPH ROUTING DATA

      RS           STORAGE ROUTING
                         NSTPS            1  NUMBER OF SUBREACHES
                          ITYP         STOR  TYPE OF INITIAL CONDITION
                        RSVRIC        -1.00  INITIAL CONDITION
                             X         0.00  WORKING R AND D COEFFICIENT

      SV            STORAGE         0.0      400.0    30000.0    35000.0    40000.0

      SE          ELEVATION      840.00     845.00     855.00     857.00     859.00

      SQ          DISCHARGE          0.      1250.      1500.      1800.      2000.

                                                                ***
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIO 1 0.11	RATIO 2 0.26	RATIO 3 0.45	RATIO 4 0.65	RATIO 5 0.86	RATIO 6 1.00	RATIO 7 1.20	RATIO 8 1.40	RATIO 9 1.50
					RATIOS APPLIED TO FLOWS								
HYDROGRAPH AT	100	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO	RCH1	35.10	1	FLOW	429.	978.	1742.	2680.	3668.	4313.	5232.	6156.	6701.
				TIME	28.00	28.00	28.00	28.00	28.00	27.00	27.00	27.00	27.00
HYDROGRAPH AT	300	49.10	1	FLOW	790.	1867.	3231.	4666.	6174.	7179.	8615.	10051.	10768.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2 COMBINED AT	300	84.20	1	FLOW	1162.	2688.	4687.	6892.	9339.	10959.	13250.	15529.	16663.
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO	RCH2	84.20	1	FLOW	964.	1257.	1273.	1291.	1312.	1326.	1347.	1369.	1379.
				TIME	28.00	33.00	37.00	39.00	40.00	41.00	43.00	45.00	46.00
			** PEAK STAGES IN FEET **										
			1	STAGE	843.86	845.27	845.90	846.65	847.48	848.05	848.89	849.74	850.17
				TIME	28.00	33.00	37.00	39.00	40.00	42.00	43.00	45.00	46.00

*** NORMAL END OF HEC-1 ***

12.10 Example Problem #10: Multiplan, Multiflood Analysis

In the previous example, the existing flooding problems of Rockbcd Watershed were quantified. Using the multiplan analysis capability of HEC-1, a number of flood protection scenarios for the subject area can be investigated in one run. In this case, two alternatives have been proposed to provide flood protection. The first alternative is to provide a reservoir upstream of damage reach RCH1 to reduce peak discharges in lower lying areas. A second alternative is to reduce flood hazard at reach RCH1 by providing a diversion channel upstream of the reach. In both alternatives, a pump will be used at damage reach RCH2 to reduce stages in the low land area. Fig. 12.7 shows these projects. A schematic of the PLAN 2 and PLAN 3 watershed models is given in Figures 12.8 and 12.9, respectively.

HEC-1 Multiplan Input Data Convention Examples:

The data needed to update the multiflood model (Problem 9) to the desired multiplan model are displayed in Table 12.10a. Two routing reaches must be added to the Problem 9 model: one for the reservoir, and one for the diversion. The inclusion of this data in the multiflood data deck is clearly shown in the Table 12.10b data deck listing which is part of the computer output. In particular, note that the multiplan option requires the use of the JP card, and that the KP and RN cards are also employed.

Preparation of the multiplan data for input into the required HEC-1 format can be simplified by following input conventions described in Section 10. Examples which demonstrate these conventions in the problem 10 data deck are as follows:

(1) Inflows from subareas 100 and 300 are only specified once for all three plans; same as for problem 9. Because the rainfall-runoff response is assumed constant in all three PLANS, ratios are taken of the runoff.

(2) Routing reach RCH2 specifies data for a storage routing in PLAN 1; a KP card specifying PLAN 2 updates the storage routing with pump information; and lastly, a KP card specifying PLAN 3, not followed by any data, indicates PLAN 2 and PLAN 3 data for reach RCH2 are equivalent.

(3) Note the use of the RN card for routing reach 200. In the existing plan, PLAN 1, a reservoir is not included, and this is indicated with an RN card. The PLAN 2 flood control scenario includes a reservoir at station 200, which is indicated by the appropriate KP card and routing data. There is no data specified for PLAN 3 in this case (the KP card is absent) and hence the program defaults to the PLAN 1 data and prints a message to that effect. This is appropriate since there is no reservoir at station 200 for PLAN 3.

(4) Only PLAN 3 calls for a diversion as part of the flood control system. However, diversion data are included in all three plans. By program input convention, the data for PLANS 1 and 2 specify a diversion of zero capacity which has the intended effect of omitting a diversion for these plans.

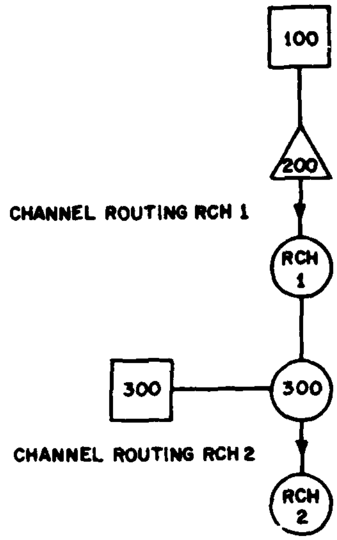


Figure 12.8 "PLAN 2" Rockbed Basin Schematic

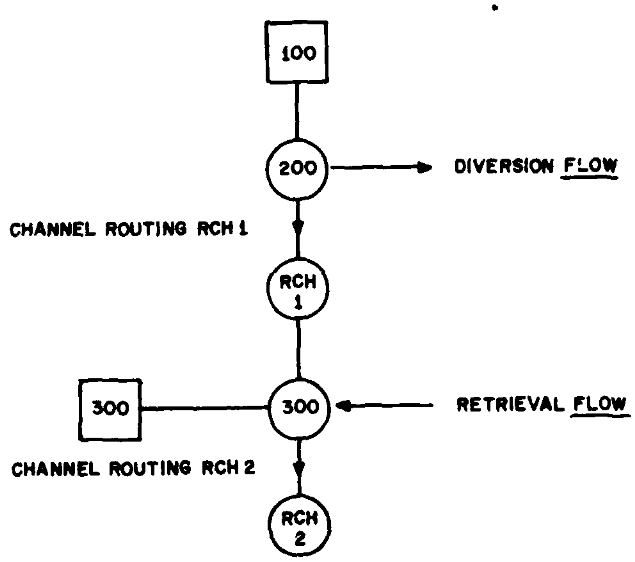


Figure 12.9 "PLAN 3" Rockbed Basin Schematic

Multiplan Analysis Results:

The computer output for the multiplan analysis run is shown in Table 12.10b. A summary table at the end of that output shows the results of the analysis for each reach, flood ratio, and PLAN. Note that the peak flows are reduced at RCH1 and RCH2 by the reservoir and pump in PLAN 2. In PLAN 3, peak flows are reduced at RCH1 by diverting a portion of the flow at reach 325 to RCH2. However this has the result of increasing the flows at RCH2 to the point where it exceeds PLAN 1 conditions.

TABLE 12.10a

Multiplan Analysis - Rockbed Watershed Flood Control Data

		CARD(S)
FLOOD CONTROL RESERVOIR, PLAN 2		
REACH ID: 200		KK
STORAGE ROUTING		RS
NSTPS	= 1	
ITYP	= STOR	
RSVRIC	= -1	
LOW-LEVEL OUTLET		SL
Invert Elevation	= 975 (m.s.l.)	
Cross section Area	= 35 (sq.ft.)	
Discharge Coefficient	= .7	
Exponent of Head	= .5	
SPILLWAY		SS
Crest Elevation	= 1105 (m.s.l.)	
Width	= 35 (ft.)	
Weir Coefficient	= 2.8	
Exponent of Head	= 1.5	
VOLUME-ELEVATION DATA		
VOLUME:	0, 2500, 4000, 5200, 6800, 9000, 11500, 15500, 21000, 30000	SV
ELEVATION:	965, 1000, 1015, 1030, 1045, 1060, 1075, 1090, 1105, 1120	SE
CHANNEL DIVERSION, PLAN 3		
REACH ID: 325		KK
DIVERSION ID: FLOW		DT
INFLOW:	0, 2300, 4100, 6300, 8800, 14300, 20200, 30400, 33250, 38000	DI
DIVERSION FLOW:	0, 1400, 2000, 3400, 4800, 8000, 12200, 16200, 18550, 20000	DT
PUMP, PLANS 2 and 3:		
REACH ID: RCH2		
PUMP DATA		WP
Threshold Reservoir Elevation	= 843.5 (ft.)	
Pump Capacity	= 3000 (cfs)	

TABLE 12.10b

Example Problem #10: Input and Output

```
                                   HEC-1 INPUT                                              PAGE  1

LINE        ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1        ID         EXAMPLE PROBLEM NO. 10
   2        ID         MULTIPLAN ANALYSIS
   3        ID         ROCKBED WATERSHED
            *DIAGRAM
   4        IT      60       0       0     130
   5        IO       4
            * ************************************** MULTI PLAN AND RATIO DATA
   6        JP       3
   7        JR    FLOW     .11     .26     .45     .65     .86    1.00    1.20    1.40    1.50

   8        KK     100
   9        KM          POTENTIAL RESERVOIR INFLOW
  10        BA    35.1
  11        QI      24      24      24      26      33      50      86     189     376     516
  12        QI     594     657     710     768     801     839     910    1044    1287    1921
  13        QI    2995    3953    4599    5077    5363    5374    5099    4603    3980    3325
  14        QI    2719    2200    1844    1540    1251     994     777     605     471     365
  15        QI     281       0       0       0       0       0       0       0       0       0
            * ************************************** PROPOSED RESERVOIR DATA

  16        KK     200
  17        KM          PROPOSED RESERVOIR
  18        RN
  19        KP       2
  20        RS       1    STOR     -1.      0.
  21        SL     975      35      .7      .5
  22        SS    1105      35     2.8     1.5
  23        SV       0    2500    4000    5200    6800    9000   11500   15500   21000   30000
  24        SE     965    1000    1015    1030    1045    1060    1075    1090    1105    1120
            * ************************************** NO RESERVOIR PLAN 3
  25        KP       3
  26        RN

  27        KK     325
  28        KM         DIVERT FLOW PLAN 3
            * ************************************** DUMMY DIVERSION
  29        DT    FLOW   20000
  30        DI       0    2300    4100    6300    8800    1430   20200   30400   33250
  31        DQ
  32        KP       2
            * ************************************** DUMMY DIVERSION
  33        DT    FLOW   20000
  34        DI       0    2300    4100    6300    8800   14300   20200   30400   33250
  35        DQ
  36        KP       3
  37        DT    FLOW   20000
  38        DI       0    2300    4100    6300    8800   14300   20200   30400   33250   38000
  39        DQ       0    1400    2000    3400    4800    8000   12200   16200   18550   20000

  40        KK    RCH1
  41        KM          POTENTIAL CHANNEL MODIFICATION REACH
  42        RS       1    STOR     -1.      0.
  43        SV      0.     50.    475.    940.   2135.   3080.      0.      0.      0.      0.
  44        SQ      0.    200.   1020.   2050.   6100.  10250.      0.      0.      0.      0.
```

```
LINE      ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

 45       KK     300
 46       KM         RUNOFF FROM SUBBASIN 300
 47       BA    49.1
 48       QI      32      32      32      35      44      67     114     252     501     688
 49       QI     789     877     940    1013    1068    1119    1214    1392    1717    2561
 50       QI    3993    4273    6139    6727    7163    7179    6789    6137    5308    4433
 51       QI    3622    2930    2458    2053    1665    1325    1032     806     628     487
 52       QI     374

 53       KK     300
 54       KM         COMBINED UPSTREAM INFLOWS
 55       HC       2

 56       KK     350
 57       KM         RETRIEVE DIVERTED FLOW
 58       DR    FLOW

 59       KK     400
 60       KM         COMBINE UPSTREAM AND DIVERTED INFLOWS
 61       HC       2

 62       KK    RCH2
 63       KM           PROPOSED PUMPING PLANT SITE
 64       RS       1    STOR     -1.      0.
 65       SV      0.    400.  30000.  35000.  40000.
 66       SE     840     845     855     857     859
 67       SQ       0    1250    1500    1800    2000
          * ************************************** PLAN 2 PUMP DATA
 68       KP       2
 69       WP   843.5    3000
 70       KP       3
 71       ZZ
```

SCHEMATIC DIAGRAM OF STREAM NETWORK

```
INPUT
LINE        (V) ROUTING            (--->) DIVERSION
NO.         (.) CONNECTOR          (<---) RETURN OF DIVERTED FLOW

  8          100
              V
              V
 16          200
              .
              .
 29           .-------.     FLOW
 27          325
              V
              V
 40         RCH1
              .
              .
 45           .          300
              .           .
              .           .
 53           300.........
              .
              .
 58           .           .,-------     FLOW
 56           .          350
              .           .
              .           .
 59           400.........
              V
              V
 62          RCH2

(***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

```
****************************************                                        ****************************************
*                                      *                                        *                                      *
*  U.S. ARMY CORPS OF ENGINEERS        *                                        *  FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *
*  THE HYDROLOGIC ENGINEERING CENTER   *                                        *         FEBRUARY 1981                *
*          609 SECOND STREET           *                                        *      REVISED 14 JUN 85               *
*      DAVIS, CALIFORNIA 95616         *                                        *                                      *
*  (916) 440-3285 OR (FTS) 448-3285    *                                        *  RUN DATE  2 JUL 85    TIME  13:45:17 *
*                                      *                                        *                                      *
****************************************                                        ****************************************


                                    EXAMPLE PROBLEM NO. 10
                                    MULTIPLAN ANALYSIS
                                    ROCKBED WATERSHED

  5 IO          OUTPUT CONTROL VARIABLES
                      IPRNT           4  PRINT CONTROL
                      IPLOT           0  PLOT CONTROL
                      QSCAL          0.  HYDROGRAPH PLOT SCALE
                       DMSG         YES  PRINT DIAGNOSTIC MESSAGES

    IT          HYDROGRAPH TIME DATA
                       NMIN          60  MINUTES IN COMPUTATION INTERVAL
                      IDATE      1    0  STARTING DATE
                      ITIME        0000  STARTING TIME
                         NQ         130  NUMBER OF HYDROGRAPH ORDINATES
                     NDDATE      6    0  ENDING DATE
                     NDTIME        0900  ENDING TIME

                  COMPUTATION INTERVAL    1.00 HOURS
                       TOTAL TIME BASE  129.00 HOURS

          ENGLISH UNITS
               DRAINAGE AREA          SQUARE MILES
               PRECIPITATION DEPTH    INCHES
               LENGTH, ELEVATION      FEET
               FLOW                   CUBIC FEET PER SECOND
               STORAGE VOLUME         ACRE-FEET
               SURFACE AREA           ACRES
               TEMPERATURE            DEGREES FAHRENHEIT

    JP          MULTI-PLAN OPTION
                      NPLAN           3  NUMBER OF PLANS

    JR          MULTI-RATIO OPTION
                    RATIOS OF RUNOFF
                   0.11      0.26      0.45      0.65      0.86      1.00      1.20      1.40      1.50

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              **************
              *            *
  8 KK        *     100    *
              *            *
              **************
                                     POTENTIAL RESERVOIR INFLOW

               SUBBASIN RUNOFF DATA


 10 BA          SUBBASIN CHARACTERISTICS
                      TAREA       35.10  SUBBASIN AREA

                                                                   ***

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

               PLAN  2 INPUT DATA FOR STATION      100 ARE SAME AS FOR PLAN  1

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

               PLAN  3 INPUT DATA FOR STATION      100 ARE SAME AS FOR PLAN  1


*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
                    **************
                    *            *
 16 KK              *     200    *
                    *            *
                    **************
                                   PROPOSED RESERVOIR

                      HYDROGRAPH ROUTING DATA

 18 RN                  NO ROUTING

                                                        ***

***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***

 19 KP              PLAN  2 FOR STATION       200

                    HYDROGRAPH ROUTING DATA

 20 RS                STORAGE ROUTING
                          NSTPS              1  NUMBER OF SUBREACHES
                          ITYP            STOR  TYPE OF INITIAL CONDITION
                          RSVRIC         -1.00  INITIAL CONDITION
                          X               0.00  WORKING R AND D COEFFICIENT

 23 SV                 STORAGE         0.0    2500.0    4000.0    5200.0    6800.0    9000.0   11500.0   15500.0   21000.0   30000.0

 24 SE                ELEVATION     965.00   1000.00   1015.00   1030.00   1045.00   1060.00   1075.00   1090.00   1105.00   1120.00

 21 SL                LOW-LEVEL OUTLET
                          ELEVL         975.00  ELEVATION AT CENTER OF OUTLET
                          CAREA          35.00  CROSS-SECTIONAL AREA
                          COQL            0.70  COEFFICIENT
                          EXPL            0.50  EXPONENT OF HEAD

 22 SS                SPILLWAY
                          CREL         1105.00  SPILLWAY CREST ELEVATION
                          SPWID          35.00  SPILLWAY WIDTH
                          COQW            2.80  WEIR COEFFICIENT
                          EXPW            1.50  EXPONENT OF HEAD

                                                       ***

                                              COMPUTED OUTFLOW-ELEVATION DATA

                      OUTFLOW       0.00       0.00     369.46     419.50     485.23     575.38     706.68     915.61    1299.94    2240.33
                    ELEVATION     965.00     975.00     978.54     979.56     981.10     983.57     987.93     996.71    1018.77    1105.00

                      OUTFLOW    2250.35    2300.47    2423.35    2651.61    3017.85    3554.66    4294.64    5270.36    6514.40    8059.34
                    ELEVATION    1105.19    1105.67    1106.45    1107.51    1108.86    1110.51    1112.45    1114.67    1117.19    1120.00

                                          COMPUTED STORAGE-OUTFLOW-ELEVATION DATA

                      STORAGE       0.00     714.29     966.82    1039.87    1149.88    1326.78    1638.21    2265.29    2500.00    4000.00
                      OUTFLOW       0.00       0.00     369.46     419.50     485.23     575.38     706.68     915.61     982.45    1242.71
                    ELEVATION     965.00     975.00     978.54     979.56     981.10     983.57     987.93     996.71    1000.00    1015.00

                      STORAGE    4301.52    5200.00    6800.00    9000.00   11500.00   15500.00   21000.00   21116.19   21404.91   21868.22
                      OUTFLOW    1299.94    1457.21    1643.95    1811.55    1964.90    2107.12    2240.33    2250.35    2300.47    2423.35
                    ELEVATION    1018.77    1030.00    1045.00    1060.00    1075.00    1090.00    1105.00    1105.19    1105.67    1106.45

                      STORAGE   22506.12   23318.62   24305.71   25467.39   26803.67   28314.54   30000.00
                      OUTFLOW    2651.61    3017.85    3554.66    4294.64    5270.36    6514.40    8059.34
                    ELEVATION    1107.51    1108.86    1110.51    1112.45    1114.67    1117.19    1120.00
*    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***

 25 KP              PLAN  3 FOR STATION       200

                    HYDROGRAPH ROUTING DATA

 26 RN                  NO ROUTING

                                                        ***

** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
                 **************
                 *            *
   27 KK         *     325    *
                 *            *
                 **************
                                    DIVERT FLOW PLAN 3

      DT          DIVERSION
                         ISTAD         FLOW  DIVERSION HYDROGRAPH IDENTIFICATION
                        DSTRMX     20000.00  MAXIMUM VOLUME TO BE DIVERTED

      DI                INFLOW         0.00   2300.00   4100.00   6300.00   8800.00  14300.00  20200.00  30400.00  33250.00

      DQ        DIVERTED FLOW          0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

                                                                     ***

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

   32 KP         PLAN  2 FOR STATION       325

      DT          DIVERSION
                         ISTAD         FLOW  DIVERSION HYDROGRAPH IDENTIFICATION
                        DSTRMX     20000.00  MAXIMUM VOLUME TO BE DIVERTED

      DI                INFLOW         0.00   2300.00   4100.00   6300.00   8800.00  14300.00  20200.00  30400.00  33250.00

      DQ        DIVERTED FLOW          0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00

                                                                     ***

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

   36 KP         PLAN  3 FOR STATION       325

      DT          DIVERSION
                         ISTAD         FLOW  DIVERSION HYDROGRAPH IDENTIFICATION
                        DSTRMX     20000.00  MAXIMUM VOLUME TO BE DIVERTED

      DI                INFLOW         0.00   2300.00   4100.00   6300.00   8800.00  14300.00  20200.00  30400.00  33250.00  38000.00

      DQ        DIVERTED FLOW          0.00   1400.00   2000.00   3400.00   4800.00   8000.00  12200.00  16200.00  18550.00  20000.00

                                                                     ***

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

                 **************
                 *            *
   40 KK         *    RCH1    *
                 *            *
                 **************
                                    POTENTIAL CHANNEL MODIFICATION REACH

                 HYDROGRAPH ROUTING DATA

   42 RS          STORAGE ROUTING
                         NSTPS            1  NUMBER OF SUBREACHES
                          ITYP         STOR  TYPE OF INITIAL CONDITION
                        RSVRIC        -1.00  INITIAL CONDITION
                             X         0.00  WORKING R AND D COEFFICIENT

   43 SV               STORAGE          0.0      50.0     475.0     940.0    2135.0    3080.0

   44 SQ             DISCHARGE           0.       200.     1020.     2050.     6100.    10250.

                                                                     ***

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

                 PLAN  2 INPUT DATA FOR STATION     RCH1 ARE SAME AS FOR PLAN  1

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

                 PLAN  3 INPUT DATA FOR STATION     RCH1 ARE SAME AS FOR PLAN  1

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
              **************
              *            *
   45 KK      *      300   *
              *            *
              **************
                                   RUNOFF FROM SUBBASIN 300

                 SUBBASIN RUNOFF DATA

   47 BA           SUBBASIN CHARACTERISTICS
                         TAREA        49.10  SUBBASIN AREA

                                                                    ***

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

                 PLAN  2 INPUT DATA FOR STATION      300 ARE SAME AS FOR PLAN  1

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

                 PLAN  3 INPUT DATA FOR STATION      300 ARE SAME AS FOR PLAN  1

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              **************
              *            *
   53 KK      *      300   *
              *            *
              **************
                                   COMBINED UPSTREAM INFLOWS

   55 HC           HYDROGRAPH COMBINATION
                         ICOMP            2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                                    ***

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              **************
              *            *
   56 KK      *      350   *
              *            *
              **************
                                   RETRIEVE DIVERTED FLOW

   58 DR           RETRIEVE DIVERSION HYDROGRAPH
                         ISTAD         FLOW  DIVERSION HYDROGRAPH IDENTIFICATION

                                                                    ***

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              **************
              *            *
   59 KK      *      400   *
              *            *
              **************
                                   COMBINE UPSTREAM AND DIVERTED INFLOWS

   61 HC           HYDROGRAPH COMBINATION
                         ICOMP            2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                                    ***

*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***

              **************
              *            *
 62 KK        *    RCH2    *
              *            *
              **************
                             PROPOSED PUMPING PLANT SITE

                HYDROGRAPH ROUTING DATA

 64 RS            STORAGE ROUTING
                       NSTPS          1  NUMBER OF SUBREACHES
                        ITYP       STOR  TYPE OF INITIAL CONDITION
                      RSVRIC      -1.00  INITIAL CONDITION
                           X       0.00 WORKING R AND D COEFFICIENT

 65 SV              STORAGE        0.0      400.0   30000.0   35000.0   40000.0

 66 SE            ELEVATION     840.00     845.00    855.00    857.00    859.00

 67 SQ            DISCHARGE         0.      1250.     1500.     1800.     2000.

                                                                  ***

***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

 68 KP          PLAN  2 FOR STATION     RCH2

                HYDROGRAPH ROUTING DATA

 64 RS            STORAGE ROUTING
                       NSTPS          1  NUMBER OF SUBREACHES
                        ITYP       STOR  TYPE OF INITIAL CONDITION
                      RSVRIC      -1.00  INITIAL CONDITION
                           X       0.00 WORKING R AND D COEFFICIENT

 65 SV              STORAGE        0.0      400.0   30000.0   35000.0   40000.0

 66 SE            ELEVATION     840.00     845.00    855.00    857.00    859.00

 67 SQ            DISCHARGE         0.      1250.     1500.     1800.     2000.

 69 WP            PUMPING DATA

                     PUMP ON    PUMPING    PUMP OFF
                    ELEVATION    RATE     ELEVATION

                      843.5     3000.       843.5
                      ISTAD              PUMP FLOW HYDROGRAPH IDENTIFICATION

                                                             ***
***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***     ***

 70 KP          PLAN  3 FOR STATION     RCH2

                HYDROGRAPH ROUTING DATA

 64 RS            STORAGE ROUTING
                       NSTPS          1  NUMBER OF SUBREACHES
                        ITYP       STOR  TYPE OF INITIAL CONDITION
                      RSVRIC      -1.00  INITIAL CONDITION
                           X       0.00 WORKING R AND D COEFFICIENT*

