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Hydrologic Engineering Center

# River Routing with HEC-1 and HEC-2

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This document describes how computer programs HEC-1 Flood Hydrograph Package and HEC-2 Water Surface Profiles can be used to model the flood-wave movement through a river. By analyzing the existing conditions and the proposed modifications for the river reach, the impact of the lost storage can be estimated.

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# River Routing with HEC-1 and HEC-2

## September 1990

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# River Routing with HEC-1 and HEC-2

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# Foreword

When hydraulic analyses are performed with a steady-flow model like HEC-2, the computations do not consider the storage effects in the routing reach. Floodplain modifications such as levees, channelization or floodplain encroachment generally reduce floodplain storage and alter the shape and timing of the flood wave as it passes through the modified reach. This document describes how computer programs HEC-1 Flood Hydrograph Package and HEC-2 Water Surface Profiles can be used to model the flood-wave movement through a river. By analyzing the existing conditions and the proposed modifications for the river reach, the impact of the lost storage can be estimated.

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# Chapter 1

# Introduction to Flood Routing

Flood routing is a technique for simulating the movement of a flood wave through a river reach or reservoir. Routing takes into account the effects of storage and flow resistance on the flood wave shape and timing. The definition sketch below shows the major changes to a discharge hydrograph as a flood wave moves down a stream.

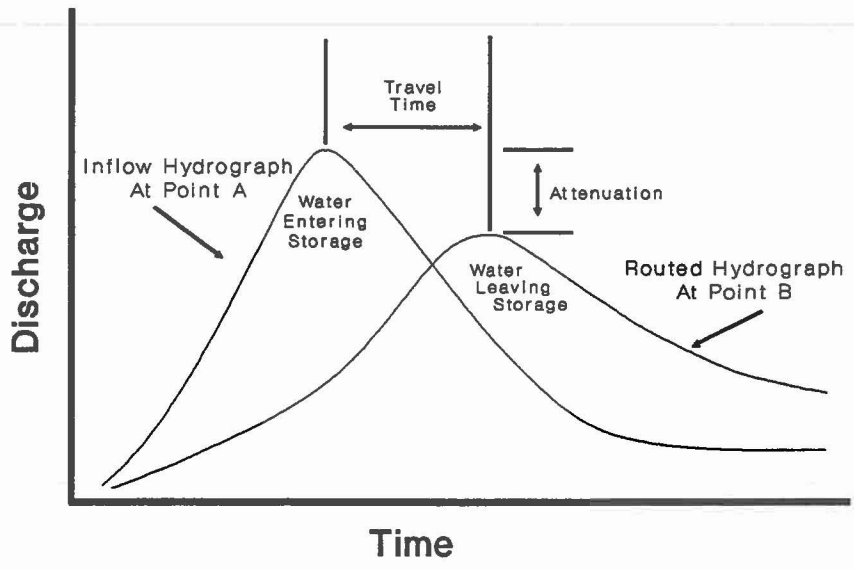


**Figure 1**
**Discharge Hydrograph Routing Effects**

## 1.1 Routing Equations

The basic equations that describe gradually varied unsteady flow in an open channel are called the Saint Venant Equations. The two equations describe flow continuity and energy (or momentum). Henderson (1966) relates the type of flow to the energy-equation variables. This concept can also be used to describe the routing methods we commonly use.

$$S_f = S_o - \frac{\partial y}{\partial x} - \frac{\partial\left(\frac{v^2}{2g}\right)}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t} \qquad \text{Energy} \qquad (1)$$

Steady
Uniform Flow

Steady
Gradually Varied Flow

Unsteady Gradually Varied Flow

$$A\frac{\partial v}{\partial x} + v\,b\frac{\partial y}{\partial x} + B\frac{\partial y}{\partial t} = q \qquad \text{Continuity} \qquad (2)$$

Where:

$S_f$ = Slope of the energy grade line (ft/ft)
$S_o$ = Slope of the channel bed (ft/ft)
y = Flow depth (ft)
x = Distance along the channel (ft)
v = Average velocity (ft/sec)
g = Acceleration of gravity (ft/sec$^2$)
t = Time (sec)
A = Cross-sectional area (ft$^2$)
B = Width of cross section at water surface (ft)
q = Local inflow (ft$^3$/sec)

## 1.2 Routing Methods

Routing methods are often characterized based on the simplifying assumptions used to develop them. One approach defines routing methods as hydrologic or hydraulic based on the simplifying assumptions and the combined use of the basic routing equations.

