APPENDIX "O"
FLOW ROUTING

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APPENDIX "O"
FLOW ROUTING

A. **INTRODUCTION** There are two types of routing: hydrologic (or lumped flow routing); and hydraulic (or distributed flow routing). Hydrologic routing involves calculation of flow as a function of time only at a particular location, while hydraulic routing involves calculation of flow as a function of space and time throughout the system. Hydrologic routing involves the continuity equation and either an analytical or empirical relationship between storage within the reach and discharge at the outlet. Hydraulic routing involves backwater calculation capability, and solution of partial differential equations of unsteady open channel flow. This appendix pertains only to hydrologic routing, except that the Muskingum-Cunge method will also be discussed, which some classify as a hydrologic method, and others a hydraulic method.

There are many routing methods, both for reservoir and channel routing. HEC-1 has the capability of using the following methods:

i) **Reservoir Routing**
- Working R&D
- Modified Puls
- Level Pool Reservoir

ii) **Channel Routing**
- Channel Losses
- Average-Lag (Tatum; Straddel-Stagger)
- Kinematic Wave
- Modified Puls (essentially Normal Depth-Storage in HEC-1)
- Muskingum
- Muskingum-Cunge
- Normal Depth-Storage (same as Modified Puls in HEC-1)

Only the latter two types of reservoir routing and latter four types of channel routing will be discussed further herein, which discussion is limited to an overview level of detail. More detailed information regarding method theory may be found in other references. Although some information is given regarding application, detailed descriptions of input data are reserved for Appendix "P", where use in HEC-1 is discussed. However, information provided herein may be useful in understanding the various methods, and in method selection for a given application.

B. **RESERVOIR ROUTING** There are two types of reservoir routing that will be briefly discussed, although application in HEC-1 is similar for both. With both methods, a level water surface across the reservoir is assumed. This assumption may be reasonable unless the reservoir is excessively long and/or the inflow hydrograph is rapidly changing with time. The inflow hydrograph must be known, and it is desired to compute the outflow hydrograph from the reservoir. Assuming that all gate and spillway openings are fixed, a unique relationship between storage and outflow can be developed, as shown in Figure O-1.

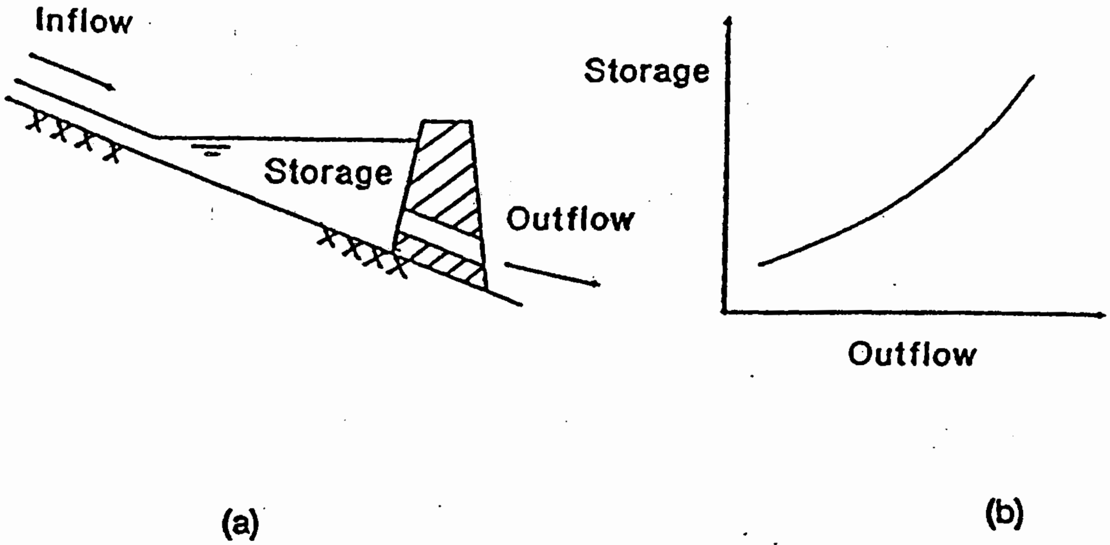

FIGURE O-1
Reservoir Storage Routing

1. <u>Modified Puls Reservoir Routing</u> The Modified Puls method applied to reservoirs, also known as the Storage Indication Method, consists of a repetitive solution of the continuity equation. Storage-outflow information must be provided. HEC-1 records used are shown in the "Given Storage-Outflow" column of Table P-6 in Appendix "P", or Table 10.7 in the HEC-1 Users Manual.

2. <u>Level Pool Reservoir Routing</u> This method may be used for conditions where there are uncontrolled (fixed) overflow spillways, and for limited gated spillway conditions. Essentially, the same HEC-1 records used for the Modified Puls reservoir routing are required, with the addition of records that define spillways, low level outlets, dam overtopping, dam break, and pumping, when involved. Reference is made to Table P-7 in Appendix "P", or Table 10.8 in the HEC-1 Users Manual.

3. <u>Input Data</u> Reservoir elevation/area or elevation/volume relationship must be known. Reservoir outflow may be computed by HEC-1, including a single (or composite) low-level outlet and a spillway. However, HEC-1 outlet procedures do not allow much flexibility nor ease of use for most reservoir applications. It usually is easier and better to calculate stage-discharge capability by some other means than HEC-1, and enter the stage-discharge information by using stage/discharge information on HEC-1 SQ/SE records.

C. FLOOD WAVE VELOCITY The flood wave velocity (V_W) is greater than the average velocity at a given cross section for a given discharge. V_W is an important parameter in several channel routing methods, and is therefore discussed here.

The flood wave velocity can be estimated by a number of different techniques, four of which are discussed in the USBR's Flood Hydrology Manual. Perhaps the simplest means of estimating flood wave velocity is to estimate the average velocity (VAVG) and multiply it by a ratio. The average velocity can be calculated from Manning's equation with a representative discharge and cross section for the routing reach. For various channel shapes, the flood wave velocity has been found to be a direct ratio of the average velocity, as provided in Table O-1.

Table O-1
Flood Wave to Average Velocity

Channel Shape	Ratio VW/VAVG
Wide rectangular	1.67
Wide parabolic	1.44
Triangular	1.33
For natural channels, an average ratio of 1.5 is suggested.	

D. CHANNEL ROUTING: MODIFIED PULS METHOD

1. General Description Routing in natural rivers is complicated by the fact that storage in a river reach is not a function of outflow alone. The water surface in a channel, during the passing of a flood wave, is not uniform. The storage and water surface slope within a river reach, for a given outflow, is greater during the rising stages of a flood wave than during the falling. Therefore, the relationship between storage and discharge at the outlet of a channel is not a unique relationship, rather it is a looped relationship.

   In order to apply the Modified Puls method to a channel routing problem, the storage within the river reach is approximated with a series of cascading reservoirs (Figure O-2). Each reservoir is assumed to have a level pool, and therefore a unique storage-discharge relationship. The cascading reservoir approach is capable of approximating the looped storage-outflow effect when evaluating the river reach as a whole.

2. Determination of the Storage-Outflow Relationship Determining the storage-outflow relationship for a river reach is a critical part of the Modified Puls procedure. In river reaches, storage-outflow relationships can be determined using one of the procedures discussed below.

a. Steady-flow water surface profiles, computed over a range of discharges, can be used to determine storage outflow relationships in a river reach.

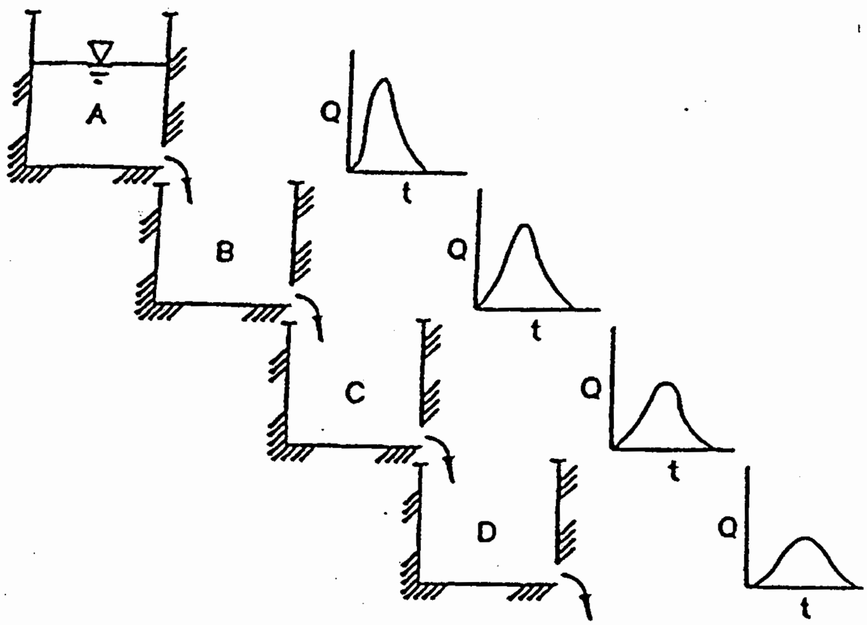

FIGURE O-2
Cascade of Reservoirs, Depicting Storage Routing in a Channel

b. Observed water surface profiles, obtained from high water marks, can be used to compute storage-outflow relationships. Sufficient stage data over a range of floods is required for this type of calculation; however, it is not likely that enough data would be available over the range of discharges needed to compute an adequate storage discharge relationship. If a few observed profiles are available, they can be used to calibrate a steady-flow water surface profile model for the channel reach of interest. Then the water surface profile model could be used to calculate the appropriate range of values to calculate the storage-outflow relationship.

c. Normal depth associated with uniform flow does not exist in natural streams; however, the concept can be used to estimate water depth and storage in natural rivers if uniform-flow conditions can reasonably be assumed. With a typical cross section, Manning's equation is solved for a range of discharges, given appropriate "n" values and an estimated slope of the energy grade line. Under the assumption of uniform-flow conditions, the energy slope is considered equal to the average channel bed slope; therefore, this approach should not be applied in backwater areas.

d. **Observed inflow and outflow hydrographs** can be used to compute channel storage by an inverse process of flood routing. When both inflow and outflow are known, the change in storage can be computed, and from that a storage vs. outflow function can be developed. Tributary inflow, if any, must also be accounted for in this calculation. The total storage is computed from some base level storage at the beginning or end of the routing sequence.

e. **Inflow and outflow hydrographs** can also be used to compute routing criteria through a process of iteration in which an initial set of routing criteria is assumed, the inflow hydrograph is routed, and the results are evaluated. The process is repeated if necessary until a suitable fit of the routed and observed hydrograph is obtained.

Of the five available procedures for determining the storage outflow relationship, only the normal depth (or normal depth-storage) procedure is available in HEC-1.

3. **Determining the Number of Routing Steps** In reservoir routing, the Modified Puls method is applied with one routing step or reach. This is under the assumption that the travel time through the reservoir is smaller than the computation interval Δt. In channel routing, the travel time through the river reach is often greater than the computation interval. When this occurs the channel must be broken down into smaller subreaches or routing steps in order to simulate the flood-wave movement and changes in hydrograph shape. The number of steps (or subreaches) affects the attenuation of the hydrograph and should be obtained by calibration. The maximum amount of attenuation will occur when the channel routing computation is done in one step. As the number of routing steps increases, the amount of attenuation decreases. An initial estimate of the number of routing steps (NSTPS parameter in HEC-1) can be obtained by dividing the total flood wave travel time (K) for the reach by the computation interval Δt (NMIN in HEC-1).

$$K = \frac{L}{V_w}$$

$$NSTPS = \frac{K}{\Delta t}$$

Where:

	K	= total travel time through the reach
	L	= channel reach length
	V_w	= velocity of the flood wave
	NSTPS	= number of routing steps (HEC-1 RS record, field one)

The time interval Δt is usually determined by ensuring that there is a sufficient number of points on the rising side of the inflow hydrograph. A general rule of thumb is that the computation interval should be less than 1/5 of the time of rise (t_r) of the inflow hydrograph.

$$\Delta t \leq \frac{t_r}{5}$$

More discussion on parameter selection as it pertains to a HEC-1 model is provided in Appendix "P", Section V-I-1.

E. CHANNEL ROUTING: MUSKINGUM METHOD

1. General Description The Muskingum method was developed to directly accommodate the looped relationship between storage and outflow that exists in rivers. With the Muskingum method, storage within a reach is visualized in two parts: Prism Storage and Wedge Storage. Prism storage is essentially the storage under the steady-flow water surface profile. Wedge storage is the additional storage under the actual water surface profile. As shown in Figure O-3, during the rising stages of the flood wave the wedge storage is positive and added to the prism storage. During the falling stages of a flood wave the wedge storage is negative and subtracted from the prism storage.

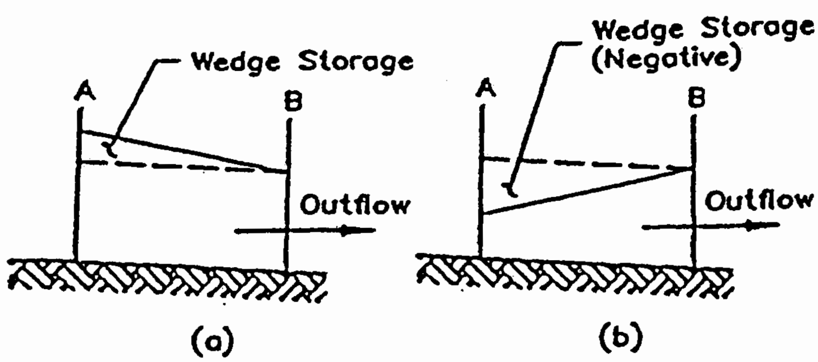

FIGURE O-3
Muskingum Prism and Wedge Storage Concept

2. Development of the Muskingum Routing Equation Prism storage is computed as the outflow (O) times the travel time through the reach (K). Wedge storage is computed as the difference between inflow and outflow (I-O) times a weighting coefficient X and the travel time K. The coefficient K corresponds to the travel time of the flood wave through the reach. The parameter X is a dimensionless value expressing a weighting of the relative effects of inflow and outflow on the storage (S) within the reach. Thus, the Muskingum method defines the storage in the reach as a linear function of weighted inflow and outflow:

$$S = \text{prism storage} + \text{wedge storage}$$

$$S = KO + KX(I-O)$$

$$S = K[XI + (1-X)O]$$

Where: S = Total storage in the routing reach
O = Rate of outflow from the routing reach
I = Rate of inflow to the routing reach
K = Travel time of the flood wave through the reach
X = Dimensionless weighting factor that is an index of wedge storage, ranging from 0.0 to 0.5

The quantity in the brackets of the above equation is considered an expression of weighted discharge. When X=0.0, the equation reduces to S = KO, indicating that storage is only a function of outflow, which is equivalent to level-pool reservoir routing with storage as a linear function of outflow. When X=0.5, equal weight is given to inflow and outflow, and the condition is equivalent to a uniformly progressive wave that does not attenuate. Thus, "0.0" and "0.5" are limits on the value of X, and within this range the value of X determines the degree of attenuation of the flood wave as it passes through the routing reach. A value of "0.0" produces maximum attenuation, and "0.5" produces pure translation with no attenuation.

Given an inflow hydrograph, a selected computation interval Δt, and estimates for the parameters K and X, the outflow hydrograph can be calculated.

In an ungauged situation a value for K can be estimated as the travel time of the flood wave through the routing reach, as discussed in Section C, page O-2. Once the wave speed has been estimated, the travel time (K) can be calculated by:

$$K = \frac{L}{V_W}$$

Where: V_W = flood wave velocity, ft/s (see Section C, page O-2); and
L = length of the routing reach, ft.

Estimating the Muskingum X parameter in an ungauged situation can be very difficult. X varies between 0.0 and 0.5, with 0.0 providing the maximum amount of hydrograph attenuation and 0.5 no attenuation. Experience has shown that for channels with mild slopes and flows that go out of bank, X will be closer to 0.0. For steeper streams, with well defined channels that do not have flows going out of bank, X will be closer to 0.5. Most natural channels have X values between O.1 and O.3, but much room is left for "engineering judgement." One equation that can be used to estimate the Muskingum X coefficient in ungauged areas has been developed by Cunge (1969). This equation is taken from the Muskingum-Cunge channel routing method, which is described hereinafter. The equation is written as follows:

$$X = \frac{1}{2}\left(1 - \frac{Q}{BSV_W \Delta x}\right)$$

Where: Q = reference flow from the inflow hydrograph;
V_W = flood wave speed;
S = friction slope or bed slope;
B = top width of the flow area;
Δx = length of the routing subreach; and
X = Muskingum coefficient with an absolute range of 0.0 to 0.5, so any value obtained by the above equation must be adjusted to the closest acceptable value.

The choice of which flow rate to use in this equation is not completely clear. Experience has shown that a reference flow based on average values (midway between the base flow and the peak flow) is in general the most suitable choice. Reference flows based on peak flow values tend to accelerate the wave much more than it would in nature, while the converse is true if base flow reference values are used (Ponce, 1983).

3. <u>Determining the Number of Routing Steps</u> The Muskingum equation has a constraint related to the relationship between the parameter K and the computation interval Δt.

Ideally, the two should be equal, but Δt should not be less than 2KX to avoid negative coefficients and instabilities in the routing procedure.

A long routing reach should be subdivided into subreaches or routing steps (NSTPS parameter in HEC-1) so that the travel time through each subreach is approximately equal to the routing interval Δt (NMIN in HEC-1). That is:

$$\text{Number of subreaches or routing steps (NSTPS)} = \frac{K}{\Delta t}$$

This assumes that factors such as channel geometry and roughness have been taken into consideration in determining the length of the routing reach and the travel time K.

More discussion on parameter selection as it pertains to a HEC-1 model is provided in Appendix "P", Section V-I-2.

F. <u>CHANNEL ROUTING: MUSKINGUM-CUNGE METHOD</u>

1. <u>General Description</u> The Muskingum-Cunge channel routing technique is a non-linear coefficient method that accounts for hydrograph diffusion based on physical channel properties and the inflowing hydrograph. The advantages of this method over hydrologic routing techniques are: (1) the parameters of the model are more physically based, which

allows a reasonable expectation of accuracy in ungauged streams without time-consuming and cumbersome parameter calibration; (2) the method has been shown to compare well against full unsteady flow equations over a wide range of flow situations (Ponce, 1983); and (3) the solution is independent of the user specified computation interval (HEC-1 NMIN value on the IT record). The major limitations of the Muskingum-Cunge technique are that it cannot account for significant backwater effects and the method begins to diverge from full unsteady flow solutions when very rapidly rising hydrographs are routed through flat channel sections (less than 2 ft/mi). Also, the Muskingum-Cunge method is not amenable for channel routing if channel transmission losses are to be included in the watershed model (HEC-1 RL record usage).

Values for Δt and Δx are chosen for accuracy and stability. First, Δt should be evaluated by looking at the following 3 criteria and selecting the smallest value: (1) the user defined computation interval; (2) the time of rise of the inflow hydrograph divided by 20 ($^{Tr}/_{20}$), and (3) the travel time through the channel reach. This is done automatically in HEC-1.

2. **Data Requirements** Data for the Muskingum-Cunge method consist of the following:

   a. Representative channel cross section;

   b. Reach length, L, in feet;

   c. Manning roughness coefficients, n (for main channel and overbanks); and

   d. Friction slope or channel bed slope.

The method can be used with a simple cross section (i.e. trapezoid, rectangle, square, triangle, or circular pipe), or a more detailed cross section (i.e. cross sections with a left overbank, main channel, and a right overbank). The cross section is assumed to be representative of the entire routing reach. If this assumption is not adequate, the routing reach should be broken up into smaller subreaches with representative cross sections for each. Reach lengths are measured directly from topographic maps. Roughness coefficients (Manning's n) must be estimated for main channels as well as overbank areas. Reference is made to Appendix "F". If information is available to estimate an approximate energy grade line slope (friction slope), that slope should be used instead of the bed slope. If no information is available to estimate the slope of the energy grade line, the channel bed slope should be used.

G. SELECTING THE APPROPRIATE ROUTING TECHNIQUE

1. **General** With such a wide range of hydraulic and hydrologic routing techniques, selecting the appropriate routing method for each specific problem is not clearly defined. However, certain thought processes and some general guidelines can be used to narrow the choices, and ultimately the selection of an appropriate method can be made.

Typically, in rainfall-runoff analyses, hydrologic routing procedures are utilized on a reach by reach basis from upstream to downstream. In general, the main goal of the rainfall-runoff study is to calculate discharge hydrographs at several locations in the watershed. In the absence of significant backwater effects, hydrologic routing models, including Muskingum-Cunge, offer the advantages of simplicity, ease of use, and computational efficiency. Also, the accuracy of hydrologic methods in calculating discharge hydrographs is normally well within the range of acceptable values. It should be remembered, however, that insignificant backwater effects alone do not always justify the use of a hydrologic method. There are many other factors that must be considered when deciding if a hydrologic model will be appropriate, or if it is necessary to use a more detailed hydraulic model.

The full unsteady flow equations have the capability to simulate the widest range of flow situations and channel characteristics. Hydraulic models, in general, are more physically based since they only have one parameter (the roughness coefficient) to estimate or calibrate. Roughness coefficients can be estimated with some degree of accuracy from inspection of the waterway, which makes the hydraulic methods more applicable to ungauged situations.

There are several factors that should be considered when evaluating which routing method is the most appropriate for a given situation. The following major factors should be considered in the selection process.