 65 SV              STORAGE        0.0      400.0   30000.0   35000.0   40000.0

 66 SE            ELEVATION     840.00     845.00    855.00    857.00    859.00

 67 SQ            DISCHARGE         0.      1250.     1500.     1800.     2000.

 69 WP            PUMPING DATA

                     PUMP ON    PUMPING    PUMP OFF
                    ELEVATION    RATE     ELEVATION

                      843.5     3000.       843.5
                      ISTAD              PUMP FLOW HYDROGRAPH IDENTIFICATION

                                                             ***
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

RATIOS APPLIED TO FLOWS

OPERATION	STATION	AREA	PLAN		RATIO 1	RATIO 2	RATIO 3	RATIO 4	RATIO 5	RATIO 6	RATIO 7	RATIO 8	RATIO 9
					0.11	0.26	0.45	0.65	0.86	1.00	1.20	1.40	1.50
HYDROGRAPH AT													
	100	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO													
	200	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	367.	617.	864.	1052.	1206.	1317.	1467.	1573.	1627.
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
			3	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			** PEAK STAGES IN FEET **										
			1	STAGE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			2	STAGE	978.51	984.95	994.56	1003.99	1012.91	1020.02	1030.80	1039.32	1043.67
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
			3	STAGE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIVERSION TO													
	FLOW	35.10	1	FLOW	0.	0.	0.	0.	0.	0.	0	0.	0.
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			2	FLOW	0.	0.	0.	0.	0.	0.	0.	0.	0.
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			3	FLOW	360.	850.	1439.	1798.	2332.	2811.	3483.	4085.	4386.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
HYDROGRAPH AT													
	325	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	367.	617.	864.	1052.	1206.	1317.	1467.	1573.	1627.
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
			3	FLOW	231.	547.	979.	1695.	2290.	2563.	2965.	3438.	3675.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO													
	RCH1	35.10	1	FLOW	429.	978.	1742.	2680.	3668.	4313.	5232.	6156.	6701.
				TIME	28.00	28.00	28.00	28.00	28.00	27.00	27.00	27.00	27.00
			2	FLOW	305.	551.	784.	980.	1135.	1241.	1389.	1504.	1557.
				TIME	34.00	38.00	39.00	41.00	41.00	41.00	42.00	43.00	43.00
			3	FLOW	199.	399.	675.	1129.	1626.	1868.	2225.	2646.	2853.
				TIME	27.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
HYDROGRAPH AT													
	300	49.10	1	FLOW	790.	1867.	3231.	4666.	6174.	7179.	8615.	10051.	10768.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	790.	1867.	3231.	4666.	6174.	7179.	8615.	10051.	10768.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	790.	1867.	3231.	4666.	6174.	7179.	8615.	10051.	10768.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2 COMBINED AT													
	300	84.20	1	FLOW	1162.	2688.	4687.	6892.	9339.	10959.	13250.	15529.	16663.
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	979.	2176.	3649.	5181.	6777.	7833.	9332.	10825.	11571.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	974.	2215.	3805.	5597.	7500.	8712.	10420.	12175.	13108.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
HYDROGRAPH AT													
	350	0.00	1	FLOW	0.	0.	0.	0.	0.	0.	0.	0.	0.
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			2	FLOW	0.	0.	0.	0.	0.	0.	0.	0.	0.
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			3	FLOW	360.	850.	1439.	1798.	2332.	2811.	3483.	4085.	4386.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2 COMBINED AT													
	400	84.20	1	FLOW	1162.	2688.	4687.	6892.	9339.	10959.	13250.	15529.	16663.
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	979.	2176.	3649.	5181.	6777.	7833.	9332.	10825.	11571.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	1333.	3065.	5244.	7395.	9832.	11523.	13903.	16261.	17494.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
PUMP FLOW TO													
		84.20	1	FLOW	0.	0.	0.	0.	0.	0.	0.	0.	0.
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			2	FLOW	0.	3000.	3000.	3000.	3000.	3000.	3000.	3000.	3000.
				TIME	1.00	23.00	21.00	19.00	17.00	16.00	14.00	13.00	13.00
			3	FLOW	3000.	3000.	3000.	3000.	3000.	3000.	3000.	3000.	3000.
				TIME	26.00	22.00	20.00	16.00	14.00	13.00	12.00	12.00	12.00
HYDROGRAPH AT													
	RCH2	84.20	1	FLOW	964.	1257.	1273.	1291.	1312.	1326.	1347.	1369.	1379.
				TIME	28.00	33.00	37.00	39.00	40.00	41.00	43.00	45.00	46.00
			2	FLOW	802.	1127.	1251.	1252.	1260.	1265.	1274.	1284.	1290.
				TIME	28.00	25.00	24.00	28.00	30.00	30.00	32.00	33.00	33.00
			3	FLOW	935.	1250.	1252.	1263.	1278.	1289.	1306.	1323.	1333.
				TIME	25.00	25.00	28.00	30.00	32.00	33.00	34.00	35.00	35.00
			** PEAK STAGES IN FEET **										
			1	STAGE	843.86	845.27	845.90	846.65	847.48	848.05	848.89	849.74	850.17
				TIME	28.00	33.00	37.00	39.00	40.00	42.00	43.00	45.00	46.00
			2	STAGE	843.21	844.51	845.02	845.09	845.41	845.62	845.97	846.36	846.60
				TIME	28.00	25.00	24.00	28.00	30.00	30.00	32.00	33.00	33.00
			3	STAGE	843.74	845.01	845.09	845.51	846.14	846.57	847.23	847.93	848.32

12.11 Example Problem #11: Flood Damage Analysis

The flood damage reduction analysis is useful in evaluating the economic viability of various flood control plans. In this example, the multiplan watershed model of Problem 10 is updated with economic data for each damage center as depicted in Fig. 12.7. The resulting model is used to calculate the expected annual damage for each plan and the inundation reduction benefit accrued due to the employment of any flood control scenario.

The data for the flood damage analysis is shown in Table 12.11a. The listing of the input data deck and a summary of the analysis results is given in Table 12.11b. Note that the economic data (beginning with the EC card) is added at the end of the multiplan-multiflood data deck (no changes are made to the multiplan-multiflood data).

Discussion of Results

An important point to note in the computer output (Table 12.11b) concerns the calculation of the damage frequency curve discussed in Section 8. The program outputs the interpolated flow-damage and flow-frequency data based on the input data and simulated flows. It is important that the damage-frequency curve calculated from this data cover the entire range of frequencies intended (including rare frequencies) for an accurate estimate of EAD. See Section 8 for a more detailed discussion of this point.

TABLE 12.11a

Flood Damage Reduction Analysis Economic Data

1. LAND USE CATEGORIES: — RECORD IDENTIFIERS: CN

CATEGORY	CATEGORY ID	CATEGORY NO.
RESIDENTIAL	RESID	1
INDUSTRIAL/COMMERCIAL	IND/COM	2
AGRICULTURAL	AGRIC	3

2. FREQUENCY-FLOW, FLOW-DAMAGE DATA, DAMAGE REACH RCH1: — QF, FR, DG, PD

HYDROLOGIC DATA

	FREQUENCY (% EXCEEDENCE)	FLOW (cfs)
1.	700	400
2.	600	490
3.	550	530
4.	450	640
5.	350	800
6.	250	1070
7.	150	1480
8.	90	1690
9.	70	1920
10.	50	2170
11.	35	2480
12.	25	2850
13.	16.5	3240
14.	10.0	3640
15.	5.0	4090
16.	2.0	4900
17.	.5	5900
18.	.1	7100

DAMAGE DATA

	FLOW (cfs)	AGRIC (THOUS $)
1.	400	0
2.	600	1
3.	730	2
4.	960	3
5.	1230	5
6.	1530	7
7.	1970	28
8.	2500	49
9.	3100	111
10.	3490	314
11.	3780	516
12.	4290	619
13.	5120	723
14.	6020	728
15.	7100	830

3. FREQUENCY-STAGE, STAGE-DAMAGE DATA, DAMAGE REACH RCH1: — SF, FR, SD, DG

HYDROLOGIC DATA

	FREQUENCY (% EXCEEDENCE)	STAGE (ft.)
1.	95	843.6
2.	81	844.8
3.	60	846.6
4.	45	846.0
5.	25	846.6
6.	11	847.3
7.	5	857.9
8.	2.5	848.4
9.	1	849.1
10.	.5	849.5
11.	.2	850.0
12.	.1	850.3

DAMAGE DATA

	STAGE (ft.)	RESID (THOUS $)	IND/COM (THOUS $)
1.	845.0	0	0
2.	845.5	720	10.5
3.	847.0	1380	15.0
4.	847.6	2710	52.5
5.	848.3	5200	105.0
6.	849.0	8000	202.5
7.	849.8	10050	540.0
8.	851.0	11250	585.0

TABLE 12.11b

Example Problem #11: Input and Output

```
                                        HEC-1 INPUT                                                        PAGE  1

 LINE       ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1        ID        EXAMPLE PROBLEM NO. 11
   2        ID        FLOOD DAMAGE ANALYSIS
   3        ID        ROCKBED WATERSHED
            *DIAGRAM
   4        IT      60       0       0     130
   5        IO       5
            * ************************************** MULTI PLAN AND RATIO DATA
   6        JP       3
   7        JR    FLOW     .11     .26     .45     .65     .86    1.00    1.20    1.40    1.50

   8        KK     100
   9        KM        DESIGN FLOOD SUBBASIN 100
  10        BA    35.1
  11        QI      24      24      24      26      33      50      86     189     376     516
  12        QI     594     657     710     760     801     839     910    1044    1287    1921
  13        QI    2995    3953    4599    5077    5363    5374    5099    4603    3980    3325
  14        QI    2719    2200    1844    1540    1251     994     777     605     471     365
  15        QI     281       0       0       0       0       0       0       0       0       0
            * ************************************** PROPOSED RESERVOIR DATA

  16        KK     200
  17        KM          PROPOSED RESERVOIR
  18        RN
  19        KP       2
  20        RS       1    STOR     -1.      0.
  21        SL     975      35      .7      .5
  22        SS    1105      35     2.8     1.5
  23        SV       0    2500    4000    5200    6800    9000   11500   15500   21000   30000
  24        SE     965    1000    1015    1030    1045    1060    1075    1090    1105    1120
            * ************************************** NO RESERVOIR PLAN 3

  25        KK     325
  26        KM        DIVERT FLOW PLAN 3
            * ************************************** DUMMY DIVERSION
  27        DT    FLOW   20000
  28        DI       0    2300    4100    6300    8800   14300   20200   30400   33250
  29        DQ
  30        KP       2
            * ************************************** DUMMY DIVERSION
  31        DT    FLOW   20000
  32        DI       0    2300    4100    6300    8800   14300   20200   30400   33250
  33        DQ
  34        KP       3
  35        DT    FLOW   20000
  36        DI       0    2300    4100    6300    8800   14300   20200   30400   33250   38000
  37        DQ       0    1400    2000    3400    4800    8000   12200   16200   18550   20000

  38        KK    RCH1
  39        KM        LOCAL PROTECTION PROJECT PROJECT FOR REACH RCH1
  40        RS       1    STOR     -1.      0.
  41        SV      0.     50.    475.    940.   2135.   3080.      0.      0.      0.      0.
  42        SQ      0.    200.   1020.   2050.   6100.  10250.      0.      0.      0.      0.

  43        KK     300
  44        KM        DESIGN FLOOD SUBBASIN 300
  45        KM        RUNOFF FROM SUBBASIN 300
  46        BA    49.1
  47        QI      32      32      32      35      44      67     114     252     501     688
  48        QI     789     877     940    1013    1068    1119    1214    1392    1717    2561
  49        QI    3993    4273    6139    6727    7163    7179    6789    6137    5308    4433
  50        QI    3622    2930    2458    2053    1665    1325    1032     806     628     487
  51        QI     374

  52        KK     300
  53        KM        COMBINED UPSTREAM INFLOWS
  54        HC       2

  55        KK     350
  56        KM        RETRIEVE DIVERTED FLOW
  57        DR    FLOW

  58        KK     400
  59        KM        COMBINE UPSTREAM AND DIVERTED INFLOWS
  60        HC       2
```

```
61          KK    RCH2
62          KM         DAMAGE REACH LOWLAND FLOODING PROBLEMS
63          KM          PROPOSED PUMPING PLANT SITE
64          RS      1    STOR     -1.     0.
65          SV     0.    400.  30000.  35000.  40000.
66          SE    840     845     855     857     859
67          SQ      0    1250    1500    1800    2000
            * ************************************* PLAN 2 PUMP DATA
68          KP      2
69          WP  843.5    3000
70          KP      3
            * ************************************* ECONOMICS DATA

71          EC

72          KK    RCH1
73          CN      3  RESID IND/COM   AGRIC
74          FR             18   700.0   600.0   550.0   450.0   350.0   250.0   150.0    90.0
75          FR   70.0    50.0    35.0    25.0    16.5    10.0     5.0     2.0      .5      .1
76          QF                    400     490     530     640     800    1070    1480    1690
77          QF   1920    2170    2480    2850    3240    3640    4090    4900    5900    7100
78          QD             15     400     600     730     960    1230    1530    1970    2500
79          QD   3100    3490    3780    4290    5120    6020    7100
80          DG            1 3       0       1       2       3       5       7      28      49
81          DG    111     314     516     619     723     728     830

82          KK    RCH2
83          CN      3  RESID IND/COM   AGRIC
84          FR             12      95      81      60      45      25      11       5     2.5
85          FR      1      .5      .2      .1
86          SF                  843.6   844.8   845.6   846.0   846.6   847.3   847.9   848.4
87          SF  849.1   849.5   850.0   850.3
88          SD              8   845.0   845.5   847.0   847.6   848.3   849.0   849.8   851.0
89          DG            1 1       0     720    1380    2710    5200    8000   10050   11250
90          DG            1 2       0    10.5    15.0    52.5   105.0   202.5     540     585
91          ZZ
```

```
                     SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE       (V) ROUTING            (--->) DIVERSION
  NO.        (.) CONNECTOR          (<---) RETURN OF DIVERTED FLOW

   8          100
               V
               V
  16          200
               .
               .
  27           .------->      FLOW
  25          325
               V
               V
  38          RCH1
               .
               .
  43           .          300
               .            .
               .            .
  52          300............
               .
               .
  57           .            .<-------     FLOW
  55           .          350
               .            .
               .            .
  58          400............
               V
               V
  61          RCH2
```

```
                    EXAMPLE PROBLEM NO. 11
                    FLOOD DAMAGE ANALYSIS
                    ROCKBED WATERSHED

IO          OUTPUT CONTROL VARIABLES
                  IPRNT           5  PRINT CONTROL
                  IPLOT           0  PLOT CONTROL
                  QSCAL          0.  HYDROGRAPH PLOT SCALE
                   DMSG         YES  PRINT DIAGNOSTIC MESSAGES

IT          HYDROGRAPH TIME DATA
                   NMIN          60  MINUTES IN COMPUTATION INTERVAL
                  IDATE      1    0  STARTING DATE
                  ITIME        0000  STARTING TIME
                     NQ         130  NUMBER OF HYDROGRAPH ORDINATES
                 NDDATE      6    0  ENDING DATE
                 NDTIME        0900  ENDING TIME

              COMPUTATION INTERVAL    1.00 HOURS
                   TOTAL TIME BASE  129.00 HOURS

      ENGLISH UNITS
            DRAINAGE AREA          SQUARE MILES
            PRECIPITATION DEPTH    INCHES
            LENGTH, ELEVATION      FEET
            FLOW                   CUBIC FEET PER SECOND
            STORAGE VOLUME         ACRE-FEET
            SURFACE AREA           ACRES
            TEMPERATURE            DEGREES FAHRENHEIT

JP          MULTI-PLAN OPTION
                  NPLAN            3  NUMBER OF PLANS

JR          MULTI-RATIO OPTION
                RATIOS OF RUNOFF
              0.11     0.26     0.45     0.65     0.86     1.00     1.20     1.40     1.50
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIO 1 0.11	RATIO 2 0.26	RATIO 3 0.45	RATIO 4 0.65	RATIO 5 0.86	RATIO 6 1.00	RATIO 7 1.20	RATIO 8 1.40	RATIO 9 1.50
					RATIOS APPLIED TO FLOWS								
HYDROGRAPH AT	100	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO	200	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.0C	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	367.	617.	864.	1052.	1206.	1317.	1467.	1573.	1627.
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
			3	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			** PEAK STAGES IN FEET **										
			1	STAGE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			2	STAGE	978.51	984.95	994.56	1003.99	1012.91	1020.02	1030.80	1039.32	1043.67
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
			3	STAGE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIVERSION TO	FLOW	35.10	1	FLOW	0.	0.	0.	0.	0.	0.	0.	0.	0.
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			2	FLOW	0.	0.	0.	0.	0.	0.	0.	0.	0.
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			3	FLOW	360.	850.	1439.	1798.	2332.	2811.	3483.	4085.	4386.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
HYDROGRAPH AT	325	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	367.	617.	864.	1052.	1206.	1317.	1467.	1573.	1627.
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
			3	FLOW	231.	547.	979.	1695.	2290.	2563.	2965.	3438.	3675.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO	RCH1	35.10	1	FLOW	429.	978.	1742.	2680.	3668.	4313.	5232.	6156.	6701.
				TIME	28.00	28.00	28.00	28.00	28.00	27.00	27.00	27.00	27.00
			2	FLOW	305.	551.	784.	980.	1135.	1241.	1389.	1504.	1557.
				TIME	34.00	38.00	39.00	41.00	41.00	41.00	42.00	43.00	43.00
			3	FLOW	199.	399.	675.	1129.	1626.	1868.	2225.	2646.	2853.
				TIME	27.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00

HYDROGRAPH AT	300	49.10	1	FLOW	790.	1867.	3231.	4666.	6174	7179.	8615.	10051	10768
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	790	1867.	3231	4666	6174	7179	8615	10051	10768
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	790	1867.	3231.	4666	6174	7179	8615	10051	10768
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2 COMBINED AT	300	84.20	1	FLOW	1162	2688	4687	6892	9339	10959	13250	15529	16663
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	979	2176	3649	5181	6777	7833.	9332	10825	11571
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	974	2215	3805	5597	7500	8712	10420	12175	13108
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
HYDROGRAPH AT	350	0.00	1	FLOW	0.	0	0	0	0	0	0	0	0
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			2	FLOW	0	0.	0	0	0	0.	0	0	0
				TIME	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
			3	FLOW	360	850	1439.	1798	2332	2811	3483	4085	4386.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2 COMBINED AT	400	84.20	1	FLOW	1162	2688	4687.	6892	9339	10959	13250	15529	16663.
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	979	2176.	3649	5181	6777	7833.	9332	10825.	11571
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			3	FLOW	1333.	3065.	5244.	7395	9832.	11523.	13903	16261	17494
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
PUMP FLOW TO		84.20	1	FLOW	0.	0.	0	0.	0	0.	0	0	0.
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			2	FLOW	0.	3000.	3000	3000.	3000	3000.	3000	3000	3000.
				TIME	1.00	23.00	21.00	19.00	17.00	16.00	14.00	13.00	13.00
			3	FLOW	3000	3000.	3000	3000.	3000.	3000.	3000	3000	3000
				TIME	26.00	22.00	20.00	16.00	14.00	13.00	12.00	12.00	12.00
HYDROGRAPH AT	RCH2	84.20	1	FLOW	964.	1257.	1273.	1291	1312.	1326.	1347.	1369.	1379.
				TIME	28.00	33.00	37.00	39.00	40.00	41.00	43.00	45.00	46.00
			2	FLOW	802	1127.	1251	1252.	1260	1265.	1274	1284	1290.
				TIME	28.00	25.00	24.00	28.00	30.00	30.00	32.00	33.00	33.00
			3	FLOW	935.	1250.	1252	1263.	1278.	1299.	1306	1323	1333
				TIME	25.00	25.00	28.00	30.00	32.00	33.00	34.00	35.00	35.00
			** PEAK STAGES IN FEET **										
			1	STAGE	843.86	845.27	845.90	846.65	847.48	848.05	848.89	849.74	850.17
				TIME	28.00	33.00	37.00	39.00	40.00	42.00	43.00	45.00	46.00
			2	STAGE	843.21	844.51	845.02	845.09	845.41	845.62	845.97	846.36	846.60
				TIME	28.00	25.00	24.00	28.00	30.00	30.00	32.00	33.00	33.00
			3	STAGE	843.74	845.01	845.09	845.51	846.14	846.57	847.23	847.93	848.32
				TIME	25.00	25.00	28.00	30.00	32.00	33.00	34.00	35.00	35.00

++DAMAGE DATA FOR PLAN 1 --

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	668.87	429.	0.00	0.00	0.00	0.15	0.15
2	279.57	978.	0.00	0.00	0.00	3.14	3.14
3	85.07	1742.	0.00	0.00	0.00	17.11	17.11
4	29.26	2680.	0.00	0.00	0.00	67.65	67.65
5	9.60	3668.	0.00	0.00	0.00	438.01	438.01
6	3.77	4313.	0.00	0.00	0.00	621.86	621.86
7	1.38	5232.	0.00	0.00	0.00	723.62	723.62
8	0.33	6156.	0.00	0.00	0.00	740.82	740.82
9	0.11	6701.	0.00	0.00	0.00	792.28	792.28
EXP ANNUAL DAMAGE				0.00	0.00	129.22	129.22

++DAMAGE DATA FOR PLAN 2 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	668.87	305.	0.00	0.00	0.00	0.00	0.00
2	279.57	551.	0.00	0.00	0.00	0.75	0.75
3	85.07	784.	0.00	0.00	0.00	2.23	2.23
4	29.26	980.	0.00	0.00	0.00	3.15	3.15
5	9.60	[illegible]	0.00	0.00	0.00	4.30	4.30
6	3.77	1241.	0.00	0.00	0.00	5.07	5.07
7	1.38	1389.	0.00	0.00	0.00	6.06	6.06
8	0.33	1504.	0.00	0.00	0.00	6.83	6.83
9	0.11	1557.	0.00	0.00	0.00	8.31	8.31
EXP ANNUAL DAMAGE				0.00	0.00	6.22	6.22

++DAMAGE DATA FOR PLAN 3 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	668.87	199.	0.00	0.00	0.00	0.00	0.00
2	279.57	399.	0.00	0.00	0.00	0.00	0.00
3	85.07	675.	0.00	0.00	0.00	1.58	1.58
4	29.26	1129.	0.00	0.00	0.00	4.25	4.25
5	9.60	1626.	0.00	0.00	0.00	11.58	11.58
6	3.77	1868.	0.00	0.00	0.00	23.13	23.13
7	1.38	2225.	0.00	0.00	0.00	38.10	38.10
8	0.33	2646.	0.00	0.00	0.00	64.10	64.10
9	0.11	2853.	0.00	0.00	0.00	85.43	85.43
EXP ANNUAL DAMAGE				0.00	0.00	6.27	6.27

++DAMAGE DATA FOR PLAN 1 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	93.53	0.	843.86	0.00	0.00	0.00	0.00
2	70.19	0.	845.27	387.69	5.65	0.00	393.34
3	48.51	0.	845.90	898.05	11.71	0.00	909.77
4	23.48	0.	846.65	1227.45	13.96	0.00	1241.41
5	8.77	0.	847.48	2451.80	45.22	0.00	2497.02
6	4.06	0.	848.05	4327.31	86.60	0.00	4413.91
7	1.36	0.	848.89	7559.55	187.16	0.00	7746.71
8	0.33	0.	849.74	9899.25	515.18	0.00	10414.43
9	0.13	0.	850.17	10422.49	553.97	0.00	10976.45
EXP ANNUAL DAMAGE				1099.86	20.21	0.00	1120.06

++DAMAGE DATA FOR PLAN 2 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	93.53	0.	843.21	0.00	0.00	0.00	0.00
2	70.19	0.	844.51	0.00	0.00	0.00	0.00
3	48.51	0.	845.02	33.27	0.49	0.00	33.76
4	23.48	0.	845.09	132.94	1.94	0.00	134.88
5	8.77	0.	845.41	595.43	8.68	0.00	604.11
6	4.06	0.	845.62	772.10	10.86	0.00	782.96
7	1.36	0.	845.97	928.80	11.92	0.00	940.72
8	0.33	0.	846.36	1099.59	13.09	0.00	1112.68
9	0.13	0.	846.60	1203.97	13.80	0.00	1217.77
EXP ANNUAL DAMAGE				139.80	1.98	0.00	141.78

++DAMAGE DATA FOR PLAN 3 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	93.53	0.	843.74	0.00	0.00	0.00	0.00
2	70.19	0.	845.01	13.18	0.19	0.00	13.37
3	48.51	0.	845.09	133.30	1.94	0.00	135.24
4	23.48	0.	845.51	726.57	10.54	0.00	737.12
5	8.77	0.	846.14	1000.79	12.41	0.00	1013.21
6	4.06	0.	846.57	1192.31	13.72	0.00	1206.03
7	1.36	0.	847.23	1900.92	29.69	0.00	1930.60
8	0.33	0.	847.93	3870.62	76.97	0.00	3947.60
9	0.13	0.	848.32	5283.32	107.90	0.00	5391.23
EXP ANNUAL DAMAGE				375.13	5.29	0.00	380.42

EXPECTED ANNUAL FLOOD DAMAGE SUMMARY

STREAM STATION	DAMAGE REACH	WATERSHED	TOWNSHIP	*	DAMAGE CATEGORY	EXPECTED ANNUAL DAMAGE PLAN 1	PLAN 2	PLAN 3
RCH1	1			*	1 RESID	0.00	0.00	0.00
				*	2 IND/COM	0.00	0.00	0.00
				*	3 AGRIC	129.22	6.22	6.27
				*				
				*	TOTAL	129.22	6.22	6.27
			DAMAGE CHANGE (BENEFITS)			BASE	123.00	122.95
RCH2	2			*	1 RESID	1099.86	139.80	375.13
				*	2 IND/COM	20.21	1.98	5.29
				*	3 AGRIC	0.00	0.00	0.00
				*				
				*	TOTAL	1120.06	141.78	380.42
			DAMAGE CHANGE (BENEFITS)			BASE	978.29	739.64
BASIN TOTAL				*	1 RESID	1099.86	139.80	375.13
				*	2 IND/COM	20.21	1.98	5.29
				*	3 AGRIC	129.22	6.22	6.27
				*				
				*	TOTAL	1249.28	148.00	386.69
			DAMAGE CHANGE (BENEFITS)			BASE	1101.28	862.59

12.12 Example Problem #12: Flood Control System Optimization

Two flood control plans for Rockbed Watershed were presented in previous tests. In each plan, a single capacity for the flood control system was explored. The flood control system optimization option of HEC-1 allows the user to determine the flood control system capacity that is optimal for the proposed project (e.g., the system capacity that leads to the greatest net benefit). For example purposes, the flood control system outlined in PLAN 2 of the previous test has been chosen to demonstrate the optimization capabilities of HEC-1. In order to further demonstrate the capabilities of HEC-1, a local protection project (a channel improvement) has been added to the flood control measures for the damage center in reach RCH1, Fig. 12.7.

The data for the optimization model is shown in Table 12.12a. A number of points should be noted about the data:

(1) Optimization runs are specified by an OS card. The initial capacity of the flood control components to be optimized are indicated as negative numbers on this card.

(2) Basic optimization data consists of maximum and minimum allowable capacity, and cost versus capacity tables for the project.

(3) The channel improvement data requires the addition of upper and lower pattern damage information for the reach (DU, DL cards).

(4) A degree of protection can be specified for any damage reach (DP card). In this example, a maximum stage of 846.9 feet at the 1% exceedence level has been specified as the protection level for damage reach RCH2.

The input data in the appropriate HEC-1 format and the output from the model are shown in Table 12.12b. Note that the cost and optimization data for the reservoir and pump are located in the stream network portion of the input data deck, whereas, the local protection and degree of protection data are located in the economic analysis portion of the data deck. The results of the optimization analysis are shown in the output summaries at the end of the computer output (Table 12.12b).

TABLE 12.12a

Flood Control System Optimization Data

RECORD IDENTIFIERS

RESERVOIR DATA

Initial Size	=	15000 (ac-ft)	OS
Maximum Capacity	=	29000 (ac-ft)	SO
Minimum Capacity	=	0 (ac-ft)	
O+M Factor	=	.023	
Discount Factor	=	.0504	

COST DATA ($ THOUS) SD

(CORRESPONDING TO ELEVATION DATA ON SE CARD)

0, 1500, 2400, 2000, 3600, 4350, 4450, 5550, 6000, 7200

PUMP DATA

Initial Size	=	8000 (cfs)	OS
Maximum Capacity	=	10000 (cfs)	WO
Minimum Capacity	=	100 (cfs)	
O+M Factor	=	.023	
Discount Factor	=	.0504	

CAPACITY-COST DATA

CAPACITY (cfs)	0,	250,	500,	1000,	2000,	6000,	8000,	10000	WC
COST ($ THOUS)	0,	670,	1000,	16000,	2300,	6000,	7860,	8670	WD

LOCAL PROTECTION PROJECT DATA

Initial Size	=	17000 (cfs)	OS
Maximum Capacity	=	21000 (cfs)	LO
Minimum Capacity	=	0 (cfs)	
O+M Factor	=	.023	
Discount Factor	=	.0504	

CAPACITY-COST DATA

CAPACITY (cfs)	0,	5000,	5500,	7000,	8300,	9300,	12000,	15000,	21000	LC
COST ($ THOUS)	0,	103,	149,	122,	283,	340,	600,	1000,	3000	LD

UPPER PATTERN-LOWER PATTERN DAMAGE TABLE

AGRICULTURAL LAND USE

(CORRESPONDS TO FLOWS ON QD CARD FOR DAMAGE REACH RCH1) DU, DL

UPPER PATTERN	0,	1,	2,	3,	5,	7,	28,	49,	111,	314,	516,	619,	723,	728,	830
LOWER PATTERN	0,	0,	0,	0,	0,	0,	0,	0,	0,	0,	0,	0,	.44,	3.5,	7.15

TABLE 12.12b

Example Problem #12: Input and Output