**Hydraulic Methods.** Generally, these methods attempt a complete numerical solution of the Saint Venant equations. However, there are several approaches that simplify, or eliminate, some of the terms in the equations. These methods require all the basic data necessary to compute steady-flow water surface profiles plus the inflow hydrograph and a downstream boundary condition, like a rating curve. Because energy and storage are both considered, the cross-sectional data includes both conveyance and storage areas. Computer programs providing complete numerical solutions are generally called **unsteady flow models**.

**Hydrologic Methods.** The routing methods provided in HEC-1 can all be classified as hydrologic methods. These methods provide a solution of the continuity equation combined with either an analytical or an assumed relationship between storage and discharge. Variations of the simplifying assumptions yield a variety of hydrologic methods; examples include Muskingum, modified Puls (or reservoir routing), average/lag methods, and kinematic wave. (While some classify

kinematic wave as a hydraulic method, it fits this definition of hydrologic methods.) These methods provide computationaly simple solutions to routing problems and, therefore, are widely used in simulation models.

While all of the hydrologic methods have been successfully used, the coefficient methods (Muskingum and average/lag) are more dependent on calibration data because they are not physically based. Methods that can be applied with basic field data have an advantage because flow data is not available for most routing reaches. Within the HEC-1 Flood Hydrograph Package the kinematic wave, modified Puls, and Muskingum-Cunge routing methods are based on a physical representation of the routing reach (HEC, 1990a).

**Kinematic Wave** channel routing is best suited for relatively steep, urban channels where there are uniform channel reaches, and no overbank flow. Referring to Equation 1, the method uses the uniform-flow portion of the energy equation. In HEC-1, a geometric channel shape represents the cross section. Because the method does not provide hydrograph attenuation, only translation, it is not generally used for floodplain applications.

**Muskingum-Cunge** routing adds the varying depth with distance term ($\partial y/\partial x$) in Equation 1 and is often referred to as the diffusion form of the equation. Missing terms include the change in velocity with distance and time. The Muskingum-Cunge method is capable of accounting for hydrograph attenuation based on physical channel properties and the inflowing hydrograph. The advantages of this method are: (1) the parameters of the model are physically based; (2) the method has been shown to compare well with the full unsteady flow equations over a wide range of flow situations; and, (3) the solution is independent of the user specified computation interval. The major limitations of the application in HEC-1 are: (1) it does not consider backwater effects, and (2) the method diverges from the full equation solution when rapidly rising hydrographs are routed through very flat slopes (less than 1 ft/mile) (Brunner, 1990).

**Modified Puls** routing in HEC-1 can be applied with either: (1) a given storage versus outflow relationship, or (2) a normal-depth storage-outflow relation. The latter approach uses the same cross-sectional data as the Muskingum-Cunge application and computes flow depth assuming uniform flow conditions. Therefore, the normal-depth approach does not consider backwater effects. Modified Puls routing with an input storage-outflow relationship is the only HEC-1 routing method that can model a steady-state backwater effect on storage, like those frequently found in floodplain situations. Computer program HEC-2 can be used to develop the storage-outflow relationship based on a single-valued downstream starting condition.

## 1.3 Modified Puls Routing

Modified Puls is a storage routing method. The method consists of repetitive solution of the continuity equation with the assumption that outflow is a unique function of storage. The continuity equation may be expressed as:

$$O_{avg} = I_{avg} - \left(\frac{\Delta S}{\Delta T}\right) \tag{3}$$

Where:

$O_{avg}$ = Mean outflow from the reservoir during $\Delta t$
$I_{avg}$ = Mean inflow into the reservoir during $\Delta t$
$\Delta S$ = change in reservoir storage during $\Delta t$
$\Delta t$ = routing time interval

Requirements for routing include:

Inflow hydrograph, defined in $\Delta t$ time intervals
Starting storage in the reservoir or routing reach
Storage-outflow relationship

Equation 3 can be approximated by:

$$\frac{(O_1 + O_2)}{2} = \frac{(I_1 + I_2)}{2} - \frac{(S_2 - S_1)}{\Delta t} \tag{4}$$

where the subscripts 1 and 2 denote the beginning and end, respectively, for a routing period, $\Delta t$. The assumption implicit in Equation 4 is that discharge varies linearly with time during a routing period $\Delta t$. This assumption is consistent with gradually varying flood applications.