2. Factors To Consider When Selecting a Routing Method

a. Backwater Effects Backwater effects can be produced by significant tributary inflows, dams, bridges, culverts, and channel constrictions. A flood wave that is subjected to the influences of backwater will be attenuated and delayed in time. Of the hydrologic methods discussed previously, only the Modified Puls method is capable of incorporating significant effects of backwater into the solution. This is accomplished by calculating a storage-discharge relationship that has the effects of backwater included in the relationship. However, this only pertains to 4 of the 5 techniques for determining storage discharge relationships. Normal depth calculations, which is the technique used in HEC-1, is not capable of including the effects of backwater into the storage-discharge relationship. Of the hydraulic methods mentioned in this Appendix, only the Kinematic Wave technique is not capable of accounting for the influences of backwater on the flood wave. This is due to the fact that the Kinematic Wave equations are based on uniform flow assumptions and a normal depth downstream boundary condition. The Muskingum-Cunge method, which is in some respects considered hydrologic routing, and in some respects hydraulic routing, can account for only minor effects of backwater.

b. Flood Plain Storage When the flood hydrograph reaches a magnitude that is greater than the channel's carrying capacity, water flows out into the overbank areas. Depending on the characteristics of the overbanks, the flow can be slowed greatly and often ponding of water can occur. The effects of the flood plains on the flood wave can be very significant. The factors that are important in evaluating to what extent the flood plain will impact the hydrograph are: (1) the width of the flood plain; (2) the slope of the flood plain in the lateral direction; and (3) the resistance to flow due to vegetation in the flood plain. In order to analyze the transition from main channel to overbank flows, the modeling technique must be able to account for varying conveyance between the main channel and the overbank areas. For one dimensional flow models, this is normally accomplished by calculating the hydraulic properties of the main channel and the overbank areas separately, then combining them to formulate a composite set of hydraulic relationships. This can be accomplished in all of the routing methods discussed previously except for the Muskingum method. The Muskingum method is a linear routing technique that uses coefficients to account for hydrograph timing and diffusion. These coefficients are usually held constant during the routing of a given flood wave. While these coefficients can be calibrated to match the peak flow and timing of a specific flood magnitude, they can not be used to model a range of floods that may remain in bank or go out of bank. When modeling floods through extremely flat and wide flood plains, the assumption of one dimensional flow in itself may be inadequate. For this flow condition, velocities in the lateral direction (across the flood plain) may be just as predominant as those in the longitudinal direction (down the channel). When this occurs, a two dimensional flow model would give a more accurate representation of the physical processes.

c. Channel Slope and Hydrograph Characteristics The slope of the channel will not only affect the velocity of the flood wave, but it can also affect the amount of attenuation that will occur during the routing process. Steep channel slopes accelerate the flood wave, while mild channel slopes are prone to slower velocities and greater amounts of hydrograph attenuation. Only the complete unsteady flow equations are capable of routing flood waves through channels that range from steep to extremely flat slopes. As the channel slopes become flatter, many of the methods begin to break down. For the simplified hydraulic methods, the terms in the momentum equation that were excluded become more important in magnitude as the channel slope is decreased. Because of this, the range of applicable channel slopes decreases with the number of terms excluded from the momentum equation. As a rule of thumb, the Kinematic Wave equations should only be applied to relatively steep channels (10 ft/mi or greater). Since the Diffusion Wave approximation includes the pressure differential term in the momentum equation, it is applicable to a wider range of slopes than the Kinematic Wave equations. The Diffusion Wave technique can be used to route slow rising flood waves through extremely flat slopes; however, rapidly rising flood waves should be limited to mild to steep channel slopes (approximately 1 ft/mi or greater). This is due to the fact that the acceleration terms in the momentum equation increase in magnitude as the time of rise of the inflowing hydrograph is decreased. Since the Diffusion Wave method does not include these acceleration terms, routing rapidly rising hydrographs through flat channel slopes can result in errors in the amount of diffusion that will occur. While "rules of thumb" for channel slopes can be established, it should be realized that it is the combination of channel slope and the time of rise of the inflow hydrograph together that will determine if a method is applicable or not.

Ponce (1978) established a numerical criteria for the applicability of hydraulic routing techniques. According to Ponce, the error due to the use of the Kinematic Wave model (error in hydrograph peak accumulated after an elapsed time equal to the hydrograph duration) is within 5 per cent, provided the following inequality is satisfied:

$$\frac{TSu}{d} \geq 171$$

Where: T = hydrograph duration in seconds
S = friction slope or bed slope
u = reference mean velocity
d = reference flow depth

When applying the above equation to check the validity of using the Kinematic Wave model, the reference values should correspond as closely as possible to the average flow conditions of the hydrograph to be routed.

The error due to the use of the Diffusion Wave model is within 5%, provided the following inequality is satisfied:

$$TS\left(\frac{g}{d}\right)^{1/2} \geq 30$$

Where: g = acceleration of gravity

For instance, assume S = 0.001, u = 3 ft/s, and d = 10 ft. The Kinematic Wave model will apply for hydrographs of duration larger than 6.59 days. Likewise, the Diffusion Wave model will apply for hydrographs of duration larger than 0.19 days.

Of the hydrologic methods, the Muskingum-Cunge method is applicable to the widest range of channel slopes and inflowing hydrographs. This is due to the fact that the Muskingum-Cunge technique is an approximation of the Diffusion Wave equations, and therefore can be applied to channel slopes of a similar range in magnitude. The other hydrologic techniques all use an approximate relationship in place of the momentum equation. Through experience it has been shown that these techniques should not be applied to channels with slopes less than 2 ft/mi. However, if there is gaged data available, some of the parameters of the hydrologic methods can be calibrated to produce the desired attenuation effects that occur in very flat streams.

d. <u>Flow Networks</u> In a dendritic stream system, if the tributary flows or the main channel flows do not cause significant backwater at the confluence of the two streams, any of the hydraulic or hydrologic routing methods can be applied. If significant backwater does occur at the confluence of two streams, then the hydraulic methods that can account for backwater (full unsteady flow and diffusion wave) should be applied. For full networks, where the flow divides and possibly changes direction during the event, only the full unsteady flow equations and the diffusion wave equations can be applied.

e. <u>Subcritical and Supercritical Flow</u> During a flood event a stream may experience transitions between subcritical and supercritical flow regimes. If the supercritical flow reaches are long, or if it is important to calculate an accurate stage within the supercritical reach, the transitions between subcritical and supercritical flow should be treated as internal boundary conditions and the supercritical flow reach as a separate routing section. This is normally accomplished with hydraulic routing methods that have specific routines to handle supercritical flow. In general, none of the hydrologic methods have knowledge about the flow regime (supercritical or subcritical). This is due to the fact that the hydrologic methods are only concerned with flows and not stages. If the supercritical flow reaches are short, they will not have a noticeable impact on the discharge hydrograph. Therefore, when it is only important to calculate the discharge hydrograph, and not stages, hydrologic routing methods can be used for reaches with small sections of supercritical flow.

f. <u>Calibrating to Observed Data</u> In general, if observed data are not available, the routing methods that are more physically based will have greater accuracy and will be easier to apply. When gaged data are available, all of the methods should be calibrated to match observed flows and/or stages as best as possible. The hydraulic methods, as well as the Muskingum-Cunge technique, are considered physically based in the sense that they only have one parameter (roughness coefficient) that must be estimated or calibrated. The other hydrologic methods may have more than one parameter to be estimated or calibrated. Many of these parameters, such as the Muskingum X and the number of subreaches (NSTPS), are not related directly to physical aspects of the channel and inflowing hydrograph. Because of this, these methods are generally not used in ungauged situations.

3. <u>Summary and Conclusions</u> The final choice of an appropriate routing method is often influenced by factors other than those mentioned previously. Some of the other factors that should be considered are: the required accuracy of the results; the type and availability of data; the type of information desired (flow hydrographs, stages, velocities, etc.); and the familiarity and experience of the user with a given method. The modeler must take all of these factors into consideration when selecting an appropriate routing technique for a specific problem. Table O-2 contains a list of some of the factors discussed previously, along with some guidance as to which routing methods are appropriate and which are not. This table should be used as guidance in selecting an appropriate method for routing discharge hydrographs. By no means is this table all inclusive.

Factors to consider in the selection of a routing technique.	Methods that are appropriate for this specific factor.	Methods that are not appropriate for this factor.
1. No observed hydrograph data available for calibration.	• Full Dynamic Wave • Diffusion Wave • Kinematic Wave • Muskingum-Cunge • Normal Depth-Storage	• Modified Puls • Muskingum • Working R&D
2. Significant Backwater that will influence discharge hydrograph.	• Full Dynamic Wave • Diffusion Wave • Modified Puls • Working R&D	• Kinematic Wave • Muskingum • Muskingum-Cunge • Normal Depth-Storage
3. Flood wave will go out of bank into the flood plains.	• All hydraulic and hydrologic methods that calculate hydraulic properties of main channel seperate from overbanks.	• Muskingum
4. Channel slope > 10 ft/mi and $\frac{TSu}{d} \geq 171$	• All methods presented	• None
5. Channel slopes from 10 to 2 ft/mi and $\frac{TSu}{d} < 171$	• Full Dynamic Wave • Diffusion Wave • Muskingum-Cunge • Modified Puls • Muskingum • Normal Depth-Storage • Working R&D	• Kinematic Wave
6. Channel slopes from < 2 ft/mi and $TS\left(\frac{g}{d}\right)^{1/2} \geq 30$	• Full Dynamic Wave • Diffusion Wave • Muskingum-Cunge	• Kinematic Wave • Modified Puls • Muskingum • Working R&D • Normal Depth-Storage
7. Channel slopes from < 2 ft/mi and $TS\left(\frac{g}{d}\right)^{1/2} < 30$	• Full Dynamic Wave	•All others

Nomenclature

T = Hydrograph duration in seconds
S = Friction slope or bed stop
u = Reference mean velocity
d = Reference flow depth
g = Acceleration of gravity

Note: As listed above, the Modified Puls method excludes the Normal Depth-Storage technique which is listed seperately.

The Muskingum-Cunge method is generally a good channel routing method to use for both natural and man-made channels. Normal Depth-Storage routing is a good selection for natural streams and channels. Kinematic wave routing, where slopes are applicable, is adequate for urban channels and non-pressurized pipe flow, and the Muskingum method is typically a good selection for larger natural channels.

SELECTING THE APPROPRIATE CHANNEL ROUTING TECHNIQUE | **TABLE O-2**

APPENDIX "P"
HEC-1 RUNOFF MODELING

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APPENDIX "P"
HEC-1 RUNOFF MODELING

I. OVERVIEW OF HEC-1

A. INTRODUCTION

1. A Comprehensive Program The Army Corps of Engineers' HEC-1 Flood Hydrograph Package is a complex computer modeling program capable of performing a large variety of operations with various hydrological methods. The Users' Manual, Army Corps of Engineers Training Manual, and conferences presented on HEC-1 may be valuable aids to learning of all of HEC-1's capabilities.

2. Focus on Essentials Information provided herein will not be comprehensive, but will only focus on the essentials of HEC-1, and a selection of operations and procedures that are commonly used and are practical in the arid and semi-arid west.

   In the arid and semi-arid west, rainfall gauge date is limited, as is stage/discharge and hydrograph information. Therefore, the common procedure is to use precipitation data from NOAA Atlas II or more recent meteorological studies in conjunction with a unit hydrograph or kinematic wave procedure. Although the Clark and Snyder unit hydrograph methods are common, and are both available for use in HEC-1, the SCS unit hydrograph is used considerably more often. The kinematic wave method has recently become popular, particularly with urban hydrology, but it requires a more complex model, has not really proven to be more accurate than unit hydrograph models, and generally is less reproducible or practical. Hence, this Appendix will only focus on use of the SCS unit hydrograph procedure of precipitation distribution. The most common rainfall loss method provided in computer models is the SCS curve number. Another loss rate method gaining wide use and popularity in recent years is the Green and Ampt method. These methods are discussed in more detail in Appendices "C" and "D", and their application in HEC-1 will be presented herein. The unit hydrograph "time" dimension discussed will be the time of concentration and lag time as presented in Appendix "E" and the SCS TR-55 and NEH-4.

   In summary, only a partial coverage of HEC-1 is provided herein, with focus on required components, most frequently used options, and basic hydrology using:
   - i) Basin total storm precipitation;
   - ii) SCS unit hydrograph;
   - iii) SCS curve number or Green and Ampt loss rates; and
   - iv) SCS time of concentration.

The scope of material presented herein is adequate to model complex urban and wildland drainage basins; however, for other options or methods, other references must be utilized.

3. **HEC-1 Structure** Various hydrological and hydraulic operations are performed by routines which are components of the overall model. Each component models an aspect of the hydrological process, whether it involves only one subbasin, or represents a process that involves more than one subbasin. Each component requires a set of parameters which specify particular characteristics and mathematical relations which describe the physical or theoretical processes.

   Modeling an individual basin for runoff, and the ability to combine basins in a watershed network, are the primary features of the HEC-1 program. All other features are merely appendages to these.

4. **Assumptions and Limitations** Simplifying assumptions are made for modeling hydrologic processes. They are:
   i) Basin rainfall (amount, intensity, and duration) is uniformly distributed, and
   ii) Losses (infiltration, surface storage detention, and evapotranspiration) are also uniformly distributed over the basin.

   The above assumptions apply not only spatially within a basin, but temporally as well, except that some loss methods, such as the Green and Ampt method, allow for infiltration losses that are not uniform with time.

   If the above assumptions do not apply, the basin must be subdivided into smaller subbasins until the assumptions are acceptable considering the purpose of the study. Also, the time interval used should be small enough so that averages over the time computation interval are applicable.

   HEC-1 is limited to a single storm event; in other words, it may not be used for continuous simulation of storms and recovery periods. Also, model results are in terms of discharge and not stage, unless a stage/discharge curve is provided. Also, streamflow or channel routings attenuate flows due to channel storage capacity, but backwater analysis is not possible; that is, hydrologic rather than hydraulic channel routings are possible.

5. **Available HEC-1 Versions** There have been many versions of the HEC-1 computer program, involving not only added capabilities, but numerous error corrections as well. As a guide to version capabilities and error corrections, a summary of PC versions since 1988 is provided below.

   a. **1988 Version**
   - The Green-Ampt infiltration equation was added as an option.
   - Kinematic Wave runoff computations were improved.
   - All the main-frame computer options were made available in the PC version.
   - A program bug is present in the application of the Green and Ampt equation in combination with the JD record option.

b. 1990 Version
   - Muskingum-Cunge channel routing was added as an option.
   - Detention basin modeling capabilities were improved.
   - A Green and Ampt error from the 1988 version was corrected.
   - A program bug is present in the Kinematic Wave runoff procedure when using the JR record option. Hydrographs do not combine properly.

c. 1991 Version
   - This version is specific to the 80386/80486 microprocessors and requires a minimum of 2.5 megabytes of total memory, or 640 kilobytes of memory and 3 megabytes of disk space.
   - The Kinematic Wave error from the 1990 version was fixed.
   - The number of hydrograph ordinates available was increased from 300 to 2,000.

6. HEC-1 Enhancements The Army Corps of Engineers HEC-1 computer model is public domain software. It has been enhanced by various vendors, ranging from simple menu-driven interfaces, to a more "user friendly" question/answer format, to programs with digital terrain modeling capability which allow for program selection and delineation of subbasins, calculate subbasin properties such as subbasin area, average slope, maximum overland flow distance, distance from the subbasin centroid to the nearest stream, stream lengths and slopes, and gauge weights, and which also establish the linking network. The user need only specify the loss rate method and parameters and routing parameters through interactive dialog boxes.

B. SIMULATING THE WATERSHED Establishing a stream network model is paramount in simulating watershed runoff characteristics. The actual watershed and subbasins must be described by parameters and linked together so that the mathematical model is representative. Simulating a watershed involves four steps.

1. Watershed Boundary The study watershed boundary must be delineated. In a natural or wildland area, this may be done using USGS or other topographic mapping. Sometimes, other mapping or investigations are required.

2. Subbasins It may be beneficial to subdivide the watershed into subbasins. Sometimes it is desirable to know runoff flow rates at various locations within the watershed (often called "concentration points"), which requires subdividing in order to be able to calculate runoff rates corresponding to each point. Also, the variability of hydrometeorological processes and basin characteristics impact the size and location, and hence the need for a number of subbasins. Each subbasin represents an area of the watershed which, on the average, has the same hydrologic/hydraulic properties. Furthermore, the assumption of uniform precipitation and infiltration over a subbasin becomes less accurate as the subbasin becomes larger. Proper selection and delineation of subbasins will allow for a more accurate model of the watershed.

3. <u>Model Components</u> Various operations may be performed for each subbasin, including not only expected runoff, but also channel and reservoir routing and diversions, as applicable.

4. <u>Linking of Subbasin Components</u> Subbasins and their components may be linked together through hydrograph combining and other operations to appropriately represent the watershed.

II. OVERVIEW OF BASIC MODEL COMPONENTS

Various components of the basic model are described in this section. Emphasis will be on those "essentials" discussed in the preceding section.

A. <u>SUBBASIN RUNOFF COMPONENTS</u> Hydrograph information may be input or generated by HEC-1 through use of precipitation data and other distribution procedures.

1. **<u>Direct Hydrograph Input</u>** Rather than have HEC-1 calculate a runoff hydrograph within a particular model, a hydrograph may be input directly. Once input, other operations may be performed on the hydrograph just as though the hydrograph had been calculated in that particular HEC-1 model.

   The advantage of this feature is that a hydrograph which has been produced by a separate analysis, either by HEC-1 or some other procedure, or a hydrograph which has been observed for an area, may be input and used directly.

2. **<u>HEC-1 Generated Hydrographs</u>** HEC-1 may produce hydrographs if provided adequate information regarding precipitation amount and distribution and loss rate.

   a. **<u>Precipitation</u>** Precipitation is assumed to be uniformly distributed over the subbasin. There are many ways to input precipitation.

      1) **<u>Basin Average Precipitation</u>** This procedure requires input of the total storm precipitation and a temporal pattern for distributing the total precipitation. This procedure is involved when using the SCS unit hydrograph method.

      2) **<u>Weighted Precipitation Gauges</u>** In areas where adequate precipitation gauge data is available, the calculated basin average total precipitation may be calculated based upon a weighting for each gauge within each subbasin. The incremental time distribution is also based upon the weighting of gauges. In the semi-arid west, there usually are not enough precipitation gauges to use this procedure.

      3) **<u>Synthetic Storms</u>** There are three methods in HEC-1 for generating synthetic storms which do not involve a unit hydrograph. One is the Probable Maximum Precipitation (PMP) used in dam analyses. Another is the Standard Project Storm, which is approximately 40% of the PMP, used often on Army Corps of Engineers' projects. The third is the Depth-Duration Data method, where a triangular distribution of precipitation is assigned. For most projects, none of these methods are used.

4) Snowfall and Snowmelt Subbasins are divided into elevation zones, and snowmelt is calculated by degree day or energy budget methods. Snowmelt sometimes results in peak runoff, but usually only for very large watershed areas, such as for the Colorado River basin. For small watersheds, snowmelt usually does not result in the peak runoff, and therefore, for most projects, this method is not used.

b. Interception/Infiltration (Loss Rate) 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 a surface area where water is not free to move as overland flow. Infiltration represents the movement of water in areas beneath the land surface. Precipitation which does not contribute to the runoff process is considered to be lost from the system.

Precipitation loss computations can be used with either unit hydrograph or kinematic wave model components. In the unit hydrograph component, 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 five methods that can be used to calculate the precipitation loss in HEC-1. With all methods, an average precipitation loss is determined for a computation interval and subtracted from the rainfall/snowmelt hyetograph. 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.

The appropriate selection of precipitation loss parameters is very important. With some loss methods, such as the SCS curve number, the percent change in value used will usually have more impact on estimated runoff than a percent differential of any other parameter, including time of concentration (or lag time), basin area, and precipitation amount (Williams, 1990).

The methods of precipitation loss available for use in HEC-1 are: Initial and Uniform loss/rate; Holton loss rate; SCS curve number; Green and Ampt; and HEC-1 Exponential loss rate. Only the SCS curve number and Green and Ampt methods are discussed in this manual (see Appendices "C" and "D") and are the only precipitation loss procedures subsequently exemplified in this appendix.

c. Precipitation Excess to Runoff There are two procedures available in HEC-1 to transform precipitation excess to runoff. These are unit hydrograph and kinematic wave overland routing procedures.

1) Unit Hydrographs There are four unit hydrograph methods that can be used in HEC-1, which are:

i) Directly input unit hydrograph;
ii) Clark unit hydrograph;
iii) Snyder unit hydrograph; and
iv) SCS unit hydrograph.

Only the SCS Unit hydrograph will be further discussed in this manual.

2) Kinematic Wave Overland Routing This procedure of estimating runoff has gained popularity in recent years, and is the fourth most frequently available hydrograph synthesis method found in computer models (ASCE Task Committee). However, the method is more complex and less frequently used than the SCS unit hydrograph method, and is not discussed in further detail here. However, such exclusion herein should not be understood to indicate that the method is not worth learning or using.

d. Base Flow Streamflow amounts existing before a storm begins is base flow. Where applicable, this may be added to the storm-generated runoff.

B. FLOOD ROUTING COMPONENTS Routing is a process used to predict the temporal and spatial variations of a flood hydrograph as it moves through a river reach or reservoir. Storage and flow resistance within a river reach or reservoir result in an attenuation and delay of the peak of the runoff hydrograph, which changes the hydrograph shape and timing as the flood wave moves from upstream to downstream. Figure P-1 shows the major changes that occur to a discharge hydrograph as a flood wave moves down a stream.

1. Routing Types In general, routing techniques may be classified into two categories: (1) hydraulic routing; and (2) hydrologic routing. Hydraulic routing techniques, which involve backwater calculation capability, are based on the solution of the partial differential equations of unsteady open channel flow. These equations are often referred to as the St. Venant or dynamic wave equations. Hydrologic routing employs the continuity equation and either an analytical or an empirical relationship between storage within the reach and discharge at the outlet.

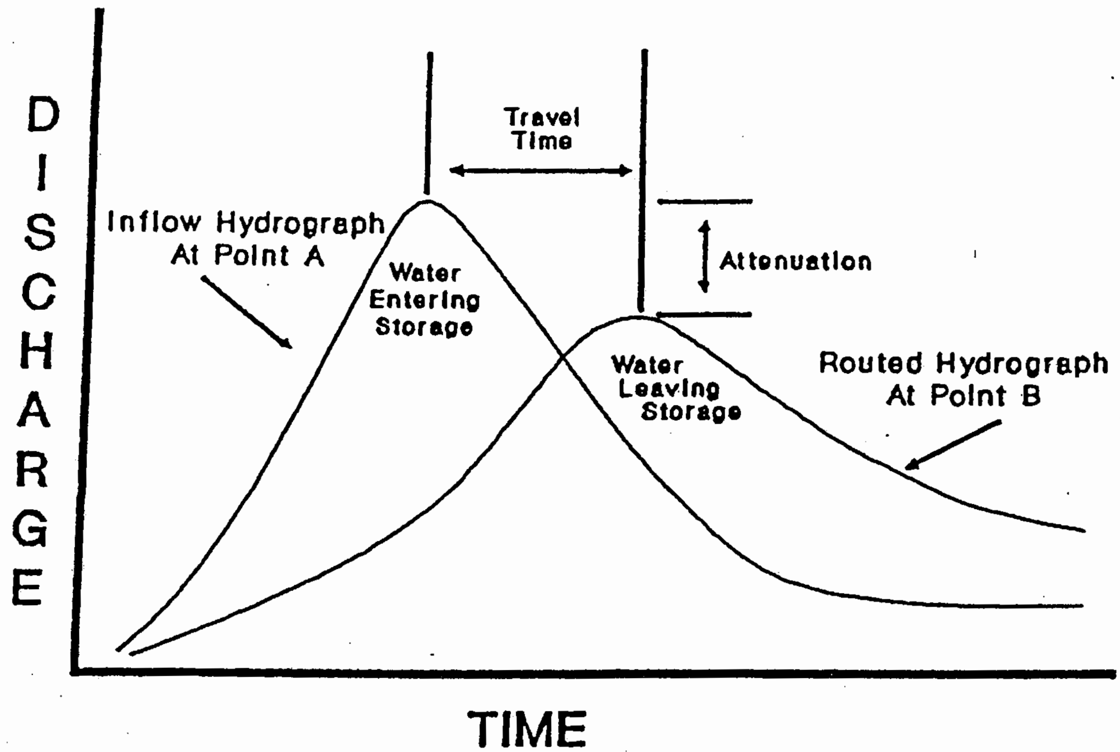


FIGURE P-1
Discharge Hydrograph Routing Effects

a. **Hydrologic Routing** Flood forecasting, reservoir and channel design, flood plain studies, and watershed simulations generally utilize some form of routing. Typically, in watershed simulation studies, hydrologic routing is utilized on a reach-by-reach basis from upstream to downstream. For example, it is often necessary to obtain a discharge hydrograph at a point downstream from a location where a hydrograph has been observed or computed. For such purposes, the upstream hydrograph is routed through the reach with a hydrologic routing technique that predicts changes in hydrograph shape and timing. Local flows are then added at the downstream location to obtain the total flow hydrograph. This type of approach is adequate as long as there are no significant backwater effects, or discontinuities in the water surface due to jumps or bores.

b. **Hydraulic Routing** When there are downstream controls that will have an effect on the routing process through an upstream reach, the channel configuration should be treated as one continuous system. This can only be accomplished with a hydraulic routing technique that can incorporate backwater effects as well as internal boundary conditions, such as those associated with culverts, bridges, and weirs. HEC-1 does not have this capability. Other programs such as the Army Corps of Engineers' HEC-2, USGS's WSPRO, and SCS's WSP-2 work well for one-dimensional flow analyses, or FESWMS-2DH for two-dimensional river analysis.