```
                              HEC-1 INPUT                                                 PAGE 1

     ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

     ID        EXAMPLE PROBLEM _ 12
     ID        FLOOD CONTROL SYSTEM OPTIMIZATION
     ID        ROCKBED WATERSHED
     *DIAGRAM
     IT      60       0       0     130
     IO       4
     OS  -15000   -8000  -17000
     * ************************************** MULTI PLAN AND RATIO DATA
     JP       2
     JR    FLOW     .11     .26     .45     .65     .86    1.00    1.20    1.40     1.5

     KK     100
     KM         POTENTIAL RESERVOIR INFLOW
     BA    35.1
     QI      24      24      24      26      33      50      86     189     376     516
     QI     594     657     710     760     801     839     910    1044    1287    1921
     QI    2995    3953    4599    5077    5363    5374    5099    4603    3980    3325
     QI    2719    2200    1844    1540    1251     994     777     605     471     365
     QI     281       0       0       0       0       0       0       0       0       0
     * ************************************** PROPOSED RESERVOIR DATA

     KK     200
     KM         PROPOSED RESERVOIR
     RN
     KP       2
     RS       1    STOR     -1.      0.
     SO       1    .023   .0504   29000       0
     SL     975      35      .7      .5
     SS    1105      35     2.8     1.5
     SV       0    2500    4000    5200    6800    9000   11500   15500   21000   30000
     SE     965    1000    1015    1030    1045    1060    1075    1090    1105    1120
     SD       0    1500    2400    3000    3600    4350    4950    5550    6000    7200

     KK    RCH1
     KM         POTENTIAL CHANNEL MODIFICATION REACH
     RS       1    STOR     -1.      0.
     SV      0.     50.    475.    940.   2135.   3080.      0.      0.      0.      0.
     SQ      0.    200.   1020.   2050.   6100.  10250.      0.      0.      0.      0.

     KK     300
     KM        RUNOFF FROM SUBBASIN 300
     BA    49.1
     QI      32      32      32      35      44      67     114     252     501     688
     QI     789     877     940    1013    1068    1119    1214    1392    1717    2561
     QI    3993    4273    6139    6727    7163    7179    6789    6137    5308    4433
     QI    3622    2930    2458    2053    1665    1325    1032     806     628     487
     QI     374

     KK     300
     KM        COMBINED UPSTREAM INFLOWS
     HC       2
     KK    RCH2
     KM         PROPOSED PUMPING PLANT SITE
     RS       1    STOR     -1.      0.
     SV      0.    400.  30000.
     SE     840     845     855
     SQ       0    1250    1500
     * ************************************** PLAN 2 PUMP DATA
     KP       2
     WO       2    .023   .0504     100   10000
     WP   843.5    3000
     WC       0     250     500    1000    2000    6000    8000   10000
     WD       0     670    1000    1600    2300    6000    7860    8670
     * ************************************** ECONOMICS DATA

     EC

     KK    RCH1
     CN       3   RESID IND/COM   AGRIC
     FR              18   700.0   600.0   550.0   450.0   350.0   250.0   150.0    90.0
     FR    70.0    50.0    35.0    25.0    16.5    10.0     5.0     2.0      .5      .1
     QF                     400     490     530     640     800    1070    1480    1690
     QF    1920    2170    2480    2850    3240    3640    4090    4900    5900    7100
     QD              15     400     600     730     960    1230    1530    1970    2500
     QD    3100    3490    3780    4290    5120    6020    7100
     DG             1 3       0       1       2       3       5       7      28      49
     DG     111     314     516     619     723     728     830
```

```
 66        LO       3    .023   .0504   21000       0
 67        LC       0    5000    5500    7000    8300    9300   12000   15000   21000
 68        LD       0     103     149     222     283     340     600    1000    3000
 69        DU               3       0       1       2       3       5       7      28      49
 70        DU     111     314     516     619     723     728     830
 71        DL               3      0.      0.      0.      0.      0.      0.      0.      0.
 72        DL      0.      0.      0.      0.    0.44     3.5    7.15

 73        KK    RCH2
 74        CM       3  RESID IND/COM   AGRIC
 75        FR              12      95      81      60      45      25      11       5     2.5
 76        FR       1      .5      .2      .1
 77        SP                   843.6   844.8   845.6   846.0   846.6   847.3   847.9   848.4
 78        SP   849.1   849.5   850.0   850.3
 79        SD               8   845.0   845.5   847.0   847.6   848.3   849.0   849.8   851.0
 80        DG             1 1       0     720    1380    2710    5200    8000   10050   11250
 81        DG             1 2       0    10.5    15.0    52.5   105.0   202.5     540     585
 82        DP       1   846.9
 83        ZZ
```

```
                  SCHEMATIC DIAGRAM OF STREAM NETWORK

       INPUT
        LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

         NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

          9         100
                     V
                     V
         17         200
                     V
                     V
         28        RCH1
                     .
                     .
         33          .         300
                     .           .
                     .           .
         41         300............
                     V
                     V
         52          .------->
         44        RCH2
```

```
                  EXAMPLE PROBLEM _ 12
                  FLOOD CONTROL SYSTEM OPTIMIZATION
                  ROCKBED WATERSHED

 5 IO        OUTPUT CONTROL VARIABLES
                  IPRNT          10  PRINT CONTROL
                  IPLOT           0  PLOT CONTROL
                  QSCAL          0.  HYDROGRAPH PLOT SCALE
                   DMSG         YES  PRINT DIAGNOSTIC MESSAGES

   IT        HYDROGRAPH TIME DATA
                   NMIN          60  MINUTES IN COMPUTATION INTERVAL
                  IDATE      1    0  STARTING DATE
                  ITIME        0000  STARTING TIME
                     NQ         130  NUMBER OF HYDROGRAPH ORDINATES
                 NDDATE      6    0  ENDING DATE
                 NDTIME        0900  ENDING TIME

             COMPUTATION INTERVAL    1.00 HOURS
                  TOTAL TIME BASE  129.00 HOURS

        ENGLISH UNITS
            DRAINAGE AREA          SQUARE MILES
            PRECIPITATION DEPTH    INCHES
            LENGTH, ELEVATION      FEET
            FLOW                   CUBIC FEET PER SECOND
            STORAGE VOLUME         ACRE-FEET
            SURFACE AREA           ACRES
            TEMPERATURE            DEGREES FAHRENHEIT

   JP         MULTI-PLAN OPTION
                  NPLAN            2  NUMBER OF PLANS

   JR         MULTI-RATIO OPTION
                RATIOS OF RUNOFF
              0.11      0.26      0.45      0.65      0.86      1.00      1.20      1.40      1.50
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIO 1 0.11	RATIO 2 0.26	RATIO 3 0.45	RATIO 4 0.65	RATIO 5 0.86	RATIO 6 1.00	RATIO 7 1.20	RATIO 8 1.40	RATIO 9 1.50
					RATIOS APPLIED TO FLOWS								
HYDROGRAPH AT	100	35.10	1	FLOW	591	1397	2418	3493	4622	5374	6449	7524	8061
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	591	1397	2418	3493	4622	5374	6449	7524	8061
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO	200	35.10	1	FLOW	591	1397	2418	3493.	4622	5374.	6449	7524	8061
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	367	617	866	1052	1206	1315	1467	1573	1627
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
			** PEAK STAGES IN FEET **										
			1	STAGE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0:00	0.00	0.00
			2	STAGE	978.51	984.95	994.55	1003.99	1012.91	1020.03	1030.80	1039.32	1043.67
				TIME	29.00	31.00	32.00	33.00	33.00	34.00	34.00	34.00	35.00
ROUTED TO	RCH1	35.10	1	FLOW	429.	978.	1742	2680.	3668.	4313.	5232.	6156.	6701.
				TIME	28.00	28.00	28.00	28.00	28.00	27.00	27.00	27.00	27.00
			2	FLOW	305.	551.	785.	980.	1135.	1239.	1389.	1504.	1557
				TIME	34.00	38.00	39.00	41.00	41.00	41.00	42.00	43.00	43.00
HYDROGRAPH AT	300	49.10	1	FLOW	790	1867.	3231.	4666.	6174.	7179.	8615.	10051.	10768
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	790	1867	3231.	4666.	6174.	7179.	8615	10051	10768
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2 COMBINED AT	300	84.20	1	FLOW	1162.	2688.	4687.	6892	9339.	10959.	13250.	15529.	16663
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	980.	2176	3649	5181	6777	7833.	9332	10825.	11571
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
PUMP FLOW TO		84.20	1	FLOW	0.	0	0.	0.	0.	0.	0	0.	0
				TIME	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			2	FLOW	0.	3000	3000	3000.	3000.	3000.	3000	3000	3000
				TIME	1.00	23.00	21.00	19.00	17.00	16.00	14.00	13.00	13.00
HYDROGRAPH AT	RCH2	84.20	1	FLOW	964.	1257	1273.	1291.	1312	1326.	1347.	1369.	1379
				TIME	28.00	33.00	37.00	39.00	40.00	41.00	43.00	45.00	46.00
			2	FLOW	802.	1127	1251.	1252	1260	1265	1274.	1284.	1290
				TIME	28.00	25.00	24.00	28.00	30.00	30.00	32.00	33.00	33.00
			** PEAK STAGES IN FEET **										
			1	STAGE	843.86	845.27	845.90	846.65	847.48	848.05	848.89	849.74	850.17
				TIME	28.00	33.00	37.00	39.00	40.00	42.00	43.00	45.00	46.00
			2	STAGE	843.21	844.51	845.02	845.09	845.41	845.62	845.97	846.36	846.60
				TIME	28.00	25.00	24.00	28.00	30.00	30.00	32.00	33.00	33.00

EXPECTED ANNUAL FLOOD DAMAGE SUMMARY

STREAM STATION	DAMAGE REACH	WATERSHED	TOWNSHIP	*	DAMAGE CATEGORY	EXPECTED ANNUAL DAMAGE PLAN 1	PLAN 2
RCH1	1			*	1 RESID	0.00	0.00
				*	2 IND/COM	0.00	0.00
				*	3 AGRIC	129.22	0.00
				*			
				*	TOTAL	129.22	0.00
			DAMAGE CHANGE (BENEFITS)			BASE	129.22
RCH2	2			*	1 RESID	1099.86	139.86
				*	2 IND/COM	20.21	1.98
				*	3 AGRIC	0.00	0.00
				*			
				*	TOTAL	1120.06	141.83
			DAMAGE CHANGE (BENEFITS)			BASE	978.23
BASIN TOTAL				*	1 RESID	1099.86	139.86
				*	2 IND/COM	20.21	1.98
				*	3 AGRIC	129.22	0.00
				*			
				*	TOTAL	1249.28	141.83
			DAMAGE CHANGE (BENEFITS)			BASE	1107.45

SUMMARY OF COMPONENT COSTS

PROJECT	LOCATION	CAPACITY	CAPITAL COST	AMORTIZED CAPITAL COST	ANNUAL O+M COST	ANNUAL POWER COST	TOTAL ANNUAL COST
RESERVOIR	200	15000.0	5475.000	275.940	125.925	0.000	401.865
PUMP	RCH2	8000.0	7860.000	396.144	180.780	100.000	676.924
LOCAL PROTECTION	RCH1	17000.0	1666.667	84.000	38.333	0.000	122.333

INITIAL ESTIMATES OF COMPONENT SIZE

VAR 1	VAR 2	VAR 3
15000.00	8000.00	17000.00

SYSTEM COST AND PERFORMANCE SUMMARY
(UNITS SAME AS INPUT - NORMALLY 1000"S OF DOLLARS)

TOTAL SYSTEM CAPITAL COST * * * * * * * * * * * * * * *	15002.	
TOTAL SYSTEM AMORTIZED CAPITAL COST * * * * * * * * * *	756.	
TOTAL SYSTEM ANNUAL O,M,POWER AND REPLACEMENT COST *	445.	
TOTAL SYSTEM ANNUAL COST * * * * * * * * * * * * * * *		1201.
AVERAGE ANNUAL DAMAGES -- EXISTING CONDITIONS * * * *	1249.	
AVERAGE ANNUAL DAMAGES -- OPTIMIZED SYSTEM * * * * *	142.	
AVERAGE ANNUAL DAMAGE REDUCTION (BENEFITS) * * * * *		1107.
AVERAGE ANNUAL SYSTEM NET BENEFITS * * * * * * * * * *		-94.

INTERMEDIATE VALUES OF OPTIMIZATION VARIABLES

```
OBJECTIVE
FUNCTION      VAR  1      VAR  2     VAR  3

             15000.000   8000.000  17000.000
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4964.224   1201.122    141.834   6.6681E+06

             14850.000*  8000.000  17000.000
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4964.24
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4964.237   1199.471    141.836   6.6599E+06

             14700.000*  8000.000  17000.000
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4964.25
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4964.250   1197.819    141.839   6.6517E+06

             10000.005*  8000.000  17000.000
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4960.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4960.000   1136.163    141.807   6.3400E+06
6340012.9    10000.005*  8000.000  17000.000
             10000.005   7920.000* 17000.000
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4960.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4960.000   1130.702    141.807   6.3129E+06

             10000.005   7840.000* 17000.000
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4960.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4960.000   1125.242    141.807   6.2858E+06

             10000.005   5333.336* 17000.000
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4960.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4960.000    954.376    141.807   5.4382E+06
5438166.8    10000.005   5333.336* 17000.000
             10000.005   5333.336  16830.000*
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4960.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4960.000    950.217    141.807   5.4175E+06

             10000.005   5333.336  16660.000*
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4960.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4960.000    946.058    141.807   5.3969E+06

             10000.005   5333.336  11333.339*
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.06     0.84  4960.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                  4960.000    871.371    141.807   5.0264E+06
5026377.1    10000.005   5333.336  11333.339*
########## SEVERAL PAGES DELETED ##########
    649.5     2886.911   2150.879+  4941.729
              2886.911   2150.879   4941.729
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.89     0.01     0.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                     0.000    413.676    235.797   6.4951E+02

              2858.042*  2150.879   4941.729
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.90     0.00     0.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                     0.000    412.404    236.412   6.4882E+02

              2829.173*  2150.879   4941.729
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.91    -0.01     0.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                     0.000    411.133    237.048   6.4821E+02

              2650.898*  2150.879   4941.729
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.96    -0.06     0.14
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                     0.142    403.282    241.953   7.3696E+02

              2816.107*  2150.879   4941.729
                                                 LOCATION    TARGET  COMP VAL  DEVIATN  PENALTY
                                                   RCH2      846.90    846.91    -0.01     0.00
                                                 TRGT PNLTY  ANN COST   ANN DAMG  OBJCT FNCTN
                                                     0.000    410.557    237.337   6.4804E+02
    648.0     2816.107*  2150.879   4941.729
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIO 1 0.11	RATIO 2 0.26	RATIO 3 0.45	RATIO 4 0.65	RATIO 5 0.86	RATIO 6 1.00	RATIO 7 1.20	RATIO 8 1.40	RATIO 9 1.50
					RATIOS APPLIED TO FLOWS								
HYDROGRAPH AT	100	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
ROUTED TO	200	35.10	1	FLOW	591.	1397.	2418.	3493.	4622.	5374.	6449.	7524.	8061.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	366.	617.	865.	1133.	2417.	3370.	4566.	5911.	6577.
				TIME	29.00	31.00	32.00	32.00	30.00	29.00	28.00	28.00	27.00
			** PEAK STAGES IN FEET **										
			1	STAGE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				TIME	28.00	33.00	37.00	39.00	40.00	42.00	43.00	45.00	46.00
			2	STAGE	978.47	984.93	994.51	1003.83	1008.62	1010.83	1013.59	1016.14	1017.26
				TIME	29.00	31.00	32.00	32.00	30.00	29.00	28.00	28.00	27.00
ROUTED TO	RCH1	35.10	1	FLOW	429.	978.	1742.	2680.	3668.	4313.	5232.	6156.	6701.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	307.	551.	787.	993.	1764.	2428.	3440.	4389.	4872.
				TIME	34.00	38.00	39.00	40.00	35.00	33.00	32.00	31.00	31.00
HYDROGRAPH AT	300	49.10	1	FLOW	790.	1867.	3231.	4666.	6174.	7179.	8615.	10051.	10768.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	790.	1867.	3231.	4666.	6174.	7179.	8615.	10051.	10768.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
2 COMBINED AT	300	84.20	1	FLOW	1162.	2688.	4687.	6892.	9339.	10959.	13250.	15529.	16663.
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	982.	2176.	3649.	5182.	6777.	7845.	9476.	11279.	12345.
				TIME	25.00	25.00	25.00	25.00	25.00	25.00	25.00	26.00	27.00
ROUTED TO	RCH2	84.20	1	FLOW	964.	1257.	1273.	1291.	1312.	1326.	1347.	1369.	1379.
				TIME	25.00	25.00	25.00	26.00	25.00	25.00	25.00	25.00	25.00
			2	FLOW	804.	1070.	1250.	1256.	1266.	1276.	1294.	1312.	1322.
				TIME	28.00	26.00	26.00	29.00	33.00	35.00	37.00	38.00	39.00
			** PEAK STAGES IN FEET **										
			1	STAGE	843.86	845.27	845.90	846.65	847.48	848.05	848.89	849.74	850.17
				TIME	28.00	33.00	37.00	39.00	40.00	42.00	43.00	45.00	46.00
			2	STAGE	843.21	844.28	845.00	845.24	845.66	846.06	846.75	847.47	847.87
				TIME	28.00	26.00	26.00	29.00	33.00	35.00	37.00	38.00	39.00