Writing Equation 4 with all the unknown terms (subscript 2) defined as a function of the known terms, at time step 1, yields:

$$\left(\frac{S_2}{\Delta t} + \frac{O_2}{2}\right) = \left(\frac{S_1}{\Delta t} + \frac{O_1}{2}\right) - O_1 + \frac{(I_1 + I_2)}{2} \tag{5}$$

The storage-outflow combination ($S/\Delta t + O/2$) in Equation 5 is called storage indication and has the units of discharge (HEC, 1990a). This equation is the basis of the modified Puls method and enables rapid direct calculation of end-of-period outflow.

## 1.4 Reservoir Routing with Modified Puls

For an uncontrolled reservoir, outflow and water in storage are both uniquely a function of lake elevation so the two functions can be combined to develop a storage-outflow relationship. In HEC-1, level-pool routing provides the capability to perform reservoir routing with several options to provide or compute the storage-outflow relationship. Typically a low-level outlet is modeled with the orifice equation and a spillway is with the weir equation. Storage-elevation data can be provided, or computed from area-elevation data.

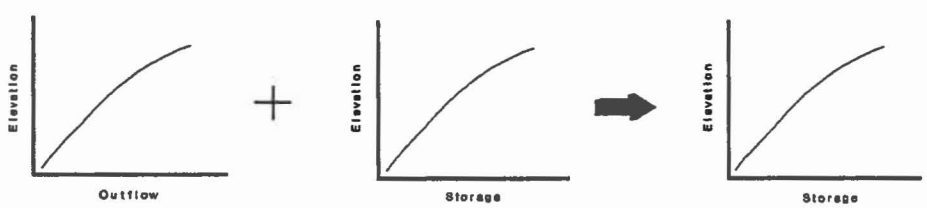


**Figure 2**
**Reservoir Storage-Outflow Curve**

The storage-outflow relationship provides the outflow for any storage level. Starting with an empty reservoir, the outflow capability would be a minimum. If the inflow is less than the outflow capability, the water would flow through. During a flood, the inflow increases and eventually exceeds

the outflow capability. The difference between inflow and outflow produces a change in storage (Equation 3). In the figure below, the difference between the inflow and outflow (on the rising portions of the hydrograph) represents the volume of water entering storage.

As water enters storage, the outflow capability increases because the pool level increases. Therefore, the outflow increases. This increasing outflow with increasing water in storage continues until the reservoir reaches a maximum level. This will occur the moment that the outflow equals the inflow, as shown in Figure 3. Once the outflow becomes greater than inflow, the storage level will start dropping. The difference between the outflow and the inflow hydrograph on the recession side reflects water withdrawn from storage.