2. HEC-1 Hydrologic Routing Techniques

a. **Theory** Hydrologic routing employs the use of the continuity equation and either an analytical or an empirical relationship between storage within the reach and discharge at the outlet. In its simplest form, the continuity equation can be written as inflow minus outflow equals the rate of change of storage within the reach:

$$I - O = \frac{dS}{dt}$$

Where: I = The average inflow to the reach during dt;
O = The average outflow from the reach during dt;
S = Storage within the reach.

b. **Routing Methods** HEC-1 is capable of using the following routing methods:

i) **Channel Routing**

- Channel Losses
- Average-Lag (Tatum; Straddel-Stagger)
- Kinematic Wave
- Modified Puls
- Muskingum
- Muskingum-Cunge
- Normal-Depth-Storage

The latter four types are discussed further in Appendix "O"; and

ii) **Reservoir Routing and Dam-Break Analysis**

- Working R&D
- Modified Puls
- Level-Pool Reservoir Routing

The latter two types are discussed further in Appendix "O".

C. PUMPING AND DIVERSION COMPONENTS

1. **Pumping** Pumping plants may be simulated for interior drainage problems where runoff ponds are in low areas or behind levees, flood walls, or detention basins. Multiple pumps may be used, each with different on and off elevations. Pumps are simulated using the level-pool reservoir routing option. 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 is 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.

2. <u>**Diversions**</u> A diversion component is used to simulate runoff diversions due to an overflow to side channel or street, stream splits, diversion dam applications, or other split in runoff. The diversion amount is based upon a linear interpolation between user input inflow-diversion data. 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 another branch of drainage system. Key points to remember about this operation are:

   i) The split is done using a discharge rating table for the diversion with a maximum volume cutoff option;

   ii) It is very important to check the shape of diverted hydrographs for oscillations and to verify that the expected results are obtained; and

   iii) When a diverted hydrograph is recalled into the stack, the drainage area associated with the hydrograph is zero. The HEC-1 summary tables may reflect incorrect areas unless the area is corrected using the manual area input option (Field 2 of the HC record) for the first combine operation downstream of the retrieved hydrograph.

D. <u>HYDROGRAPH TRANSFORMATION COMPONENTS</u>

1. <u>**Combining**</u> Runoff hydrographs may be combined together at the confluence of two or more streams or subbasins. Key points to remember when using this operation are:

   i) The maximum number of hydrograph locations (separate stream branches) that can be displayed using the "*DIAGRAM" option of HEC-1 is nine; and

   ii) The maximum number of hydrographs which can be combined at one time is five.

2. <u>**Alterations**</u> Other 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.

III. OVERVIEW OF MISCELLANEOUS FEATURES

A. HYDROGRAPH STACKING In the computation process for a multi-subbasin model, calculated discharge hydrographs are stored in a "stack." Each time a hydrograph is calculated, it is placed on top of the stack. When routing is performed, the hydrograph on top of the stack is treated as the inflow hydrograph. The calculated outflow hydrograph then replaces the inflow hydrograph on top of the stack. When N hydrographs are combined, the top N hydrographs in the stack are added together. The resulting combined hydrograph replaces the N hydrographs in the stack.

When a diversion hydrograph is calculated, the hydrograph of flow remaining after the diversion is placed on top of the stack. The diverted-flow hydrograph is not placed in the stack. However when the diverted -flow hydrograph is retrieved, it is placed on top of the stack.

To provide for proper sequencing of computations, it is necessary to arrange components in an upstream to downstream order until a confluence is reached. Before simulating below the confluence, all flows above that confluence must be computed and routed to that confluence.

Hydrograph stacking is exemplified in Table P-1.

B. MULTIFLOOD/MULTIPLAN 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. This is exemplified in Figure P-2.

For additional information, see the HEC-1 manual.

C. CALIBRATION/OPTIMIZATION ANALYSIS Calibration of any model is extremely important, and should not be overlooked when enough data exists to allow for calibration. Unfortunately, in the arid and semi-arid west, adequate data is usually lacking.

When gauged data is available, the information can be used with HEC-1's optimization techniques to estimate some hydrologic parameters, such as those required for unit hydrograph, loss rate, baseflow, and channel routing operations. The HEC-1 Users Manual contains a chapter on parameter calibration.

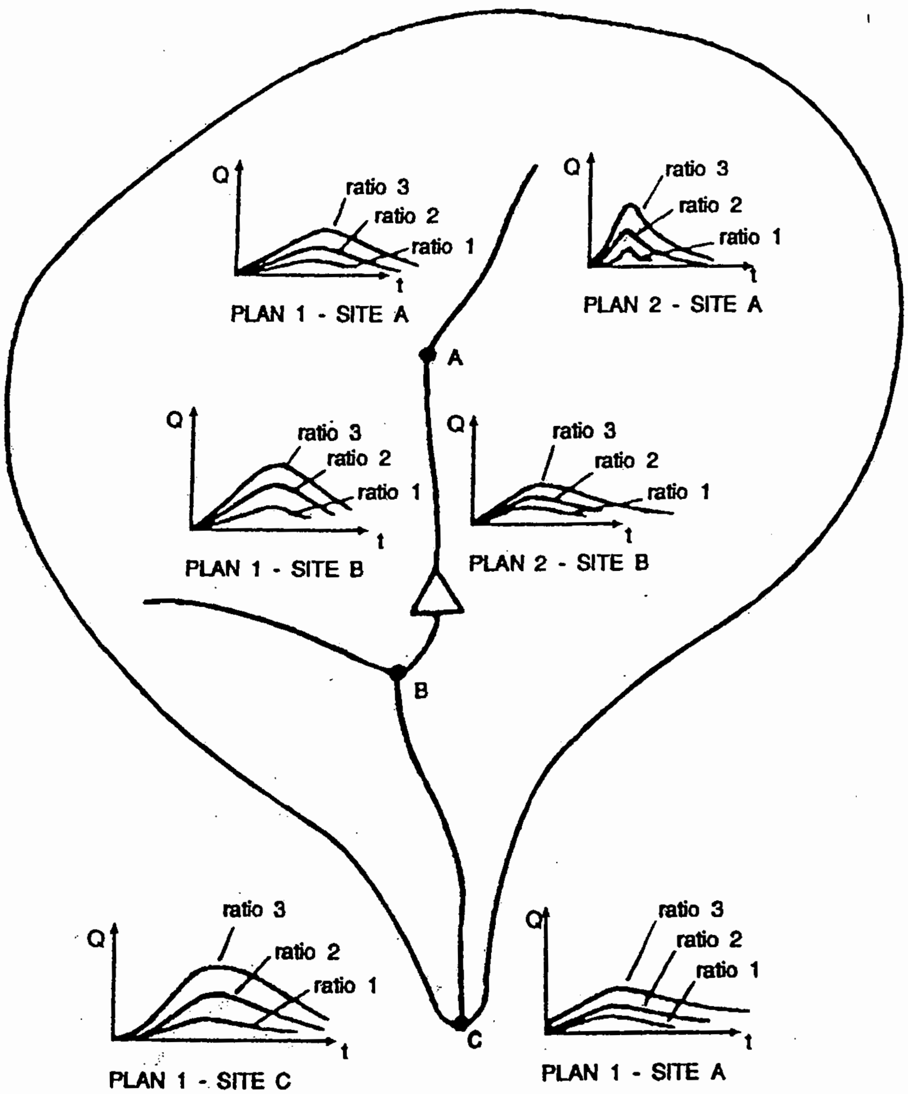
D. DAM SAFETY The dam safety feature of HEC-1 allows estimation of the potential of dam overtopping or failure and resultant consequences on downstream areas. A chapter of the HEC-1 Users Manual is devoted to dam safety options.

STEP NO.	DESCRIPTION OF HEC-1 OPERATION	NAME OF NEW HYDROGRAPH	HYDROGRAPHS IN STACK (LISTED IN ORDER FROM TOP TO BOTTOM OF STACK)
1.	Basin A Runoff Calculated	A	A
2.	Route hydrograph	RA	RA
3.	Basin B Runoff Calculated	B	B, RA
4.	Combine 2 hydrographs	(B + RA)	(B + RA)
5.	Basin C Runoff Calculated	C	C, (B + RA)
6.	Basin D Runoff Calculated	D	D, C, (B + RA)
7.	Combine 2 hydrographs	(D + C)	(D + C), (B + RA)
8.	Route hydrograph	R(D + C)	R(D + C), (B + RA)
9.	Basin E Runoff Calculated	E	E, R(D + C), (B + RA)
10.	Combine 3 hydrographs	Z	Z

EXAMPLE OF HYDROGRAPHIC STACKING

TABLE P-1

THIS IS A REPRODUCTION FROM THE HEC-1 USERS MANUAL



MULTIFLOOD AND MULTIPLAN HYDROGRAPHS	FIGURE P-2

IV. OVERVIEW OF INPUT DATA

This section provides a summary of data input format, special input features, the data identification scheme, organization of data, and also a brief discussion of some data records. In conformance with the focus on essentials discussed earlier, only selected material is covered. The HEC-1 Users Manual should be consulted for additional information.

A. INPUT FORMAT

1. **Fixed Format** HEC-1 input files have the following format:

   i) 80 columns per line or record;

   ii) The first two columns contain the record identifier (or asterisk);

   iii) Ten data fields, the first consisting of 6 columns (eight minus the two used for the record identifier), and the remaining 9 fields have 8 columns each; and

   iv) Data must be right justified in each field.

   The Army Corps of Engineers and private vendors have developed editing and data input software that facilitates entering data correctly within the fields.

2. **Free Format** HEC-1 also allows data to be input using an optional free format. To use the free format option, a "*FREE" record is used, and thereafter all data may be input with data fields separated from each other and the record identifier by commas or blanks. Consecutive commas form a blank field. To avoid confusion, it may be helpful to use only commas.

   Although record identifiers are discussed later, it may be well to note here that, when free formatting is used, a comma is not required after the three record identifiers used to input text description rather than numerical data. They are the "ID", "*_", and "KM" records. If used, the comma is assumed to be part of the desired descriptive text. Also, a comma should not be used after the ZZ record.

3. **Formatting Examples** Input data for fixed and free formats are exemplified below, where underlines are only used to show spacing, and are not a part of the input data:

   Fixed RS_____1____ELEV___851.2

   Free RS,1,ELEV,851.2

Notice that for the fixed format, after the two column identifier, there is a six column field followed by eight column fields, whereas in the free format, data entry is simplified.

4. <u>Format Selection</u> If the user does not have data entry software that automatically places data into the appropriate fields, the free format option is strongly recommended. The only disadvantage of free formatting is that when the program is run, it first takes time to reformat the data into a fixed format. However, with most file sizes and the speed of computers today, the additional time is hardly noticeable.

B. <u>SPECIAL FEATURES</u> HEC-1 has several special input control features, all of which begin with an "*" in lieu of the two letter record identifier. The "*FREE" feature was presented above; there are five more.

1. <u>*FIX</u> If free formatting is being used, and it is desirable to switch back to the fixed format, a "*FIX" may be used as a record. Switching back and forth from free to fixed format is possible throughout the input file.

2. <u>*NOLIST</u> Even if a reprint of input data is not otherwise requested (on the IO record), free formatted data will be printed before output data in a fixed format unless this special record is used.

3. <u>*LIST</u> This will cause the program to print out reformatted input data prior to printing output data. However, this will occur anyway if a 3 or 4 is used in field one of the IO record.

4. <u>*DIAGRAM</u> This is an extremely useful feature of HEC-1. The diagram structure can be portrayed diagrammatically by using the "*DIAGRAM" record at the beginning of the data deck. This option causes a flow chart of the stream network simulation to be printed. The user should verify that this flow chart conforms to the intended network of subbasins and routing reaches.

5. <u>*</u> This feature allows one to insert messages or spacing of record data in an input file. It may help clarify to the user and reviewer what is being done and why. The only place those comments will appear in the output file is in the reproduction of input data, but not in the output of results. For messages to appear in the results portion of the output file, a KM record is required. Note that at least one space must follow the "*". Note that, when free formatting is used, a comma after the asterisk and space is unnecessary.

C. <u>RECORD IDENTIFICATION</u> HEC-1 basin simulation data are all identified by a unique two-character alphabetic code in columns one and two as previously mentioned. The first character of the code identifies the general category of data, and the second character identifies a specific type of simulation option. Table P-2 presents a selection of categories, codes, and simulation description which pertains to the scope of discussion in this Appendix.

THIS IS A SCALED DOWN VERSION OF TABLE 10.1 OF THE HEC-1 MANUAL. SEE THE MANUAL FOR ADDITIONAL DATA TYPE AND OPTIONS.

Data Category	Records Identification	Description of Data
Job Initialization	ID	Job IDentification Records
	IT	Job Time Control
	IO	General Output Controls
	IN	Time Control for INput Data Arrays
Job Type	JP	Multi-Plan Data
	JR	Multi-Ratio Data
Job Step Control	KK	Stream Station Identification
	KM	Alphanumeric Message Record
	KO	Output Control for This Station
	KP	Multi-plan Label
Hydrograph Transformation	HC	Combine Hydrographs
Hydrograph Data	QI	Direct Input Hydrograph
Basin Data	BA	Basin Area
	BF	Base Flow Characteristics
	BI	Input Hydrograph from Prior Job
Precipitation Data	PB	Basin-Average Total Precipitation
	PI	Incremental Precipitation Time Series
	PC	Cumulative Precipitation Time Series
Loss Rate Data	LE	HEC's Exponential Rainfall Loss Rate Function
	LU	Initial and Uniform Rates
	LS	SCS Curve Number
	LH	Holtan's Function
	LG	Green and Ampt
Unitgraph Data	UI	Direct Input Unitgraph
	UC	Clark Unitgraph
	US	Snyder Unitgraph
	UD	SCS Dimensionless Unitgraph
	UK	Kinematic Overland
	RK	Kinematic Wave Channel (collector, main)

HEC-1 INPUT DATA IDENTIFICATION SCHEME
(Selected Data Only)

TABLE P-2a

THIS IS A SCALED DOWN VERSION OF TABLE 10.1 OF THE HEC-1 MANUAL. SEE THE MANUAL FOR ADDITIONAL DATA TYPE AND OPTIONS.

Data Category	Record Identification	Description of Data
Routing Data	RD	Muskingum-Cunge Parameters
	RM	Muskingum Parameters
	RS	Storage Routing Option, follow with SV and SQ cards if Modified Puls is used
	RC	Channel Characteristics for Normal Depth Storage Routing
	RX	Cross Section X Coordinates
	RY	Cross Section Y Coordinates
Storage Routing Data	SL	Low Level Outlet Characteristics
	ST	Top of Dam Characteristics
	SW/SE	Width/Elevation for Non-Level Top of Dam Geometry
	SS	Spillway Characteristics
	SG	OGee or Trapezoidal Spillway Option
	SQ/SE	Discharge/Elevation Tailwater Rating
	SV	Reservoir Volume
	SQ	Discharge
	SA	Surface Area, and
	SE	Water Surface Elevation Data
Diversion Data	DR	Retrieve Diverted Flow
	DT	Flow Diversion Characteristics
	DI	Variable Diversion Q as Function of Inflow
	DQ	
End of Job	ZZ	Required to end job

HEC-1 INPUT DATA IDENTIFICATION SCHEME
(Selected Data Only)

TABLE P-2b

D. DATA REPETITION Often, physical characteristics are similar for two or more subbasins. Some data groups do not need to be repeated — if left out, HEC-1 automatically uses data from the previous subbasin. This is true for the following data type shown below.

Description	Identifier
Precipitation	P_
Loss rates	L_
Base Flow	BF
Snowmelt	M
Unit Hydrograph	US, UC, UD

With the exception of the precipitation data, the above data records involve only one line each with little input. It may be better to avoid error by including the data with each subbasin operation. On the other hand, precipitation data usually involves all fields on a record, and consists of several records. For most watersheds, the precipitation data will remain the same for all subbasins, and therefore it is convenient to input it only in the first subbasin operation.

E. ORGANIZATION OF DATA HEC-1 input records must be arranged in the proper order. At first this may appear to be a major task, but with some understanding of the HEC-1 data organization scheme, it is less formidable. There are only three categories of simulation data. Table P-3, which is a scaled down version of that provided in the HEC-1 Users Manual, identifies the categories and record types under each.

TABLE P-3
Organization of Data

Job Control	Hydrology & Hydraulics	Economics & End of Job
I__, Job Initialization J__, Job Type	K__, Job step control H__, Hydrograph transformation B__, Basin data Q__, Hydrograph data P__, Precipitation data L__, Loss (infiltration) data U__, Unitgraph data R__, Routing data S__, Storage data D__, Diversion data W__, Pump Withdrawal data	E__, etc., Economics, data ZZ, End of job

All Job Control records (except the "IN" record) must precede Hydrology and Hydraulics records, which in turn must precede economics and end of job records. Also, within the categories shown, records required for an operation shall be used in the order shown in Table P-3. The one exception is that if gauged data is used, "B__" records would follow PG and PI records, and precede other "P__" records.

Section II of this Appendix provided an overview of HEC-1 components. Essentially, a component is a block of records that result in the performance of a complete operation. Groups of records required for various operations on HEC-1 components are provided in Tables P-4 to P-7. Again, data records must be used in the sequence provided in the tables. Also for additional methods or operations, see the HEC-1 Users Manual.

Figure P-8 is a variation of Figure 10-1 from the HEC-1 Users Manual, which exemplifies the organization of categories, components or operations, and record use within the operations.

TABLE P-4

Precipitation Data Input Options
(Reproduced from HEC-1 Users Manual)

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 P-5

Hydrograph Input or Computation Options
(Reproduced from HEC-1 Users Manual)

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

TABLE P-6

Channel and Reservoir Routing Methods Input Data Options
Excludes spillway and overtopping analysis
(Reproduced from HEC-1 Users Manual)

Type of Data	Routing Technique Record Identification				
	Muskingum	Modified Puls: Given Storage-Outflow	Modified Puls: Normal Depth-Storage Outflow	Kinematic Wave	Muskingum-Cunge
Routing control	RM	RS	RS	RK	RD
Storage Discharge Relationships	–	SV/SQ*	–	–	–
Rating-Curve	–	SQ/SE*	–	–	–
Channel Hydraulic Characteristics	–	–	RC, RX, RY	RK	RC, RX, RY**

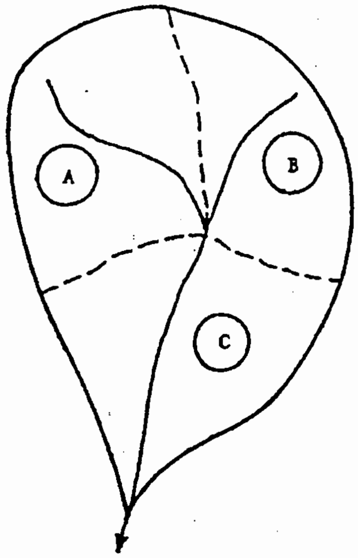
* These data may be computed from options listed in Table P-7
**These records are only used if the natural channel option of Muskingum-Cunge routing is used.

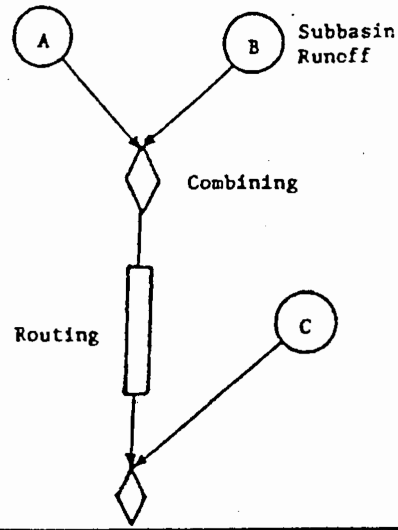
TABLE P-7

Spillway Routing, Dam Overtopping, and Dam Failure
Input Data Options
(Reproduced from HEC-1 Users Manual)

Type of Data	Hydrograph Derivation Option and Records			
	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**	ST**	ST**	ST**
Dam failure data	SB*	SB*	SB*	SB*

* Optional
**Required to obtain special summary printout for spillway adequacy and dam overtopping





Category	Operation	Record	Description of Record
Job Control		ID IT IO	Title Time interval and beginning time Output control option for whole job
Hydrology & Hydraulics	Subbasin A runoff	KK BA BF P_ L_ U_	Station Name Area Base flow Select one precipitation method, use IN if necessary Select one loss rate method Select one rainfall excess transformation method
	Subbasin B runoff	KK BA BF P_ L_ U_	Similar to above for Subbasin A. P_, L_, and U_ records are not needed if they are the same as for Subbasin A. It is likely that precipitation is the same, and would not be repeated.
	Combine A + B	KK KM HC	Station Name Combine runoff from A & B (message option) Indicate 2 hydrographs are to be combined
	Route (A+B) through C	KK RL R_	Station Name Channel loss optional Select one routing method
	Subbasin C runoff	KK BA BF P_ L_ U_	Similar to above for Subbasin A. P_, L_, and U_ records are not needed if they are the same as for Subbasin B. It is likely that precipitation is the same, and would not be repeated.
	Combine Routed (A+B) with C	KK HC	Station name Indicate 2 hydrographs are to be combined
	Comparison	KK IN QO	Compare computed and observed flows
Economics & End of Job		ZZ	End

EXAMPLE INPUT DATA ORGANIZATION — **TABLE P-8**

V. GUIDANCE ON USE OF HEC-1 RECORDS

The type of data to be input in HEC-1 record fields is provided in Appendix "A" of the HEC-1 Users Manual. However, little guidance is given therein regarding parameter selection. In this section, guidance is provided for several HEC-1 records that may frequently be used in accordance with procedures prescribed in this manual.

A. __JOB INITIALIZATION RECORDS__ With the exception of the IN record, these records must be used prior to any hydrology, hydraulic, or economic component records.

1. __ID Records__ At least one ID record is required. Since ID records always contain descriptive text, a comma after the "ID" is not required when free formatting. If used, the comma will be considered part of the text. The following are typical uses of ID records:

i) The first ID record should contain the project name/number, modeler's name, and date of analysis.

ii) Additional ID records should be used to document the analysis, i.e., special model input, unique assumptions, unusual watershed conditions, etc.

iii) Revisions should be clearly identified on subsequent ID records.

2. __IT Record__ The IT record is required in an input file. Data fields and input parameters are discussed below.

a. __NMIN__ This variable is input in field one, and is defined as the integer number of minutes in the tabulation interval used to define the spacing of the hydrograph ordinates, thus setting the duration of the hydrograph. Too large a value will result in inaccuracies in peak discharge; too small a value may result in truncation of hydrographs and low runoff volume calculations if an appropriate NQ parameter is not used [see (c) below], or in unnecessary excessive computer computation and output. Also, HEC-1 will not accept a NMIN value less than one minute, nor anything other than an integer.