```
          **************
          *            *
56 KK     *    RCH1    *
          *            *
          **************
```

FR	PERCENT EXCEEDANCE			700.0	600.0	550.0	450.0	350.0	250.0	150.0	90.0
		70.0	50.0	35.0	25.0	16.5	10.0	5.0	2.0	0.5	0.1
QF	PEAK FLOW			400.	490.	530.	640.	800.	1070.	1480.	1690.
		1920.	2170.	2480.	2850.	3240.	3640.	4090.	4900.	5900.	7100.

DAMAGE DATA

FLOW	RESID	IND/COM	AGRIC	TOTAL
400.0	0.000	0.000	0.000	0.000
600.0	0.000	0.000	1.000	1.000
730.0	0.000	0.000	2.000	2.000
960.0	0.000	0.000	3.000	3.000
1230.0	0.000	0.000	5.000	5.000
1530.0	0.000	0.000	7.000	7.000
1970.0	0.000	0.000	28.000	28.000
2500.0	0.000	0.000	49.000	49.000
3100.0	0.000	0.000	111.000	111.000
3490.0	0.000	0.000	314.000	314.000
3780.0	0.000	0.000	516.000	516.000
4290.0	0.000	0.000	619.000	619.000
5120.0	0.000	0.000	723.000	723.000
6020.0	0.000	0.000	728.000	728.000
7100.0	0.000	0.000	830.000	830.000

++DAMAGE DATA FOR PLAN 1 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	668.87	429.	0.00	0.00	0.00	0.15	0.15
2	279.57	978.	0.00	0.00	0.00	3.14	3.14
3	85.07	1742.	0.00	0.00	0.00	17.11	17.11
4	29.26	2680.	0.00	0.00	0.00	67.65	67.65
5	9.60	3668.	0.00	0.00	0.00	438.01	438.01
6	3.77	4313.	0.00	0.00	0.00	621.86	621.86
7	1.38	5232.	0.00	0.00	0.00	723.62	723.62
8	0.33	6156.	0.00	0.00	0.00	740.82	740.82
9	0.11	6701.	0.00	0.00	0.00	792.28	792.28
EXP ANNUAL DAMAGE				0.00	0.00	129.22	129.22

++DAMAGE DATA FOR PLAN 2 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	668.87	307.	0.00	0.00	0.00	0.00	0.00
2	279.57	551.	0.00	0.00	0.00	0.00	0.00
3	85.07	787.	0.00	0.00	0.00	0.00	0.00
4	29.26	993.	0.00	0.00	0.00	0.00	0.00
5	9.60	1764.	0.00	0.00	0.00	0.00	0.00
6	3.77	2428.	0.00	0.00	0.00	0.00	0.00
7	1.38	3440.	0.00	0.00	0.00	0.00	0.00
8	0.33	4389.	0.00	0.00	0.00	0.00	0.00
9	0.11	4872.	0.00	0.00	0.00	0.00	0.00
EXP ANNUAL DAMAGE				0.00	0.00	0.00	0.00
AVERAGE ANNUAL BENEFITS				0.00	0.00	129.22	129.22

```
              **************
              *            *
  73 KK       *     RCH2   *
              *            *
              **************
```

FR	PERCENT EXCEEDANCE	95.0	81.0	60.0	45.0	25.0	11.0	5.0	2.5			
		1.0	0.5	0.2	0.1							
SP	PEAK STAGE	843.6	844.8	845.6	846.0	846.6	847.3	847.9	848.4			
		849.1	849.5	850.0	850.3							

DAMAGE DATA

STAGE	RESID	IND/COM	AGRIC	TOTAL
845.0	0.000	0.000	0.000	0.000
845.5	720.000	10.500	0.000	730.500
847.0	1380.000	15.000	0.000	1395.000
847.6	2710.000	52.500	0.000	2762.500
848.3	5200.000	105.000	0.000	5305.000
849.0	8000.000	202.500	0.000	8202.500
849.8	10050.000	540.000	0.000	10590.000
851.0	11250.000	585.000	0.000	11835.000

++DAMAGE DATA FOR PLAN 1 -- ++

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	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	93.53	0.	843.86	0.00	0.00	0.00	0.00
2	70.19	0.	845.27	387.69	5.65	0.00	393.34
3	48.51	0.	845.90	898.05	11.71	0.00	909.77
4	23.48	0.	846.65	1227.45	13.96	0.00	1241.41
5	8.77	0.	847.48	2451.80	45.22	0.00	2497.02
6	4.06	0.	848.05	4327.31	86.60	0.00	4413.91
7	1.36	0.	848.89	7559.55	187.16	0.00	7746.71
8	0.33	0.	849.74	9899.25	515.18	0.00	10414.43
9	0.13	0.	850.17	10422.49	553.97	0.00	10976.45
EXP ANNUAL DAMAGE				1099.86	20.21	0.00	1120.06

++DAMAGE DATA FOR PLAN 2 -- ++

	FREQ	FLOW	STAGE	RESID	IND/COM	AGRIC	TOTAL
1	93.53	0.	843.21	0.00	0.00	0.00	0.00
2	70.19	0.	844.28	0.00	0.00	0.00	0.00
3	48.51	0.	845.00	6.75	0.10	0.00	6.85
4	23.48	0.	845.24	340.86	4.97	0.00	345.84
5	8.77	0.	845.66	789.61	10.97	0.00	800.58
6	4.06	0.	846.06	965.48	12.17	0.00	977.66
7	1.36	0.	846.75	1269.03	14.24	0.00	1283.28
8	0.33	0.	847.47	2423.43	44.42	0.00	2467.85
9	0.13	0.	847.87	3663.36	72.60	0.00	3735.96
EXP ANNUAL DAMAGE				234.03	3.31	0.00	237.34
AVERAGE ANNUAL BENEFITS				865.83	16.90	0.00	882.73

EXPECTED ANNUAL FLOOD DAMAGE SUMMARY

STREAM STATION	DAMAGE REACH	WATERSHED	TOWNSHIP	*	DAMAGE CATEGORY	EXPECTED ANNUAL DAMAGE PLAN 1	PLAN 2
RCH1	1			*	1 RESID	0.00	0.00
				*	2 IND/COM	0.00	0.00
				*	3 AGRIC	129.22	0.00
				*			
				*	TOTAL	129.22	0.00
			DAMAGE CHANGE (BENEFITS)			BASE	129.22
RCH2	2			*	1 RESID	1099.86	234.03
				*	2 IND/COM	20.21	3.31
				*	3 AGRIC	0.00	0.00
				*			
				*	TOTAL	1120.06	237.34
			DAMAGE CHANGE (BENEFITS)			BASE	882.73
BASIN TOTAL				*	1 RESID	1099.86	234.03
				*	2 IND/COM	20.21	3.31
				*	3 AGRIC	129.22	0.00
				*			
				*	TOTAL	1249.28	237.34
			DAMAGE CHANGE (BENEFITS)			BASE	1011.95

SUMMARY OF COMPONENT COSTS

PROJECT	LOCATION	CAPACITY	CAPITAL COST	AMORTIZED CAPITAL COST	ANNUAL O+M COST	ANNUAL POWER COST	TOTAL ANNUAL COST
RESERVOIR	200	2816.1	1689.664	85.159	38.862	0.000	124.021
PUMP	RCH2	2150.9	2439.563	122.954	56.110	100.000	279.064
LOCAL PROTECTION	RCH1	4941.7	101.800	5.131	2.341	0.000	7.472

OPTIMIZATION RESULTS

VAR 1	VAR 2	VAR 3
2816.11	2150.88	4941.73

SYSTEM COST AND PERFORMANCE SUMMARY
(UNITS SAME AS INPUT - NORMALLY 1000'S OF DOLLARS)

TOTAL SYSTEM CAPITAL COST * * * * * * * * * * * * * * *	4231.	
TOTAL SYSTEM AMORTIZED CAPITAL COST * * * * * * * * * *	213.	
TOTAL SYSTEM ANNUAL O,M,POWER AND REPLACEMENT COST *	197.	
TOTAL SYSTEM ANNUAL COST * * * * * * * * * * * * * * *		411.
AVERAGE ANNUAL DAMAGES -- EXISTING CONDITIONS * * * *	1249.	
AVERAGE ANNUAL DAMAGES -- OPTIMIZED SYSTEM * * * * *	237.	
AVERAGE ANNUAL DAMAGE REDUCTION (BENEFITS) * * * * *		1012.
AVERAGE ANNUAL SYSTEM NET BENEFITS * * * * * * * * * *		601.

***** OPTIMIZATION OBJECTIVE - MAXIMIZE SYSTEM NET BENEFITS FOR TARGET PROTECTION LEVEL *****

*** NORMAL END OF HEC-1 ***

Note: The results of this test are dependent on the machine word size. Results are likely to be within five percent of the answer shown above.

Section 13

COMPUTER REQUIREMENTS

13.1 Program Operations and File Structure

Figure 13.1 shows the sequence of operations for most jobs. HEC-1 uses up to 16 I/O and scratch files. These can be stored on disk, tape, or whatever medium is available. The program knows these files by their assigned unit numbers. Table 13.1 shows the unit numbers used by HEC. These numbers can be changed for a particular installation by changing their definition in BLOCK DATA. All files are sequential.

13.2 Compile & Execution Requirements

HEC-1 requires a FORTRAN IV compiler. The distributed version of HEC-1 uses "END =" in READ statements to check for end-of-file. This may need to be changed for some compilers.

Table 13.2 lists compile time and memory required for execution. Also, execution times are given for the example problems described in Section 12 of this manual.

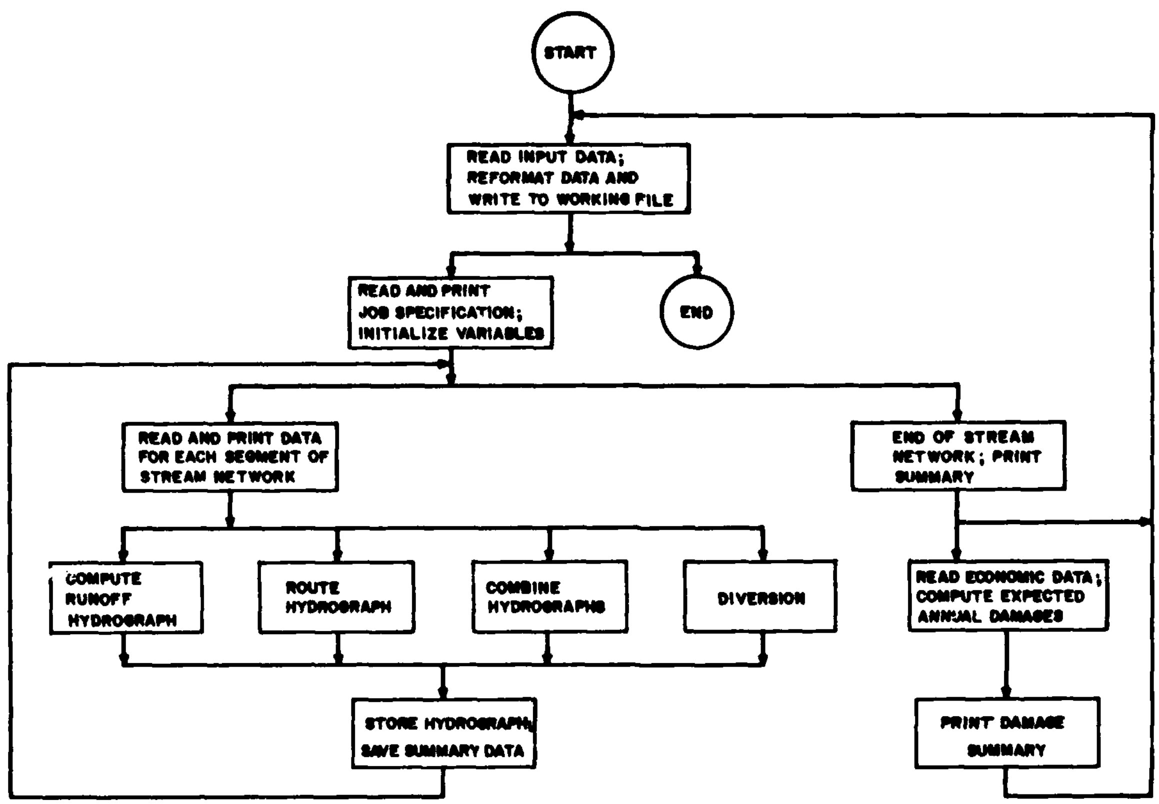

Figure 13.1 HEC-1 Program Operations Overview

TABLE 13.1

I/O and Scratch Files

Unit Number	Variable Name	Description	Formatted, F Unformatted, U	Max Record Length
5	INP	Primary input	F	80 characters
6	IP	Primary output file (printer)	F	132 characters
7	IPU	Punch	F	80 characters
23	IC	Working input file; reformatted input data with line number and next record ID appended to front of each record	F	89 characters
24	IS*	Dam-overtopping summary report	F	132 characters
25	IU*	Runoff parameter optimization	F	132 characters
32	IDIV	Scratch, saves diversion hydrographs	U	4895 real + 3 integer words
33	IE	Scratch; expected annual damage summary data	U	50 real + 6 integer words
34	IR	Scratch; data for first plan in multiplan run	U	61 real words
35	ISOP	Scratch; data for flood control system optimization	U	2400 real words
36	LSFIL	Scratch; data for user-defined output tables	U	301 real words
38	ND	Scratch; output summary data	U	91 real + 4 integer words
**	IOUT	Output data; used to save hydrographs for a subsequent job	F	131 characters
**	IQIN	Input data; hydrographs from a previous job	F	131 characters

* File is copied to primary output file (IP) by subroutine PRT

** Unit number is defined by user on KO or BI records (The unit numbers specified should not conflict with other file definitions, for example, 21 and 22 are possible choices).

Table 13.2

Computer Memory and Time Requirements

	IBM PC XT (with 8087)	CDC Cyber 175	Harris 500
Central Memory Required **	512 k bytes	337 k words	525 k bytes
Compile time*		40	570
Execution time* for Example Problems of Section 12			
1. Stream Network Model	160	.7	27
2. Kinematic Wave Watershed Model	110	.5	19
3. Snowmelt Runoff	80	.3	14
4. Unit Graph and Loss Rate Optimization	130	.7	19
5. Routing Optimization	50	.1	7
6. Precipitation Depth-Area	100	.5	13
7. Dam Safety Analysis	130	1.0	12
8. Dam Failure Analysis	300	2.8	38
9. Multiflood Analysis	70	.3	13
10. Multiplan, Multiflood Analysis	190	1.6	30
11. Flood Damage Analysis	***	1.7	30
12. Flood Control System Optimization	***	34.6	317

*central processing unit (cpu) seconds

**same dimensions, as noted in programmers manual, were used on all computers shown here, except for the PC version which does not include the flood damage computation routines.

***PC version does not contain flood damage computation capability.

Section 14

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Appendix A

HEC-1 INPUT DESCRIPTION

Preface

This appendix contains a description of the input data for the HEC-1 computer program. It is only applicable to the 1981 version of the program. Do not use this input format for any previous version (e.g. Dam Break) of the program.

Please contact the HEC if errors in documentation or the computer program are encountered. The HEC also encourages comments regarding improvements to the program or documentation.

The yellow pages, A-1 through A-20, describe the general structure of the input data, and data requirements and options for JOB DESCRIPTION and JOB INITIALIZATION.

The blue pages, A-21 through A-92, describe the input data requirements and options for HYDROGRAPH CALCULATIONS throughout a river basin. Record types are arranged in alphabetical order.

The yellow pages, A-93 through A-111, describe the input data requirements and options for ECONOMIC ANALYSES of flood damage, the required END-OF-JOB record, and a SUMMARY of all input data records and variables.

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1 INTRODUCTION

1.1 ORGANIZATION OF THIS INPUT DESCRIPTION

This input description is organized into three major types of data: 1) job description and initialization data, 2) hydrograph calculation data, and 3) economic analysis data. This corresponds to the general sequence of data necessary to build the digital model of a river basin as described in the next subsection on Input Data Structure.

The first group (pages A-8 through A-20), JOB DESCRIPTION AND INITIALIZATION DATA, begins with the I records and goes through the V records. The ID and IT records are required and are described first. The other records are optional and are described in a recommended input sequence, i.e., I, J, O, V records as desired.

The second group (pages A-21 through A-92), HYDROGRAPH CALCULATION DATA, comprises all of the data necessary to simulate the various river basin processes. The input data in this group are organized ALPHABETICALLY, beginning with the B records and ending with the W records. The required and recommended order to input these data are described in the next subsection, Input Data Structure.

The third group (pages A-93 through A-106), ECONOMIC ANALYSIS DATA, consists of data to be supplied after all of the hydrologic and hydraulic calculations are completed. These data are optional and begin with the EC record and are organized in the recommended sequence of input.

The last record described is the REQUIRED ZZ RECORD, page A-107, to end the job.

1.2 INPUT DATA STRUCTURE

The input data set is divided into three sections - job description and initialization data, hydrograph calculation data, and economic analysis data.

The first section begins with an ID record. This section contains an alphanumeric description of the job, sets the job type, output control, time interval and time span, and the type of units to be used.

Section two contains data for calculating hydrographs. Each hydrograph calculation begins with a KK record, and the records following the KK record provide information on how the hydrograph is to be calculated.

The third section begins with an EC record. All data following the EC record are for calculation of expected annual damages.

Finally the job is terminated by a ZZ record. Data for a new job beginning with an ID record may follow immediately after the ZZ record.

The record sequence for a typical job is shown on the next page. A dash, -, is used to indicate the second character of a record identification which will be selected at the option of the user.

Continued

HEC-1 INPUT DESCRIPTION
INPUT DATA STRUCTURE

	ID	Job identification	
	IT	Time specification	
	I-*	Additional initialization data	
	J-*	Job type	
	O-*	Optimization	
	VV*,VS*	Variable output summary tables	
(	KK	Hydrograph computation identification	)
(			)
(		KK-record groups describing RUNOFF,	)
(	.	ROUTING, COMBINING, etc., components	)
(	.	are repeated as necessary to simulate	)
(	.	the processes and connectivity of a	)
(	.	river basin. See following pages.	)
	EC*	Economic data identification	
	.	(See section on economic data)	
	ZZ	End-of-job record	

*Optional records

Continued

Data input for RUNOFF calculations will be retained and used for subsequent runoff calculations until new data are read. Thus the data used in calculating runoff need only be read once, unless they are to be changed for a new basin. A typical record sequence for computing subbasin rainfall-runoff is:

```
(    KK           Hydrograph computation identification   )
(                                                         )
(    BA           Basin area                              )
(                                                         )
(    BF*          Base flow data                          )
(                                                         )
(    P-           Precipitation data                      )
(                                                         )
(    L-           Loss data                               )
(                                                         )
(    U-           Unit graph or kinematic wave data       )

(    KK           Hydrograph computation identification   )
(                                                         )
(    BA                                                   )
(                                                         )
(    BF*               If BF, P-, L-, U-records           )
(                                                         )
(    P-*               do not appear, data from           )
(                                                         )
(    L-*               previous calculation will          )
(                                                         )
(    U-*               be used.                           )