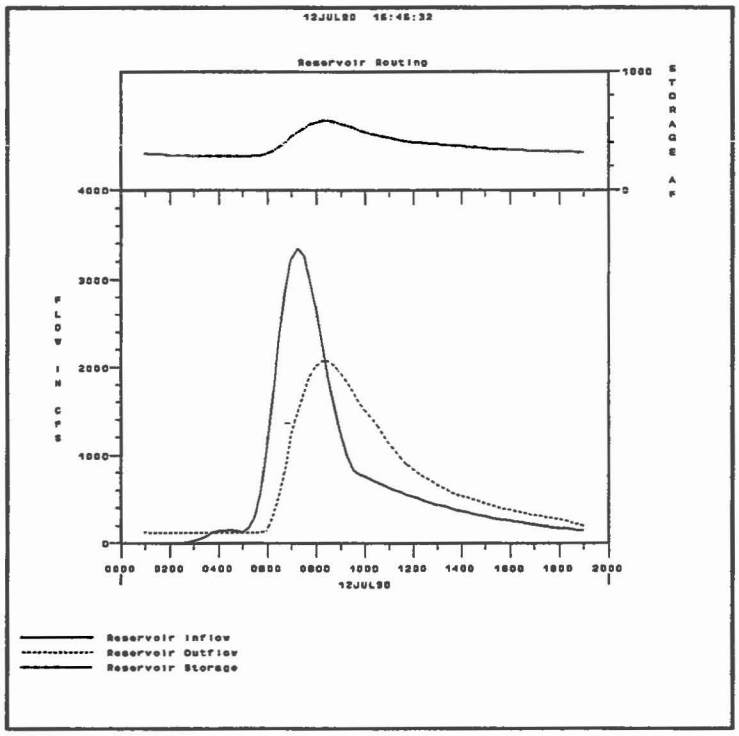


**Figure 3**
**Reservoir Routing**

## 1.5 Channel Routing with Modified Puls

Modified Puls routing for rivers is applied in the same manner as for reservoirs. However, the storage-outflow relationship is developed differently. The water surface in a reach is not level and the outflow is not usually controlled by an outlet works. However, we still must assume a unique storage-outflow relationship to apply the method.

The necessary assumptions to use storage routing in a river reach are consistent with the assumptions for applying a steady-flow model to compute water surface profiles for flood flows. Therefore, storage routing is generally compatible with the use of HEC-2 to compute flood profiles.

**Unique Storage-Outflow Relationship.** The figure below illustrates the possible storage loop effect in a river reach. For a given outflow, the storage on the rising limb of the hydrograph is larger than for the recession limb (curve b). The dashed single-value storage-outflow line (curve a) reflects the average-value curve we would expect from HEC-2.

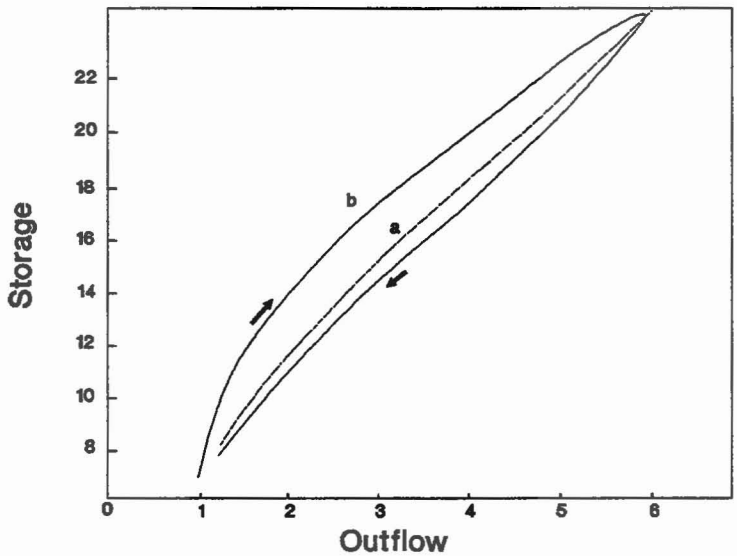


**Figure 4**
**Looped Storage-Outflow Curve**

In very flat streams, the storage-outflow relationship can be extremely looped, and dependent on the flood event. Figure 4 is taken from a report reviewing the application of modified-Puls routing in Chuquatonchee Creek, a stream with a channel slope of 0.000462 (2.4 feet/mile) (Strelkoff, 1980a). The curve was developed for an in-bank flood. A second out-of-bank flood provided an extremely looped function with the initial rising limb inflow essentially all going into storage without any appreciable increase in outflow. The very small bottom slope required a substantial depth gradient to move the flood flow. The wide flat floodplain provided a large amount of storage for the increased depth. At the early stage of the flood, the increasing flow is primarily going into wide floodplain storage with practically no change in outflow. Then the outflow increased rapidly when the flood front arrived downstream, and relatively little storage was added. The study concluded that even storage-outflow relationships computed from observed inflow and outflow hydrographs ".. do not serve the purpose, in principle, because each different event is characterized by a different relation..."

**Unique Stage-Discharge Relationship.** Another way of looking at the unique storage-outflow relationship is to examine the relationship between stage and discharge. A rating curve at a river location shows the relationship between stage (or elevation) and discharge. A rating curve computed with HEC-2 is a single-valued function, i.e. a unique stage-discharge relation-ship. It doesn't matter whether it is for the rising or falling portion of the hydrograph, the maximum stage occurs at the maximum discharge. For some river reaches, there can be a significant difference between the maximum stage and maximum discharge. This often occurs on flat river reaches where the backwater affect from the higher downstream flow causes a higher upstream water surface elevation than the elevation associated with the peak discharge at that location. The maximum stage occurs after the maximum discharge has passed. Hydrologic routing methods, including modified Puls, do not model flood wave movement in very flat streams as well as hydraulic methods.