The computation interval (NMIN) shall be selected to correspond to the time of concentration for the unit hydrograph. This requirement is necessary to adequately define the shape of the unit hydrograph. For the SCS Dimensionless Unit Hydrograph, the unit rainfall duration is to equal 0.133Tc, and, although small variation in the selection of a computation interval is allowed, the SCS recommends that the duration not exceed 0.25 Tc. As a general rule, the computation interval NMIN should fall in the following range:

$$[0.10 \times \text{largest } Tc] \leq NMIN \leq [0.25 \times \text{smallest } Tc]$$

If NMIN is greater than 0.174 Tc (or greater than 0.29 TL), then HEC-1 will provide a warning. Notwithstanding the HEC-1 warning, calculations should be acceptable when NMIN is not greater than 0.25Tc as prescribed above.

The above criteria may require that watersheds with significantly different subbasin sizes be modeled with some subbasins run separately and the outflow hydrographs from these separate runs read directly into the multi-basin model. Alternatively, larger subbasins could be split into sizes having Tc values more comparable with other subbasin Tc values.

Additional guidelines for NMIN values are provided in Table P-9.

b. **IDATE and ITIME** These records identify the date and time of the start of rainfall. When using a synthetic unit hydrograph such as the SCS dimensionless unit graph, the fields may be left blank.

c. NQ NQ is the integer number of hydrograph ordinates to be computed. There are a maximum of 300 allowed for the normal MSDOS version, and 2,000 for the extended memory MSDOS version. The total time base for the model is therefore NQ x NMIN, and this product must be greater than the total storm duration. Guidelines for meeting both NMIN and NQ criteria are presented in Table P-9.

There may be situations requiring a different selection than those provided in Table P-9 which may result in hydrograph truncation. In these cases, inspect the HEC-1 output for each subbasin to verify that the last discharge that is tabulated for the tail of the hydrograph is less than about 5 percent of the peak discharge for that hydrograph. If it is not, then either NQ or NMIN or both must be increased. When increasing either NQ or NMIN, care should be taken to ensure that values for both parameters conform with criteria presented here and in (a) above.

d. **NDDATE and NDTIME** These are usually left blank and not used.

3. **IN Record** The IN record prescribes the time interval and starting time for time series data which are read into the program, such as on the PC, PI, and QI records. The IN card is not always required, and may be used nearly anywhere in the input data. However, very often the same precipitation data applies to the entire watershed and QI records are not used, in which case the IN record would only be used once, and that prior to or within the first subbasin's runoff block.

a. **JXMIN** This parameter, input in field one of the IN record, identifies the integer number of minutes in the precipitation or runoff tabulation interval found on PI, PC, or QI records. If JXMIN matches NMIN on the IT record, and the starting time and date are the same (if used), then the IN record is not needed. Using SCS precipitation data per Appendix "A", JXMIN values would typically be as shown in Table P-9.

b. <u>JXDATE and JXTIME</u> If the starting date and time of time series data are the same as the NDDATE and NDTIME on the IT record, then these parameters are not needed and may be left blank. Using SCS unit hydrograph methods, they are not required.

TABLE P-9
SUGGESTED HYDROLOGICAL TIME SPECIFICATIONS

Storm Duration (hours)	IT Record NMIN Value* (minutes)	Range of Appropriate Subbasin Tc Values (minutes)	IT Record NQ Value (#)	IN Record JXMIN Value** (minutes)
2	1	4 - 10	130	2
6	2	8 - 20	200	12
24	5	20 - 50	300	15
	10	40 - 100	150	15
	15	60 - 150	100	15***

*If Modified Puls (Normal Depth-Storage) or Muskingum channel routing is performed, NMIN values are involved, and a review of Section V-I-1&2 (pages P-31 to P-36) and VI-B (page P-41) is recommended.
**When using precipitation data per Appendix "A".
***When the JXMIN value matches the NMIN value, the IN record probably is unnecessary.

4. <u>IO Record</u> The IO record prescribes output options to be used for the entire job, which may be overridden for individual operation components by use of a KO record. The IO record is not required, but the default setting results in full calculations and output that may not be necessary. Use of an IO record is recommended, with revisions on successive file runs as model refinement proceeds. Data fields and input parameters are discussed below.

a. <u>IPRT</u> For the first model run, a value of 4 is recommended, resulting in an output consisting of input data and a master summary. This results in minimal review or printing time to see if the file will run, and can be used to detect major structural or data input errors. On a second run, Level 3 is suggested because some error messages may not be printed with higher level settings.

The KO record may be used to override the IPRT setting for individual operations, allowing more flexibility in output specifications. Use of Level 0, 1, or 2, which will cause all output to be displayed, is generally unnecessary. Once the user is confident that the file is debugged and adequately refined, a Level 4 or 5 may be used. For inclusion in reports, a Level 4 is recommended because it provides the input data which helps the reviewer.

b. IPLT This parameter pertains to preparation and plotting of hydrograph output. As was the case with IPRT discussed in (a) above, it is well to limit computer output preparation and plotting on the first run, provide more detailed output for review on a subsequent run, and a reduced level of hydrograph plotting on final runs.

A selection of zero or one for IPLT will result in no hydrograph plot preparation or plotting, which is suggested for the first run. It may be desirable on the second run to have more detailed output, including hydrographs. However, if there are a lot of hydrograph operations, it may be beneficial to leave IPLT zero or one, and use a KO record to request hydrograph plotting for selected hydrograph operations. If the model run will result in only one or two hydrographs, use of a two for IPLT is reasonable for both the initial and subsequent runs. Otherwise, it is suggested to change hydrograph output using a KO record from more detailed to less detailed as one proceeds from the second round of runs to the final runs.

c. QSCAL Generally, this field is left blank, allowing the program to select the scale of plots. Once the magnitude of the hydrograph is known, a specific scale of output may be desirable.

B. JOB TYPE RECORDS Job type records, when used, follow job initialization and precede hydrology, hydraulic, or economic component records.

1. JP Record When the multi-plan feature is used, such as when a watershed is modeled under existing and proposed conditions in the same run, then a JP record is used. The number of plans or scenarios to be investigated must be input. If the JP record is used, the KP record will also be necessary.

2. JR Record When the multi-ratio feature is used, such as when various storm events are to be analyzed in the same run, then a JR record is used.

a. RTIO Typically, usage will be for various precipitation events, such as for the 2-year and 100-year storm event per criteria presented in this manual. This would require input of "PREC" in this data field.

b. RTIO (1) and (2), Etc. Fields 2 through 9 are used to input ratios. If "PREC" is used in field one, and the 2- and 100-year storm events are to be analyzed per procedures presented in this manual, then RTIO(1) could be 1.0, RTIO(2) would be the ratio of the 100-year to 2-year storm precipitation, and the 2-year total storm precipitation value would be used on the PB record.

3. JP & JR Limits The product of job plans and job ratios may not exceed 45, nor may the product of job plans, job ratios, and number of calculation steps (NQ parameter on the IT record) exceed 4800.

C. JOB STEP CONTROL RECORDS These records pertain to each group or block of hydrograph operation records that make up a component of HEC-1.

1. KK Record This record is required at the opening of each group or block of hydrograph operation records. Field one contains the name of the station or operation. A station description may also be provided in subsequent fields.

2. KM Record This record is optional, but may be used to provide descriptions which will appear in the results portion of the output file at the beginning of each station or plan. There is no limit to the number of records used. They may be used in most locations within a file, but not interspersed within precipitation or kinematic wave records. They typically are used immediately following the KK record. If a description or comment is desired that will only appear in a reproduction of the input portion of the output file, but not in the results, then use the "*_" record discussed in Section IV-B-5 (page P-16).

   In the free format, a comma is not required after the "KM", and if used is assumed to be part of the description.

3. KO Record This record is used to override the output option that is specified on the IO record. It will only apply to the component or operation pertaining to the group or block of records in which it is placed.

   a. JPRT and JPLT These correspond to IPRT (printed output) and IPLT (plotted output) on the IO record, and may be varied on initial and subsequent runs to provide detailed output only when and as needed.

   b. QSCAL This is the same as QSCAL on the IO record, and sets the scale of the plotted hydrograph. If left blank, the program will select the scale.

   c. FIELDS 4 - 8 These are adequately explained in Appendix "A" of the HEC-1 Users Manual. These fields are usually left blank, but field 5 may be useful on occasion. It allows one to write a hydrograph to a separate file which may be recalled and used later in the same run or in another input file by use of a BI record.

4. KP Record If the multi-plan option and JP record are used, KP records are involved. These identify a component operation as being specific to a particular plan. For example, plan 1 may represent existing conditions, and plan 2, a potential storage reservoir. Within

the group or block of reservoir routing operation records, the KP record would be used, with field one containing a 2 for plan 2. If an operation group does not contain a KP record, the operation is assumed to pertain only to plan 1.

D. HYDROGRAPH RECORDS

1. **HC Record** This record is used to combine hydrographs, which operation has been explained in Section II-D (page P-10). Stacking procedures, which relate to hydrograph combining, was explained in Section III-A (page P-12).

    a. **ICOMP** This parameter indicates how many hydrographs are to be combined. The default is two. No more than five hydrographs may be combined at a time. If *DIAGRAM is used, be aware that no more than nine separate hanging (stream branch) hydrographs may be carried on a schematic diagram.

    b. **TAREA** This parameter is the total area, in square miles. It is usually left blank. TAREA should be specified if a previously diverted hydrograph is to be added at that point, or if a hydrograph is brought in from another job using a BI record, the area of the imported watershed may be added using the TAREA parameter in field 2 of the HC record once a hydrograph combination operation is performed.

2. **QI Record** This record allows direct input of a hydrograph. More than one record may be used, and input values are the sequential hydrograph ordinates in cfs corresponding to the time interval specified on an IN card.

E. BASIN RECORDS

1. **BA Record** Using procedures specified in this manual, data will only be entered into the TAREA field. This is the total contributing subbasin area, in square miles.

2. **BF Record**

    a. Stream baseflow, in cfs, can be added to the runoff hydrograph to reflect desired conditions such as flow antecedent to the storm, upstream reservoir release, etc.

    b. Use of BF for a subbasin should be reset to zero (or other value) for the following subbasin or the previous BF value will be carried over to <u>each</u> subsequent subbasin.

3. **BI Record** Hydrographs generated by HEC-1 may be stored as a separate file for later retrieval within the same HEC-1 run, or for use as an automatic direct input hydrograph in other HEC-1 runs. The hydrograph must be stored using field 5 of the KO record as described in Section V-C-3c (page P-28). The name of the stored file is the name of the station where the hydrograph was calculated; that is, the hydrograph file name is the name

of the ISTAQ parameter on the KK record in the record block where the hydrograph was directed to be stored. The KO record in that same record block would identify unit 21 or 22 where the file is to be stored.

As an example, a hydrograph is generated with a KK station ISTAQ name of SAVE. Within that group of records, a KO record is used, with a "21" in field five. This results in a hydrograph named SAVE being stored in Unit (or tape) 21. Later in the same HEC-1 model run, or in a separate HEC-1 model, the hydrograph SAVE may be retrieved. The BI record would be used as follows (free format shown):

BI, SAVE, 21

A word of caution: Saving to unit 21 or 22 does not replace existing data — it adds to it. If subsequent runs are made, unit 21 or 22 may contain several output files. Prior to a final run, the unit 21 or 22 file should be deleted to clear it.

F. PRECIPITATION RECORDS

1. **PB Record** This record is used to identify the basin-average storm total precipitation for the watershed or subbasin which is a method used with the SCS dimensionless unit hydrograph. This value provides the vertical or runoff rate dimension of the hydrograph. This record must be included in the KK record group (a group of records that define an operation or HEC-1 simulation component). However, once input, the information will be used for subsequent subbasins unless overridden or revised. Typically, PB is only used in the first subbasin. Values may be obtained from NOAA Atlas II, Appendix "A" of this manual, or from more recent data. If a multiflood run will be used, it is logical to start with the total precipitation for the lowest storm event, such as the 2-year storm, and through use of a JR record, a ratio may be applied to yield the results of other storm events, such as for the 100-year storm.

2. **PC Record** This record contains cumulative precipitation distribution data. Data is input incrementally corresponding to the time interval specified as JXMIN on the IN record. Appendix "A" of this manual provides SCS unit hydrograph data and completed sets of PC records for the various storm types discussed in this manual.

G. LOSS RATE RECORDS

Although a number of loss rate methods are available for use in HEC-1, records of only two are presented herein.

1. LS Record (SCS Curve Number Method)

a. **STRLT** This parameter is identified as initial abstraction, which on the LS record includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration *before* runoff begins. Usually, this value is left at zero, which results in a default value calculated based upon the SCS curve number.

b. CRVNBR This refers to the subbasin SCS curve number, which should be selected based upon information provided in Appendix "C" of this manual or the SCS TR-55.

c. RTIMP Rainfall loss parameters are averages, and are assumed to be evenly distributed for the subbasin. The percent impervious value (RTIMP) is the percent of the subbasin area for which one hundred percent runoff will be computed. For the SCS CN values presented in Appendix "C" and TR-55 for urbanized areas, directly connected impervious surface is supposed to be accounted for already. This parameter should be used with care, and is often left blank. Reference is made to Appendix "C" or TR-55.

2. LG Record (Green and Ampt Method)

a. IA This value is surface retention loss, in inches. This is less than initial abstraction. Reference is made to Appendix "D" of this manual.

b. DTHETA, PSIF and XKSAT These are the area weighted values of the Green and Ampt parameters. Reference is made to Appendix "D" of this manual.

c. RTIMP Rainfall loss parameters are averages, and are assumed to be evenly distributed for the subbasin. The percent impervious value (RTIMP) is the percent of the subbasin area for which one hundred percent runoff will be computed. This means that the impervious area is assumed to be hydraulically connected to the concentration point. This parameter should be used with care. For urban areas, RTIMP is the effective or directly connected impervious area which is usually less than the total impervious area. Rock outcrop is not often directly connected to the watershed outlet. Care must be exercised when estimating RTIMP for rock outcrop.

H. SCS UNIT GRAPH RECORD

1. UD Record On the UD record, the subbasin lag time in hours is entered. This provides the horizontal or time dimension to the SCS dimensionless unit hydrograph. Note that there are many different lag time equations: for the SCS method, TLAG is 0.6 times Tc. The time of concentration Tc may be obtained by methods presented in the SCS TR-55 or Appendix "E" of this manual.

2. NMIN Note that, for a multiple subbasin model, all subbasin unit hydrographs will have a computation time interval per NMIN on the IT record.

I. CHANNEL ROUTING RECORDS

For a discussion on hydrologic routing principles, reference is made to Appendix "O".

1. Modified Puls/Normal Depth-Storage

a. RS Record

1) NSTPS This is the number of computation steps that will be used in the routing calculation. The number of steps is equivalent to the number of subreaches used in routing. The subreach length is the distance traveled by the flood wave during one computation time interval (NMIN on the IT record). The number of necessary subreaches corresponds to the integer NSTPS, which is a key parameter used in routing a hydrograph through a channel reach. The minimum reach length should satisfy the following expression:

$$L = NSTPS \cdot V_W \cdot 60 \cdot NMIN; \text{ or } NSTPS = \frac{L}{V_W \cdot 60 \cdot NMIN}$$

Where:

L	=	the minimum reach length, in feet;
NSTPS	=	a minimum of 1, but preferably more than 1;
NMIN	=	integer number of minutes in field one of the IT record; and
V_W	=	an estimate of the average velocity, in ft/sec

The above equation should be used as a guide in estimating the minimum channel routing length ($RLNTH_{min}$) before delineating subbasins in a multibasin watershed model, and also to estimate the minimum reach length to use in the model for improved model accuracy. Thereafter, the NSTPS parameter may be estimated by iteration as outlined below:

i) Make an initial estimate of NSTPS for each reach using an assumed average velocity for the peak discharge, times the applicable V_W/V_{AVG} ratio (see Appendix "O", Section C), and NMIN which has been selected per Section V-A-2 (page P-24).

ii) Run the model and calculate the discharge velocity for each reach. This velocity can be approximated by either of two methods.

The most accurate, and preferred, method is to perform a normal depth calculation using Manning's equation. The normal depth calculation should use the same channel data that is entered on the RC, RX and RY records in the HEC-1 model. The average peak discharge between the upstream and downstream routing locations (obtained from the first run of the model) should used for the velocity calculation.

A more simplified and less time consuming method (although less accurate than the previous method) is to estimate the discharge velocity by dividing the routing length on the RC record by the difference between "Time of

Peak" at the upstream and downstream routing limits. The "Time of Peak" values are listed in the Runoff Summary of HEC-1 output file.

The accuracy of this second method is subject to compromise because of program rounding when printing the "Time of Peak". The times to peak are based on multiples of the user selected computation interval (NMIN). Errors are created when the actual routing time is not an exact multiple of NMIN.

iii) Estimate the new NSTPS values for each reach based on the calculated discharge velocity. Update and run the HEC-1 model.

iv) Perform Steps (ii) and (iii) until the NSTPS values stabilize. This normally occurs within three iterations.

2) ITYP Insert FLOW indicating that the discharge for the beginning of the first time period is specified in the next field.

3) RSVRIC This defines the initial condition of the flow in the channel at the start of the routing computation. Normally the initial condition that is used is the discharge in the channel and this will often be 0 (dry channel). If the channel is expected to have flow in the channel prior to the modeled storm, or a baseflow, then use the appropriate discharge data. The channel water surface elevation at the start of the routing computation can be used, if desired instead of initial discharge conditions.

b. RC Record

1) ANL, ANCH, and ANR The Manning's roughness coefficient, n, is a measure of the flow resistance of a channel or overbank flow area. The flow resistance is affected by many factors including size of bed material, bed form, irregularities in the cross section, depth of flow, vegetation, channel alignment, channel shape, obstructions to flow, and quantity of sediment being transported in suspension or as bed load. In general, all factors that retard flow and increase turbulent mixing tend to increase n. Appendix "F" is devoted to Manning "n" values. HEC-2 users, note that "n" values are input in a different order than in HEC-2.

2) RLNTH This is the length in feet of the channel or major flow path. One of the most critical aspects of watershed modeling using subbasins and channel routing is the selection of channel routing lengths (RLNTH) in conjunction with NSTPS (RS record) and NMIN (IT record). The numeric procedure used in routing calculations requires that the travel time through each routing reach be a multiple of the selected computation interval (NMIN). For this reason, the selection of too short a RLNTH could result in the computation of zero travel time through the routing reach (instantaneous translation of the flood wave through the

reach). This could result in erroneously large peak discharges at downstream concentration points in the watershed model. A watershed model of numerous small subbasins and connecting short routing reaches can result in progressively larger overestimation of peak discharges in a downstream direction producing grossly overestimated peak discharge at the watershed outlet.

3) <u>SEL</u> This is the slope of the energy grade line and is not normally known. For normal flow, it is parallel to the channel bed slope. It is usually estimated as the channel bed slope, calculated by dividing the difference in bed elevation between the upper and lower ends of the watercourse by the routing reach length. The units of SEL are ft/ft.

4) <u>ELMAX</u> Not usually used. May be left blank.

c. <u>RX and RY Records</u>

1) All eight stations must be used.

2) Values are in feet.

3) Sequential values on the RX record must not decrease in magnitude.

4) The cross section must be "typical" for the routing reach.

5) The defined cross section must have adequate capacity to contain the peak discharge If not, HEC-1 will extend the two end stations vertically, and this is usually inappropriate for broad, shallow overbanks.

6) Care must be exercised in defining the channel geometry to avoid non-effective flow areas. Also, note that the points selected must coincide with specific locations on the cross-section as described in Appendix A, HEC-1 Users Manual.

d. <u>General Procedures</u> The following steps should be used with the Normal Depth routing method:

i) From the watershed base map, identify the routing reaches.

ii) Compile information on the characteristics of those reaches (detailed topographic maps to define channel geometry, photographs of the channels and overbanks, other hydrologic reports for the area, etc.)

iii) Conduct a field reconnaissance of the watershed and routing reaches, if practical. Observe and note the characteristics of the routing reaches; variations in the channel cross sections, irregularity of the channel, and degree of meandering of the main channel. Determine the hydraulically representative section of the routing reaches. Make note of and photograph the representative sections paying particular attention to flow resistance characteristics; bed material, obstructions to flow (rock outcrop, boulders, debris, etc.), and vegetation in the channel and overbank floodplains. If adequate maps are not available to define the channel geometry of the representative sections, field surveys or field measurements can be made of the channel and overbank floodplains.

iv) Prepare a sketch of the representative section of each routing reach, and prepare the channel geometry input (RX and RY records).

v) Estimate the main channel roughness coefficient, ANCH. Methods prescribed in Appendix "F" are recommended.

vi) If an 8-point cross section is used that contains overbank floodplains, select the n for each of the overbanks ANL and ANR. Reference is made to Appendix "F".

vii) Measure the routing reach length, RLNTH, from the base map.

viii) Estimate the energy gradient (SEL), by calculating the channel bed slope from the base map.

ix) Input the routing information into the RS, RC, RX and RY records.

2. Muskingum The Muskingum method of routing only requires use of one record after the KK record, and that is the RM record. The following parameters pertain to the RM record.

a. NSTPS This parameter is the integer number of steps, equal to the number of subreaches, used in Muskingum routing. As was the case with the Modified Puls/Normal Depth-Storage method, this is a key routing parameter, and proper selection is critical. The NSTPS value is dependent upon the AMSKK and X parameters used on the RM record, and also on the NMIN parameter used on the IT record. The relation between these and the allowable range is discussed below in subsection d. Note that NSTPS should be refined in a similar manner as was described by the four steps (i) - (iv) for the Modified Puls/Normal Depth-Storage method in subsection 1 above (pages P-32 and P-33).

b. AMSKK This parameter is the Muskingum K coefficient, which is the flood wave travel time in hours for the entire reach, or the entire reach length divided by the flood wave velocity. Note that the flood wave velocity is faster than the average flow velocity. If an average flow velocity can be reasonably estimated using Manning's equation, the flood-wave velocity may be estimated using ratios provided in Appendix "O", Section C.

The AMSKK, X, NSTPS, and NMIN parameters must have a relationship that falls within a defined range. this is discussed below in subsection d.

c. X This is a dimensionless weighting factor, which has a range of 0.0 to 0.5. A value of 0.0 produces maximum attenuation (outflow reduction), and is equivalent to level-pool reservoir routing. A value of 0.5 results in pure translation of the hydrograph with no attenuation. Experience has shown that for channels with mild slopes and flows that go out of bank, X will be closer to 0.0. For steeper streams with well defined channels that do not have flows that go out of bank, X will be closer to 0.5. Most natural channels have X values between 0.1 and 0.3, but much room is left to engineering judgement. The more embankment undulation and flood storage in floodplains, and the more irregular the stream channel is, the lower the X value will be. An equation for X is given in Appendix "O", Section E-2 which may be helpful, but it is only a guide.

d. Parameter Interrelationship The X, ANSKK, NSTPS, and IT record NMIN parameters all interrelate, and must conform to the following equation:

$$\frac{1}{2(1-x)} \leq \frac{60 \cdot AMSKK}{NMIN \cdot NSTPS} \leq \frac{1}{2X}$$

In the above equation, AMSKK is a physically based parameter: the length is given, and there is an associated wave velocity, although estimated. This is the first parameter that should be selected. X is also somewhat physically based, in that it helps to account for differences in storage capacity of various channel reaches. Both X and AMSKK are initially selected independent of any other parameter, although X may require subsequent adjustment inasmuch as it is not entirely independent of other parameters, particularly reach length. The NMIN value must also meet criteria which are discussed in Section V-A-2 (page P-26), and shown in Table P-9 (page P-24). There may be some flexibility in the NMIN value selected, but the NSTPS must be selected to conform to the above equation given the other parameters.