(    KK           Etc.                                    )
(                                                         )
```

*Optional records

Continued

For hydrograph ROUTING the record sequence is:

(	KK	Hydrograph computation identification	)
(			)
(	R-	Routing option	)
(			)
(	S-*	Reservoir data or dam-break analysis	)

For DIVERSIONS the record sequence is:

(	KK	Hydrograph computation identification	)
(			)
(	DT	Diversion identification	)
(			)
(	DI	Inflow to diversion point	)
(			)
(	DQ	Diverted flow	)
(	KK	Etc., for other parts of stream	)
(		network	)
.			
.			
.			
(	KK	Hydrograph computation identification	)
(			)
(	DR	Retrieve diversion hydrograph	)
(	KK	Etc., for routing/combining of return	)
(		flow	)
.			
.			
.			

*Optional records

Continued

INPUT DATA STRUCTURE

Each input record is described in detail on the following pages. Variable locations on each record are shown by field numbers which indicate the relative position of the data on the record.

When data are entered in FIXED FORMAT the record is divided into ten fields of eight columns each, except field one. Variables occurring in field one may only occupy columns 3-8 because columns 1 and 2 are reserved for the record identification characters. Integer and alphanumeric values must be right justified in their fields.

Data may also be entered in FREE FORMAT where fields are separated by a comma or one or more spaces. Successive commas are used to indicate blank fields. When entering time series data (flow, precipitation, etc.), more (or less) than 10 values can be placed on a record.

1.3 INPUT CONTROL RECORDS

The following records may be used to control the format and printing of the input data. An input comment record is also described which may be inserted anywhere in the input data stream.

RECORD IDENTIFICATION	DESCRIPTION OF INPUT CONTROL
*LIST	Causes echo print of input data following this record until a *NOLIST record is encountered. *LIST is the default assumption.
*NOLIST	Stops echo print listing of input data until a *LIST record is encountered.
*FREE	Indicates a free format will be used for the input following this record and before a *FIX record is encountered. Fields may be separated by a comma or by one or more spaces. Successive commas would indicate blank fields. When entering time-series data (flow, precipitation, etc.), more (or less) than 10 values may be placed on a record. Default is fixed format.
*FIX	Indicates a standard HEC fixed format (10 8-column fields) will be used for the data following this record and before a *FREE record is encountered. Default is fixed format.
*	This is a COMMENT record that is printed only with the input echo listing. The comment occupies columns 3 through 80. Any number of comment records may be inserted at any point in the input data stream.
*DIAGRAM	Causes a diagram of the stream network to be printed. In multiple job runs this option is reset so a diagram is generated only for those jobs which contain this record.

NOTE - The asterisk (*) must be in column 1 and followed by the remainder of the identification. If column 2 is blank, it is assumed to be a COMMENT record.

2 JOB INITIALIZATION (I Records)

The ID and IT records are required to begin the job. The other records (IM AND IO) are only used if those options are desired.

2.1 ** ID RECORD - JOB TITLE INFORMATION

At least one ID record is required but any number may be used as desired to title the output from this job. The title information is contained in columns 3-80 inclusive and any characters or symbols may be used.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	ID	Record identification.
1-10	ITLS	AN	Job title information.

**REQUIRED

HEC-1 INPUT DESCRIPTION
JOB INITIALIZATION (I Records)

2.2 ** IT RECORD - TIME SPECIFICATION

The IT record is used to define time interval, starting date and time, and length of hydrographs calculated by the program.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	IT	Record identification.
1	NMIN	+	Integer number of minutes in tabulation interval. Minimum value is one minute.
2	IDATE*	+	Day, month, and year of the beginning of the first time interval (e.g., 17MAR78 is input for March 17,1978). Required to specify pathname part D when using DSS.
3	ITIME*	+	Integer number for hour and minute of the beginning of the first time interval (e.g., 1645 is input for 4:45 pm).
4	NQ	+	Integer number of hydrograph ordinates to be computed (300 max). If end date and time are specified in Fields 5 and 6, NQ will be computed from the beginning and end dates and times.
5	NDDATE	+	Day, month, and year of last ordinate (used to compute NQ).
6	NDTIME	+	Integer number for time of last ordinate (used to compute NQ).

*CAUTION: IDATE and ITIME are the time of initial flow conditions. No runoff calculations are made from precipitation preceding this time.

Use 3-character code for month: JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG, SEP, OCT, NOV, DEC. Use of any other code for month means this is not a date, and days will be numbered consecutively from the given day. Default is day = 1.

**REQUIRED

2.3 IN RECORD - TIME INTERVAL FOR INPUT DATA

The IN record is used to define time interval and starting time for time series data which are read into the program on PC, PI, QO, QI, QS, MD, MS, MT and MW records.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	IN	Record identification.
1	JXMIN	+	Integer number of minutes in tabulation interval.
2	JXDATE	+	Day, month, year at beginning of the first time interval (e.g., March 17, 1978 is input as 17MAR78).
3	JXTIME	+	Hour and minute at the beginning of the first time interval (e.g., 4:45 pm is input as 1645).

If an IN record is not used the time interval and starting time for all time series will be the values specified on the IT record.

IN records may appear anywhere (exception: not after JD and before PI) in the input stream. The same time interval and starting time will be used for all time series data until these values are reset by reading new values on an IN record.

When time series data are read from PC, PI, QO, QS, QP, MD, MS, MT, or MW records, values to be used by the program are computed using linear interpolation to match the tabulation interval specified on the IT record.

For times preceeding or following the given ordinates, the first or last value is repeated as necessary to define NQ (IT-4) ordinates.

Data on PC, QI, QO, QP and QS records are <u>instantaneous</u> values. The first value will occur at JXDATE and JXTIME.

Data on PI, MD, MS, MT and MW records are <u>cumulative</u> or average values over a time interval. The first value on these records is for the time interval beginning at JXDATE, JXTIME and ending at JXTIME + JXMIN.

2.4 IO RECORD - OUTPUT CONTROL

The IO record is used to control output for the entire job. The KO record may be used to change output control for each hydrograph calculation.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	IO	Record identification.
1	IPRT	0,1,2	Print all output.
		3	Print input data and intermediate and master summaries.
		4	Print input data and master summary.
		5	Print job specification and master summary only.
2	IPLT	0,1	No printer plots for entire job unless overridden temporarily by a KO record for any station operation.
		2	Plot every computed hydrograph for entire job unless overridden by a KO record for that station.
3	QSCAL	0 or, Blank	Program will choose scale for streamflow plots.
		+	Desired scale for streamflow plots in units per 10 printer characters (e.g., 100 for 100 cfs per 10 characters).

2.5 IM RECORD - METRIC UNITS

This record is required if input is in metric units. Include one record with IM beginning in column 1. No other fields on the record are presently used.

3 JOB TYPE OPTION (J - Records)

J records are required only if one of the following special jobs is desired.

3.1 JP RECORD - MULTIPLAN

Required only if more than one plan is being analyzed.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	JP	Record identification.
1	NPLAN*	+	Number of plans desired.

NOTE - The product NPLAN*NRATIO (NRATIO is the number of ratios as defined on JR record) can not exceed 45. The product NPLAN*NRATIO*NQ (NQ defined on IT record) cannot exceed 4800. These limits may be changed if the dimensions are changed as noted in the HEC-1 Programmers Manual.

* Must be greater than or equal 2 for economic analysis

3.2 JR RECORD - MULTIRATIO

Required only if multiple ratios are desired for each plan.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	JR	Record identification.
1	IRTIO	PREC	Indicates ratios are to be taken of precipitation (default).
		FLOW	Indicates ratios are to be taken of runoff.
2	RTIO(1)	+	Ratio by which all hydrograph or precipitation ordinates of each subarea are to be multiplied for all plans.
3	RTIO(2)	+	Same as above for up to 9 ratios as desired. Ratios must be in ascending order for use in economic calculations.

3.3 JD RECORD - DEPTH/AREA STORM

Required only if stream system is to be simulated using a consistent depth/area relationship. Each JD record may be followed by a set of PC or PI records giving the precipitation pattern to be used for that depth and area. If no pattern is given following any of the second through ninth JD records, the previous pattern will be used. A maximum of 9 depth-area storms (max of 9 JD records) may be used.

Precipitation patterns may be generated using the hypothetical storm option. The convention for specifying hypothetical storms with a JD, PH record combination is somewhat different than for gage rainfall (i.e. with PI or PC records). In this case only a single PH record following the first JD record is required for all depth area storms. The variable PNHR(I) on the PH record (see pg A-51) specifies the depth duration data for point rainfall. This point rainfall may be adjusted for a partial to annual series correction (variable PFREQ on the PH record) and for a point to areal rainfall correction (see pg 13 in this manual). The areal correction is made by using the value TRDA on the JD record in place of the variable TRSDA on the PH record. Consequently, a different storm is obtained by applying the areal correction for the area specified on the JD records to the point precipitation. The total storm depth is obtained from the adjusted rainfall on the PH record and need not be specified as STRM on the JD record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	JD	Record identification.
1	STRM	+	Average precipitation in inches (mm). Not required with hypothetical storm.
2	TRDA	+	Area in square miles (sq km).

4 OPTIMIZATION OPTION (O Records)

* 4.1 OU RECORD - UNIT GRAPH AND LOSS RATE OPTIMIZATION

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	OU	Record identification.
1	IFORD	0,1 or Blank	Begin optimization at first simulated value.
		+I	Begin optimization at Ith simulated value.
2	ILORD	0, or Blank	End optimization at last simulated value.
		+I	End optimization at Ith simulated value.

* ZZ record at the end of each optimization required if summary of multiple optimizations are desired.

4.2 OR RECORD - ROUTING OPTIMIZATION

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	OR	Record identification.
1	IFORD	0,1 or Blank	Begin optimization at first simulated value.
		+I	Begin optimization at Ith simulated value.
2	ILORD	0, or Blank	End optimization at last simulated value.
		+I	End optimization at Ith simulated value.

4.3 OS RECORD - FLOOD CONTROL SYSTEM OPTIMIZATION

When HEC-1 is used to determine optimal sizes of flood control system components, initial estimates for sizes of the components are entered on the OS record. The following records are used later in the input set to refer to variables initialized on the OS record -

DO	Diversion
SO	Reservoir
WO	Pump
LO	Local protection projects and uniform degree of protection

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	OS	Record identification.
1	VAR(1)	+	Size of flood control system component. Reservoir volume in acre-ft (1000 cu m), diversion, and pump in cfs (cu m/sec), local protection in cfs (cu m/sec) or feet (meters), uniform degree of protection in percent. Size will not be optimized.
		0	Zero capacity indicates component will be ignored during simulation.
		-	Initial estimates of component; size will be optimized.
2-10	VAR(I)	+,-	Similar to Field 1. Up to 10 values.

HEC-1 INPUT DESCRIPTION
OPTIMIZATION OPTION (O Records)

4.4 OF RECORD - FIXED FACILITY COSTS

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	OF	Record identification.
1	FCAP	+	Capital cost of system facilities other than those to be optimized (fixed facilities). Same dollar units as system components.
2	FDCNT	+	Equivalent annual cost of FCAP. Same dollar units as system components.
		+.0000	Discount factor (capital recover factor) to compute equivalent annual cost from capital cost. (Example .05)
3	FAN	+	Equivalent annual cost of operation, maintenance power and replacement of FCAP system facilities.
		+.0000	Proportion of capital cost that will be required for annual operation, maintenance, power and replacement.

4.5 OO RECORD - SYSTEM OPTIMIZATION OBJECTIVE FUNCTION

Used to modify objective function.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	OO	Record identification.
1	ANORM	0	Default value of 0.1 will be used.
		+	Proportion of target flow for normalized objective function. May wish to reduce if target flow deviation is excessive. Do not reduce to below .02.
2	CNST	0	Default value of 1.0 will be used.
		+	Relative weight between net benefits and performance target deviation in objective function.

5 USER-DEFINED OUTPUT TABLES (V Records)

VS and VV records define tables which may be used to display selected time series output. Each table may contain up to 10 columns of data as defined on one pair of VS/VV records. Up to 5 tables may be output by using 5 successive pairs of VS/VV records.

5.1 VS RECORD - STATIONS DESIRED

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	VS	Record identification.
1	ISTA(1)	AN	Station identification corresponding to ISTAQ on KK record where special output summary is desired. Variable to be printed is described by SMVAR(1) on the VV record.
2	ISTA(2)	AN	Same as above for up to 10 stations; same station must be repeated in order to print several time series for the same station.

5.2 VV RECORD - INFORMATION DESIRED

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	VV	Record identification.
1	SMVAR(1)	+	Numeric code describing the first column of output, identified as V.PR where V is the variable to be printed in the table, P is the plan number, and R is the ratio number (corresponding to ISTA(1) on a VS record). Values of V correspond to: 1. Observed flow 2. Calculated flow 3. Rainfall values 4. Rainfall loss values 5. Rainfall excess value 6. Storage values 7. Stage values
2	SMVAR(2)	+	Same as above corresponding to ISTA(2). Up to 10 values.

6 BASIN RUNOFF DATA (B - Records)

These records are required for direct input of a hydrograph or for computing runoff from precipitation on a basin/subbasin.

6.1 BA RECORD - SUBBASIN AREA

Required for subbasin runoff computation or direct input of a hydrograph on QI records. If QI records are used, they should follow the BA record and an IN record if necessary. The next hydrograph computation specification record (KK) should follow the last QI record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	BA	Record identification.
1	TAREA	+	Drainage area in square miles (sq km).
2	SNAP	+	Normal annual precipitation for the drainage area above. Will be overridden by computed normal annual for snowmelt zone, if used.
		0 or Blank	Weighting by basin normal annual precipitation will not be performed.
3	RATIO	+	Multiply each hydrograph ordinate by this value.

6.2 BF RECORD - BASE FLOW CHARACTERISTICS

Base flow parameters (STRTQ, QRCSN, and RTIOR) will be assumed equal to zero unless this record is supplied. Once this record is supplied, all following subbasins will be assumed to have these values unless overriden by another BF record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	BF	Record identification.
1	STRTQ	+	Flow at start of storm in cfs (cu m/s). Will be receded in same manner as QRCSN below.
		-	When negative, this is cfs/sq mi (cu m/s/sq km) which will be multiplied by subbasin area, TAREA, to determine STRTQ.
2	QRCSN	+	Flow in cfs (cu m/s) below which base flow recession occurs in accordance with the recession constant RTIOR. QRCSN is that flow where the straight line (in semilog paper) recession deviates from the falling limb of the hydrograph.
		-	When negative, it is the ratio by which the peak discharge is multiplied to compute QRCSN.
3	RTIOR	+	Ratio of recession flow, QRCSN to that flow occurring one hour later. Must be greater than or equal to 1.

NOTE - The definition of RTIOR has been changed from the old version of HEC-1. The old value is QA/QB in the following equation:

New RTIOR = (QA/QB)**(1/DT)

Where QB is a recession flow occurring DT hours after recession flow QA.

6.3 BR RECORD - SAM RUNOFF PARAMETERS

This record is inserted in place of BF, U and L records to specify that these data will be read from the SAM, Spatial Data Management System.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	BR	Record identification.
1	ISTA	AN	Station name which identifies data to be read from station file. (Default is ISTAQ on KK record.)

6.4 BI RECORD - READ HYDROGRAPH FROM A FILE

A BI record is used to identify a hydrograph on a file created earlier by HEC-1. The hydrograph is read from this file and converted to the time interval and starting time for the current job.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	BI	Record identification.
1	ISTA	AN	Station name for hydrograph to be read from file on unit IQIN (default is ISTAQ on KK record).
2	IQIN	+	Unit number for file which contains hydrographs to be read. Unit 21 or 22 may be used.

7 DIVERSION DATA (D Records)

Streamflow may be diverted or retrieved at any stream station operation (KK record series).

7.1 DR RECORD - RETRIEVE PREVIOUSLY DIVERTED FLOW

The DR record is used to retrieve a hydrograph which was created by a previous diversion. This hydrograph can then be treated like any other hydrograph in the system. Retrieval of a diversion hydrograph is a separate operation, so the DR record must be preceded by a KK record which identifies the hydrograph which has been retrieved.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DR	Record identification.
1	ISTAD	AN	Station name corresponding to the name given a previously diverted flow with a DT record.

7.2 DT/DI/DQ RECORDS - FLOW DIVERSION

Flow diversion is considered to be a separate operation, so the D records must be preceded by a KK record which identifies the hydrograph which remains after diversion. Diversions are specified as a function of main channel flow on the DI/DQ records.

For multiplan simluations (JP record), diverison data (DI and DQ records) must be supplied for all plans. If no water is be diverted for a particular plan, then the DQ record would contain only zeroes. Diversicn hydrographs are saved for all plans using the name in Field 1 of the DT record.

7.2.1 DT RECORD - DIVERSION IDENTIFIER

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DT	Record identification.
1	ISTAD	AN	Name to be assigned to the diverted flow for future retrieval purposes with DR record.
2	DSTRMX	+	Maximum volume of diverted flow in acre-feet (1000 cu m) (not used if zero or blank).
3	DVRSMX	+	Peak flow (cfs) that can be diverted in any computation period. (default: 1×10^{10})

7.2.2 DI RECORD - DIVERSION INFLOW TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DI	Record identification.
1	DINFLO(1)	+	Inflow (cfs, cu m/s) to the diversion station, corresponding to DIVFLO(1) (DQ record), the flow to be diverted.
2-10	DINFLO(I)		Etc., up to 20 values (2 records) corresponding to the amount of flow to be diverted on the DQ records.

7.2.3 DQ RECORD - DIVERSION OUTFLOW TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DQ	Record identification.
1	DIVFLO(1)	+	Rate of flow (cfs,cu m/s) to be diverted, corresponding to the main channel flow rate (before diversion) on DINFLO, DI records.
2-10	DIVFLO(I)	+	Etc., up to 20 values (2 records) corresponding to values on DI records.

HEC-1 INPUT DESCRIPTION
DIVERSION DATA (D Records)

7.3 DO RECORD - DIVERSION OPTIMIZATION

Data required for optimization of diversion capacity are:

Diversion Identification	DT record
Diverted Flow vs. Inflow	DI, DQ records
Cost vs. Capacity	DC, DD records
Cost Factors, Range	DO record

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DO	Record identification.
1	IOPTD	+	Number of field on OS record which contains capacity of diversion. (overrides DSTRMX on DT record).
		0, or Blank	Diversion capacity is not optimized.
2	DANCST	+	Proportion of capital cost of diversion that will be required for annual operation and maintenance.
3	DDSCNT	+	Discount factor (capital recovery factor) to compute equivalent annual cost from capital cost.
4	DVRMX	+	Maximum permissible capacity of diversion in cfs (cu m/sec). Used as a constraint on optimization.
5	DVRMN	+	Minimum permissible capacity of diversion cfs (cu m/sec). Used as a constraint on optimization.

7.4 DC RECORD - DIVERSION CAPACITY TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DC	Record identification.
1	DCAP(1)	+	Diversion capacity in cfs (cu m/sec) corresponding to costs on DD record.
2-10	DCAP(I)	+	Etc., up to 10 values.

7.5 DD RECORD - DIVERSION COST TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DD	Record identification.
1	DCST(1)	+	Diversion capital cost corresponding to capacity on DC record.
2-10	DCST(I)	+	Etc., up to 10 values.

8 HYDROGRAPH TRANSFORMATION (H Records)

These records describe operations which combine or reshape hydrographs.

8.1 HB RECORD - HYDROGRAPH BALANCE

This record is required only if it is desired to balance the current hydrograph according to these specified volumes/durations.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	HB	Record identification.
1	NQB(1)	+	Number of ordinates to be included in the shortest duration.
2	SUMB(1)	+	Sum of flows corresponding to duration NQB(1) shortest duration.
3	NQB(2)	+	Number of ordinates for the next larger duration (including the prior duration).
4	SUMB(2)	+	Sum of flows corresponding to duration NQB(2).
5-10			Pairs of numbers and sums, up to five durations.

8.2 HC RECORD - COMBINE HYDROGRAPHS

Hydrograph combination is considered as a separate operation, so the HC record must be preceded by a KK record which identifies the resulting hydrograph. The HC record indicates the number of hydrographs which will be combined.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	HC	Record identification.
1	ICOMP	2-5	Indicates ICOMP hydrographs will be combined at this stream station. Default is 2.
2	TAREA	+	For depth-area jobs (JD records), this field may be used to set the cumulative basin area for the combined hydrograph. This option is useful when combining diversion hydrographs. The area associated with a diversion hydrograph is zero when combined with another hydrograph. This option may also be useful to set the area when combining a hydrograph brought in with a BI record.
		0	Use basin area calculated by program to compute interpolated hydrographs.

8.3 HL RECORD - LOCAL FLOW

HL records are used in conjunction with observed QO records to compute local flow. The local flow is the difference between the last computed hydrograph and the observed flows. Note that the current hydrograph now corresponds to the observed flows. The last computed hydrograph is removed from the stack and is no longer available for computations.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	HL	Record identification.
1	TAREA	+	Basin area (sq mi) corresponding to observed hydrograph.

8.4 HQ/HE RECORDS - RATING TABLE FOR STAGE HYDROGRAPH

HQ and HE records may be included in any hydrograph calculation to compute stages from the computed hydrograph.

8.4.1 HQ RECORD - FLOWS FOR RATING TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	HQ	Record identification.
1-10	QSTG	+	Flows in cfs (cu m/sec) corresponding to stages on HE record. Up to 20 values on 2 records.

8.4.2 HE RECORD - STAGES FOR RATING TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	HE	Record identification.
1-10	STGQ	+	Stages in feet (meters) corresponding to flows on HQ record. Up to 20 values on 2 records.

9 JOB STEP CONTROL (K Records)

9.1 ** KK RECORD - STATION COMPUTATION IDENTIFIER

The KK record must be repeated at the beginning of each station computation (i.e., subbasin runoff, routing, combining, diversion, etc.).

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	KK	Record identification.
1	ISTAQ	AN	Stream station location identification. Must be a uniques identifer for entire run when used in conjuction with a damage reach in economic analysis.
2-10	NAME	AN	Station description.

9.2 KM RECORD - MESSAGE

The message on the KM record will be printed at the beginning of the output for each stations or plan. There is no limit on the number of KM records. KM records may not be interspersed in certain record sequences such as precipitation records or kinematic wave records.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	KM	Record identification.
1-10	ITLS	AN	Station- or computation-description message.

**REQUIRED

9.3 KO RECORD - OUTPUT CONTROL OPTION

Use this record to temporarily override output control specified on IO record until the next KK record is read.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	KO	Record identification.
1	JPRT	0 or Blank	Use print control specified on IO record.
		1,2	Print all output for this station.
		3	Print input data and summaries for this computation.
		4	Print basin input data only for this computation.
		5	No printout for this computation.
2	JPLT	0 or Blank	Use plot control specified on IO record.
		1	No printer plots for this computation.
		2	Plot computed hydrograph for this computation.
3	QSCAL	0 or Blank	Use plot scale specified on IO record.
		+	Desired scale for streamflow plot in units per 10 printer characters (e.g., 100 for 100 cfs per 10 characters).
4	IPNCH	0	No hydrograph is to be saved on unit 7 for this station.
		+	Hydrograph computed at this station is to be saved on unit 7; this may be treated as a punch file.. A KF record may be used to specify format for unit 7 file. Default format is (2HQI,I6,9I8). See Table 13.1, page 187.

Continued

9.3 KO RECORD - OUTPUT CONTROL OPTION (Continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
5	IOUT	0	No hydrograph written to tape/disk file for this station.
		+	Unit number for tape/disk file on which to write computed hydrograph. Unit 21 or 22 may be used.
6	ISAV1	+	First ordinate to be punched (unit 7) or saved on tape. Default is 1.
7	ISAV2	+	Last ordinate to be punched (unit 7) or saved on tape. Default is NQ (IT-4).
8	TIMINT	+	Time interval in hours for hydrograph to be punched or saved on tape. Ordinates will be interpolated from current hydrograph. Default is time interval specified on IT record (IT-1).

9.4 KF RECORD - UNIT 7 OUTPUT FORMAT

Use this record to specify format for the hydrographs on unit 7.(See KO-4). This format will be used until a new KF record is read. Default format is (2HQI,I6,9I8). KF record should not be used unless format is to be changed. This file may be used to punch cards.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	KF	Record identification.
1	FLOTQ	YES	Convert hydrograph to floating point numbers before writing.
		NO	Write hydrograph in integer format (default).
2-10	IFMT	AN	Alphanumeric format specification for output. This format must be consistent with the choice of integer or floating point indicated in Field 1.

9.5 KP RECORD - PLAN LABEL

This record is required to identify (number) a plan in a multiplan run. If hydrograph computation data is provided before (or without) a KP record, it is assumed to be plan 1. The data provided after a KP record need only be that required to change what was computed in the previous plan. All plans not specifically identified with a KP record are assumed to be the same as the first plan processed. See following example.

```
KK
KP 1
.
. Data for PLAN 1
.
KP 3
.
. Data for PLAN 3
.
 *Data for PLAN 2 is not provided and thus will be the same as
   PLAN 1
KK
```

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	KP	Record identification.
1	ISTM	+	Plan number identifier.

10 LOSS RATE DATA (L Records)

One of four different rainfall loss rate procedures may be used for a subbasin runoff computation. A different loss rate may be used for each subbasin and/or plan. Snowmelt loss rate (LM record) may be used in conjunction with the exponential (LE record) or uniform (LU record) loss rates.

10.1 LU RECORD - INITIAL AND UNIFORM LOSS RATE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LU	Record identification.
1	STRTL	0,+	Initial rainfall/snowmelt loss in inches (mm) for snow free ground. If operating in the optimization mode (OU record), this variable will be fixed at this value and not optimized.
		-1	For optimization only (OU record previously supplied), program will assume a starting value and then optimize.
		-	Same as (-1) above but program uses this value (after sign change) as the starting point for the optimization.
2	CNSTL	0,+ or -	Uniform rainfall/snowmelt loss in inches/hour (mm/hr) which is used after the starting loss STRTL is completely satisfied. See field 1 for meaning of VALUE.
3	RTIMP	+	Percent of drainage basin that is impervious. No losses are computed for this portion of the basin.
4-6			Specify loss rate variables similar to Fields 1-3 for second kinematic subcatchment.

10.2 LE RECORD - HEC EXPONENTIAL LOSS RATE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LE	Record identification
1	STRKR	+,0	Initial value of STRKR in inches/hour (mm/hr) for HEC's exponential rain loss rate function. If doing an optimization (OU record), this variable will not be optimized and will be fixed at this value.
		-1	For optimization only (OU record previously supplied), program assumes a starting value and then optimizes.
		-	For optimization only (OU record previously supplied), program uses this (after sign change) as the starting value for the optimization.
2	DLTKR	0,+ or -	DLTKR is the amount in inches (mm) of initial accumulated RAIN loss during which the loss coefficient is increased. See Field 1 for meaning of value.
3	RTIOL	0,+ or -	Rate of change of the rain loss-rate parameter computed as the ratio of STRKR to a value of STRKR after 10 inches (10MM) of accumulated loss. See field 1 for an explanation of the values.
4	ERAIN	0,+ or -	Exponent of precipitation for loss rate function. See Field 1 for meaning of value.
5	RTIMP	+	Percent of subbasin which is impervious. 100 percent runoff will be computed for this portion of the subbasin.
6-10			Specify loss rate variables similar to Fields 1-5 above, for the second kinematic subcatchment. UK record is used. No optimization may be performed.

10.3 LM RECORD - HEC EXPONENTIAL SNOWMELT LOSS RATE

This record is used in conjunction with the LE or LU records to compute the loss rate for snowmelt. Only the exponential loss can be used with the optimization option.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LM	Record identification.
1	STRKS	+,0	Initial value of STRKS in inches/hour (mm/hr) for HEC exponential snowmelt loss rate function. When used with LE record, or uniform meltwater loss rate, inches/hour (mm/hour) when used with LU record. If doing an optimization (OU record) this variable will not be optimized and will be fixed at this value.
		-1	For optimization of exponential loss only (OU record previously supplied), program assumes a starting VALUE and then optimizes.
		-	For optimization of exponential loss only (OU record previously supplied), program uses this (after sign change) as the starting VALUE for the optimization.
2	RTIOK	0,+ or -	Rate of change of the snowmelt loss-rate parameter computed as the ratio STRKS to a value of STRKS after 10 inches (10 mm) of accumulated loss. See Field 1 for the meaning of VALUE. Not used for uniform meltwater loss rate.

10.4 LS RECORD - SCS CURVE NUMBER LOSS RATE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LS	Record identification.
1	STRTL	+	Initial rainfall abstraction in inches (mm) for snow free ground. For an optimization job (OU record) this variable is fixed at the given value.
		0	Initial abstraction will be computed as 0.2*(1000-10*CRVNBR)/CRVNBR. For an optimization job, initial abstraction will vary with CRVNBR.
		-1	For optimization only (OU record previously supplied), program will assume a starting value and then optimize.
		-	Same as (-1) above but program uses this value (after sign change) as the starting point for the optimization.
2	CRVNBR	0,+	SCS curve number for rainfall/snowmelt losses on snow-free ground. If this is an optimization job (OU record supplied), this variable will be fixed at this value and not optimized.
		-	Same as (-1) above but program uses this value (after sign change) as the starting point for the optimization.
3	RTIMP*	+	Percent of drainage basin that is impervious. No losses are computed for this portion of the basin.
4-6			Specify loss rate variables similar to Fields 1-3 for second kinematic subcatchment if used.

*This factor should only be used for directly connected imperivous areas not already accounted for in the curve number land use.

HEC-1 INPUT DESCRIPTION
LOSS RATE DATA (L Records)

10.5 LH RECORD - HOLTAN LOSS RATE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LH	Record identification.
1	FC	0,+	Holtans long term equilibrium loss rate in inches /hour (mm/hr) for rainfall/snowmelt losses on snowfree ground. If this is an optimization job (OU record supplied), this variable will be fixed at this value and not optimized.
		-1	For optimization only (OU record previously supplied), program will assume a starting value and then optimize.
		-	Same as (-1) above except program uses this value (after sign change) as the starting point for the optimization.
2	GIA	0,+ or -	Infiltration rate in inches/hour per (inch**BEXP) or mm/hr per (mmm***BEXP) of available soil moisture storage capacity (i.e., 1 - soil moisture). See field 1 for meaning of VALUE.
3	SAI	0,+ or -	Initial value of SA avaiable soil moisture capacity in inches (mm). See Field 1 for meaning of VALUE.
4	BEXP	0,+ or -	Exponent of available soil moisture storage, SA. Default value is 1.4. See Field 1 for meaning of VALUE.
5	RTIMP	+	Percent of drainage basin that is impervious. No losses are computed for this portion of the basin. This variable is not optimized.
6-10			Repeat Fields 1-5 for second kinematic subcatchment if used.

11 SNOWMELT DATA (M Records)

M records are required only if snowfall/melt computations are to be made. Snow computations are accomplished in separate, equally incremented, elevation zones within each subbasin. Melt may be computed by the degree-day or energy-budget method.

11.1 MA RECORD - ELEVATION ZONE DATA

These records are required for snowfall/melt simulation.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	MA	Record identification.
1	AREA(1)	+	Drainage area in sq mi (sq km) in Zone 1 (lowest zone).
2	SNO(1)	+	Average water equivalent in inches (mm) of snowpack at start of this job (first interval of NQ) in Zone 1, corresponding to AREA(1).
3	ANAP(1)	+	Normal annual precipitation in inches (mm) for Zone 1, corresponding to AREA (1).

NOTE: Up to 10 records, one for each zone. Zones must be in equal elevation increments corresponding to lapse rate coefficient TLAPS (MC-1).

HEC-1 INPUT DESCRIPTION
SNOWMELT DATA (M Records)

11.2 MC RECORD - MELT COEFFICIENT

This record is required for any snowfall/melt simulation.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	MC	Record identification.
1	TLAPS	+	Temperature lapse in degrees F (C) per elevation zone. All zones must have same increment of elevation.
2	COEF	+	Snowmelt coefficient, usually about 0.07 for degree-day method and 1.0 for energy-budget method.
		-1	For optimization only (OU record previously supplied), program assumes a starting value and then optimizes.
		-	For optimization only (OU record previously supplied), program uses this (after sign change) as the starting value for optimization.
3	FRZTP	+ or -	Index temperature at which snow will melt in degrees F (C). Precipitation will be assumed to fall as snow at temperature of FRZTP+2°F (FRZTP+2°C) and below.

11.3 MT RECORD - TEMPERATURE TIME SERIES

These data are required for any snowfall/melt simulation. See IN record description for discussion of time interval and number of values.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	MT	Record identification.
1	TEMPR(1)	+	Air temperature for first interval in degrees F (C) at bottom of lowest elevation zone. Will be adjusted to each zone by use of TLAPS (MC-1).
2	TEMPR(2)	+	Air temperature as above for second interval.
3	TEMPR(3)	+	Etc.

11.4 MS RECORD - ENERGY BUDGET SHORTWAVE RADIATION

The MS, MD, and MW records are only used for the energy budget snowmelt simulation. See IN record description for discussion of time interval and number of values.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	MS	Record identification.
1	SOL(1)	+	Shortwave radiation in Langleys during first interval.
2	SOL(2)	+	Shortwave radiation during second interval.
3	SOL(3)	+	Etc.

11.5 MD RECORD - ENERGY BUDGET DEW POINT

See MS record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	MD	Record identification.
1	DEWPT(1)	+	Dew point during first interval in degrees F (C) at bottom of lowest elevation zone. Will be adjusted to each zone by use of 0.2 TLAPS (MC-1).
2	DEWPT(2)	+	Dew point as above for second interval.
3	DEWPT(3)	+	Etc.

11.6 MW RECORD - ENERGY BUDGET WIND SPEED

See MS record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	MW	Record identification.
1	WIND(1)	+	Wind speed in mi/hr (km/hr) at 50 ft (15 m) above surface, average for basin during first interval.
2	WIND(2)	+	Wind speed as above for second interval.
3	WIND(3)	+	Etc.

12 PRECIPITATION DATA (P Records)

Precipitation data can be input as either precipitation gage data or subbasin-average precipitation.

A typical record sequence for GAGE data is as follows:

```
     ID
     IT            Etc., for job initialization

     PG            Non-recording gage (total storm precipitation)
     PG            Non-recording gage (total storm precipitation), etc.
     PG            This is a recording gage if the PG record is followed
                   by PI or PC records.
     PI
     .
     .