**Effect of Inflow.** The use of the storage-outflow relationship in the routing procedure assumes that the inflow does not significantly affect the storage in the reach. Storage routing can model the inflow effect on storage by adding an "X" parameter for weighing the inflow contribution to the storage-outflow relationship. In HEC-1, this method is called Working R & D. The parameter "X" is similar to that used in the Muskingum routing method. The value of "X" varies from 0 to 0.5. A value of zero makes Working R & D the same as modified Puls, in that inflow has no effect on storage. A value of zero for "X" also yields the maximum attenuation for a given storage-outflow relationship. A value of

0.5 eliminates attenuation and only yields translation of the routed hydrograph. The problem is selecting an appropriate value of "X". With observed upstream and downstream hydrographs, the value can be calibrated to achieve the best routing results. However, without observed data the value is somewhat of a guess. For this reason, the "X" value is not generally used with storage routing.

When applying HEC-2 to compute flood profiles, we assume that the flow does not rapidly change with time. Also, we assume that the peak discharge persists long enough to treat it as a steady discharge. Both assumptions are generally accepted for most naturally occurring floods because the flood discharge changes gradually with time. During a flood, the water surface in a routing reach gradually rises and falls such that a person standing at a location on the bank would hardly perceive the changing conditions. If the water surface profile is gradually rising and falling in the river reach, the difference between inflow and outflow in any single time step should not significantly affect the storage in the reach, except for the previously described condition for very flat streams. Also, the use of sub-reaches, or steps, accounts for some of the differences between inflow and outflow in a river reach. Figures 5 and 6 illustrate the application of subreaches.

**Hydrograph Volume.** Storage routing assumes that the routing reach is fully occupied with water, like a reservoir. When we use HEC-2 to compute profiles in a floodplain, we assume that there is a sufficient volume of water, and a sufficient length of time, for the flood wave to fully occupy the floodplain up to the calculated water surface elevation. Therefore, this method would not be appropriate for flood hydrographs that contain a small volume of water in comparison to the floodplain storage.

**General Application.** Given the general considerations described above, the modified Puls routing method can adequately model flood wave movement through river reaches. Notable exceptions include: (1) very flat stream slopes (less than 3 feet/mile), (2) time varying downstream boundary (e.g., tidal conditions), and (3) rapidly rising flood waves (e.g., dam-break floods). The following discussion presents the combined use of HEC-2 to develop storage-discharge relationships and HEC-1 to route flood hydrographs.

## 1.6 Application with HEC-1 and HEC-2

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, as illustrated in Figure 5. Each reservoir is assumed to have a level pool, and therefore a unique storage-discharge relationship. The

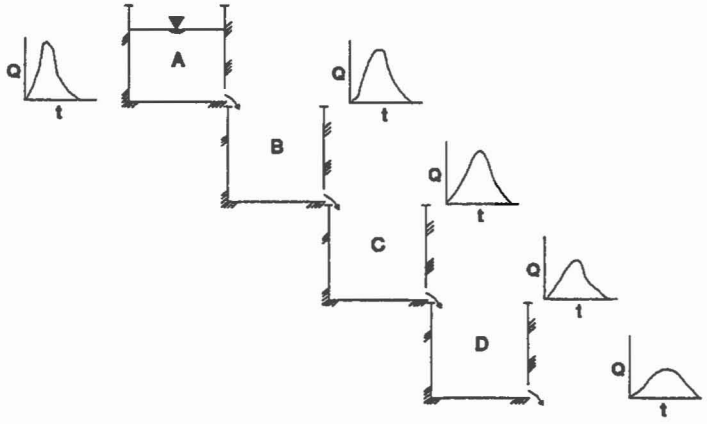


**Figure 5**
**River Reach as a Cascade of Reservoirs**

cascading reservoir approach is capable of approximating the looped storage-outflow effect when evaluating the river reach as a whole. The rising and falling portions of the flood wave are simulated with different storage levels in the cascade of reservoirs, thus producing a looped effect for the storage-outflow function for the total river reach. This is illustrated in Figure 6.