In Table P-9, NMIN values of 1, 2, 5, 10, and 15 are shown. Table P-10 uses these NMIN values along with the allowed range of X to show the corresponding limits of AMSKK with respect to NSTPS.

TABLE P-10
Allowed Range of (60 • AMSKK)/NSTPS

Muskingum X value	NMIN (value in minutes on field one of the IT record)				
	1	2	5	10	15
0.0	0.50 to ∞	1.00 to ∞	2.50 to ∞	5.00 to ∞	7.50 to ∞
0.1	0.56 to 5.00	1.11 to 10.00	2.78 to 25.00	5.55 to 50.00	8.33 to 75.00
0.2	0.63 to 2.50	1.25 to 5.00	3.12 to 12.50	6.25 to 25.00	9.38 to 37.50
0.3	0.71 to 1.67	1.43 to 3.33	3.57 to 8.33	7.14 to 16.67	10.71 to 25.00
0.4	0.83 to 1.25	1.67 to 2.50	4.16 to 6.25	8.35 to 12.50	12.50 to 18.75
0.5*	1.00	2.00	5.00	10.00	15.00

*Although this results in pure translation with no attenuation, it does allow for hydrograph travel time, which should be considered to prevent unrealistic hydrograph combinations. However, it is unlikely that 60 • AMSKK/NSTPS will be able to exactly equal the required values; therefore, if the travel time is of significance, use of an X value of 0.4 might be considered.

3. Muskingum-Cunge Prior to running the HEC-1 model, channel capacity must be checked to assure that the depth and the side slope or channel boundaries are properly selected for flow conveyance. Otherwise, HEC-1 will automatically extend the channel boundaries vertically to contain the flow.

HEC-1 procedures use three criteria to select a proper computation time step. Once an appropriate time step is selected, the reach length is automatically divided as appropriate into subreaches for model accuracy and stability.

This method may be used with urbanized reaches and natural reaches. HEC-1 application is quite different for the two methods.

a. Urbanized Channel The RD record is used to input the reach length in feet, channel energy (or bed slope), and Manning's "n" value. Also, a channel shape is identified by cross section type and other parameters. HEC-1 will calculate all other Muskingum-Cunge parameters for use in routing.

b. Natural Channel The RD record is used, but all fields are left blank. RC, RX, and RY records are used following the RD record. Reference is made to the Modified Puls/Normal Depth-Storage routing in subsection 1 above for information on RC, RX, and RY records.

J. RESERVOIR ROUTING RECORDS

1. RS Record

a. NSTPS This is the number of steps used in the calculation. NSTPS=1 for reservoir storage routing.

b. ITYP Use STOR if the initial condition of the reservoir will be indicated by an existing storage volume. Use FLOW if the initial condition of the reservoir or channel will be identified by an existing discharge. Use ELEV if the initial condition of the reservoir or channel will be identified by an existing water surface elevation.

c. RSVRIC This is the value of the initial routing condition (storage, in acre-feet; discharge, in cfs; or elevation, in feet) as indicated by ITYP.

2. SV/SA Records

a. When using the SV record, RCAP is storage volume, in acre-feet, corresponding to the elevation value in the same field in the following SE record.

b. When using the SA record, RAREA is surface area, in acres, corresponding to the elevation value in the same field in the following SE record.

3. SE Record

a. This record is placed immediately after either an SV, SA, or SQ record.

b. ELEV This is the water surface elevation, in feet, corresponding to values in the same field of either the SV, SA, or SQ record.

c. SV/SA or SQ and SE values should correspond to an established volume/area or discharge versus elevation rating curve.

4. SQ Record This record is used to define a stage-discharge relation. DISQ is discharge in cfs corresponding to the previous SV/SA and SE records, or a separate SE record may be used immediately after the SQ record.

K. DIVERSION RECORDS

1. DT Record An alphanumeric name having up to six characters may be given to the diverted flow hydrograph. The diverted hydrograph will not remain in the stack, but will be written to a file that may be retrieved with a DR record. Both maximum volume and peak flow may be input, if desired.

2. DI/DQ Records These records allow inflow/diversion flow data to be entered.

VI. WATERSHED MODELING

An overview of HEC-1 has been provided, along with an overview of basic HEC-1 components, miscellaneous features, and input data. Guidance has also been provided in the use of selected data records and parameter selection. Now it is time to bring the modeling process together.

A. MODELING PROCESS An outline of general steps involved or encouraged in performing a watershed analysis is provided below.

1. **Information Gathering** Collect all pertinent information for the watershed:

   i) maps

   ii) aerial photography

   iii) soil surveys

   iv) land-use maps/reports

   v) reports of flooding

   vi) streamflow data (if available)

   vii) reports of other flood studies (FEMA, county, etc.)

2. **Drainage Map** Prepare a watershed base map using the best available map and most practical map scale.

3. **Subbasin Delineation** Perform a preliminary subbasin delineation. Reference is made to subsection B which follows.

4. **Field Check** Conduct a field reconnaissance. Field observations should include as a minimum:

   i) observation and documentation of the drainage network, and hydraulic roughness characteristics of the basin and channels and overbanks, with supportive photos;

   ii) observation of soil and geologic conditions, soil types, depth of topsoil, groundwater, rock, and impervious areas, whether connected or unconnected;

   iii) observation of vegetal cover type and extent; and

   iv) land use.

5. Revise Subbasins Finalize the subbasin delineation per field check and study purpose.

6. Precipitation Prepare the precipitation input. When using basin average total storm precipitation, as is done when using the SCS unit hydrograph, this consists only of obtaining total storm precipitation values, such as from Appendix "A" or NOAA ATLAS II.

7. Precipitation Losses Prepare the precipitation loss input. Reference is made to Appendix "C" for SCS curve number information, or Appendix "D" for Green and Ampt parameter information.

8. Unit Hydrograph Prepare the unit hydrograph input. When using the SCS unit hydrograph, use cumulative precipitation values which are provided in Appendix "A". The dimensionless unit hydrograph has a magnitude parameter per (6) above, but a time parameter must be added, which is the lag time per Appendix "E" or TR-55.

9. Routing Prepare all routing input. Hydrologic routing is discussed in Appendix "O".

10. Network Diagram Prepare a preliminary network diagram of the various components of subbasin runoff, routing, combining, etc.

11. HEC-1 Input File Prepare HEC-1 input file in ASCII format, assembling all the data in HEC-1 format per the network diagram.

12. First Run Execute the HEC-1 model. Use reduced output controls per suggestions given regarding the IO record in Section V-A-4 (page P-26), and the KO record in Section V-C-3 (page P-28). Also, use of "*DIAGRAM" option is strongly recommended (see Section IV-B-4, page P-16).

13. Model Revisions Debug the model, and calibrate where possible. Check the output of input data for errors, check the network diagram against watershed mapping, correct errors found by the program, and look for output data that may indicate possible errors in the model. Reference is made to subsection C which follows.

14. Second Run Execute the HEC-1 model again, with more detailed output for more extensive review. Reference is made to recommendations given in Sections V-A-4 (page P-26) and Section V-C-3 (P-28).

15. Evaluate Results Evaluate the model and results based on available information. Reference is made to subsection C which follows.

16. Fine Tuning Revise the model, as appropriate, to best represent actual watershed conditions.

17. Revised Run Execute the final HEC-1 model.

18. **Evaluate Results** Make final model verifications and evaluations.

B. **SUBBASIN DELINEATION** The process of breaking down a watershed into subbasins should be done with careful consideration given to the purpose of the study, critical concentration points where information is desired, and technical restraints of the model. Defining these factors prior to beginning the delineation will help to ensure that the model remains within the limitations of the methodology used and will also help avoid extensive revisions.

1. **Concentration Points** Identify locations where peak flow rate or runoff volumes are desired. The following locations, as a minimum, should be considered:

   i) Confluences of watercourses where a significant change in peak discharge may occur;

   ii) Drainage structures, such as inlets, culverts, and detention/retention basins;

   iii) Crossing of watercourses with streets or to ensure conformance with street inundation requirements; and

   iv) Jurisdictional boundaries.

2. **Subbasin Size** Using the concentration point locations, estimate a target average subbasin size to strive for.

3. **Time of Concentration** Based upon subbasin size and slopes, preliminarily estimate the time of concentration (Tc) for the smallest and largest subbasin. If Tc values will not conform to criteria specified in Section V-A-2 (page P-24), it may be well to modify subbasin delineation.

4. **Homogeneity** Considerations for subbasin homogeneity, in order to meet the basin average assumption are:

   i) The subbasin sizes should be as uniform as possible;

   ii) Each subbasin should have nearly homogeneous land-use and surface characteristics. For example, mountain, hillslope, and valley areas should be separated into individual subbasins wherever possible; and

   iii) Soils and vegetation characteristics for each subbasin should be as homogeneous as reasonably possible.

The average subbasin size may need to be adjusted (addition of concentration points) as required, in order to satisfy the key assumptions upon which the HEC-1 model is based.

5. **Routing Lengths** Channel reach lengths defined as a result of delineation may be a significant factor to consider while breaking down watersheds, particularly for the Normal Depth-Storage and Muskingum methods of routing. A key routing parameter used in these methods is the number of steps (NSTPS).

   a. Normal Depth-Storage The minimum reach length should satisfy the criteria prescribed in Section V-I-1 (page P-31). Conformance thereto may improve modeling accuracy and will minimize routing instability warnings in the model output. Appendix "O" should be consulted for discussion of problems that may result if this recommendation is not followed.

   b. Muskingum The travel time for a reach in minutes divided by NSTPS and NMIN must fall within a defined range as explained in Section V-I-2 (page P-35).

C. EVALUATING RESULTS Sometimes it is difficult to find errors or problems in input data unless the program is run and the output results are thoroughly checked for errors, warnings, proper diagramming through use of the *DIAGRAM feature, and hydrological output results. Evaluating results is a very important part of the analysis.

1. Program Crash While the program is running, the screen will show the KK operation in process on newer HEC-1 versions. If the program is terminated while in process, it means that there is a problem in or after the last operation shown on the screen. A message will appear such as: "Return code 7777"; or "Run-time error M6103: Math — floating-point error: divide by 0". When the program crashes, the end of the output file should be viewed, where error messages will help locate the problem.

   If one of the above messages appears after the last KK operation during computation, it is likely that the only problem is an inability to recognize the ZZ record. The output file will provide a message regarding a missing ZZ record, and perhaps a "card out of sequence" message, because the program is unaware that it is at the end of the file, and continues looking for data, even at the beginning of the input file. If the ZZ record really is missing from the input file, add it. If it is already there and in the correct place, the problem may be resolved by following the following two steps:

   i) With some editing or typing programs, it is necessary to hit the "enter" or "return" key after the "ZZ" for HEC-1 to recognize the ZZ during program execution, even though it will show up in the HEC-1 input data portion of the output file; and

   ii) Make sure that the file ends at the beginning of the line following the ZZ record. Blank lines below the ZZ record can cause program execution failure.

2. Errors All error messages must be checked. Output level (IPRT) 3 or less should be entered on the IO record for all error messages to appear. The HEC-1 Users Manual contains a section explaining the error messages and how to correct them.

3. **Diagram** Check the schematic. Follow the diagram on the watershed map and see if it is correct and reasonable. As a minimum, check the following:

   i) Make sure there are no "hanging hydrographs" left;

   ii) Make sure that all of the diverted hydrographs have been accounted for; and

   iii) Make sure that all of the subareas are attached and are being combined in the proper sequence. All upstream subareas must be combined before routing through a downstream channel.

4. **Area** Check the accuracy of the total drainage area. Normally, for basins with a single outlet, the easiest way is to check the last number on the "area" column in the HEC-1 summary table. For basins with several outlets, the contributing area for each outlet may have to be added together and then checked for accuracy.

   If USGS stream gauges are present in the watershed, the HEC-1 area above the gauge concentration point should be compared to USGS published reports. Previous studies of the watershed may also prove useful for comparison of areas.

5. **Losses** Look through the output for each subbasin. Check the total rainfall, total losses and total runoff. If zero or a very small number is noticed in any of these columns, the input for that subbasin must be examined. It is possible to have forgotten a loss record (LG,LS) and not get an error statement in the output, because the previous loss record will be used which may not be correct (see Section IV-D [page P-19] regarding repetitive data). Check the loss columns for inconsistency. Inconsistencies in estimated losses must be examined.

6. **Routing**

   a. Check the applicability of the routing methodology applied. Reference is made to Appendix "O", particularly Table O-2.

   b. Verify that the inflow is equal to or greater than the outflow. If it is, then routing stability is probably acceptable, despite warnings.

   c. Check for instability in the outflow hydrograph. This can be done by using level 1 (IPRT) output or by plotting the hydrograph.

   d. Check to see that flow is contained within the channel. HEC-1 will normally extend the banks vertically if the channel cross section area is not large enough.

   e. Check travel time. Travel time can be translated back to velocity or wave celerity. If the travel time seems too long or too short, examine the input parameters for the routing. Routing steps in the input can be checked against the output velocity.

f. Routing procedures will normally result in some attenuation of the peak flow. This attenuation (or lack of) should be checked for reasonableness.

g. Routing will not only attenuate (reduce) the flow, but will also delay the peaks and therefore separate them in time. This separation of peaks can have a substantial effect when combining hydrographs and on the resulting peak at the outlet. Selecting short reaches or using large computation time intervals will cause the peak time to default to the nearest time interval. The cumulative effect of this may result in substantial error.

7. **Peak Runoff** Since HEC-1 does not have a summary table showing unit discharge (cfs/square mile), it is recommended that reviewers develop this information themselves. Unit discharges could be used to compare flows from one subbasin with another. Since unit discharge depends on many factors such as area, slope, losses, etc., this comparison may be difficult. However, large differences in unit discharge should alert the reviewer to check the input for discrepancies.

8. **Time To Peak** Check the time to peak column in the HEC-1 summary table. Generally Tp's are expected to increase with drainage area size. If all the Tp's appear to coincide or are very close, the computation time interval (NMIN) on the IT record should be examined or changed and routing operations should be changed.

9. **Volumes** Check the output to determine if the volume of runoff is reasonable. This may prove to be somewhat difficult since there are very few "yard sticks" developed for comparing runoff volumes. Experience and published reports should be relied upon to determine if the runoff volumes are reasonable.

10. **General Considerations**

a. Keep the subbasin areas as uniform as possible. Otherwise, it is easy to overestimate the peaks for small subbasins and underestimate the peaks for large subbasins.

b. Separate mountainous areas from the adjacent valleys. Most of the peak is generated from hill slopes and attenuated in the valley. Mixing the two may cause incorrect results.

c. Time of concentration and lag time are not interchangeable. It is important to use them properly since peak flows are extremely sensitive to these parameters.

d. Manning's friction coefficient for routing must be used properly for main channel and overbanks. If sheet flow is present, the "n" values must be adjusted accordingly.

e. When comparing existing versus proposed conditions, all the model parameters (rainfall losses, unit hydrographs, routing, etc.) must be adjusted accordingly. Proposed storm sewer pipe flows usually have higher velocity than surface flows and can increase peak discharges. For more frequent storms, where depth of flow is small, introducing street networks may affect the flow paths. This may require a re-examination of subbasin boundaries.

D. <u>EXAMPLE INPUT FILE</u> An example problem demonstrates the procedures presented herein. Data is selected at random. The purpose of this example is to show conversion of data to a HEC-1 input file, and what the HEC-1 output looks like.

I. **<u>Input Data</u>**

a. **<u>Subbasin A</u>**
Area = 0.5 square miles
SCS CN = 89 (includes directly connected impervious areas)
Tc = 0.61 hours, TL = 0.6 x 0.61 = 0.35 hours

b. **<u>Subbasin B</u>**
Area = 0.5 square miles
Green & Ampt: Surface retention loss = 0.20 inches; DTHETA = 0.15; PSIF = 8.2 in.; XKSAT = 0.04 in/hr; RTIMP = 0%
TL = 0.35 hours

c. **<u>Reach 1</u>** (Use Muskingum-Cunge, urban channel)

Channel Type:	Trapezoidal
Channel Length:	2000 feet
Side Slopes:	3H:1V
Bottom Width:	20 feet
Manning's "n":	0.020
Channel Slope:	0.002 feet/foot

d. **<u>Diversion</u>**
Do not divert polluted low flow (≤ 20 cfs)
Beyond the initial 20 cfs direct as much flow as is possible up to a maximum of 80 cfs to the pond, limited to a maximum of 20 acre-feet.

e. **<u>Reach 2</u>** (Muskingum-Cunge, natural channel)
Channel Type: Natural   Manning's "n" values 0.50, 0.35, 0.55
Channel Length: 500 feet
Channel Slope: 0.002 feet/foot

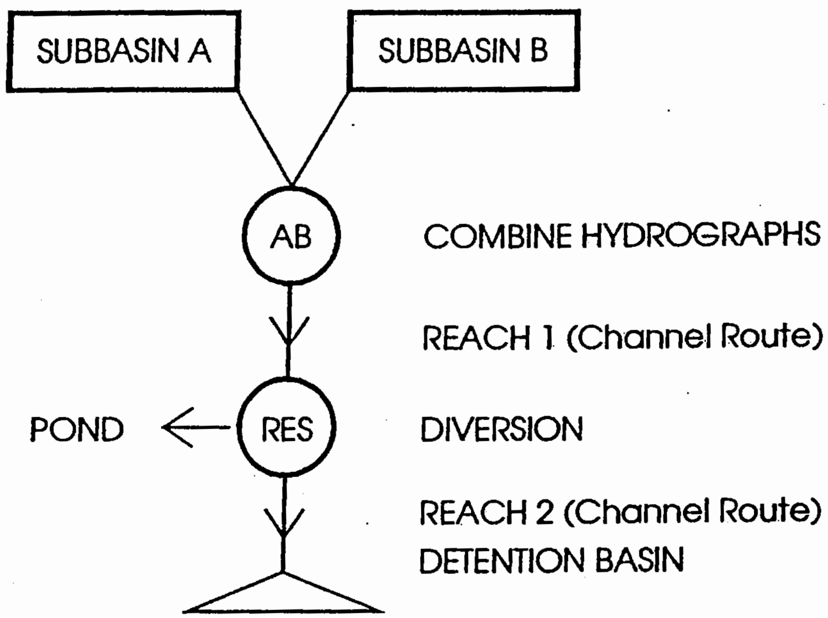
Station	100,	105,	110,	115,	125,	130,	140,	145
Elevation	50,	28,	27.5,	20,	19,	23,	26,	50

f. **Reservoir**
Detention pond dry at start of storm

Area (acres):	3, 4, 6, 8
Elevation:	100, 101, 102, 104
Discharge (cfs):	0, 50, 150, 400
Elevation:	100, 101, 102, 104

g. **Precipitation Data**
2 Year Storm: 0.70 in
100 Year Storm: 2.01 in
Ratio 2.01/0.70: = 2.87

2. **Input Diagram**



3. **Input File**

```
ID Example #1
*FREE
*DIAGRAM
IT,5,,,300
IN,15
I0,4,0
JR,PREC,1.0,2.87
*
KK,BASINA
KM RUNOFF GENERATED ON SUBBASIN A
BA,0.5
```

```
PB,0.70
*
* SCS TYPE II RAINFALL DISTRIBUTION (24 HOUR)
*
PC,.000,.002,.005,.008,.011,.014,.017,.020,.023,.026
PC,.029,.032,.035,.038,.041,.041,.048,.052,.056,.060
PC,.064,.068,.072,.076,.080,.085,.090,.095,.100,.105
PC,.110,.115,.120,.126,.133,.140,.147,.155,.163,.172
PC,.181,.191,.203,.218,.236,.257,.283,.387,.663,.707
PC,.735,.758,.776,.791,.804,.815,.825,.834,.842,.849
PC,.856,.863,.869,.875,.881,.887,.893,.898,.903,.908
PC,.913,.918,.922,.926,.930,.934,.938,.942,.946,.950
PC,.953,.956,.959,.962,.965,.968,.971,.974,.977,.980
PC,.983,.986,.989,.992,.995,.998,1.00
LS,0,89
UD,0.35
*
KK,BASINB
KM Runoff generated on subbasin B
BA,0.5
LG,0.12,0.15,8.2,0.04,25
UD,0.35
*
KK,AB
KM Combine subbasins A & B
HC,2
*
KK,RT-AB
KM Route the combined hydrograph AB using
KM Muskingum-Cunge, urban channel method
RD,2000,.002,0.020,,TRAP,20,3
*
KK,RES
KM Portion of flow is diverted to the pond (hydrograph name is "POND")
KM Balance of flow continues on to the reservoir.
DT,POND,20,80
DI,0,1,20,21,100,10000
DQ,0,0,0,1,80,80
*
KK,RT-RES
KM Route the non-diverted hydrograph "RES" to the detention basin
KM Use Muskingum-Cunge, natural channel method
RD
RC,0.50,0.35,0.55,500,.002
RX,100,105,110,115,125,130,140,145
```

RY,50,28,27.5,20,19,23,26,50
*

KK,DET
KM Storage route hydrograph RT-RES through the detention basin
RS,1,STOR,0
SA,3,4,6,8
SE,100,101,102,104
SQ,0,50,150,400
ZZ