     KK            Subbasin runoff computation
     BA
     BF
(    PT            Specification of stations and weightings for   )
(    PW            computation of the storm total precipitation   )
(    PR            and its time patter for this subbasin.  If     )
(    PW            recording stations are to be used in the       )
(                  computation of subbasin-average TOTAL          )
(                  precipitation, their gage identification must )
(                  also be on the PT record.                      )
     L-
     U-

     KK            Etc.
     .
     .
```

PG and PG + PI/PC record combinations can be included at any point in the data set following the IT record. It is usually convenient to group them together as a precipitation data bank before the first KK record. Different storms can then be simulated by simply inserting different data banks, as long as the gage identification and weightings are the same.

Continued

12 PRECIPITATION DATA (P Records) (Continued)

Subbasin-average precipitation can be specified using historical storm data (PB and PI/PC records) or synthetic storm data (PM, PS or PH records).

A typical record sequence is as follows:

```
ID
IT

KK
.
.
.
PB              Subbasin-average precipitation specified as
PI              part of this subbasin runoff computation.
.
.
.
KK
.
PM, PS or PH    Synthetic storm data for this subbasin.
.
.
.
.
```

Once precipitation data has been specified for a subbasin runoff computation, those data will be used for subsequent runoff calculations until changed by reading new precipitation data.

12.1 PB AND PI/PC RECORDS - STORM TOTAL AND DISTRIBUTION OPTION

These records are used if the basin-average, storm total precipitation is known along with a time pattern with which to distribute the storm total. They must be included in the KK record group for a runoff calculation.

12.1.1 PB RECORD - BASIN AVERAGE PRECIPITATION

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PB	Record identification.
1	STORM	0	Total storm, basin-average precipitation will be computed from values given on the following PI or PC records.
		+	Total storm, basin-average precipitation in inches (mm). If this value is given, the following PI or PC records' values for PRCPR will be used as a distribution pattern for the STORM amount.

HEC-1 INPUT DESCRIPTION
PRECIPITATION DATA (P Records)

12.1.2 PI RECORD - INCREMENTAL PRECIPITATION TIME SERIES

PI records contain an incremental precipitation time distribution. They are only used after a PG, PB or JD record which identifies the distribution. The interval length and starting time for the first interval will be as specified on the last IN record which has been read. The program reads all consecutive PI records and interpolates incremental precipitation values for the computation time interval and time period specified on the IT record. If an IN record is not specified the parameters on the IT record will be used. A maximum of 300 values can be specified on up to 30 records. A negative one may be used to signify missing data when using more than one recording gage in conjunction with PG records. The precipitation will be computed based on the weighted average of the remaining stations.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PI	Record identification.
1	PRCPR(1)	+	Precipitation in inches (mm) during the interval from JXTIME (IN record) to JXTIME + JXMIN.
2	PRCPR(2)	+	Etc.

12.1.3 PC RECORD - CUMULATIVE PRECIPITATION TIME SERIES

PC records contain a cumulative precipitation distribution. They are only used after a PG, PB or JD record which identifies the distribution. The interval of ordinates and time of first mass curve ordinate are as specified on previous IN record. If an IN record is not specified the parameters on the IT recorded will be used. The program reads all consecutive PC records and interpolates incremental precipitation values for the computation time interval and time period specified on the IT record. A maximum of 300 values can be specified on up to 30 records.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PC	Record identification.
1	PRCPR(1)	+	Cumulative precipitation at beginning of storm.
2	PRCPR(2)	+	Cumulative precipitation at end of first period.
3	PRCPPR(3)	+	Cumulative precipitation at end of second period.
4	PRCPR(4)	+	Etc.

12.2 PG RECORD - STORM TOTAL PRECIPITATION FOR A STATION (GAGE)

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PG	Record identification.
1	ISTAN	AN	Station identification.
2	PRCPN	0	Total storm precipitation will be computed from following PI or PC records.
		+	Total storm precipitation in inches (mm) for above station.
3	ANAPN	+	Normal annual precipitation for above station. Used to compute basin mean precipitation by weighted average of station normal precipitation.
		0 or Blank	Weighting by normal annual precipitation will not be performed.
4	ISTANX	AN	Station to be replaced by station identified in Field 1.

All precipitation gages are total-storm stations. Some stations may also have temporal distributions associated with the storm-total precipitation. These stations are also called recording stations when referring to the temporal pattern. The temporal distribution is defined on PI or PC records immediately following a PG record.

Up to 70 stations may be entered on PG records. However, precipitation time series (PI or PC records) can be stored for only 15 stations. If more stations are required, additional PG records may be entered later in the input stream and the data from these records will replace data for the station identified by ISTANX.

PR, PT and PW records are used within each KK, BA, etc., record series to specify weightings of precipitation station data to compute the subbasin-average precipitation distribution.

12.3 PH RECORD - HYPOTHETICAL STORMS

These records are used to compute a hypothetical storm over a subbasin. The total storm will be automatically distributed according to the specified depth/duration data. A triangular precipitation distribution is constructed such that the depth specified for any duration occurs during the central part of the storm.

The duration of the storm will be the duration for the last non-zero depth which is specified. The first non-zero depth specified will be the most intense portion of the storm. Depths must be specified for all durations between these limits.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PH	Record identification.
1	PFREQ	50,20, 10	Storm frequency in percent. Rainfall will be converted to annual-series rainfall for 50, 20, & 10 percent storms. No conversion is made for any other frequency (see Table 3.3, page 13).
		Blank	No conversion is made from partial-duration to annual series.
2	TRSDA	+	Storm area to be used in computing reduction of point rainfall depths per TP-40.
		0, or Blank	Basin area from BA record will be used to compute reduction of point rainfall depths, for the stream network option or from the JD record (TRDA) for the depth area option.
3	PNHR(1)	+	5-minute duration depth for PFREQ storm.
4	PNHR(2)	+	15-minute duration depth for PFREQ storm.
5	PNHR(3)	+	60-minute duration depth for PFREQ storm.
6	PNHR(4)	+	2-hour duration depth for PFREQ storm.
7	PNHR(5)	+	3-hour duration depth for PFREQ storm.
8	PNHR(6)	+	6-hour duration depth for PFREQ storm.
9	PNHR(7)	+	12-hour duration depth for PFREQ storm.
10	PNHR(8)	+	24-hour duration depth for PFREQ storm.

Continued

12.3 PH RECORD - HYPOTHETICAL STORMS (Continued)

Continue on second PH record (if needed).

FIELD	VARIABLE	VALUE	DESCRIPTION
1	PNHR(9)	+	2-day duration depth for PFREQ storm.
2	PNHR(10)	+	4-day duration depth for PFREQ storm.
3	PNHR(11)	+	7-day duration depth for PFREQ storm.
4	PNHR(12)	+	10-day duration depth for PFREQ storm.

12.4 PM RECORD - PROBABLE MAXIMUM PRECIPITATION

This record is used for automatic computation of a Probable Maximum Storm (PMS) according to the outdated Hydrometeorological Report No. 33. This capability has been retained in HEC-1 to allow recomputation of hydrographs according to the old HMR No. 33 method.

NOTE: Hydrometeorological Report No. 33 has been superseded by HMR No. 51 and No. 52. Computer program HMR52 (HEC, 1984) may be used to calculate PMS hyetographs.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PM	Record identification.
1	PMS	+	Probable maximum index precipitation from HYDROMET Report 33.
2	TRSPC	0	TRSPC defaults to the Hop Brook factor (reference EC-1110-2-163). The adjustment is automatically made by the program. The precipitation is adjusted based on drainage area size using the following criteria.

HOP BROOK ADJUSTMENT FACTOR

DRAINAGE AREA SQ. MI.	PRECIPITATION REDUCTION	ADJUSTMENT FACTOR
1000	10	.90
500	10	.90
200	10	.89
100	13	.87
50	15	.85
10 OR LESS	20	.80

\+ Direct input of the transposition coefficient as desired (use 1.0 if no adjustment is desired).

Continued

12.4 PM RECORD - PROBABLE MAXIMUM PRECIPITATION (Continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
3	TRSDA	0	Defaults to TAREA (BA-1).
		+	Drainage area in square miles (sq km) for which storm is transposed. Transposition drainage area is used to compute the storm reduction coefficient (TRSPC) for probable maximum storm. TRSDA may be different from the actual subbasin area TAREA (BA-1). Example: It is desired to center a PMS over a 500 sq mi watershed and calculate the corresponding runoff for a 200 sq mi subbasin of that watershed. For this condition TAREA = 200 and TRSDA = 500.
4	SWD	NO	Precipitation will be distributed according to EM 1110-2-1411 (default).
		YES	Precipitation will be distributed according to Southwestern Division criteria (see Table 3.1, p. 11).
5	R6	+	Maximum 6-hour precipitation in percent of index PMS.
6	R12	+	Maximum 12-hour percentage of PMS.
7	R24	+	Maximum 24-hour percentage of PMS.
8	R48	+	Maximum 48-hour percentage of PMS (optional).
9	R72	+	Maximum 72-hour percentage of PMS (optional).
10	R96	+	Maximum 96-hour percentage of PMS (optional).

Duration of the computed PMS will correspond to the last non-zero percentage entered. Minimum duration is 24 hours.

12.5 PS RECORD - STANDARD PROJECT PRECIPITATION (SPS)

This record is used for automatic computation of the Standard Project Storm according to EM-1110-2-1411.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PS	Record identification.
1	SPFE	+	Standard project index precipitation from EM 1110-2-1411.
2	TRSPC	+	Storm reduction coefficient for standard project storm computations. This parameter is equal to the shape factor of the basin and should be input directly.
3	TRSDA	0	Default to TAREA (BA-1).
		+	Drainage area to be used in computing the peak 24-hour precipitation.

12.6 PR, PT, AND PW RECORDS - PRECIPITATION GAGE WEIGHTING

These records are used to identify the gages and their relative weightings for computing this subbasin's average precipitation.

Both PR and PT records are required to compute a hyetograph. Rainfall for stations on the PT record are weighted to get the total rainfall for the storm, and hyetographs for stations on the PR record are weighted to get a temporal distribution for this total rainfall.

12.6.1 PR RECORD - RECORDING STATIONS TO BE WEIGHTED

CAUTION - Weighting of 2 or more hyetographs may result in loss of detail for intense precipitation periods.

The recording precipitation distribution is computed as (WTR*PRCPR)/(SUM OF WTR) for all intervals. This precipitation distribution is used as the pattern to distribute the computed basin average total precipitation from the PT/PW records.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PR	Record identification.
1	ISTR(1)	AN	Alphanumeric station identification of recording gage to be used and corresponding to weighting in Field 1 on the following PW record. Must correspond to a station name on a previous PG record.
2-5	ISTR(I)	AN	Etc., for up to 5 stations.

12.6.2 PT RECORD - STORM-TOTAL STATIONS TO BE WEIGHTED

Basin-average total precipitation is computed as (WTR*PRCPN)/(SUM OF WTR) for all stations used. Recording gages can also be used in this computation of subbasin-average storm total precipitation; if used, their gage idetification must be specified on the PT record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PT	Record identification.
1	ISTN(1)	AN	Alphanumeric station identification for total storm station. Must correspond to one of the station names on a previous PG record.
2-10	ISTN(I)	AN	Etc., up to 10 stations corresponding to weightings on following PW record.

12.6.3 PW RECORD WEIGHTINGS FOR PRECIPITATION STATIONS

This record is used to specify weights to be assigned to precipitation gages. If used, this record must follow immediately after a PR and/or PT record. If no PW record is used, each gage on the PR or PT record will have the same relative weight.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PW	Record identification.
1	WTR(1)	+	Relative weight in any units for the station name specified in Field 1 on the previous PR or PT record.
2-10	WTR(I)	+	Etc., corresponding to stations on previous PR record and/or PT record.

13 HYDROGRAPH TIME-SERIES DATA (Q Records)

These records contain hydrograph time series data. The first value on the record is at the starting time specified on the previous IN record. Subsequent values are spaced at the time interval specified on the IN record. The program reads all consecutive Q records and interpolates values for the computation time interval and time period specified on the IT record. If the computation time period extends before or beyond the Q data supplied, the first or last value will be repeated as necessary to produce a hydrograph for the full time period.

13.1 QO RECORD - OBSERVED HYDROGRAPH

These records are used to input an observed hydrograph for an optimization job (OU or OR records) or for comparing the computed with an observed flow at any point in a river network. For optimization jobs, QO records are included in the data for runoff calculation. For comparison of hydrographs, QO records are separated from other data with a KK record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	QO	Record identification.
1	QO(1)	+	Observed flow in cfs (cu m/s) at the beginning of the first period.
2	QO(2)	+	Etc.

13.2 QI RECORD - DIRECT INPUT HYDROGRAPH

These records are used to input a hydrograph directly (without rainfall-runoff computations) at any point in a river network.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	QI	Record identification.
1	QI(1)	+	Hydrograph ordinate in cfs (cu m/s) at beginning of first period.
2	QI(2)	+	Etc.

13.3 QS RECORD - STAGE HYDROGRAPH

These records are used to input a stage hydrograph for comparison with the computed hydrograph. A rating table, on HQ and HE RECORDS, must also be supplied. Comparison of hydrographs is a distinct operation which must be separated from other operations with a KK RECORD.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	QS	Record identification.
1	QS(1)	+	Stage in feet (m) at the beginning of the first time interval.
2	QS(2)	+	Etc.

13.4 QP RECORD - PATTERN HYDROGRAPH

These records are used to input a pattern hydrograph for which local inflow will be distributed in a routing optimization job (OR record) only.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	QP	Record identification.
1	QP(1)	+	Pattern hydrograph for local inflow which will be adjusted for volume in routing coefficient derivation.
2	QP(2)	+	Etc.

14 ROUTING DATA (R Records)

Routing of streamflows may be accomplished by several different methods. One of the following methods should be selected and put in the record set immediately after the streamflows to be routed have been computed.

Routing is considered to be a separate operation, so the R records must be preceded by a KK record which identifies the routed hydrograph.

14.1 RN RECORD - NO ROUTING OPTION FOR THIS PLAN

The RN record is used in a multiplan job to indicate that no routing occurs for this plan.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RN	Record identification.

14.2 RL RECORD - CHANNEL LOSS

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RL	Record identification.
1	QLOSS	+	Constant channel loss in entire routing in cfs (cu m/sec). This value is subtracted from every ordinate of the inflow hydrograph.
2	CLOSS	+	Ratio of remaining flow (after QLOSS) which is lost for entire routing. Each inflow hydrograph ordinate (after QLOSS is subtracted) is multiplied by (1-CLOSS).
3	PERCRT	+	Percolation Rate cfs/acre (cu m/sec-acre) for wetted surface area of channel. This option is used in conjunction with storage routing and requires SA or SV/SE records.
4	ELVJNV	+	Average invert elevation of channel L used to compute flow surface area for PERCRT.

14.3 RM RECORD - MUSKINGUM ROUTING

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RM	Record identification.
1	NSTPS	+	Integer steps (equal to number of subreaches) for the Muskingum routing.
		-1	Number of steps will be optimized. OR record must have been previously supplied.
2	AMSKK	+	Muskingum K coefficient in hours for entire reach*. The program will automatically compute the subreach Muskingum K as AMSKK/NSTPS. AMSKK, etc., must be within the following limits: $$\frac{1}{2(1-X)} \leqslant \frac{(AMSKK*60.)}{(NMIN * NSTPS)} \leqslant \frac{1}{2X}$$ Where NMIN is the integer number of minutes in tabulation interval.
		-1	Muskingum K coefficient will be optimized. OR record must have been previously supplied.
3	X	+	Muskingum X coefficient for Muskingum routing or working R&D routing.
		-1	Muskingum X coefficient will be optimized. OR records must have been previously supplied.

*NOTE: The Muskingum K coefficient input is DIFFERENT than in the pre-1981 versions of HEC-1. It is now input as the TOTAL K for the routing reach, not the K for the subreach.

14.4 RS RECORD - STORAGE ROUTING

This record is required to perform a storage-discharge routing. The record contains the starting conditions for the routing. A storage-discharge relation may be input directly on the SV and SQ records, or computed from surface area and elevation on SA and SE records and stage-discharge data on SE and SQ records, or computed from channel characteristics on RC, RX and RY records. Thus, storage routing may be accomplished by one of the following sequences of records:

CHANNEL ROUTING: (choose one method)

RS,RC,RX,RY	Normal depth storage
RS,SV,SQ	Modified Puls

RESERVOIR ROUTING: RS + volume + outflow

VOLUME: (choose one method)

SV (SE optional)	Known volume
SA,SE	Compute volume

OUTFLOW: (choose one method)

SQ (SE optional)	Known outflow (and rating)
SS, (SL and ST optional) requires SE record onoutflow volume specifications.	Computed weir spillway
SS, (SL and ST optional) SG, SQ, SE	Computed ogee or trapezoidal spillway outflow

Continued

14.4 RS RECORD - STORAGE ROUTING (Continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RS	Record identification.
1	NSTPS	+	Number of steps to be used in the storage routing. Usually about equal to (reach length/ average velocity)/time interval. NSTPS is usually equal to 1 for a reservoir.
2	ITYP	STOR	Storage (acre-feet or 1000 cu m) for the beginning of the first time period is specified in next field (default).
		FLOW	Discharge (cfs or cu m/s) for the beginning of the first time period is specified in the next field.
		ELEV	Elevation in (feet or meters) for the beginning of the first time period is specified in the next field.
3	RSVRIC	+	Storage (acre-ft or 1000 cu m), discharge (cfs or cu m/s), or elevation (ft or m), as indicated by previous field ITYP, corresponding to the desired starting condition at the beginning of the first time period IDATE/ITIME (IT-2/IT-3).
		-1	The initial outflow will be set to the initial inflow.
4	X	0	Working R&D method not used.
		+	Wedge storage coefficient (Muskingum X) to be used in a working R&D routing using a computed or given storage-discharge relationship.

14.5 RC RECORD - NORMAL-DEPTH CHANNEL ROUTING

This record is used in combination with the RX and RY records to describe the channel in a routing reach. Manning's equation is used to compute a table of storage and outflow values for use in modified puls routing. These values are based on uniform subcritical flow in the reach. An RS record is required to provide initial conditions for modified puls routing.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RC	Record identification.
1	ANL	+	Left overbank Manning's n value.
2	ANCH	+	Channel Manning's n value.
3	ANR	+	Right overbank Manning's n value.
4	RLNTH	+	Reach length, in feet (m), for which computations are represented.
5	SEL	+	Energy grade line slope in ft/ft (m/m) for normal flow rate computations. If unknown, may be estimated as equal to channel or floodplain slope.
6	ELMAX	+	Maximum elevation for which storage and outflow values are to be computed (default is maximum elevation on RY record.)

14.6 RX RECORD - CROSS SECTION X COORDINATES*

Left bank and right bank of channel are assumed to be located at points 3 and 6, respectively, of the cross section.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RX	Record identification.
1	X(1)	+	Horizontal station, in feet (m), of first point in cross section on the LEFT OVERBANK. Corresponds to first elevation Y(1) on RY record.
2	X(2)	+	Similar to above for another point on LEFT OVERBANK. Corresponds to second elevation Y(2) on RY record.
3	X(3)	+	Similar to above for LEFT BANK of CHANNEL.
4	X(4)	+	Similar to above for a point in CHANNEL.
5	X(5)	+	Similar to above for another point in CHANNEL.
6	X(6)	+	Similar to above for RIGHT BANK of CHANNEL.
7	X(7)	+	Similar to above for a point on RIGHT OVERBANK.
8	X(8)	+	Similar to above for another point on RIGHT OVERBANK.

*All eight points must be used. Stationing (x distance) must continuously increase.

14.7 RY RECORD - CROSS SECTION Y COORDINATES

Left bank and right bank of channel are assumed to be located at points 3 and 6, respectively, of the cross section.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RY	Record identification.
1	Y(1)	+	Vertical elevation, in feet (m), of first point in cross section on the LEFT OVERBANK. Corresponds to first station on RX record. Must be a positive value.
2	Y(2)	+	Similar to above for another point on the LEFT OVERBANK. Corresponds to second station on RX record.
3	Y(3)	+	Similar to above for LEFT BANK of CHANNEL.
4	Y(4)	+	Similar to above for a point in CHANNEL.
5	Y(5)	+	Similar to above for another point in CHANNEL.
6	Y(6)	+	Similar to above for RIGHT BANK of CHANNEL.
7	Y(7)	+	Similar to above for a point on RIGHT OVERBANK.
8	Y(8)	+	Similar to above for another point on RIGHT OVERBANK.

14.8 RK RECORD - KINEMATIC WAVE CHANNEL ROUTING

This record is used for kinematic wave routing of a previously computed hydrograph. For channel routing in conjunction with runoff calculation, see the section on UK/RK records.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RK	Record identification.
1	L	+	Channel length (ft).
2	S	+	Channel slope (ft/ft).
3	N	+	Channel roughness.
4			Not used. This field is only used with the UK/RK record combination.
5	SHAPE	TRAP,0, Blank	Trapezoidal channel (including triangular and rectangular). (Default)
		DEEP	Deep rectangular (square) channel. Flow depth is approximately equal to channel width.
		CIRC	Circular channel shape. This cross section only approximates flow in a pipe or culvert. Flow depths are allowed to exceed the pipe diameter.
6	WD	+	Channel bottom width or diameter (ft). (Default value is zero.)
7	Z	+	Side slopes, if required (default value is 1.0 when WD, RK-6, is zero).
8			Not used. This field is only used with the UK/RK record combination.

14.9 RT RECORD - STRADDLE/STAGGER ROUTING

NOTE - The variables used for this routing method are dependent on the computation time interval. The user should make proper adjustments when using different time intervals.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	RT	Record identification.
1	NSTPS	+	Integer number of routing steps to be used for routing by Tatum method
		0	LAG method.
		-1	If number of steps for Tatum method is to be derived by the program. OR record must have been previously supplied.
		1	If routing by Straddle-Stagger method.
2	NSTDL	+	Integer number of ordinates to be averaged in the Straddle-Stagger routing.
		-1	If straddle is to be derived by the program. OR record must have been previously supplied.
		2	If routing by the Tatum method with or without derivation.
3	LAG	+	Integer number of intervals hydrograph is to be lagged.
		-1	If lag is to be derived by the program. OR record must have been previously supplied.
		0	Tatum

15 STORAGE ROUTING DATA (S Records)

S records are used to provide storage and outflow data for storage routing.

STORAGE data can be input in two ways:

1. Storage volume on SV records
2. Surface area and elevation on SA and SE records

OUTFLOW data can be input in three ways:

1. Discharge on SQ records
2. Weir and orifice data on SS and SL records
3. Ogee spillway data on SL, SS, SG, SQ, and SE records

When spillway data (weir or ogee) are provided, the program computes a steady flow rating curve, then interpolates from that rating curve during the routing calculation. Elevation data may be input for storage or outflow by following SV or SQ records with SE records.

HEC-1 INPUT DESCRIPTION
STORAGE ROUTING DATA (S Records)

15.1 SV OR SA RECORDS - RESERVOIR STORAGE DATA

One of these sets of records is required in order to compute the storage relationship for a reservoir routing. If the storage volumes are not known, they may be computed by the conic method using surface area-elevation information.

15.1.1 SV RECORD - RESERVOIR VOLUME

These records are to be used if the reservoir volumes are known. Do not use if SA records are supplied.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SV	Record identification.
1-10	RCAP(1-10)	+	Reservoir storage in acre-feet (1000 cubic meters), up to 20 values on 2 records.

15.1.2 SA RECORD - RESERVOIR SURFACE AREAS OPTION

These records are used if the reservoir volumes (SV record) are not known. Do not use if SV records are supplied.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SA	Record identification.
1-10	RAREA(1-10)	+	Reservoir surface area in acres (1000 square meters), up to 20 values on 2 records.

15.2 SE RECORD - ELEVATION

SE records may be used immediately after SV, SA, or SQ records to specify elevations for the values on those records.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SE	Record identification.
1-10	ELEV(1-10)	+	Elevation in feet (m) corresponding to value in same field on preceding SV, SA, or SQ record (up to 20 values on 2 records). Note that the SE record must follow an SV or SA record

15.3 SQ RECORD - DISCHARGE

The SQ record gives outflow data for storage routing. Values should correspond to storage data, or if elevation data are provided for both storage and outflow, the program will interpolate discharges for the given storages.

The SQ and SE records are also used to specify tailwater data for the ogee spillway option.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SQ	Record identification.
1-10	DISQ(1-10)	+	Discharge in cfs (cu m/s) up to 20 values on 2 records.

15.4 SL RECORD - LOW-LEVEL OUTLET

This record is necessary to describe flow through a low-level outlet. An SS record is also required if the SL record is used.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SL	Record identification.
1	ELEVL	+	Centerline elevation, in feet (m), of downstream end of low-level outlet. This low-level outlet may be used with the weir, trapezoidal, or ogee spillways.
2	CAREA	+	Cross-sectional area, a, in square feet (sq m), in the low-level outlet orifice equation as described below for COQL.
3	COQL	+	Discharge coefficient, c, in orifice equation, q=ca(2gh)**e, for the low-level outlet.
4	EXPL	+	Exponent, e, of head h in orifice equation for low-level outlet as described in previous two fields. Usually equals 0.5.

15.5 SS RECORD - SPILLWAY CHARACTERISTICS

This record is used to compute flow for weir or ogee spillways. If the dam overtopping summary is requested (ST record), the spillway crest elevation should be provided on this record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SS	Record identification.
1	CREL	+	Spillway crest elevation, in feet (m). This crest elevation is also required in the weir, trapezoidal, and ogee spillway computations.
2	SPWID	+	Spillway length, in feet (m) corresponding to l in the WEIR equation as described below for COQW or the bottom width of the TRAPEZOIDAL spillway or the length of the OGEE spillway.
3	COQW	+	Discharge coefficient, c, in the spillway WEIR flow equation q=clh**e.
4	EXPW	+	Exponent e of head, h, in spillway WEIR flow equation. Usually equals 1.5.

15.6 ST RECORD - TOP-OF-DAM OVERFLOW

This record is used to compute flow over the top of a dam. Flow computed using the weir coefficients specified on this record is added to outflow computed from the spillway (SQ, SS, SL, or SG records). Use of this record calls for the dam overtopping summary (spillway crest elevation should be provided on SS record). This record is required if the non-level top-of-dam option (SW/SE records) is used. The discharge over the top of dam is added to the discharge elevation relationship generated by the program (SL, SS, SG options) or specified by the user (SQ, SE option).

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	ST	Record identification.
1	TOPEL	+	Elevation, in feet (m), of the top of the dam at which overtopping begins.
2	DAMWID	+	Length, in feet (m), of the top-of-dam which is actively being overtopped - corresponds to l in the weir equation q=clh**e. Does not include spillway.
3	COQD	+	Discharge coefficient, c, in the above weir equation. If SQ/SE records include flow over top of dam, Field 3 should be zero.
4	EXPD	+	Exponent, e, in the above weir equation. Usually equals 1.5.

15.7 SW/SE RECORDS - NON-LEVEL TOP-OF-DAM OPTION

If a non-level top-of-dam has a significant impact on the flow over the top of the dam, the following records should be used to describe the geometry of the top of the dam. These records are used in addition to the ST record.

15.7.1 SW RECORD - NON-LEVEL CREST LENGTHS

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SW	Record identification.
1-10	WIDTH(1-10)	+	Accumulated dam crest length at or below corresponding elevation on SE record (up to 10 values).

15.7.2 SE RECORD - NON-LEVEL CREST ELEVATIONS

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SE	Record identification.
1-10	ELVW(1-10)	+	Elevation in feet (m) for corresponding crest length on SW record (up to 10 values).

15.8 SG RECORD - TRAPEZOIDAL AND OGEE SPILLWAY

This record is used only if a trapezoidal or ogee spillway is to be simulated in detail (see users manual for details). Tailwater rating curve must be provided on SQ and SE records which follow immediately after SG record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SG	Record identification.
1	IABCOA	0 or Blank	Abutment contraction coefficients are to be based on adjacent EARTH non-overflow section.
		10	Abutment contraction coefficients are to be based on adjacent CONCRETE non-overflow sections.
2	ISPITW	0	Spillway tailwater will be given on SQ/SE records.
		10	Spillway tailwater will be computed using specific energy equation. The low-level outlet tailwater will be on SQ/SE records in either case.
3	ISPCTW	0 or Blank	Both spillway and low-level outlet cause submergence of low level outlet.
		10	Low-level outlet discharges only shall be used in computing low-level outlet submergence.
4	NGATES	+	Number of spillway gates, i.e., spillway openings (or intermediate piers plus one). Used in computation of pier losses.
5	SS	0	For ogee spillway.
		+	Side slope of trapezoidal spillway. Slope is horizontal over vertical, e.g., 2.0 for 2 to 1 side slopes.
6	DESHD	+	Design head for ogee spillway, in feet (m).
7	APEL	+	Apron elevation, in feet (m), at base of spillway.

Continued

15.8 SG RECORD - TRAPEZOIDAL AND OGEE SPILLWAY (Continued)

FIELD	VARIABLE	VALUE	DESCRIPTION
8	APWID	+	Spillway apron width, in feet (m).
9	APLOSS	+	Approach-channel head loss in feet (m), at the design head.
10	PDPTH	+	Approach depth for ogee spillway, in feet (minimum of ten percent of design head).

NOTE- SQ and SE records to define the tailwater must follow this SG record. If a low-level outlet is specified, it should precede the SG record to prevent error message.

HEC-1 INPUT DESCRIPTION
STORAGE ROUTING DATA (S Records)

15.9 SB RECORD - DAM-BREACH SIMULATION

This record is required only to simulate a dam breach. Both an SB and an ST record are required for dam breach calculations.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SB	Record identification.
1	ELBM	+	Elevation, in feet (m), of the bottom of the breach when breach is at maximum size.
2	BRWID	+	Width, in feet (m), of the bottom of the breach when breach is at maximum size.
3	Z	+	Side slope of breach (z horizontal to 1 vertical).
4	TFAIL	+	Time, in hours, for breach to develop to maximum size.