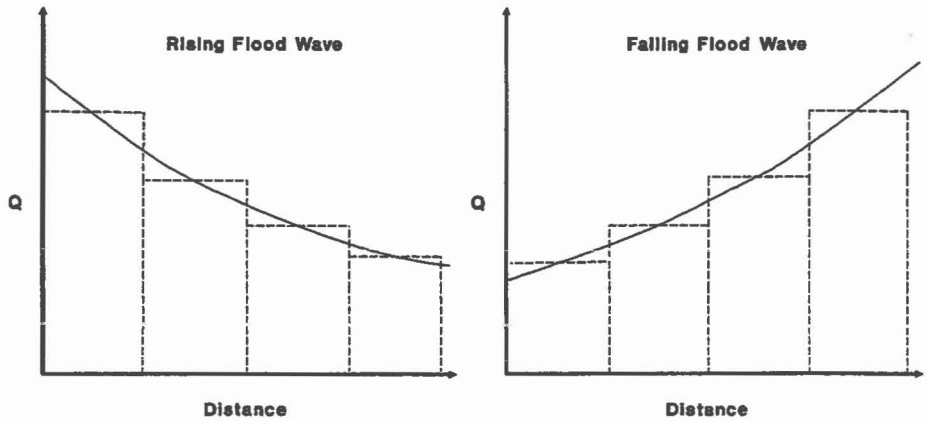


**Figure 6**
**Modified Puls Application to Rising and Falling Flood Waves**

**Determination of Storage-Outflow Relationship.** Steady-flow water surface profiles, computed over a range of discharges, can be used to determine a storage outflow relationship in a river reach. Each computed profile provides one storage-outflow value, as illustrated in Figure 7. The relationship required for routing is determined by computing a series of water surface profiles, corresponding to a range of discharges. The range of discharges should encompass the range of flows that will be routed through the river reach. The storage volumes are computed by multiplying the cross-sectional area, at the computed water surface elevation, by the channel reach lengths. Therefore, the computed storage values are not level pools, but represent storage under the water surface profile.

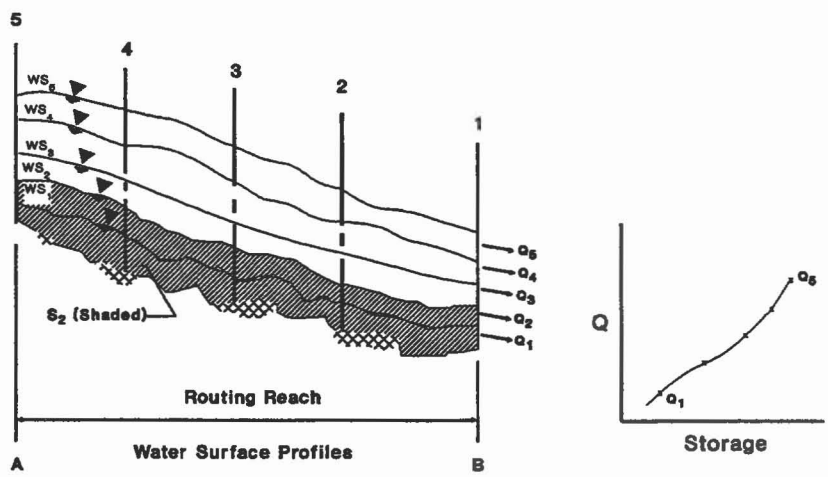


**Figure 7**
**Steady-Flow Water Surface Profiles to Compute Storage-Outflow**

**Effect of Routing Steps.** Level-pool reservoir routing should be performed with a single step (NSTPS = 1). This assumes the travel time through the reservoir is much smaller that the computation interval $\Delta t$. However, in channel routing the travel time through the river reach is often

greater than the computation interval. When this occurs, the river reach must be treated in multiple-steps to simulate the flood-wave movement and changes in shape. The number of steps, or sub-reaches, affects the attenuation of the hydrograph, and ideally should be obtained by calibration. The maximum amount of attenuation will occur when the channel routing computation is done in one step. Also, one-step routing would indicate a downstream response, in one time step ($\Delta t$), from any change in the inflow discharge. As the number of steps or sub-reaches increase, the amount of attenuation decreases. In the limit, a large number of steps would only provide hydrograph translation like kinematic wave routing (Strelkoff,1980b).