4. HEC-1 Output

```
1***************************************                       ***************************************
*                                      *                       *                                     *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                       *   U.S. ARMY CORPS OF ENGINEERS      *
*            SEPTEMBER 1990            *                       *   HYDROLOGIC ENGINEERING CENTER     *
*             VERSION 4.0              *                       *        609 SECOND STREET            *
*                                      *                       *     DAVIS, CALIFORNIA 95616         *
* RUN DATE  04/06/1994  TIME  17:19:25 *                       *        (916) 756-1104               *
*                                      *                       *                                     *
***************************************                        ***************************************


                    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. THIS IS THE FORTRAN77 VERSION
     NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
     DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL    LOSS RATE:GREEN AND AMPT INFILTRATION
     KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM


              1        ID   FILE EXAMPLE1.IN
*** FREE ***
                       *DIAGRAM
              2        IT       5                         300
              3        IN      15
              4        IO       4        0
              5        JR    PREC     1.00     2.87
                       *

              6        KK  BASINA
              7        KM   RUNOFF GENERATED ON SUBBASIN A
              8        BA      .5
              9        PB     .70
                       *
                       * SCS TYPE II RAINFALL DISTRIBUTION (24 HOUR)
                       *
             10        PC    .000     .002     .005     .008     .011     .014     .017     .020     .023     .026
             11        PC    .029     .032     .035     .038     .041     .044     .048     .052     .056     .060
             12        PC    .064     .068     .072     .076     .080     .085     .090     .095     .100     .105
             13        PC    .110     .115     .120     .126     .133     .140     .147     .155     .163     .172
             14        PC    .181     .191     .203     .218     .236     .257     .283     .387     .663     .707
             15        PC    .735     .758     .776     .791     .804     .815     .825     .834     .842     .849
             16        PC    .856     .863     .869     .875     .881     .887     .893     .898     .903     .908
             17        PC    .913     .918     .922     .926     .930     .934     .938     .942     .946     .950
             18        PC    .953     .956     .959     .962     .965     .968     .971     .974     .977     .980
             19        PC    .983     .986     .989     .992     .995     .998     1.00
             20        LS       0       89
             21        UD     .35
                       *

             22        KK  BASINB
             23        KM   RUNOFF GENERATED ON SUBBASIN B
             24        BA      .5
             25        LG    0.20     0.15      8.2     0.04        0
             26        UD     .35
                       *

             27        KK      AB
             28        KM    COMBINE RUNOFF FROM AREAS A & B
             29        HC       2
                       *

             30        KK   RT-AB
             31        KM    ROUTE THE COMBINED HYDROGRAPH AB USING
             32        KM    MUSKINGUM-CUNGE URBAN CHANNEL METHOD
             33        RD    2000     .002      .02                TRAP       20        3
                       *

             34        KK     RES
             35        KM   PORTION OF FLOW IS DIVERTED TO THE POND
             36        KM   (HYDROGRAPH NAME IS POND). BALANCE OF
             37        KM   FLOW CONTINUES TO THE RESERVOIR.
             38        DT    POND       20       80
             39        DI       0        1       20       21      100    10000
             40        DQ       0        0        0        1       80       80
                       *
```

```
            41           KK  RT-RES
            42           KM   ROUTE THE NON-DIVERTED HYDROGRAPH "RES" TO
            43           KM   THE DETENTION BASIN. USE MUSKINGUM-CUNGE
            44           KM   NATURAL CHANNEL METHOD.
            45           RD
            46           RC       .5      .35     .55     500     .002
            47           RX      100      105     110     115      125     130     140     145
            48           RY       50       28    27.5      20       19      23      26      50
                         *

            49           KK     DET
            50           KM   STORAGE ROUTE HYDROGRAPH "RT-RES" THROUGH
            51           KM   THE DETENTION BASIN.
            52           RS       1     STOR       0
            53           SA       3        4       6       8
            54           SE     100      101     102     104
            55           SQ       0       50     150     400
            56           ZZ
1
              SCHEMATIC DIAGRAM OF STREAM NETWORK
INPUT
 LINE       (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

 NO.        (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

   6        BASINA
              .
  22          .       BASINB
              .         .
              .         .
  27         AB...........
              V
              V
  30        RT-AB
              .
              .
  38          .------->    POND
  34         RES
              V
              V
  41       RT-RES
              V
              V
  49         DET

(***) RUNOFF ALSO COMPUTED AT THIS LOCATION
1*************************************                                        *************************************
*                                   *                                        *                                   *
*  FLOOD HYDROGRAPH PACKAGE  (HEC-1) *                                       *  U.S. ARMY CORPS OF ENGINEERS     *
*          SEPTEMBER 1990            *                                       *  HYDROLOGIC ENGINEERING CENTER    *
*           VERSION 4.0              *                                       *         609 SECOND STREET         *
*                                    *                                       *     DAVIS, CALIFORNIA 95616       *
* RUN DATE  04/06/1994  TIME  17:19:25 *                                     *         (916) 756-1104            *
*                                    *                                       *                                   *
*************************************                                        *************************************



                    FILE EXAMPLE1.IN

  4 IO         OUTPUT CONTROL VARIABLES
                     IPRNT          4  PRINT CONTROL
                     IPLOT          0  PLOT CONTROL
                     QSCAL         0.  HYDROGRAPH PLOT SCALE

    IT         HYDROGRAPH TIME DATA
                      NMIN          5  MINUTES IN COMPUTATION INTERVAL
                     IDATE     1    0  STARTING DATE
                     ITIME       0000  STARTING TIME
                        NQ        300  NUMBER OF HYDROGRAPH ORDINATES
                    NDDATE     2    0  ENDING DATE
                    NDTIME       0055  ENDING TIME
                     ICENT         19  CENTURY MARK

               COMPUTATION INTERVAL    .08 HOURS
                    TOTAL TIME BASE  24.92 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 PRECIPITATION
                  1.00      2.87

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

           **************
           *            *
  6 KK     *   BASINA   *
           *            *
           **************
                    RUNOFF GENERATED ON SUBBASIN A

  3 IN         TIME DATA FOR INPUT TIME SERIES
                    JXMIN         15  TIME INTERVAL IN MINUTES
                   JXDATE     1    0  STARTING DATE
                   JXTIME          0  STARTING TIME

            SUBBASIN RUNOFF DATA

  8 BA         SUBBASIN CHARACTERISTICS
                    TAREA        .50  SUBBASIN AREA

               PRECIPITATION DATA

  9 PB                STORM      .70  BASIN TOTAL PRECIPITATION
```

10 PI INCREMENTAL PRECIPITATION PATTERN

.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.01	.00	.01
.01	.01	.01	.01	.01	.01	.01	.01	.03	.03
.03	.09	.09	.09	.01	.01	.01	.01	.01	.01
.01	.01	.01	.01	.01	.01	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00		

20 LS SCS LOSS RATE
STRTL .25 INITIAL ABSTRACTION
CRVNBR 89.00 CURVE NUMBER
RTIMP .00 PERCENT IMPERVIOUS AREA

21 UD SCS DIMENSIONLESS UNITGRAPH
TLAG .35 LAG

***

UNIT HYDROGRAPH
23 END-OF-PERIOD ORDINATES

69.	217.	445.	593.	613.	541.	426.	283.	199.	144.
102.	72.	51.	35.	25.	18.	13.	9.	6.	5.
3.	2.	1.							

*** ***

22 KK * BASINB *

RUNOFF GENERATED ON SUBBASIN B

SUBBASIN RUNOFF DATA

24 BA SUBBASIN CHARACTERISTICS
TAREA .50 SUBBASIN AREA

PRECIPITATION DATA

9 PB STORM .70 BASIN TOTAL PRECIPITATION

10 PI INCREMENTAL PRECIPITATION PATTERN

.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.01	.00	.01
.01	.01	.01	.01	.01	.01	.01	.01	.03	.03
.03	.09	.09	.09	.01	.01	.01	.01	.01	.01
.01	.01	.01	.01	.01	.01	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
.00	.00	.00	.00	.00	.00	.00	.00		

25 LG GREEN AND AMPT LOSS RATE
STRTL .20 STARTING LOSS
DTH .15 MOISTURE DEFICIT
PSIF 8.20 WETTING FRONT SUCTION
XKSAT .04 HYDRAULIC CONDUCTIVITY
RTIMP .00 PERCENT IMPERVIOUS AREA

26 UD SCS DIMENSIONLESS UNITGRAPH
TLAG .35 LAG

***

UNIT HYDROGRAPH
23 END-OF-PERIOD ORDINATES

69.	217.	445.	593.	613.	541.	426.	283.	199.	144.
102.	72.	51.	35.	25.	18.	13.	9.	6.	5.
3.	2.	1.							

*** ***

```
              **************
              *            *
  27 KK       *        AB  *
              *            *
              **************
                              COMBINE RUNOFF FROM AREAS A & B

  29 HC          HYDROGRAPH COMBINATION
                       ICOMP            2  NUMBER OF HYDROGRAPHS TO COMBINE

                                                              ***

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

              **************
              *            *
  30 KK       *     RT-AB  *
              *            *
              **************
                              ROUTE THE COMBINED HYDROGRAPH AB USING
                              MUSKINGUM-CUNGE URBAN CHANNEL METHOD

               HYDROGRAPH ROUTING DATA

  33 RD          MUSKINGUM-CUNGE CHANNEL ROUTING
                        L        2000.  CHANNEL LENGTH
                        S        .0020  SLOPE
                        N         .020  CHANNEL ROUGHNESS COEFFICIENT
                       CA          .00  CONTRIBUTING AREA
                    SHAPE         TRAP  CHANNEL SHAPE
                       WD        20.00  BOTTOM WIDTH OR DIAMETER
                        Z         3.00  SIDE SLOPE

                                                              ***

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

              **************
              *            *
  34 KK       *       RES  *
              *            *
              **************
                              PORTION OF FLOW IS DIVERTED TO THE POND
                              (HYDROGRAPH NAME IS POND). BALANCE OF
                              FLOW CONTINUES TO THE RESERVOIR.

     DT          DIVERSION
                      ISTAD          POND  DIVERSION HYDROGRAPH IDENTIFICATION
                     DSTRMX         20.00  MAXIMUM VOLUME TO BE DIVERTED

     DI              INFLOW           .00       1.00      20.00      21.00     100.00   10000.00

     DQ       DIVERTED FLOW           .00        .00        .00       1.00      80.00      80.00
                                                              ***

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

              **************
              *            *
  41 KK       *    RT-RES  *
              *            *
              **************
                              ROUTE THE NON-DIVERTED HYDROGRAPH "RES" TO
                              THE DETENTION BASIN. USE MUSKINGUM-CUNGE
                              NATURAL CHANNEL METHOD.

               HYDROGRAPH ROUTING DATA

  45 RD          MUSKINGUM-CUNGE CHANNEL ROUTING

  46 RC          NORMAL DEPTH CHANNEL
                        ANL         .500  LEFT OVERBANK N-VALUE
                       ANCH         .350  MAIN CHANNEL N-VALUE
                        ANR         .550  RIGHT OVERBANK N-VALUE
                      RLNTH         500.  REACH LENGTH
                        SEL        .0020  ENERGY SLOPE
                      ELMAX           .0  MAX. ELEV. FOR STORAGE/OUTFLOW CALCULATION

                                      CROSS-SECTION DATA
                            --- LEFT OVERBANK --- + ------ MAIN CHANNEL ------- + --- RIGHT OVERBANK ---
  48 RY         ELEVATION     50.00     28.00     27.50     20.00     19.00     23.00     26.00     50.00
  47 RX          DISTANCE    100.00    105.00    110.00    115.00    125.00    130.00    140.00    145.00
                                                              ***

                                     COMPUTED STORAGE-OUTFLOW-ELEVATION DATA

         STORAGE      .00       .15       .41       .74      1.19      1.74      2.36      3.04      3.73      4.43
         OUTFLOW      .00      2.46     10.88     25.25     46.34     74.61    112.90    159.54    212.49    271.18
       ELEVATION    19.00     20.63     22.26     23.89     25.53     27.16     28.79     30.42     32.05     33.68

         STORAGE     5.15      5.88      6.62      7.38      8.15      8.93      9.73     10.54     11.36     12.20
         OUTFLOW   335.28    404.55    478.80    557.91    641.74    730.22    823.25    920.77   1022.72   1129.04
       ELEVATION    35.32     36.95     38.58     40.21     41.84     43.47     45.11     46.74     48.37     50.00
```


```
                                     COMPUTED STORAGE-OUTFLOW-ELEVATION DATA

         STORAGE      .00       .15       .41       .74      1.19      1.74      2.36      3.04      3.73      4.43
         OUTFLOW      .00      2.46     10.88     25.25     46.34     74.61    112.90    159.54    212.49    271.18
       ELEVATION    19.00     20.63     22.26     23.89     25.53     27.16     28.79     30.42     32.05     33.68

         STORAGE     5.15      5.88      6.62      7.38      8.15      8.93      9.73     10.54     11.36     12.20
         OUTFLOW   335.28    404.55    478.80    557.91    641.74    730.22    823.25    920.77   1022.72   1129.04
       ELEVATION    35.32     36.95     38.58     40.21     41.84     43.47     45.11     46.74     48.37     50.00
```


```
*** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

```
                 ***************
                 *             *
    49 KK        *     DET     *
                 *             *
                 ***************
                              STORAGE ROUTE HYDROGRAPH "RT-RES" THROUGH
                              THE DETENTION BASIN.

                  HYDROGRAPH ROUTING DATA

    52 RS           STORAGE ROUTING
                       NSTPS           1  NUMBER OF SUBREACHES
                        ITYP        STOR  TYPE OF INITIAL CONDITION
                      RSVRIC         .00  INITIAL CONDITION
                           X         .00  WORKING R AND D COEFFICIENT

    53 SA               AREA         3.0       4.0       6.0       8.0

    54 SE          ELEVATION      100.00    101.00    102.00    104.00

    55 SQ          DISCHARGE          0.       50.      150.      400.

                                                                   ***

                                                  COMPUTED STORAGE-ELEVATION DATA

           STORAGE         .00      3.49      8.45     22.41
         ELEVATION      100.00    101.00    102.00    104.00
1

                 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 PRECIPITATION
   OPERATION       STATION      AREA    PLAN             RATIO 1  RATIO 2
                                                           1.00     2.87

   HYDROGRAPH AT
 +                 BASINA        .50      1   FLOW          22.     250.
                                              TIME        12.33    12.25

   HYDROGRAPH AT
 +                 BASINB        .50      1   FLOW          50.     364.
                                              TIME        12.25    12.25

    2 COMBINED AT
 +                     AB       1.00      1   FLOW          71.     614.
                                              TIME        12.25    12.25

   ROUTED TO
 +                  RT-AB       1.00      1   FLOW          68.     596.
                                              TIME        12.42    12.33

   DIVERSION TO
 +                   POND       1.00      1   FLOW          48.      80.
                                              TIME        12.42    11.92

   HYDROGRAPH AT
 +                    RES       1.00      1   FLOW          20.     516.
                                              TIME        12.25    12.33

   ROUTED TO
 +                 RT-RES       1.00      1   FLOW          15.     423.
                                              TIME        12.92    12.33

   ROUTED TO
 +                    DET       1.00      1   FLOW          10.     206.
                                              TIME        13.58    12.67

                                           ** PEAK STAGES IN FEET **
                                           1  STAGE      100.20   102.45
                                              TIME        13.58    12.67
1
                                              SUMMARY OF KINEMATIC WAVE - MUSKINGUM-CUNGE ROUTING
                                                  (FLOW IS DIRECT RUNOFF WITHOUT BASE FLOW)
                                                                       INTERPOLATED TO
                                                                    COMPUTATION INTERVAL
          ISTAQ     ELEMENT      DT       PEAK    TIME TO    VOLUME      DT      PEAK    TIME TO     VOLUME
                                                    PEAK                                   PEAK

                                (MIN)     (CFS)    (MIN)      (IN)     (MIN)     (CFS)    (MIN)       (IN)

         FOR PLAN = 1  RATIO=  .00
           RT-AB   MANE        1.75      68.39    743.75      .10      5.00      68.20    745.00       .10

CONTINUITY SUMMARY (AC-FT) - INFLOW= .5490E+01 EXCESS= .0000E+00 OUTFLOW= .5467E+01 BASIN STORAGE= .1611E-01 PERCENT ERROR=    .1

         FOR PLAN = 1  RATIO=  .00
           RT-AB   MANE        4.80     601.61    739.46      .91      5.00     596.12    740.00       .91

CONTINUITY SUMMARY (AC-FT) - INFLOW= .4846E+02 EXCESS= .0000E+00 OUTFLOW= .4840E+02 BASIN STORAGE= .4950E-01 PERCENT ERROR=    .0

         FOR PLAN = 1  RATIO=  .00
           RT-RES  MANE        1.75      15.49    777.00      .07      5.00      15.43    775.00       .07

CONTINUITY SUMMARY (AC-FT) - INFLOW= .3797E+01 EXCESS= .0000E+00 OUTFLOW= .3704E+01 BASIN STORAGE= .4490E-01 PERCENT ERROR=   1.3

         FOR PLAN = 1  RATIO=  .00
           RT-RES  MANE        5.00     423.44    740.00      .67      5.00     423.44    740.00       .67

CONTINUITY SUMMARY (AC-FT) - INFLOW= .3728E+02 EXCESS= .0000E+00 OUTFLOW= .3580E+02 BASIN STORAGE= .1466E+00 PERCENT ERROR=   3.6


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

APPENDIX "Q"
NOMENCLATURE

TABLE OF CONTENTS PAGE

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APPENDIX "Q"
NOMENCLATURE

A. SYMBOLS, ABBREVIATIONS, AND ACRONYMS

For the most part, symbols used in this manual are consistent with conventional usage. However, there are variations, particularly with symbols that involve more than one letter, and also subscripts. Letters which are conventionally used as subscripts are generally used as smaller case letters herein, reserving subscript usage mostly for the following:

2	=	2-year storm frequency
100	=	100-year storm frequency
h	=	historic or existing condition
d	=	developed or proposed condition
i	=	inlet or at the inlet of a catch basin, pipe, or culvert
o	=	outlet or at the outlet of a catch basin, pipe, or culvert
1, 2, 3	=	First, Second, and Third in a series, such as V_1 and V_2 is the first and second velocities, respectively.

However, due to the use of a large number of figures and tables from other sources, there are some symbols used which do not conform with the above general approach. An attempt was made to include all symbols used in this manual unless the symbol is unique to and fully explained in the figure or table which it appears.

A,a	=	Area
A_o, Ao	=	Area of flow at outlet of culvert, ft^2
Ap	=	Area of partial (not full) conduit flow, ft^2
ACOE	=	Army Corps of Engineers
ADOT	=	Arizona Department of Transportation
AC	=	Acres
AMC	=	Antecedent Moisture Condition.
APWA	=	American Public Works Association.
ARC	=	Antecedent Runoff Condition.
ASAE	=	American Society of Agricultural Engineers.
ASCE	=	American Society of Civil Engineers.
AVG	=	Average
AWRA	=	American Water Resources Association.
B,b	=	Breadth of weir (thickness or width in direction of flow), feet; Base width of rectangular or trapezoidal channel or culvert, feet
C	=	Rational Method runoff coefficient; hydraulic coefficient such as the coefficient of discharge for orifice flow or weir coefficient; superelevation coefficient; combined riprap stability and specific gravity factor.
CA	=	Rational Method "C" value times the acreage over which it pertains (Table "H-3").

C_B	=	Adjustment coefficient for manhole benching
Ce	=	Coefficient of expansion
C_D	=	Adjustment coefficient for pipe diameter
C_d	=	Adjustment coefficient for flow depth
CDH	=	Colorado Department of Health.
CDOT	=	Colorado Department of Transportation.
CDPS	=	Colorado Discharge Permit System (CDH's version of NPDES)
CFS, cfs	=	Cubic feet per second
Ck	=	Ratio of Hydraulic Conductivity to Bare Ground Hydraulic Conductivity (used to adjust Green and Ampt "XKSAT" parameter due to vegetative cover)
CN	=	SCS Curve Number runoff coefficient
Cpa	=	Riprap pier or abutment adjustment factor.
C_p	=	Adjustment coefficient for plunging flow
C_Q	=	Adjustment coefficient for relative manhole inflows
CR	=	Curb Return; corrosion resistance number
Csf	=	Stability Factor
D	=	Diameter, depth of conduit, or distance in feet
d	=	Flow depth or distance in feet
d/D	=	Depth of flow to conduit diameter or depth ratio
d_n/D	=	Same as d/D, except flow depth is from normal flow.
DDF	=	Depth-Duration-Frequency, where depth is rainfall in inches for a given storm duration in hours for a given storm frequency, or expected return period in years.
De	=	Equivalent culvert diameter, ft
Dh	=	hydraulic depth
di	=	initial estimate of flow depth
D_{mh}	=	Diameter of Manhole, ft
D_x, d_x	=	The rock or particle size for which "x" % of the surface particles are finer by weight
dc, d_c	=	Critical flow depth, ft
dn, d_n	=	Normal flow depth, ft
EGL	=	Energy grade line
EL_{hd}	=	Elevation of design headwater, ft
EL_{HGL}	=	Elevation of hydraulic grade line, ft
EL_{hi}	=	Elevation of headwater required by inlet control, ft
EL_{ho}	=	Elevation of headwater required by outlet control, ft
EL_i	=	Inlet invert elevation, ft
EL_o	=	Outlet invert elevation, ft
fc	=	Constant rainfall loss rate
FEMA	=	Federal Emergency Management Agency
FHWA	=	Federal Highway (also FHWY)
FIS	=	Flood Insurance Study.
FPS, fps	=	Feet per second

Fr	=	Froude Number (may also appear as "F")
Fr_1	=	Upstream Froude Number
FT	=	Foot
g	=	Gravitational constant, generally assumed as 32.2 ft/second^2
H, h	=	Height or head in feet; horizontal; head loss through culvert due to outlet control, ft.
HGL	=	Hydraulic grade line
HSG	=	SCS Hydrologic Soil Group
Hc	=	Curved conduit flow headloss, ft
He	=	Sewerline exit headloss to outfall, ft
Hf	=	Frictional head loss
Hg	=	Hydraulic Gradient
Hi	=	Inlet head loss due to contraction
HL	=	Sum of frictional, bend, outlet, and inlet Losses; height of water above lower stage outlet
Hm	=	Flow headloss in a manhole due to expansion, bends, plunge or inlet inflows, and contraction in a manhole, or flow headloss at a sewerline junction without a manhole, ft
Ho	=	Outlet head loss due to expansion
h_o	=	Maximum expected height of culvert flow at the outlet, ft
Hr	=	Hour
Ht	=	Total head, including static and velocity, feet
Hs, h_s	=	Height of scour or height of drop to scour basin, ft
Hu	=	Height of water above upper stage outlet
HW	=	Headwater required by inlet control, ft
H1	=	Head upstream of weir
H2	=	Head downstream of weir
I, i	=	Intensity (Rational Method), inches/hour
Ia	=	Intensity of rainfall corresponding to Ta (Table "H-3"), in/hr
IA	=	Initial Abstraction
Ic	=	Individual basin rainfall intensity at Tc (Table "H-3"), in/hr
ID	=	Inside Diameter
Id	=	Storm intensity at the critical time of duration Td, inches/hour
IDF	=	Intensity-Duration-Frequency
K	=	Ratio of historic time of concentration Tc_h to developed time of concentration Tc_d; Factor used in converting data between two different channel cross-slopes.
Kb	=	Factor of maximum shear stress on channel bends; coefficient of bend headless in conduit flow, cfs
K_e	=	Conduit entrance loss coefficient
K_{fm}	=	Stone failure/stone movement factor (value of 1.35 in CSU/ABT equation)
K_{fc}	=	Channel flow concentration factor
K1	=	Shear Stress Ratio, side of channel/bottom of channel
K2	=	Tractive force ratio, side of channel/bottom of channel

k	=	Measurement of permeability
K_o	=	Initial velocity headloss coefficient for manhole flow based upon the manhole diameter and pipe angle
L	=	Length, in feet unless noted otherwise
La	=	Adjusted length of weir crest
Lc	=	Length across channel at a weir
Lp	=	Length of channel erosion protection at an outlet or before or after a channel bend.
Ln	=	Natural logarithm
Lt	=	Length of transition
Lw	=	Length of weir crest
MIN	=	Minutes
N	=	Resistance factor for overland flow (Appendix "E")
NPDES	=	National Pollution Discharge Elimination System
n	=	Manning's "n" value; sequential number
OD	=	Outside Diameter
P	=	Height of weir above approach floor, feet
Pw	=	Wetted perimeter, feet
Q	=	Flow rate in cfs
q	=	Unit discharge flow rate, or total flow (Q) divided by the base width (B), ft^2/s
Qa	=	Accumulated basin runoff at Ta and Ia (Table "H-3"), cfs
Qb	=	Flow that bypasses either a catch basin inlet or storage reservoir, cfs
Qc	=	Individual basin peak runoff using Ic (Table "H-3"), cfs
Qd	=	Flow rate at the time of critical duration Td, cfs
Qi	=	Flow capacity or inflow into catch basin inlet, cfs;
QL	=	Discharge through the lower stage outlet of a detention pond, cfs; Individual basin flow added to a main sewerline from a lateral (Table "H-3"), cfs
Qmax	=	Maximum amount (at peak ponding depth) that may be released from a stormwater storage reservoir
Qo	=	Flow capacity or inflow through an orifice, cfs
Qp	=	Peak flow, the greatest amount of flow generated by a given storm event, cfs; flow in pipe (Table "H-3"), cfs.
Qr	=	Average reservoir release rate, cfs
Qs	=	Total runoff remaining on the surface (Table "H-3"), cfs
Qt	=	Total discharge through detention pond outlet facilities, cfs; total peak accumulated runoff in the system to the design point (Table "H-3"), cfs
Qu	=	Discharge through the upper stage outlet of a detention pond, cfs
Qw	=	Flow capacity or flow through a weir, cfs
R,r	=	Radius, (Also hydraulic radius on some design charts — be careful), ft.
Rc	=	Channel centerline radius
Rh	=	Hydraulic Radius (caution — listed as "R" on some design charts), ft
ROW	=	Right Of Way

S	=	Slope
SCS	=	U.S. Soil Conservation Service
Sf	=	Frictional pipe slope
SG	=	Specific Gravity
Sg	=	Gutter cross slope
So	=	Overland slope (may also appear simply as "S")
Sx	=	Street cross slope
SWMP	=	Storm Water Management Plan
T	=	width of the spread of water at the surface, ft
Ta	=	System accumulative time of concentration (Table "H-3"), minutes
Tc	=	Time of Concentration, usually minutes unless noted otherwise
Tch	=	Channel flow travel time, minutes
Td	=	Time of critical storm duration (Modified Rational Method), minutes
Tf	=	Time when constant lost rate begins
TL	=	Lag time
To	=	Overland flow travel time
Tp	=	Time to ponding, or the time elapsed from the start of rainfall to the start of runoff; time to peak runoff in SCS unit hydrograph
Tr	=	Travel time through a reach
Ts	=	Shallow concentrated flow travel time
TW	=	Tailwater (also Y_t), ft.
U	=	Froude Parameter ($Q/D^{2.5}$ for circular or square conduit, $Q/BH^{1.5}$ for rectangular, $q/H^{1.5}$ for other shapes)
UD&FCD	=	Urban Drainage and Flood Control District (Denver)
UH	=	Unit Hydrograph
USGS	=	United States Geological Survey.
V	=	Volume (ft^3); vertical; velocity (fps)
VL	=	Velocity at a distance "L" from brink of culvert, fps
V_o	=	Velocity of flow at conduit outlet, fps
Vp	=	Permissible velocity, fps
W	=	Width, feet; weir
W_x	=	The rock particle weight for which "x" % of the surface particles are finer by weight
WCQD	=	CDH Water Quality Control Division
Wb	=	Width of apron liner at the brink of a culvert, ft.
W_{Lp}	=	Width of apron liner at end of protection, ft
Wo	=	Width of culvert opening, whether circular or non-circular, ft (same as "B")
Ws	=	Water Surface
Yc	=	Critical depth (See also dc)
Ye	=	Equivalent depth at exit of outlet, equal to Yo for rectangular conduits, and $(A/2)^{0.5}$ for non-rectangular sections.
Yn	=	Normal depth (See also dn)
Yo	=	Brink depth , or flow depth at outlet end of a culvert, ft.