5	FAILEL	+	Elevation, in feet (m), of water surface which will cause dam to fail (begins breach computation).

NOTE - Tables and plots of dam-breach hydrographs for each plan are generated automatically when IPRNT (IO-1 or KO-1) is less than 4. Those tables and plots show how well the breach hydrograph is represented by the normal time interval specified on the IT record.

15.10 SO RECORD - RESERVOIR VOLUME OPTIMIZATION

Data required for determining optimum volume of a reservoir are:

Low-Level Outlet data	SL record
Spillway data	SS record
Volume vs. Elevation data	SV, SE records
Costs vs. Volume data	SD record
Cost Factors, Range	SO record

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SO	Record identification.
1	IOPTR	+	Number of field on OS record which contains reservoir volume (overrides CREL on SS record).
		0, or Blank	Reservoir volume is not to be optimized. To be used during initial data set testing and to fix size of the reservoir.
2	RANCST	+	Proportion (decimal) of capital cost of reservoir that will be required for annual operation and maintenance.
3	RDSCNT	+	Discount or capital recovery factor (decimal) to compute equivalent annual cost from capital cost.
4	CAPMX	+	Maximum permissible storage capacity of reservoir in acre-feet (1000 cu m). Used as a constraint on optimization.
5	CAPMN	+	Minimum permissible storage capacity of reservoir in acre-feet (1000 cu m). Used as a constraint on optimization.

15.11 SD RECORD - RESERVOIR COST

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SD	Record identification.
1	RCST(1)	+	Reservoir capital cost corresponding to storage on SV record.
2-10	RCST(I)	+	Etc., up to 10 values.

16 UNIT GRAPH/KINEMATIC DATA (U Records)

Five different methods are available to transform rainfall/snowmelt excesses into runoff. Choose one technique for each subbasin.

16.1 UI RECORD - GIVEN UNIT GRAPH

The given unit hydrograph must have been derived for the time interval on the IT record (IT-1, IT-2). For example, if the time interval is 15 minutes, then a 15-minute unit hydrograph must be used.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	UI	Record identification.
1	QUNGR(1)	+	Unit hydrograph flow in cfs (cu m/sec) at end of first interval.
2	QUNGR(2)	+	Same for second interval.
3	QUNGR(3)	+	Etc., up to 150 values on successive UI records.

16.2 UC RECORD - CLARK UNIT GRAPH

Clark's time-area data is supplied on UA records if desired or a synthetic time-area curve is used if the UA record is not supplied.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	UC	Record identification.
1	TC	+	TC is the time of concentration in hours for the Clark unit hydrograph. Neither TC nor R are to be optimized. The value of R, Field 2, must also be positive. Value of variable is fixed at the given value. TC must be greater than or equal to NMIN (IT-1).
		-1	TC and R will both be optimized and the value of R (Field 2) must also be -1. The program will supply the starting value for the optimization scheme. OU record must have been previously supplied.
		-2	Ratio R/(TC+R) is to be read in the next field (2) and held constant. TC and R will both be optimized but the specified ratio will not be changed. Field 2 must be a positive ratio R/(TC+R). OU record must have been supplied.
		-X	Where X is the desired starting value for TC in the optimization and the starting value of R, Field 2, must also be supplied as a negative number. Cannot be equal to -1 or -2. X (when converted to minutes) must be greater than or equal to NMIN (IT-1). OU record must have been supplied.
2	R	+	R is the Clark storage coefficient in hours. No optimization of TC or R unless TC is equal to -2. If TC is -2, this field contains the constant value for the ratio R/(TC+R). R must be greater than or equal to 0.5 NMIN.
		-Y	Where Y is the desried starting value for R in the optimization and the starting value of TC must also be supplied as a negative number. Cannot be -1. R (when converted to minutes) must be greater than or equal to 0.5 NMIN.

16.3 US RECORD - SNYDER UNIT GRAPH

A time-area curve may be supplied on UA records, following this record if desired.

If it is desired to optimize the Snyder coefficient, an OU record must have been previously supplied. Optimization is accomplished using the Clark function to compute a continuous unit graph and then estimate the Snyder parameters.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	US	Record identification.
1	TP	+	Snyder's standard lag in hours. If in the optimization mode (OU record previously supplied), this variable is fixed at the given value and not optimized.
		-1	For optimization only (OU record previously supplied). Program will assume a starting value and optimize.
		-	Same as (-1) above except program uses this value (after a sign change) as the starting point for the optimization.
2	CP	+or-	Snyder's peaking coefficient, CP. See Field 1 for meaning of VALUE.

16.4 UA RECORD - TIME-AREA DATA

This time-area data may be used with either the Clark or Snyder methods. This data may be in any units, since area is scaled to the subbasin area and time is scaled to time of concentration. The areas contribute to runoff at the basin outlet at equally spaced time intervals. A synthetic time-area curve will be used if the UA record is not supplied.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	UA	Record identification.
1	QCLK(1)	+	Area in any units, that contributes at time zero (usually area of reservoir, if any) at concentration point.
2	QCLK(2)	+	Total area contributing runoff during first time interval. The time intervals may be of any length, but the same equal interval must be used for all points on this time area relationship, QCLK(I).
3	QCLK(3)	+	Cumulative area contributing runoff during second such interval.
4	QCLK(4)	+	Etc., up to 150 values.

16.5 UD RECORD - SCS DIMENSIONLESS UNIT GRAPH

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	UD	Record identification.
1	TLAG	+	SCS lag in hours. If in the optimization mode (OU record previously supplied), this variable is fixed at the given value and not optimized.
		-1	For optimization only (OU record previously supplied) program will assume a starting value and optimize.
		-	Same as (-1) above except program uses this value (after a sign change) as the starting point for the optimization.

16.6 UK/RK RECORDS - KINEMATIC WAVE EXCESS TRANSFORMATION

At least one UK record and one RK record are required to define characteristics for kinematic wave routing of precipitation excess to the subbasin outlet.

16.6.1 UK RECORD - KINEMATIC OVERLAND FLOW

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	UK	Record identification.
1	L	+	Overland flow length (ft) (m).
2	S	+	Representative slope (ft/ft) (m/m).
3	N	+	Roughness coefficient, see users manual.
4	A	+	Percentage of subbasin area that this element represents (percent).

If the percentage in Field 4 is less than 100, a second UK record must be supplied to describe another subcatchment contributing to the same collector system (RK record). The percentages for two subcatchments must add up to 100. Two separate subcatchments are typically used to describe the pervious and impervious portions of a subbasin.

The first and second loss rates specified on a previous L record will be used for the first and second UK subcatchments, respectively.

16.6.2 RK RECORD - SUBCATCHMENT KINEMATIC WAVE COLLECTOR/MAIN CHANNELS

Overland flow is routed to the subbasin outlet through channels described on the RK records. UK record(s) may be followed by up to 2 RK records representing successive collector channels and 1 RK record representing the main channel. The outflow from the first collector channel is inflow to the second, etc.

FIELD	VARIABLE	VALUE	DESCRIPTION.
Col 1+2	ID	RK	Record identification.
1	L	+	Channel length (ft).
2	S	+	Channel slope (ft/ft).
3	N	+	Channel roughness (Manning's n).
4	CA	+	Contributing area to a typical collector (sq mi or sq km). On the last RK record (main channel) the contributing area is assumed to be TAREA (BA-1).
5	SHAPE	TRAP	Trapezoidal channel, includes triangular and rectangular (default).
		DEEP	Deep rectangular (square) channel. Flow depth is approximately equal to channel width.
		CIRC	Circular channel shape. This cross section only approximates flow in a pipe or culvert. Flow depths are allowed to exceed the pipe diameter.
6	WD	+	Channel bottom width or diameter (feet). (Default value is zero.)
7	Z	+	Side slopes, if required. Default = 1 when WD, RK-6, is zero.
8	UPSTQ		This field is only used for main channels.
		YES	Upstream hydrograph will be routed through main channel, in addition to lateral inflow from this subbasin.
		NO	Do not route upstream hydrograph (default).

HEC-1 INPUT DESCRIPTION
PUMP DATA (W Records)

17 PUMP DATA (W Records)

A pump may be included as a part of level-pool reservoir routing to withdraw water from the system. Pumped water leaves the system and can be retrieved at another location (see WR record).

17.1 WP RECORD - PUMP OPERATION

WP records are added to storage routing data to simulate operation of a pumping station. Up to 5 pumps may be used at different elevations for a pump station. Pumped water leaves the system and cannot return at another location.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	WP	Record identification.
1	PMPON	+	Elevation in feet (m) at which is turned on.
2	PUMPQ	+	Pump flow in cfs (cu m/sec).
		0	Number of pumps is reset to zero. This is used for multiplan runs where a plan has no pumps.
3	PMPOFF	+	Elevation in feet (m) at which pump truns off.
4	ISTAD	AN	Name assigned to pumped flow for future retrieval with WR record.

The program checks the elevation at the end of the previous time interval to see if a pump should be turned on or off. The use of the WP record with the multiplan capability requires some special conventions. A single WP record with a non-zero (can be set very small) pump flow is required (PUMPQ, field 2) for Plan 1. All other plans (Plan 2, 3, etc.) must specify first a WP record with zero PUMPQ and them a second WP record with the desired pumping rate; for example:

Field	1	2	3	4
WP		0		
WP	843.5	3000		PMPQ1

17.2 WR RECORD - RETRIEVE PREVIOUSLY PUMPED FLOW

The WR record is used to retrieve a hydrograph which was created by a previous diversion. This hydrograph can then be treated like any other hydrograph in the system. Retrieval of a diversion hydrograph is a separate operation, so the WR record must be preceded by a KK record which identifies the hydrograph which will be retrieved.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	WR	Record identification.
1	ISTAD	AN	Station name corresponding to the name given a previous pump operation WP record.

17.3 WO RECORD - PUMP OPTIMIZATION

Data required for optimization of pump capacity are :

Storage Routing data	RS, S records
Pump Operation data	WP record
Cost vs. Capacity	WC, WD record
Cost Factors, Range	WO record

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	WO	Record identification.
1	IOPTP	+	Number of field on OS record which contains pump capacity (overrides PUMPQ on WP record).
		0, or Blank	Pump capacity on WP record is used.
2	PANCST	+	Proportion of capital cost of pump that will be required for annual operation and maintenance.
3	PDSCNT	+	Discount or capital recovery factor (decimal) to compute equivalent annual cost from capital cost.
4	PWRCST	+	Average annual power cost for capacity on OS or WP record. Cost is computed as a function of volume pumped for each size pump during the optimization.
5	PMPMX	+	Maximum permissible capacity of pumping plant in cfs (cu m/sec). Used as a constraint on optimization.
6	PMPMN	+	Minimum permissible capacity of pumping plant in cfs (cu m/sec). Used as a constraint on optimization.

17.4 WC RECORD - PUMP CAPACITY TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	WC	Record identification.
1	PCAP(1)	+	Pump capacity in cfs (cu m/sec) corresponding to PCST(1) on following WD record.
2-10	PCAP(I)	+	Etc., up to 10 values.

17.5 WD RECORD - PUMPING PLANT COST TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	WD	Record identification.
1	PCST(1)	+	Pumping plant capital cost corresponding to capacity on WC record.
2-10	PCST(I)	+	Etc., up to 10 values.

18 ECONOMIC DATA

Data for economic evaluation of flood damage is placed in the data set following the last hydrograph calculation and before the ZZ record. The first record in the economic data is an EC record, and all records between the EC and ZZ records are economic-data records.

A typical sequence for economic data is:

EC	Identifies following records as containing economic data
CN	Damage category names
PN*	Plan names
WN*	Watershed names
TN*	Township names
KK	Station identification to a unique KK record station in the previous river network simulation data
WT*	Watershed and township identification
FR	Frequency data
QF,SF*	Flows for frequency data
SQ*	Stages for rating curve
QS*	Flows for rating curve
QD,SD*	Flows or stages for damage data
DG	Damage data
KK, Etc.	For other damage centers in the river network

*Optional records

18.1 ** EC RECORD - ECONOMIC DATA

This record is required as the first record of economic data. It indicates that following records will contain data for calculation of expected annual damages.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	EC	Record identification.

18.2 ** CN RECORD - DAMAGE CATEGORY NAMES

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	CN	Record identification.
1	NCAT	+	The number of different damage categories (or types), e.g., urban, rural, utility, etc. Dimensioned for 10 categories.
2	NMCAT	AN	Alphanumeric name for first damage category. Damage data (DG records) must be identified by the order input here.
3-10	NMCAT	AN	Repeat as required by NCAT (CN-1). If NCAT is 10, the tenth name must be in Field 2 of the next record.

** These records are REQUIRED for flood damage analysis.

18.3 PN RECORD - PLAN NAMES

This record is used for description of the plans. One record is used for each plan. A maximum of 5 plans (PN records) may be used.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	PN	Record identification.
1	IPLN	+	Plan number to which this description applies.
2-10	NMPLN	AN	Alphanumeric description of above plan number (may use remainder of record).

18.4 WN RECORD - WATERSHED NAME

WN, TN,and WT records may be used to identify damage reaches by watershed and township. If this option is used expected annual damages will be listed in summary tables according to watershed and township.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	WN	Record identification.
1	NWAT	+	Number of watershed names to read. Dimensioned for 15 watersheds.
2	WID	AN	Alphanumeric name for first watershed.
3-10	WID	AN	Repeat for each watershed as required by NWAT (WN-1). If NWAT is greater than 9 the tenth name must be in Field 3 of the next record.

18.5 TN RECORD - TOWNSHIP NAME

See WN record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	TN	Record identification.
1	NTWN	+	Number of township names to read. Dimensioned for 15 townships.
2	TID	AN	Alphanumeric name for first township.
3-10	TID	AN	Repeat for each township as required by NTWN (TN-1). If NTWN is greater than 9 the tenth name must be in Field 3 of the next record.

18.6 ** KK RECORD - STATION COMPUTATION IDENTIFIER

The KK record must be repeated at the beginning of each damage reach.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	KK	Record identification. Default value for pathname part B if FR record not used (DSS use only).
1	ISTAQ	AN	Stream station location identification. It must correspond identically to the station identification used on the KK record in the hydrologic calculations, see page A-32.
2-10	NAME	AN	Station description.

18.7 WT RECORD - WATERSHED AND TOWNSHIP IDENTIFICATION

This record is used to identify the watershed and township for the stream station given on the KK record. Watershed and township designations will be the same for all stations until a new WT record is read.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	WT	Record identification.
1	IWAT	+	Integer corresponding to watershed name on WN record.
2	ITWN	+	Integer corresponding to township name on TN record.

18.8 ** *FR RECORD - FREQUENCY DATA*

This record is required for the first station. These frequency values will be used until changed by a new FR record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	FR	Record identification.
1		+	Pathname part B (DSS use only).
2	NFRQ	+	Number of exceedence frequency values to be read on FR records. Dimensioned for 18.
3	PFREQ	+	Exceedence frequency values (in percent). Must be in descending order (99,90,.....,10, etc.).
4-10	PFREQ	+	Repeat as required by NFRQ (FR-2). If there are more than 8 values, the ninth value must be in the first field of the next record.

** REQUIRED

18.9 QF RECORD - FLOWS FOR FREQUENCY CURVE

This record is required for each station if SF record is not provided.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	QF	Record identification.
1			Not used.
2			Not used.
3-10	QFRQ	+	Peak flow values corresponding to exceedence frequencies on FR record. Repeat as required by NFRQ (FR-2). If there are more than 8 values the ninth value must be in the first field of the next record.

18.10 SF RECORD - STAGES FOR FREQUENCY CURVE

This record should be used only if peak stage have been calculated in the hydrologic portion of HEC-1. This record is required for each station if QF record is not provided.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SF	Record identification.
1			Not used.
2			Not used.
3-10	SFRQ	+	Peak stages corresponding to exceedence frequencies on FR record. Repeat as required by NFRQ (FR-2). If there are more than 8 values, the ninth value must be in the first field of the next record.

18.11 SQ RECORD - STAGES FOR RATING CURVE

A stage-flow rating curve is required when stage-damage data are provided and stages are not computed in the river network simulation.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SQ	Record identification.
1			Not used.
2	NSTG	+	Number of stage values to be read on SQ records. Dimensioned for 18.
3-10	STGQ	+	Stage values correspding to flows on QS records. Values must be in ascending order. Repeat as required by NSTG (SQ-2). If there are more than 8 values, the ninth value must be in the first field of the next record.

18.12 QS RECORD - FLOWS FOR RATING CURVE

This record must be preceded by an SQ record.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	QS	Record identification.
1			Not used.
2			Not used.
3-10	QSTG	+	Flow values corresponding to stages on the SQ record. Repeat as required by NSTG (SQ-2). If there are more than 8 values, the ninth value must be in the first field of the next record.

18.13 SD RECORD - STAGES FOR DAMAGE DATA

Do not use this record if flow-damage data are to be used. Provide one SD record for each station. If stage-damage data change for each plan, a new SD record must be provided for each plan.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	SD	Record identification.
1			Not used.
2	NDMG	+	Number of stage values to be read. Dimensioned for 18.
3-10	SDMG	+	Stage values corresponding to damage on DG record. Values must be in ascending order. Repeat as required by NDMG (SD-2). If there are more than 8 values, the ninth value must be in field one of the next record.

18.14 QD RECORD - FLOWS FOR DAMAGE DATA

This record is required if SD record is not provided. If flow-damage data change for each plan, a new QD record must be provided for each plan.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	QD	Record identification.
1			Not used.
2	NDMG	+	Number of flow values to be read, dimensioned for 18.
3-10	QDMG	+	Flow values corresponding to damages on DG record. Values must be in ascending order. Repeat as required by NDMG (QD-2). If more than 8 values are to be read, the ninth value must be in field one of the next record.

18.15 ** DG RECORD - DAMAGE DATA

Damage data must be provided for each station. One (two if NDMG is greater than 8) record is required for each damage category.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DG	Record identification.
1			Not used.
2			A 3-digit number containing the PLAN and damage category in columns 14-16. Do not leave imbedded blanks.
	IPLN	+	Column 14 contains the 1-digit PLAN number to which this data applies.
		0	If column 14 is zero, the same data is used for all plans.
	ICAT	+	Columns 15 and 16 contain the 2-digit damage category number, e.g., 01, 02, ... Or 10.
3-10	DAMG	+	Damage values for category ICAT corresponding to stage (SD) or flow (QD). Repeat as required by NDMG (SD-2 or QD-2). If more than 8 values are to be read, the ninth value must be in field one of the next record.

**REQUIRED

HEC-1 INPUT DESCRIPTION
ECONOMIC DATA

18.16 EP RECORD - END OF PLAN

This record is required to indicate the end of data for a plan. The current plan will be evaluated and new data will be read for the next plan. If there are no additional data, the last data set read will be used to compute expected annual damages for any plan which has not been evaluated.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	EP	Record identification.

The following data conventions must be followed in using the EP record:

- The frequency curve (FR and QF/SF records) cannot be changed.
- The stages for a rating curve (SQ record) cannot be changed.
- The discharges for a rating curve (QS record) can be changed.
- The damage data (SD/QD and DG records) can be changed.
- Labels such as Plan Name (PN) and Damage Category Name (CN) can be changed. Plan Names could be specified for all plans in the first group of data (for the first plan).

18.17 LO RECORD - OPTIMIZE LOCAL-PROTECTION PROJECT

Data required for optimization of a local protection project or uniform degree of protection are:

Damage Data with Improvements	DU, DL records
Cost vs. Capacity Table	LC, LD records
Cost Factors, Range	LO record

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LO	Record identification.
1	IOPTLP	+	Number of field on OS record which contains capacity of local protection project.
		-	Number of field on OS record which contains uniform degree of protection.
2	XANCST	+	Proportion of local protection project capital cost that will be required for annual operation and maintenance.
3	XDSCNT	+	Discount factor (capital recovery factor) to compute equivalent annual cost from capital cost.
4	LPMX	+	Maximum permissible design capacity of local protection project in same units as QD or SD record. This is the design level associated with lower pattern damage function on DL records. Used as a constraint on optimization.
5	XLPMN	+	Minimum permissible design capacity of local protection project in same units as QD or SD record. This is the design level associated with upper pattern damage function on DU records. Used as a constraint on optimization.

18.18 LC RECORD - LOCAL-PROTECTION CAPACITY TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LC	Record identification.
1	XLCAP(1)	+	Local project design capacity in same units as QD or SD record.
2-10	XLCAP(I)	+	Etc., up to 10 values.

18.19 LD RECORD - LOCAL-PROTECTION COST TABLE

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	LD	Record identification.
1	XLCST(1)	+	Capital cost of local protection project corresponding to capacity on LC record.
2	XLCST(I)	+	Etc., up to 10 values.

18.20 DU RECORD - UPPER PATTERN DAMAGE TABLE

Pattern damage table for minimum design level (XLPMN) for local protection project.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DU	Record identification.
1			Not used.
2	ICAT	+	Damage category number.
3-10	TUDAMG	+	Damage values for category ICAT corresponding to stage (SD) or flow (QD) values. Repeat as required by NDMG (SD-2 or QD-2). If more than 8 values are to be read, the ninth value must be in Field 1 on the next record.

18.21 DL RECORD - LOWER PATTERN DAMAGE TABLE

Pattern damage table for maximum design level (XLPMX) for local protection project.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DL	Record identification.
1			Not used.
2	ICAT	+	Damage category number.
3-10	TLDAMG	+	Damage values for category ICAT corresponding to stage (SD) or flow (QD) values. Repeat as required by NDMG (SD-2 or QD-2). If more than 8 values are to be read, the ninth value must be in Field 1 on the next record.

18.22 DP RECORD - DEGREE OF PROTECTION

Degree of protection and target level are used as performance constraints on optimization of a flood control system.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	DP	Record identification.
1	DGPRT	+	Target degree of protection for this location in percent exceedence frequency.
2	TRGT	+	Target level for degree of protection corresponding to exceedence frequency, DGPRT, above. TRGT is elevation in feet (meters) if SF record is used, or TRGT is flow in cfs (cu m/sec) if QF record is used.

19 END-OF-JOB (** ZZ RECORD)

This record identifies the end of an HEC-1 job and causes summary computations and printout to occur. Another job may be started with another ID, IT, etc., record series if desired. If another job does not follow, the control is passed back to the computer operating system.

FIELD	VARIABLE	VALUE	DESCRIPTION
Col 1+2	ID	ZZ	Record identification.

**REQUIRED

20 HEC-1 INPUT RECORD SUMMARY FIELD

NO	1	2	3	4	5	6	7, ..., 10	Page
*LIST								A-7
*NOLIST								A-7
*FIX								A-7
*FREE								A-7
* (comment beginning in column 3								A-7
*DIAGRAM								A-7
ID		(TITLE)						A-8
IT	NMIN	IDATE	ITIME		NQ	NDDATE	NDTIME	A-9
IN	JXMIN	JXDATE	JXTIME					A-10
IM								A-11
IO	IPRT	IPLT	QSCAL					A-11
JP	NPLAN							A-12
JR	IRTIO	RTIO	. . .					A-13
JD	STRM	TRDA						A-14
OU	IFORD	ILORD						A-15
OR	IFORD	ILORD						A-15
OS	VAR	. . .						A-16
OF	FCAP	FDCNT	FAN					A-17
OO	ANORM	CNST						A-18
VS	ISTA	. . .						A-19
VV	SMVAR	. . .						A-20
BA	TAREA	SNAP						A-21
BF	STRTQ	QRCSN	RTIOR					A-22
BR	ISTA							A-23
BI	ISTA	IQIN						A-23
DR	ISTAD							A-24
DT	ISTAD	DSTRMX						A-25
DI	DINFLO	. . .						A-26
DQ	DIVFLO	. . .						A-26
DO	IOPTD	DANCST	DDSCNT	DVRMX	DVRMN			A-27
DC	DCAP	. . .						A-28
DD	DCST	. . .						A-28
HB	NQB(1)SUMB(1)		NQB(2)SUMB(2)		. . .			A-29
HC	ICOMP	TAREA						A-30
HL	TAREA							A-30
HQ	QSTG							A-31
HE	STGQ							A-31

Continued

HEC-1 INPUT RECORD SUMMARY

KK	ISTAQ	NAME								A-32
KM										A-32
KO	JPRT	JPLT	QSCAL	IPNCH	ITAPE	ISAV1	ISAV2	TIMINT		A-33
KF	FLOTQ	IFMT								A-35
KP	ISTM									A-36
LU	STRTL	CNSTL	RTIMP							A-37
LE	STRKR	DLTKR	RTIOL	ERAIN	RTIMP					A-38
LM	STRKS	RTIOK								A-39
LS	STRTL	CRVNBR	RTIMP							A-40
LH	FC	GIA	SAI	BEXP	SAI					A-41
MA	AREA	SNO	ANAP							A-42
MC	TLAPS	COEF	FRZTP							A-43
MT	TEMPR	. . .								A-44
MS	SOL	. . .								A-44
MD	DEWPT	. . .								A-45
MW	WIND	. . .								A-45
PB	STORM									A-48
PI	PRCPR	. . .								A-49
PC	PRCPR	. . .								A-49
PG	ISTAN	PRCPN	ANAPN	ISTANX						A-50
PH	PFREQ	TRSDA	PNHR	. . .						A-51
PM	PMS	TRSPC	TRSDA	SWD	R6	R12	R24	R72	R96	A-53
PS	SPFE	TRSPC	TRSDA	SWD						A-55
PR	ISTR	. . .								A-56
PT	ISTN	. . .								A-57
PW	WTR	. . .								A-57
QO	QO	. . .								A-58
QI	Q	. . .								A-59
QS	QS	. . .								A-59
QP	QP	. . .								A-60
RN										A-61
RL	QLOSS	CLOSS								A-61
RM	NSTPS	AMSKK	X							A-62
RS	NSTPS	ITYP	RSVRIC	X						A-63
RC	ANL	ANCH	ANR	RLNTH	SEL	ELMAX				A-65
RX	X	. . .								A-66
RY	Y	. . .								A-67
RK	L	S	N	---	SHAPE	WD	Z			A-68
RT	NSTPS	NSTDL	LAG							A-69

Continued

HEC-1 INPUT RECORD SUMMARY

SE	ELEV	. . .									A-72
SQ	DISQ	. . .									A-72
SL											A-73
SS	CREL	SPWID	COQW	EXPW							A-74
ST	TOPEL	DAMWID	COQD	EXPD							A-75
SW	WIDTH										A-76
SE	ELVW	. . .									A-76
SG	IABCOA	ISPITW	ISPCTW	NGATES	SS	DESHD	APEL	APWID	APLOSS	PDPTH	A-77
SB	ELBM	BRWID	Z	TFAIL	FAILEL						A-79
SO	IOPTR	RANCST	RDSCNT	CAPMX	CAPMN						A-80
SD	RCST	. . .									A-81
UI	QUNGR	. . .									A-82
UC	TC	R									A-83
US	TP	CP									A-84
UA	QCLK	. . .									A-85
UD	TP										A-86
UK	L	S	N	A							A-87
RK	L	S	N	CA	SHAPE	WD	Z	UPSTQ			A-88
WP	PMPON	PUMPQ	PMPOFF								A-89
WR	ISTAD										A-90
WO	IOPTP	PANCST	PDSCNT	PWRCST	PMPMX	PMPMN					A-91
WC	PCAP										A-92
WD	PCST										A-92
EC											A-94
CN	NCAT	NMCAT	. . .								A-94
PN	IPLN	NMPLN									A-95
WN	NWAT	WID	. . .								A-96
TN	NTWN	TID	. . .								A-96
KK	ISTAQ	NAME	. . .								A-97
WT	IWAT	ITWN									A-98
FR	NFRQ	PFREQ	. . .								A-98
QF	---	---	QFRQ								A-99
SF	---	---	SFRQ	. . .							A-99
SQ	---	NSTG	STGQ	. . .							A-100
QS			QSTG	. . .							A-100
SD	---	NDMG	SDMG	. . .							A-101
QD	---	NDMG	QDMG	. . .							A-101
DG	---	IPLN	DAMG	DAMG	. . . .						A-102
EP											A-103
LO	IDPTLP	XANCST	XDSCNT	LPMX	XLPMN						A-104
LC	XLCAP										A-105
LD	XLCST										A-105
DU		ICAT	TUDAMG								A-106
DL		ICAT	TLDAMG								A-106
DP	DGPRT	TRGT									A-107
ZZ											A-108

Appendix B

HEC-1 USAGE WITH HEC DATA STORAGE SYSTEM

B.1 Introduction

The HEC Data Storage System (DSS) (HEC, 1983) has been developed to allow transfer of data between HEC programs. The data are identified by unique labels called PATHNAMEs which are specified when the data are created or retrieved. Thus, a hydrograph computed by HEC-1 can be labeled and stored in DSS for later retrieval as input data to HEC-5, for instance. The DSS has several utility programs for manipulating data. These programs enable editing of information, changing pathnames, purging unwanted data sets and insertion of other data sets. Graphic and tabular portrayal of DSS data are also available.

The interested user is encouraged to contact HEC for up-to-date information and documentation on the DSS and companion utility programs. It should be emphasized, however, that application of DSS does not require familiarity with all the intracacies of the general purpose DSS system. The DSS system capability is presently only operational on Corps-supported computer systems. Work is underway to make the DSS available on other computer systems in the near future.

B.1.1 Pathnames for Identifying Data

The pathname is separated into six different parts by a slash "/" delimiter so that each part refers to a specific, unique identifier. One convention that has been developed to simplify definition of pathname parts for typical hydrologic data is shown below:

PATHNAME PART	DESCRIPTION
A	General identifier (e.g., river basin or project name)
B	Location or gage number
C	Data type such as FLOW, ELEV, PRECIP, etc.
D	Beginning date for data (blank for HEC-1 usage)
E	Data year (blank when manipulating time-series data with HEC-1)
F	Additional user-defined description to further define the data, such as PLAN A, FORECAST 1, etc.

In general, DSS software finds the data associated with a pathname by using each of the six parts to search the DSS file structure, which is hierarchical, or "tree-like." An example of a pathname for a time-series data record is:

/MISSISSIPPI/CAIRO/STAGE/01JAN85/HOUR/OBSERVED/

This pathname would represent a block of observed hourly stages on the Mississippi River at Cairo for all or part of 1985 beginning January 1.

B.1.2 Access to/from DSS

HEC-1 can interact with DSS as follows: retrieve runoff parameters stored in DSS by program HYDPAR (Corps of Engineers, 1978); retrieve and/or store time-series data; and store flow-frequency curves. The access to this data is accomplished using the BZ, ZR and ZW records in the HEC-1 input data set.

The ZR and ZW records are used in a somewhat different manner depending on which type of the above data is being manipulated. In each case, however, these records are used to specify the appropriate DSS pathname. The BZ record is used specifically for the retrieval of runoff parameters.

The HEC-1 input conventions do not require that information be specified for all parts of the pathname. In general, pathname part D is left blank and other parts are only used as required by the type of data being manipulated. Part D is obtained by requiring that the date in field 2 of the IT record be specified.

B.2 Retrieval of HYDPAR Runoff Parameters

Retrieval of runoff parameters is accomplished with a record sequence as shown in Table B.1. In this instance the BZ record is substituted for the record used to specify the basin area (BA record) and the ZR record is used to retrieve either the SCS loss rate and unit graph data (LS and UD records) or the Snyder unit graph data (US Record). If the Snyder unit graph is retrieved from DSS, the loss rate must be supplied separately in the HEC-1 input data.

Table B.1

Record Sequence to Access HYDPAR Runoff Parameter Data from DSS

ID	
IT	
IO	
JP	(required for multiplan simulation)
JR	(required for multiratio simulation)
:	
KK	
KP	(only required if multiplan simulation)
ZR	
BZ	
L	(only required if Snyder unit graph is used)
KP	(only required if multiplan simulation)
ZR	
BZ	
:	
:	
KK	
:	
ZZ	

The BZ and ZR records can be used in either fixed or free format modes independent o. the input mode for the rest of the data. As an example of the BZ and ZR record formats, consider the pathname,