The number of steps, or subreaches, will depend on the length of the routing reach, as well as the channel geometry, and the inflow hydrograph. For example, if a long river reach is modeled with a single storage-outflow function, the function would normally be subdivided into subreaches for routing applications (NSTPS > 1). For non-uniform cross sections, it is preferable to divide the reach into subreaches with separate storage-outflow sets. HEC-1 can subdivide the storage-outflow data into NSTPS sets of storage; however, most floodplain reaches are not uniform. Also, HEC-1 does not provide intermediate routing results from the NSTPS routing; only the final outflow hydrograph is provided.

An initial estimate of the number of routing steps, or sub-reaches, can be obtained by dividing the total flood wave travel time (K) for the reach by the computation interval ($\Delta t$).

$$K = \frac{L}{V_W} \quad \text{and} \quad NSTPS = \frac{K}{\Delta t} \tag{6}$$

Where:

| | | |
|---|---|---|
| K | = | Total flood wave travel time (sec) |
| L | = | Channel reach length (ft) |
| $V_w$ | = | Velocity of the flood wave (ft/sec) |
| $\Delta t$ | = | Time interval for routing (sec) |
| NSTPS | = | Number of routing steps |

**The time interval ($\Delta t$)** is usually determined by ensuring that there is a sufficient number of computational points on the rising side of the inflow hydrograph. A general rule of thumb is the computation interval should be less than 1/5 of the time of rise ($T_r$) for the inflow hydrograph.

$$\Delta t < \frac{T_r}{5} \tag{7}$$

**The velocity of the flood wave $V_w$** is greater than the average velocity at a given cross section, for a given discharge. The flood wave velocity can be estimated by several techniques.

(1) Using Seddan's law, a flood wave velocity can be approximated from the discharge rating curve of a station whose cross-section is representative of the routing reach. The slope of the discharge rating curve is equal to dQ/dy. The flood wave velocity, and therefore the travel time K, can be estimated as follows:

$$V_w = \frac{1}{B}\frac{dQ}{dy} \tag{8}$$

$$K = \frac{L}{V_w} \tag{9}$$

Where:

$V_w$ = flood wave velocity, ft/s
B = top width of the water surface
L = length of the routing reach, ft

(2) Another means of estimating flood wave velocity is to estimate the average velocity 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.

| Channel Shape | Ratio $\frac{V_w}{V}$ |
|---|---|
| Wide rectangular | 1.67 |
| Wide parabolic | 1.44 |
| Triangular | 1.33 |

For natural channels, an average ratio of 1.5 is suggested. Once the wave speed has been estimated, the travel time (K) can be calculated with Equation 6.

**The routing procedure with HEC-1 and HEC-2** is illustrated in Figure 8. The procedure requires an HEC-2 model to compute the steady-flow water surface profiles. Each profile is computed with a constant flow, and the flow values cover the range of flow for routing the inflow hydrograph(s). The profile computation provides the storage-outflow data for the reach. The data set requires additional input to define the inflow hydrograph and complete the HEC-1 routing data requirements. HEC-1 is then run with the design flood, or multiple flood representing an array of flood events. The routed flood hydrograph peak flows are then transferred back into the HEC-2 data set at the appropriate downstream cross section for each sub-reach. The final step is to compute the water surface profile with the peak discharges.