Yr	=	Year
Z	=	Distance compared to a unit distance; maximum perpendicular distance between the projected channel centerline and the natural floodplain limit, ft.
Δd	=	Theoretical increase in water depth due to superelevation of flow around bends; difference in water surface elevation through a transition, ft.
τ	=	Shear stress
τb	=	Shear stress in a channel bend
τd	=	Calculated design shear stress
τp	=	Permissible shear stress
τs	=	Side shear stress
θ	=	Angle between sewerlines or horizontal change in channel width transition; angle of repose, degrees
ϕ	=	Angle of channel side slope

An example of the above symbols with subscripts follows:

Qp_{100d} = Peak flow (cfs) for the 100-year storm, developed condition
Tc_{2h} = Time of concentration (minutes) for the 2-year storm, historic condition

B. GLOSSARY Most of the definitions provided are from "Maricopa County", "UD&FCD", and "USWRC".

ABUTMENTS Walls supporting the end of a bridge or span, and sustaining the pressure of the abutting earth. In a drop structure, the walls which form the sides of the crest of the drop. In some structures, wingwalls (transition walls) extend upstream of the abutment walls to create a smooth transition from the upstream channel.

AGGRADATION A progressive buildup or raising of the channel bed due to sediment deposition. Permanent or continuous aggradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place, see Degradation.

ALLUVIUM Unconsolidated material deposited by a stream in a channel, floodplain, alluvial fan, or delta.

ARMOR Surfacing of channel bed, banks, or embankment slope to resist erosion.

ARMORING (a) Natural process whereby an erosion-resistant layer of relatively large particles is formed on a streambank due to the removal of finer particles by streamflow. (b) Placement of a covering on a streambank to prevent erosion.

ARTERIAL STREET SYSTEM The arterial system should carry a major portion of trips entering and leaving the urban area, as well as the majority of movements through the central city. Frequently, the arterial system will carry important intra-urban as well as intercity bus routes. Arterials are typically located on one-mile intervals on section lines.

BACKFILL Replacement material in a trench or excavation.

BACKWATER EFFECT The rise in water surface elevation caused by some obstruction such as a narrow bridge opening, buildings, or fill material that limits the area through which the water must flow. Also referred to as "heading up".

BAFFLE CHUTE A type of drop structure or outlet structure that incorporates baffles for energy dissipation.

BAFFLES Deflector vanes, blocks, guides, grids, gratings or similar devices constructed to: 1) check or effect a more uniform distribution of velocities; 2) dissipate energy; 3) divert, guide, or agitate flow; and 4) check eddy currents.

BASE FLOOD A term used in the National Flood Insurance Program to indicate the minimum size flood to be used by a community as a basis for its floodplain management regulations; presently required by regulation to be that flood which has a one-percent chance of being equaled or exceeded in any given year. Also known as a 100-year flood or one-percent chance flood.

BASELINE GENERAL PERMIT A permit applicable to a number of classes or categories of discharge.

BASIN The total area from which surface runoff is carried away by a drainage system. Other comparable terms are "drainage area", "catchment area", and "watershed".

BASIN AREA The area which contributes stormwater to a concentration point such as a lake, stream, or drainage system.

BASIN FLOOR The bottom of a stormwater retention facility which has been specifically designed for the purpose of disposing stored runoff following a storm event by the process of infiltration into the subsurface.

BASIN SEDIMENT YIELD The total sediment outflow from a watershed or a drainage area at a point or reference and in a specified time period. This outflow is equal to the sediment discharge from the drainage area.

BED MATERIAL Material found on the bed of a stream (may be transported as bed load or in suspension).

BED SEDIMENT DISCHARGE The part of the total sediment discharge that is composed of grain sizes found in the bed and is equal to the transport capability of the flow.

BERM An earthen mound used to direct the flow of runoff around or through a structure.

BEST MANAGEMENT PRACTICE (BMPs) Structural devices or nonstructural practices that are designed to prevent pollutants from entering into stormwater flows, to direct the flow of stormwater or to treat polluted stormwater flows.

BUFFER STRIP OR ZONE Strip of erosion-resistant vegetation between a waterway and an area of more intensive land use.

BUILDING CODE Regulations adopted by a governmental body which set forth standards for the construction of buildings and other structures for the purpose of protecting the health, safety and general welfare of the public.

CATCH BASIN A chamber or well, usually built at the curb line of a street, for the admission of surface water to a storm sewer or sub-drain.

CFS Cubic feet per second. Used to describe the amount of flow passing a given point in a stream channel. One cubic foot per second is equivalent to approximately 7.5 gallons per second.

CHANNEL A natural or artificial watercourse with definite bed and banks to confine and conduct flowing water.

CHANNEL CAPACITY The maximum flow which can pass through a channel without overflowing the banks.

CHANNEL FAILURE Sudden collapse of a channel due to an unstable condition, such as the removal of a bank by scour.

CHANNEL REACH A segment of stream length that is arbitrarily bounded for purposes of study.

CHANNEL STABILIZATION Methods of achieving slope and cross-section which allow a channel to transport the water and sediment delivered from the upstream watershed without aggradation or streambank erosion.

CHECK DAM A low dam or weir across a channel,for the diversion of irrigation. Also used herein for a low dam to control stream gradient, typically associated with small streams or the low flow channel of a floodplain or other channel.

CHECK STRUCTURE A small drop structure constructed in the low flow portion of a channel for the purpose of controlling stream gradient.

CLEAN WATER ACT (CWA) (33 U.S.C. 1251 et seq.) requirement of the NPDES program are defined under Sections 307, 402, 318 and 405 of the CWA.

CLEAR-WATER SCOUR Scour which occurs when there is no movement of the bed material of the stream upstream of the crossing, but occurs as a result of acceleration of the flow and vortices created by piers or abutments causing material at their base to move.

COEFFICIENT OF DISCHARGE The coefficient of discharge Cd is the ratio of the actual to ideal discharge through an orifice or hydraulic device. It is the product of the coefficient of velocity and coefficient of contraction.

COLLECTOR STREET SYSTEM Collector streets may penetrate neighborhoods and may carry a minor amount of through traffic.

CONCRETE APRONS A concrete pad designed to prevent scour holes developing at the outlet ends of culverts, outlet pipes, grade stabilization structures, and other water control devices.

CONDUIT Any channel or pipe for directing the flow of water.

CONTRACTION SCOUR General scour resulting from the acceleration of flow due to a natural channel constriction or bridge contraction.

CONVEYANCE Any channel or pipe for directing the flow of water.

CREST That portion of the drop structure which controls the gradient of the upstream channel. In a vertical drop structure the crest is a wall typically constructed of reinforced concrete or sheet pile. In a sloping drop structure, the crest is the portion of the drop at the top of the slope and usually incorporates a buried cutoff wall for seepage control.

CRITICAL DEPTH The depth at which a given discharge flows in a given channel with a minimum specific energy. For depths greater and lower than critical, the flow is said to be subcritical and supercritical, respectively.

CRITICAL FLOW This refers to flow at critical depth or velocity, where the specific energy is a minimum for a given discharge. Critical flow is very unstable.

CRITICAL SLOPE This refers to the slope which, for a given cross-section and flow rate, results in critical flow.

CRITICAL VELOCITY This refers to the velocity of flow under critical flow conditions.

CULVERT A hydraulically short conduit which conveys surface water runoff through a roadway embankment or through some other type of flow obstruction. Culverts are constructed from a variety of materials and are available in many different shapes and configurations. Culvert selection factors include roadway profiles, channel characteristics, flood damage evaluations, construction and maintenance costs, and estimates of service life.

DEGRADATION A progressive lowering of the channel bed due to scour. Permanent or continuing degradation is an indicator that a change in the stream's discharge and sediment load characteristics is taking place. It is the opposite of aggradation.

DENUDED Land stripped of vegetation such as grass, or land that has been worn down due to impacts from the elements or humans.

DESIGN DISCHARGE Maximum flow a structure or channel is expected to accommodate without contradicting the adopted design constraints.

DESIGN FLOOD Commonly used to mean the magnitude of flood used for design and operation of flood control structures or other protective measures. It is sometimes used to denote the magnitude of flood used in floodplain regulations.

DESIGN FREQUENCY The nth-year storm for which it is expected that the structure or facility designed for that storm would experience an actual hydrological event of a given or greater magnitude, once, on average, in n years. For example, a 50-year storm has a 2 percent chance of occurring in any given year. Also called the return period, excedence interval, or recurrence interval.

DETENTION BASIN A basin or reservoir where water is stored for regulating a flood. It has gravity-flow outlets for outflows during floods.

DIKE An embankment to confine or control water, often built along the banks of a river to prevent overflow of lowlands; a levee.

DISCHARGE A release or flow of stormwater from a conveyance or storage facility.

DRAINAGEWAY A route or watercourse along which storm runoff moves, or may move, to drain a catchment area.

DRIP GUARD A device used to prevent drips of fuel, or corrosive or reactive chemicals from contacting other materials or areas.

DROP STRUCTURE A structure constructed in a conduit, canal, or open channel for the purpose of gradient (bottom slope) control.

DRY WELL An engineered subsurface chamber designed to accept surface runoff and allow it to drain into the subsurface strata.

EMBANKMENT A man-made earth fill structure.

EMERGENCY SPILLWAY An outflow spillway from a stormwater detention/retention facility that provides for the safe overflow of floodwaters for storm events in excess of the design capacity of the primary outlet structure, or in the event of malfunction or debris blockage of the primary outlet structure.

ENERGY GRADE LINE (EGL) An inclined line representing the total energy of the flowing water. For an open channel, the EGL is above the water surface by a value of the velocity head. In a closed pressure conduit, the EGL is above the pressure head line by a value of the velocity head.

EQUILIBRIUM The state of balance of natural channels between hydraulic forces or actions. Equilibrium occurs when the streambed has achieved a graded condition when the slope and energy of the stream are just sufficient to transport material delivered to it. Natural channels which have small changes resulting from periods of low and high flows are considered in equilibrium.

EROSION The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land clearing practices related to farming, residential or industrial development, road building, or timber-cutting.

EXCAVATION The process of removing earth, stone, or other materials.

FERTILIZER Materials such a nitrogen and phosphorus that provide nutrients for plants. Commercially sold fertilizers may contain other chemicals or may be in the form of processed sewage sludge.

FILTER Layer of fabric, sand, gravel, or graded rock placed (or developed naturally where suitable in-place materials exist), between the bank revetment and soil for one or more of three purposes: 1) to prevent the soil from moving through the revetment by piping, extrusion, or erosion; 2) to prevent the revetment from sinking into the soil; and 3) to permit natural seepage from the streambank, thus preventing buildup of excessive hydrostatic pressure.

FILTER FABRIC Textile of relatively small mesh or pore size that is used to: (a) allow water to pass through while keeping sediment out (permeable); or (b) prevent both runoff and sediment from passing through (impermeable).

FINE SEDIMENT LOAD (OR WASHLOAD) That part of the total sediment load that is composed of particle sizes finer than those represented in the bed. Normally, the fine-sediment load is finer than 0.062 mm for a sand-bed channel. Silt, clay, and sand could be considered fine sediment load in a coarse gravel and cobble bed channel. The washload generally comes from the watershed.

FLOOD CONTROL Keeping flood waters away from specific developments and/or populated areas by the construction of flood storage reservoirs, channel alterations, dikes and levees, bypass channels, or other engineering works.

FLOOD FREQUENCY A statistical expression of the average time period between floods equaling or exceeding a given magnitude. For example, a 100-year flood has a magnitude expected to be equaled or exceeded on the average of once every hundred years; such a flood has a one-percent chance of being equaled or exceeded in any given year. Often used interchangeably with "recurrence interval".

FLOOD FRINGE The portion of the floodplain outside of the floodway or coastal high hazard area but still subject to flooding. Sometimes referred to as "floodway fringe". Also used to refer to areas subject to flooding by water with little or no velocity.

FLOOD HAZARD BOUNDARY MAP An official map of a community issued by the Federal Insurance Administration on which the boundaries of the floodplain (i.e., subject to the 100-year flood), mudslide and/or flood-related erosion areas having special hazards have been drawn.

FLOOD INSURANCE Insurance on structures and/or their contents for their restoration or replacement if damaged by floodwater. The term is usually applied to flood insurance under the National Flood Insurance Act of 1968, as administered by the Federal Insurance Administration.

FLOOD INSURANCE EMERGENCY PROGRAM A phase of the National Flood Insurance Program intended primarily as an interim program to provide a limited amount of insurance at federally-subsidized rates on all existing and new construction begun prior to publication of a detailed flood insurance rate map for an area.

FLOOD INSURANCE RATE MAP An official map of a community on which the Federal Insurance Administration has delineated the area in which the purchase of flood insurance is required under the Flood Insurance Program and the rate zones applicable to such area.

FLOOD PEAK The largest value of the runoff flow which occurs during a flood event, as observed at a particular point in the drainage basin.

FLOOD PROBABILITY A statistical expression of the chance (usually as a percentage) that a flood of given magnitude has of being equaled or exceeded in any one year (see flood frequency).

FLOOD ROUTING The mathematical simulation of a flood wave as it moves downstream along a watercourse or through a detention/retention facility.

FLOODPLAIN The low lands adjoining the channel of a river, stream or watercourse, or ocean, lake, or other body of standing water, which have been or may be inundated by flood water. The channel of a stream or watercourse is a part of the floodplain.

FLOODPLAIN DELINEATION The process of showing in a graphical form, usually on a map or photo mosaic, areas which have been inundated by a specific flood or which can be expected to be inundated by a predicted flood of specific magnitude.

FLOODPLAIN MANAGEMENT The operation of a program intended to lessen the damaging effects of floods, maintain and enhance natural values, and make effective use of related water and land resources within the floodplain. It is an attempt to balance values obtainable from use of floodplains with potential losses arising from such use. Floodplain management stresses consideration of the full range of measures potentially useful in achieving its objectives.

FLOODPLAIN REGULATIONS A general term for the full range of codes, ordinances, and other regulations relating to the use of land and construction within stream channels and floodplain areas. The term encompasses zoning ordinances, subdivision regulations, building and housing codes, encroachment line statutes, open-space regulations, and other similar methods of control affecting the use and development of these areas.

FLOODPROOFING A combination of structural changes and adjustments to new or existing structures and facilities, their contents and/or their sites for the purpose of reducing or eliminating flood damages by protecting against structural failure, keeping water out, or reducing the effect of water entry.

FLOODWAY The channel of a watercourse and those portions of the adjoining floodplain required to provide for the passage of the selected flood (normally the 100-year flood) with an insignificant increase in the flood levels above that of natural conditions. As used in the National Flood Insurance Program, floodways must be large enough to pass the 100-year flood without causing an increase in elevation of more than a specified amount (one foot in most areas).

FREEBOARD The vertical distance above a design water surface elevation that is provided as a contingency or allowance for waves, surges, water-borne debris, or other factors.

FROUDE NUMBER A dimensionless number (expressed as $V/(gd)^{0.5}$) that represents the ratio of inertial to gravitational forces. High Froude numbers (values greater than 1) indicate supercritical flow with associated high velocity and scour potential.

GABION OR WIRE-ENCLOSED BASKET A basket or compartmented rectangular container made of steel wire mesh. When filled with cobbles or rock of suitable size, the gabion becomes a flexible and permeable block with which flow-control structures can be built.

GATE A special kind of orifice in a hydraulic structure which allows for closure of the opening, for which there are no standards of design, and no standard coefficient of discharge "C".

GENERAL PERMIT A permit applicable to a class or category of dischargers.

GENERAL SCOUR Scour in a channel or on a floodplain that is not localized at a pier, abutment, or other obstruction to flow. In a channel, general scour usually affects all or most of the channel width.

GEOMORPHOLOGY That branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and in the buildup of erosional debris.

GRADE CONTROL STRUCTURE (SILL, CHECK DAM) A structure across a stream channel placed bank to bank (usually with its central axis perpendicular to flow) to control bed slope and prevent scour or headcutting.

GRADIENT The rate of change of a characteristic per unit of length. The term is usually applied to such things as channel/stream bed slope elevation, conduit invert elevation, velocity, pressure, etc.

GRADING The cutting and/or filling of the land surface to a desired slope or elevation.

GUIDE BANK A dike extending upstream from the approach embankment at either or both sides of the bridge opening to direct the flow through the opening. Some guide banks extend downstream from the bridge.

HAZARDOUS WASTE By-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed.

HAZARDOUS SUBSTANCE 1. Any material that poses a threat to human health and/or the environment. Typical hazardous substances are toxic, corrosive, ignitable, explosive, or chemically reactive. 2. Any substance named by EPA to be reported if a designated quantity of the substance is spilled into the waters of the United States or if otherwise emitted into the environment.

HEADCUTTING Channel bottom erosion moving upstream along a waterway indicating that a readjustment of the channel's slope and its discharge and sediment load characteristics is taking place. Headcutting is evidenced by the presence of abrupt vertical drops in the stream bottom or rapidly moving water through an otherwise placid stream. Headcutting often leaves stream banks in an unstable condition as it progresses along the channel.

HOLDING POND A pond or reservoir, usually made of earth, built to store polluted runoff for a limited time.

HYDRAULIC DEPTH (Dh) The hydraulic depth is the ratio of area in flow to the width of the channel at the fluid surface, or Dh = A/T.

HYDRAULIC GRADIENT (Hg) The slope of the hydraulic grade line is the hydraulic gradient.

HYDRAULIC GRADE LINE (HGL) For an open channel, it is coincident with the water surface. In a closed pressure conduit, it is the line representing the pressure head of the conduit. HGL will always be EGL minus the velocity head.

HYDRAULIC JUMP The hydraulic jump is an abrupt rise in the water surface which occurs in an open channel when water flowing at supercritical velocity is retarded by water flowing at subcritical velocity or a stationary pool. The transition through the jump results in a marked change in energy, evidenced by turbulence of the flow within the area of the jump. The hydraulic jump is often used as a means of energy dissipation.

HYDRAULIC RADIUS (R) The hydraulic radius is the cross-sectional area of flow divided by the wetted perimeter, or R = A/Pw.

HYDRAULIC STRUCTURES Facilities used to impound, accommodate, convey or control the flow of water, such as dams, weirs, intakes, culverts, channels, and bridges.

HYETOGRAPH A map which shows temporal or spatial distribution of precipitation.

HYDROGRAPH The functional relationship between time and flow discharge, as observed at a particular point within a drainage basin. In the case of a detention/retention facility, an Inflow Hydrograph depicts the relationship of time and runoff inflow to the facility, and an Outflow Hydrograph is a graph of flow discharge from the facility versus time.

ILLICIT CONNECTION Any discharge to a municipal separate storm sewer that is not composed entirely of stormwater except discharges authorized by an NPDES permit (other than the NPDES permit for discharges from the municipal separate storm sewer) and discharges resulting from fire-fighting activities.

IMPERVIOUS A term applied to a material through which water cannot pass, or through which water passes with great difficulty.

INCISED STREAM A stream that flows in an incised channel with high banks. Stream banks that stand more than 15 feet above the water surface at normal stage are regarded as high banks.

INFILTRATION 1. The penetration of water through the ground surface into sub surface soil or the penetration of water from the soil into sewer or other pipes through defective pipes, connections, or manhole walls. 2. A land application technique where large volumes of wastewater are applied to land and allowed to penetrate the surface and percolate through the underlying soil.

INLET An entrance into a ditch, storm sewer, or other waterway.

INTENSITY Rainfall rate expressed in inches per hour.

INTERCEPTION Refers to the process by which precipitation is caught and held by foliage, twigs, branches of trees, shrubs, and buildings, never reaching the surface of the ground.

INTERCEPTION RATE As applied to storm water inlet design, interception rate refers to the ratio of flow intercepted by an inlet to the gutter flow delivered to an inlet.

INVERT The floor, bottom, or lowest portion of the internal cross section of a conduit. Used particularly with reference to aqueducts, sewers, tunnels, and drains.

INVERTED SIPHON Refers to conduit flowing freely up and down stream but which is pressurized in a depressed section to carry water underneath an obstacle.