```
   A         B        E      F
/MISSISSIPPI/CAIRO///1985/PLAN A/
```

the BZ and ZR record would then have the following fixed form:

Field	Variable Value	
0	ID=BZ	
1	ISTA=CAIRO	(Part B)

Field	Variable Value	
0	ID=ZR	
1-2	PRNAME=MISSISSIPPI	(Part A)
3-5	PLNAME=PLAN A	(Part F)
6	IYR=1985	(Part E)
7	CODE=BZ	(right justified columns 55-56)
8	PLAN=1	(corresponds to appropriate plan)

or in free format:

```
BZ     B=CAIRO
ZR     A=MISSISSIPPI     E=1985     F=PLAN A
```

Note, that only parts A, E and F are entered on the ZR record. Pathname part B is entered on the BZ record and parts C and D are left blank.

The format and content of the BZ and ZR records for HYDPAR parameter retrieval in fixed format are as follows:

BZ record - HYDPAR Parameter Retrieval (Fixed Format Option)

Field	Variable	Value	Description
0	ID	BZ	Record identification.
1	ISTA	AN*	Station name (part B of pathname). This must be identical to the station name used in the HYDPAR run.

ZR record - HYDPAR Parameter Retrieval (Fixed Format Option)

Field	Variable	Value	Description
0	ID	ZR	Record identification.
1-2	PRNAME	AN	Study, basin, etc. name (part A of pathname).
3-5	PLNAME	AN	Alternative name or designation (part F of pathname).
6	IYR	+	Data year (part E of pathname) in columns 45-48.
7	CODE	BZ	Record type for DSS read; columns 55-56.
8	PLAN	+	Plan number. Enter a right-justified integer.

* AN=Alphanumeric data

and the input for the free format is as follows:

<u>BZ record</u> - HYDPAR Parameter Retrieval (Free Format Option)

Field	Variable	Value	Description
0	ID	BZ	Record identification.
1	-	B=AN	Station name (part B of pathname). This must be identical to the station name used in the HYDPAR run.

<u>ZR record</u> - HYDPAR Parameter Retrieval (Free Format Option)

Field	Variable	Value	Description
0	-	ZR	Record identification.
1	-	A=AN	Study, basin, etc. name, beginning or after column 4 (part A of pathname).
2	-	E=AN	Data year (part E of pathname)
3	-	F=AN	Alternative name or designation (part F of pathname).

B.3 Retrieval of Time-Series Data

The time-series data that can be retrieved with the ZR record are cumulative or incremental precipitation and discharge hydrographs, corresponding to data which can be specified on PC, PI, QI or QO records. The record sequence needed to perform this operation is shown in Table B.2. This option is useful in either stream network or multiplan-multiratio simulations.

Table B.2

Record Sequence to Read or Write DSS Time-Series Data

ID	
IT	
IO	
JP	(required for multiplan simulation)
JR	(required for multiratio simulation)
:	
KK	
:	other input data
KP	(required for multiplan simulation)
ZR or ZW	
:	other input data
KK	
:	
ZZ	

Pathname parts D and E are not used. The program uses information on the IT record in the place of information normally specified with parts D and E. As an example application, consider the pathname needed to retrieve an observed hydrograph:

<u>A</u> <u>B</u> <u>C</u> <u>F</u>
/MISSISSIPPI/CAIRO/FLOW///OBS/

Retrieval of that data requires a ZR record as follows:

ZR =QO A=MISSISSIPPI B=CAIRO C=FLOW F=OBS

where all the pathname part descriptors and the type of time-series data is specified by the "=QO". Note that the additional parameter "=aa", must set the value "aa" equal to PC, PI, QI or QO to indicate the type of time-series data.

In contrast to the HYDPAR data retrieval, the ZR time series retrieval format is used with the free field format input for the rest of the data. Further, for multiplan simulations, a KP record must be used with each ZR record for each plan. The program will then retrieve a single time-series sequence with each plan and apply the ratios specified on the JR record. The retrieved time series data will be interpolated from any standard DSS time interval to the computation interval of the program.

The format and content of the ZR record are as follows:

<u>ZR record</u> - Retrieval of Time-Series Data (Free Format Required)

Field	Variable	Value	Description
0	ID	ZR	Record identification.
1	-	=AN	HEC-1 record identifier. It must begin in or after column 4 and be identical to one of the following: =PC Cumulative precipitation. =PI Incremental precipitation. =QI Input hydrograph. =QO Observed hydrograph.
2	-	A=AN	Pathname part A - usually the study, project, or river basin name.
3	-	B=AN	Pathname part B - usually the location name. If only part B is not specified, it will be defined by the first field in the preceding KK record.
4	-	C=AN	Parameter name (options are FLOW or PRECIP)

Field	Variable	Value	Description
5	-	E=AN	Time interval of DSS data (e.g., E=15MIN) computation interval specified on IT record. Must be a standard DSS time interval; 5MIN, 10MIN, 15MIN, 30MIN, 1HOUR, 2HOUR, 3HOUR, 4HOUR, 6HOUR, 1DAY (see HECDSS User's Guide and Utility Program Manuals, pg. C-3).
6	-	F=AN	Additional parameter qualifier (e.g., OBS for observed flow).

B.4 Storing Time-Series Data

Flow, storage or stage time-series data may be stored in DSS using the ZW record. The ZW convention is similar to the use of the ZR record (see Table B.2). Using the previous example for the ZR record, the ZW record specifies the pathname as:

ZW A=MISSISSIPPI B=CAIRO C=FLOW F=OBS

The pathname part C dictates which type of data (flow, storage or stage) is written to DSS. If more than one type of data is to be written as part of a DSS command sequence, then only part B and C need be repeated. Using the above example, if an addition to flow, stage and storage are to be written, then the following records would be specified:

ZW B=CAIRO C=STOR
ZW B=CAIRO C=STAGE

Note that parts A and F need not be repeated. If part B were not used, then the station name on the KK record would be used for location name.

As in the case of the ZR record, the ZW data may be used in the free field format mode. However, the application of the ZW record differs slightly in that for each plan all ratios of the computed time series are saved (as opposed to a single time-series trace for the ZR record). The pathname part F need not be repeated for each plan, as the program automatically assumes the description given for plan 1. As in the case of the ZR record, a KP record must be used with each ZW record for each plan.

ZW record - Writing Time-Series Data to DSS (Free Format Required)

Field	Variable	Value	Description
0	ID	ZW	Record identification.
1	-	A=AN	Pathname part A - beginning in or after column 4.
2	-	B=AN	Pathname part B - usually study, project or river basin name. If part B is not specified, it will be defined by the first field in the preceding KK record.

Field	Variable	Value	Description
3	-	C=AN	Parameter name - it must be identical to one of the following: C=FLOW C=STORE C=STAGE C=ELEV
4	-	F=AN	Additional parameter qualifier (e.g., OBS for observed flow). Required for plan 1.

B.5 Storing Flow- or Stage-Frequency Curves

Flow- or stage-frequency curves may be stored in DSS using the ZW record (see Table B.3). This option is most useful with multiplan flood damage computations; however, flood damage computations are not required in order to write the flow-frequency curves to DSS. Although a single frequency curve may be stored using a single plan, it is probably easier to directly input a single frequency curve to the EAD program (Hydrologic Engineering Center, 1979a).

Table B.3

Record Sequence to Store Flow-Frequency Curves in DSS

ID	
IT	
IO	
JP	
JR	
:	
KK	
:	
EC	
MK	
CM	(only required for flood damage computation)
PM	(repeat PM, ZW for each plan, maximum 5)
ZW	
:	
QF	(required to write frequency curves)
FR	
QD	(only required for flood damage computation)
DG	
:	
ZZ	

Flow or stage frequency data are stored for each plan as indicated by a PM, ZW record combination. In addition, a frequency curve for plan 1 on the QF or SF, FR records is required. The economic calculation will be carried out if additional information on flood damage is included (e.g., CM, QD, and DG records). For frequency curve storage, the ZW record utilizes a fixed or free field format to specify the pathname. Either format mode may be used independently of the input mode for the rest of the data.

ZW record - Writing Flow Frequency Curves to DSS (Fixed Format Option)

Field	Variable	Value	Description
0	-	ZW	Record identification.
1-2	PRNAME	AN	Study, project or basin name (part A of the DSS pathname).
3-5	PLNAME	AN	Study or plan alternative (part F of the DSS pathname).
6	IYR	AN	Data year (part E of the DSS pathname). The data year must be entered in columns 45-48.

ZW record - Writing Flow Frequency Curves to DSS (Free Format Option)

Field	Variable	Value	Description
0	-	ZW	Record identification.
1	-	A=AN	Study, project or basin name (pathname part A) beginning in or after column 4.
2	-	E=AN	Data year (part E of the DSS pathname).
3	-	F=AN	Study or plan alternative (part F of the DSS pathname).

This record must always follow a PN record in the economic data. The conventions for specifying this record are analogous to the reading of HYDPAR data.

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