LAG TIME The definition of lag time T_L varies depending upon the hydrological method. For SCS procedures, T_L is the time from the center of rainfall mass to the peak of the unit graph.

LATERAL STREAM MIGRATION Change in position of a channel by lateral erosion of one bank and simultaneous accretion of the opposite bank. Movement in which the material has a dominate lateral component.

LAUNCHING Release of undercut material (stone riprap, rubble, slag, etc.) downslope; if sufficient material accumulates on the streambank face, the slope can become effectively armored.

LEACHING The process by which soluble constituents are dissolved in solvent such as water and carried down through the soil.

LEVEL SPREADER A device used to spread out stormwater runoff uniformly over the ground surface as sheetflow (i.e., not through channels). The purpose of level spreaders are to prevent concentrated erosive flows from occurring and to enhance infiltration.

LINER 1. A relatively impermeable barrier designed to prevent leachate from leaking from a landfill. Liner materials include plastic and dense clay. 2. An insert or sleeve for sewer pipes to prevent leakage or infiltration.

LIVE-BED SCOUR Scour which occurs when the bed material upstream of the crossing is also moving.

LOCAL AGGRADATION Aggradation in a channel or on a floodplain that is localized at a pier, abutment, or other obstruction to flow.

LOCAL SCOUR Scour in a channel or on a floodplain that is localized at a pier, abutment, or other obstruction to flow.

LOCAL STREET SYSTEM The local street system comprises all facilities not on one of the higher systems. It offers the lowest level of mobility and usually contains no bus routes. Service to through traffic movement usually is deliberately discouraged.

LOW FLOW CHANNEL A channel within a larger channel which typically carries low and/or normal flows.

MANHOLE A hole through which a person may go, especially to gain access to an underground or enclosed structure.

MASTER PLANNING A "systems" approach to the planning of facilities, programs and management organizations for comprehensive control and use of stormwater within a defined geographical area or drainage basin.

MATERIAL STORAGE AREAS On site locations where raw materials, products, final products, by-products, or waste materials are stored.

MEANDERING CHANNEL A channel exhibiting a characteristic process of bank erosion and point bar deposition associated with systematically shifting meanders.

MEDIAN DIAMETER The particle diameter at the 50 percentile point on a size distribution curve such that half of the particles (by weight for samples of sand, silt or clay and by actual measurement for samples of gravel and riprap) are larger and half are smaller. The median diameter is denoted D_{50}.

MULCH A natural or artificial layer of plant residue or other materials covering the land surface which conserves moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

MULTI-PURPOSE FACILITY A detention or retention facility that provides benefits in addition to the primary function of flood control. Such benefits may include recreation, parking, or visual buffers.

NAPPE The sheet or curtain of water overflowing a weir or dam. When freely overflowing the crest of a structure, it usually has a well-defined upper and lower surface.

NPDES PERMIT An authorization, license, or equivalent control document issued by EPA or an approved State agency to implement the requirements of the NPDES program.

OFF-STREAM DETENTION/RETENTION FACILITY A facility that is located near or adjacent to a watercourse (i.e., the stream does not flow directly into the facility). Inflow to the facility is typically accomplished by means of side weirs. It is also referred to as an Off-Line Detention/Retention Facility.

OIL AND GREASE TRAPS Devices which collect oil and grease, removing them from water flows.

OIL SHEEN A thin, glistening layer of oil on water.

OIL/WATER SEPARATOR A device, usually installed at the entrance to a drain, which removes soil and grease from water flows entering the drain.

ON-SITE DETENTION/RETENTION The temporary storage of excess storm runoff within a drainage basin. This type of facility is typically within a subdivision, primarily by an individual development.

ON-STREAM DETENTION/RETENTION FACILITY A facility that is located within the path of a stream or watercourse, and thereby intercepts the entire flow from the upstream drainage basin. It is also referred to as an On-line Detention/Retention Facility.

ONE-HUNDRED YEAR FLOOD A flood having a one-percent chance of occurring in any given year and which, over a very long period of time, can be expected to be equalled or exceeded on the average of once every hundred years.

ORGANIC POLLUTANTS Substances containing carbon which may cause pollution problems in receiving streams.

ORGANIC SOLVENTS Liquid organic compounds capable of dissolving solids, gases, or liquids.

ORIFICE An orifice is a horizontal or vertical opening with a closed perimeter through which water flows. If the perimeter is not closed, or if the horizontal or vertical opening has only partial full flow, then the orifice acts as a weir.

OUTFALL The point, location, or structure where wastewater or drainage discharges from a sewer pipe, ditch, or other conveyance to a receiving body of water.

OUTLET STRUCTURE A hydraulic structure placed at the outlet of a conduit, open channel, spillway, etc., for the purpose of dissipating energy and providing a transition to the channel or conduit downstream. Outlet structures may consist of culverts, weirs, orifices (gated or un-gated), dry wells, or any combination thereof.

OVERLAND RUNOFF That portion of precipitation which is not intercepted by vegetation, absorbed by the land surface, or evaporated, and thus flows overland into a depression, stream, lake or ocean (runoff called "immediate subsurface runoff" also takes place in the upper layers of the soil).

PERCOLATION To pass through a permeable substance such as ground water flowing through an aquifer.

PERMEABILITY The quality of a soil that enables water or air to move through it. Usually expressed in inches/hour or inches/day.

PERMIT An authorization, license, or equivalent control document issued by an approved agency to implement the requirements of a regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

PERVIOUS Applied to a material through which water passes relatively freely.

PLUNGE POOL An energy dissipation device placed downstream of a conduit, channel or vertical wall drop structure. The plunge pool basin is typically lined with rock riprap, concrete or other protective covering and dissipates the energy of free falling water through impact and turbulence.

POINT SOURCE Any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.

POLLUTANT Generally, any substance introduced into the environment that adversely affects the usefulness of a resource.

POROSITY (1) An index of the void characteristics of a soil or stratum as pertaining to percolation; degree of perviousness. (2) The ratio, usually expressed as a percentage, of (a) the volume of the interstices in a given quantity of material, to (b) the total volume of the material.

POROUS PAVEMENT A surface that will allow water to penetrate through and percolate into soil (porous asphalt pavement). Pavement is comprised of irregular shaped crush rock pre-coated with asphalt binder. Water seeps through into lower layers of gravel for temporary storage, then filters naturally into the soil.

PRECIPITATION Any form of rain or snow.

PRESSURE HEAD In a closed pressure conduit, it represents the energy per unit weight stored in the fluid by virtue of the fluid being under pressure. In an open channel, the pressure head is zero.

PREVENTATIVE MAINTENANCE PROGRAM A schedule of inspections and testing at regular intervals intended to prevent equipment failures and deterioration.

PUMP STATION A facility housing stormwater pumps, controls, power plants and their appurtenances.

RAINFALL, EFFECTIVE As applied to runoff analysis, refers to the portion of rainfall which becomes surface runoff or runoff excess.

REACH Any length of river or channel. Usually used to refer to sections which are uniform with respect to discharge, depth, area or slope, or sections between gaging stations.

RECURRENCE INTERVAL The average interval of time within which a given event will be equalled or exceeded once. For an annual series (as opposed to a partial duration series) the probability of occurrence in any one year is the inverse of the recurrence interval. Thus a flood having a recurrence interval of 100 years has a 1 percent probability of being equalled or exceeded in any one year.

REGIONAL DETENTION/RETENTION The temporary storage of excess runoff by means of large storage facilities located at strategic sites within a drainage basin. Sites are generally planned to provide control of excess runoff from an entire drainage basin with an optimum (presumably a minimum) number of storage facilities to achieve the most cost-effective drainage system. Regional detention/retention sites are normally maintained by a public or quasi-public agency.

REGULATORY FLOODPLAIN That portion of the floodplain subject to floodplain regulations (usually the floodplain inundated by the one-percent chance flood).

REGULATORY FLOODWAY The channel and that portion of the adjacent land area that is required through regulations to pass flood flows without increasing the water surface elevation more than a designated height.

REPORTABLE QUANTITY (RQ) The quantity of a hazardous substance or oil that triggers reports under CERCLA or the Clean Water Act. If a substance is released in amounts exceeding its RQ the release must be reported to the National Response Center, the State Emergency Response Commission, and community emergency coordinators for areas likely to be affected.

RESERVOIR A natural or artificially created pond, lake, or other space used for storage, regulation, or control of water. May be either permanent or temporary.

RESIDUAL Amount of pollutant remaining in the environment after a natural or technological process has taken place, e.g., the sludge remaining after initial wastewater treatment, or particulates remaining in air after the air passes through a scrubbing or other pollutant removal process.

RESIDUAL FREEBOARD For an embankment dam, the vertical distance between the maximum water surface elevation and the minimum dam crest elevation.

RETENTION Temporary or permanent storage of stormwater.

RETENTION BASIN A basin or reservoir wherein water is stored for regulating a flood; however, it does not have gravity-flow outlets for outflows during floods as detention basins do. The stored water must be disposed by some other means such as by infiltration into soil, evaporation, injection (or dry) wells, or pumping systems.

RETROFIT The modification of stormwater management systems in developed areas through the construction of wet ponds, infiltration systems, wetland plantings, stream bank stabilization, and other BMP techniques for improving water quality. A retrofit can consist of the construction of a new BMP in the developed area, the enhancement of an older stormwater management structure, or a combination of improvement and new construction.

RILL EROSION The formation of numerous, closely spread streamlets due to uneven removal of surface soils by stormwater or other water.

RIPARIAN HABITAT Areas adjacent to rivers and streams that have a high density, diversified, and productive plant and animal species relative to nearby uplands.

RIPRAP Broken stone or boulders placed compactly or irregularly on dams, levees, ditches, dikes, etc., for protection of earth surfaces against the erosive action of water.

RIPRAP TOE PROTECTION In the restricted sense, layer or facing or broken rock or concrete dumped or placed at the toe of a channel to protect a structure or embankment from erosion; also the broken rock or concrete suitable for such use. Riprap has also been applied to almost all kinds of armor, including wire-enclosed riprap, grouted riprap, sacked concrete, and concrete slabs.

ROUTING, HYDRAULIC (1) The derivation of an outflow hydrograph of a channel or stream from known values of upstream inflow. (2) The process of determining progressively the timing and shape of a flood wave at successive points along a stream or channel.

ROUTING, HYDROLOGIC Flow routing that involves calculation of flow as a function of time only at a particular location.

RUNOFF That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into the receiving waters.

RUNON Stormwater surface flow or other surface flow which enters property other than that where it originated.

SCOUR The clearing and digging action of flowing water, especially the downward erosion caused by stream water in sweeping away mud and silt from the stream bed and outside bank of a curved channel.

SECONDARY CONTAINMENT Structures, usually dikes or berms, surrounding tanks or other storage containers and designed to catch spilled material from the storage containers.

SEDIMENT DISCHARGE The quantity of sediment that is carried past any cross section of a stream in a unit of time. Discharge may be limited to certain sizes of sediment or to a specific part of the cross section.

SEDIMENT TRAP A device for removing sediment from water flows, usually installed at outfall points.

SEDIMENTATION The process of depositing soil particles, clays, sands, or other sediments that were picked up by runoff.

SEDIMENTATION FOREBAY A bay or pond that precedes a detention or retention basin, designed to accept and detain runoff long enough to allow a significant amount of sediment to settle.

SEEPAGE The movement of water through pores and voids of pervious material such as soil, gravel, synthetic filter media, etc.

SEEPAGE CUTOFF WALL An impervious subsurface barrier constructed of clay, concrete or synthetic material for the purpose of increasing the length of travel of subsurface water flow and thereby reducing and/or controlling the action of such flows (for example, uplift forces) at hydraulic structures.

SHEET EROSION Erosion of thin layers of surface materials by continuous sheets of running water.

SILL A raised edge at the downstream end of a stilling basin. The sill typically has a notch or opening to allow normal stream flows to pass through and/or to allow the basin to drain completely following a storm.

SIPHON A closed conduit, a portion of which lies above the hydraulic grade line. This results in a pressure less than atmospheric in that portion, and hence requires that a vacuum be created to start flow.

SLOPE, FRICTION The friction head or loss per unit length of channel or conduit. For uniform flow the friction slope coincides with the energy gradients, but where a distinction is made between energy losses due to bends, expansions, and contractions. A distinction must also be made between the friction slope and the energy gradient. The friction slope is equal to the bed or surface slope only for uniform flow in uniform open channels.

SLOPE, CRITICAL The slope or grade of a channel that is exactly equal to the loss of head per foot resulting from flow at a depth that will give uniform flow at critical depth; the minimum slope of a conduit which will produce critical flow.

SLOUGHING The movement of unstabilized soil layers down a slope due to excess water in soils.

SOIL The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants.

SOURCE CONTROL A practice or structural measure (such as covering) to prevent pollutants from entering stormwater runoff or other waste materials.

SPILL GUARD A device used to prevent spills of liquid materials from storage containers.

SPILLWAY (a) A low-level passage serving a dam or reservoir through which surplus water may be discharged; usually an open ditch around the end of a dam, or a gateway or a pipe in a dam. (b) An outlet pipe, flume, or channel serving to discharge water from a ditch, ditch check, gutter or detention/retention pond.

STAGE The depth of water within a stormwater storage facility, as measured above an established datum.

STORAGE RESERVOIR OF PUMP STATION A reservoir wherein peak flows from storm drains are stored for reducing capacity requirements of the pump station to pump runoff to an appropriate outlet.

STORM DRAIN A slotted opening leading to an underground pipe or an open ditch for carrying surface runoff.

STORM DRAINAGE SYSTEM A drainage system for collecting runoff of stormwater and removing it to appropriate outlets. The system includes inlets, catch basins, storm sewers, main drains, storage reservoirs, detention basins, and pump stations.

STORMWATER Runoff from a storm event, snow melt runoff, and surface runoff and drainage. For the purpose of the NPDES program, stormwater is designed as storm water as used in the Clean Water Act.

STORMWATER DETENTION FACILITY A stormwater storage facility which temporarily stores surface runoff and releases it at a controlled rate through a positive outlet.

STORMWATER RETENTION FACILITY A stormwater storage facility which stores surface runoff. Stored water is infiltrated into the subsurface or released to the downstream drainage system or watercourse (via a gravity outlet or pump) after the storm event.

STREAMBANK EROSION Removal of soil particles from a bank surface due primarily to water action. Other factors such as weathering, ice and debris abrasion, chemical reactions, and land use changes may also directly or indirectly lead to streambank erosion.

STREAMBANK PROTECTION Any technique used to prevent erosion or failure of a streambank.

STREET NOMENCLATURE

1. Crown In the pavement, it is the highest point in the paving cross-section.
2. Grade The longitudinal slope measured along the crown.
3. Crown Slope The slope of the pavement perpendicular to the crown, often given in the form of a horizontal distance "Z" to a vertical distance of one.
4. Curb The lateral side of the pavement terminated by either a vertical or a sloped section.
5. Curb and Gutter Section A curb section constructed integrally with the gutter.
6. Cross Fall In a lateral pavement cross-section, cross fall is the difference in elevation between the gutter flow lines.
7. Cross Pan or Valley Pan A concaved paved surface crossing a street, usually at pavement intersections, for the purpose of carrying surface water across the street to continue the surface flow.
8. Gutter A paved section designed to carry surface flow. Often the gutter is terminated with a curb when located at the edge of a street section.

SUBDIVISION REGULATIONS Ordinances or regulations governing the subdivision of land with respect to such things as adequacy and suitability of building sites, utilities and public facilities.

SUBDRAIN An underground conduit, usually perforated and surrounded by an engineered granular filter material that is designed to permit infiltration for the purpose of collecting and conveying groundwater.

SUBGRADE EROSION Erosion of the material underlying that portion of the stream bed which is subject to direct action of the flow.

SUBSOIL The bed or stratum of earth lying below the surface soil.

SUBSTANTIAL IMPROVEMENT A term used in connection with the National Flood Insurance Program for determining when its regulations must be applied to actions involving existing structures. It means any repair, reconstruction, or improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure either: (a) before the improvement or repair is started; or (b) if the structure has been damaged, and is being restored, before the damage occurred.

SUBSURFACE DISPOSAL Drainage of stormwater runoff into the subsurface by the process of infiltration. This is typically accomplished through the use of dry wells, engineered seepage pit floors, etc.

SUMP A pit or tank that catches liquid runoff for drainage or disposal. Also a low point in a vertical curve or roadway gutter.

SURFACE IMPOUNDMENT Treatment, storage, or disposal of liquid wastes in ponds.

SURFACE WATER All water naturally open to the atmosphere (rivers, lakes, reservoirs, streams, wetlands impoundments, seas, estuaries, etc.); also refers to springs, wells, or other collectors which are directly influenced by surface water.

SWALE An elongated depression in the land surface that is at least seasonally wet, is usually heavily vegetated, and is normally without flowing water.

TAILWATER The water surface elevation in the channel downstream of a hydraulic structure.

THALWEG The line extending down a channel that follows the lowest elevation of the bed. This should not be confused with the centerline of the channel, which is the invert.

TIME OF CONCENTRATION The time after commencement of rainfall excess when all portions of the drainage basin are contributing simultaneously to flow at the point of interest or outlet of the subbasin.

TOPOGRAPHY The physical features of a surface area including relative elevations and the position of natural and man-made features.

TOTAL DISSOLVED SOLIDS (TDS) The total dissolved (filterable) solids as determined by the use of methods specified in 40 CFR part 136.

TOTAL FREEBOARD For an embankment dam, the vertical distance between the emergency spillway crest and the minimum crest elevation of the dam.

TOXIC POLLUTANTS Materials contaminating the environment that cause death, disease, and/or birth defects in organisms that ingest or absorb them. The quantities and length of exposure necessary to cause these effects can vary widely.

TRANSPORT RATE Rate at which sediment particles are carried when hydraulic conditions exceed the critical condition for motion. Transport rates are calculated analytically by the use of transport functions.

TRASH RACK A metal bar or grate structure located at the outlet structure of a stormwater detention/retention facility and designed to prevent blockage of the outlet structure by water-borne debris.

TRIBUTARY A river or stream that flows into a larger river or stream.

TRICKLE CHANNEL Also called the low flow channel, the trickle channel is that portion of a major channel which is sized to carry the normal low flow.

TUBE An orifice with prolonged sides which are at least 2 or 3 times as long as the plate or wall thickness.

UNDERDRAIN See Subdrain.

UNIFORM FLOW Flow of constant water area, depth, discharge, and average velocity through a reach of a channel.

UNIT HYDROGRAPH A unit hydrograph is defined as the hydrograph of one inch of direct runoff from the tributary area resulting from a unit storm. A unit storm is a rainfall of such duration that the period of surface runoff is not appreciably less for any rain of shorter duration. The unit hydrograph thus represents the integrated effects of factors such as tributary area, shape, stream pattern, channel capacities, and stream and land slopes.

UPLIFT PRESSURE Pressure caused by uncontrolled seepage or groundwater flow beneath a structural slab which can lead to cracking and displacement of the structure.

VEGETATIVE FILTER STRIP Usually long, relatively narrow area of undisturbed or planted vegetation used to retard or collect sediment for the protection of watercourses, reservoirs, or adjacent properties.

VELOCITY HEAD Represents the kinetic energy of the flowing fluid generally expressed as $V^2/2g$ in feet, but actually is the energy per pound of flowing fluid.

VORTEX Local current accelerations which cause a whirling or circular motion that tends to form a cavity or vacuum at its center, thus moving sediment toward the cavity.

WATER SURFACE ELEVATION The heights, usually in relation to mean sea level, reached by flows of various magnitudes and frequencies at pertinent points in a watercourse or body of water.

WATER TABLE The depth or level below which the ground is saturated with water.

WATERCOURSE A natural or artificial channel in which a flow of water occurs either continually or intermittently.

WATERS OF THE UNITED STATES As defined by 40 FRC 404:

(a) All waters which are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;

(b) All interstate waters, including interstate "wetlands;"

(c) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, "wetlands," sloughs, prairie potholes, wet meadows, playa, lakes, or natural ponds the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce including any such waters:
    (1) Which are or could be used by interstate or foreign travelers for recreational or other purposes;
    (2) From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
    (3) Which are used or could be used for industrial purposes by industries in interstate commerce;

(d) All impoundments of waters otherwise defined as waters of the United States under this definition;

(e) Tributaries of waters identified in paragraphs (a) through (d) of this definition;

(f) The territorial sea; and

(g) `Wetlands' adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (a) through (f) of this definition.

Waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA [other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition], are not waters of the United States. This exclusion applies only to manmade bodies of water in which neither were originally created in waters of the United States (such as disposal area in wetlands) nor resulted from the impoundment of waters of the United States.

WATERSHED An area confined by drainage divides, often having only one outlet for discharge.

WATERWAY A channel for the passage or flow of water.

WEEP HOLE Openings in an impermeable wall or revetment to relieve the neutral stress or pore water pressure. Weep holes are typically combined with reverse filter drains to form a total system for seepage control.

WEIR A weir is a notch of regular form through which water flows. The term is also applied to the structure containing such a notch (Brater & King). Weirs may be a depression in a tank or reservoir, and overflow drain, a channel, or other non-closed opening through which water may flow. Weirs are classified by shape, such as rectangular, triangular or V-notch, trapezoidal, parabolic, or natural (irregular) weir.

WEIR, BROAD-CRESTED A weir "having a horizontal or nearly horizontal crest sufficiently long in the direction of flow so that the nappe will be supported and hydrostatic pressures will be fully developed for at least a short distance" (Brater & King). (See Figure "K"-2 in Appendix "K".)

WEIR, CONTRACTED A weir or weir flow condition where side or end contraction occurs. This applies to conditions where the approach flow is wider than the weir, or where the height of weir flow is significant with respect to the weir length. While dams, spillways, channels, and street surface flows typically do not fit into this category, measuring and metering weirs usually do. (See Figure "K-4" in Appendix "K".)

WEIR, CREST The edge or surface over which the water flows. (See Figure "K-1" in Appendix "K".)

WEIR, SHARP-CRESTED A weir that has a maximum of a 90° angle on the upstream edge of the crest, and which is short enough in the direction of flow, or angled enough, that the nappe will not be supported. (See Figure "K-2" in Appendix "K".)

WEIR, SUPPRESSED A weir or weir flow condition for which the side or end contractions are suppressed. This occurs when the weir length is equivalent to the approach width. It also applies when the length of the weir greatly exceeds the height of flow over the weir. Dams, spillways, channels, and most surface flows fit into this category. (See Figure "K-3" in Appendix "K".)

WET WELL A chamber used to collect water or other liquid, and to which a pump is attached.

WETLANDS An area that is regularly saturated by surface or ground water and subsequently is characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions. Examples include: swamps, bogs, fens, marshes, and estuaries.

WETTED PERIMETER (Pw) The wetted perimeter is the portion of the perimeter of a flow conveyance facility that is in contact with the flowing liquid.

WIND BREAK Any device design to block wind flow and intended for protection against any ill effects of wind.

ZONING ORDINANCE An ordinance under the State or local government's police power which divides an area into districts and, within each district, regulates the use of land and buildings, height and bulk of buildings or other structures, and the density of population.

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APPENDIX "R"
BIBLIOGRAPHY

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APPENDIX "R"
BIBLIOGRAPHY

References used in the preparation of this manual are presented in this appendix. First, references will be listed alphabetically by the name of the reference, then alphabetically by the name of the author or agency that prepared the material.

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