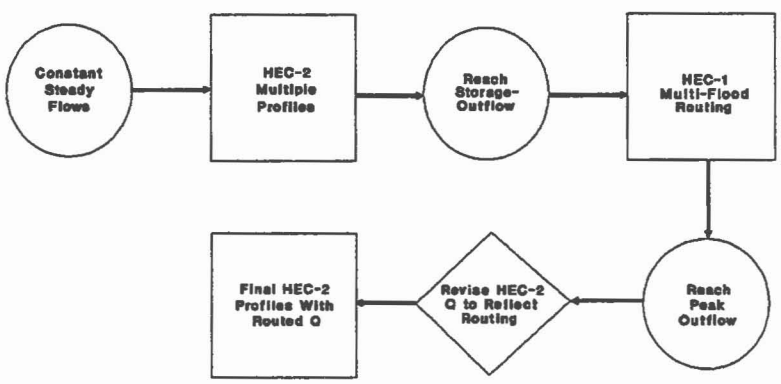


**Figure 8**
**Modeling Flow Chart**

It is common practice to take the storage-outflow data from the modified-flow HEC-2 run and repeat the routing with HEC-1. However, the multiple-reach approach, described on pages 7 and 8, is better served by the storage-outflow data computed with constant-flow water surface profiles. As shown in Figures 5 and 6, the subreaches, or steps, provide incremental pools of storage-outflow for the entire reach. As the flow cascades from subreach to subreach, the changing discharge (outflow) becomes the inflow to the next subreach. By this method, the change in flow with distance is accounted for as the flow passes from subreach to subreach. For both rising and falling portions of the hydrograph, each subreach represents an average condition. If the storage-outflow relationship were based on the peak flow profile, it would tend to bias the storage function to only one position of the hydrograph, instead of the entire routing cycle.

There are several advantages to the combined HEC-2 and HEC-1 application of the Modified Puls routing method. With the current HEC-2 option to write a storage-discharge output file, the storage table can be directly used in HEC-1. The routing effects on a flood wave can be evaluated for the HEC-2 modeled river reach and, if considerable peak attenuation occurs, the HEC-1 computed peak discharges can be used to recompute the peak discharge profile with HEC-2. If channel modifications are being evaluated, the impact of the modification on flood routing can be evaluated using the same procedure. The following sections describe the steps required to perform the routing.

# Chapter 2

# HEC-2 Modeling to Compute Storage

Computer program HEC-2 computes the cumulative storage under the computed water surface profile (output variable **VOL** in Acre-feet or 1000 cubic meters) (HEC, 1990b). An estimate of the volume of water in a reach, for any profile, can be computed by taking the difference between the cumulative storage values for the upstream and downstream cross sections that define the reach. The computed difference would be one point in a storage-outflow relation. By computing multiple-profiles, ranging from low- to high-flow values, a storage-outflow curve can be developed. This approach is the basis for applying modified Puls routing for channels. The September 1988 version of HEC-2 has the added capability to compute and write the storage-outflow data in the HEC-1 input format. The **J4** record provides the necessary added input to request the storage-discharge output and to define the routing reaches.

The storage-discharge data is written to a scratch file **TAPE7**. For each routing reach, the output file contains HEC-1 **KK** and **KM** records, with the cross-section numbers for the reach on the **KM** record. The storage and corresponding discharge values are written to **SV** and **SQ** records, respectively. The required **RS** record is also written; however, none of the input variables can be defined by the HEC-2 program. The "HEC-1 Model for Modified Puls Routing" section of this document provides the procedure for utilizing this data. The HEC-1 User's Manual provides complete program input requirements.

## 2.1 HEC-2 Input for Storage Function Output

The following assumes that you have a calibrated HEC-2 model for a river reach and you would like to evaluate the routing effects for this reach. Perhaps there is sufficient storage within the reach to change the peak discharge at the downstream end. Or, perhaps you have an alternative condition for the river reach and you want to compare the routing affects for the modified condition with those for the original reach. The added HEC-2 input and modeling considerations for storage calculations are described in this section, along with an example data set.

The **J4** record is an added input on the first profile of a multiple profile computer run. It follows the **J1** (and the **J2** and **J3**, if present). The **J4** input includes the downstream cross-section number (Field 1) and the upstream cross-section number (Field 2) that define a routing reach. The section numbers must match the given section numbers (**SECNO**) on the **X1** records. The program will compute the difference in cumulative volume between the given section numbers for every profile in the computer run.

Each pair of section numbers defines a routing reach for output. Different subdivisions of the same HEC-2 data set can be used in a single run. For example, the entire data set could be defined as one pair; while an additional two sets of cross-section numbers could define the entire data set as two reaches, dividing the entire data set in half. Routing through two sub-reaches will give different results that routing through the whole reach. Generally, using **NSTPS** in HEC-1 (**RS** record) or subdividing into sub-reaches with the **J4** input provides less attenuation than treating the routing reach as one whole step.

**Selection of Reach Lengths.** The ends of routing reaches should be selected with reference to the storage characteristics of the river valley (USACE, 1960). A section should be selected that acts as a control and creates large storage upstream, e.g., a bridge constriction. No subdivision should be made for areas within a reach that performs like a reservoir. In long river reaches, the subdivisions would be made at major tributaries, gaging locations, and according to the criteria that the travel time should approximately equal the time interval for routing.

In this example, the sub-reaches were selected to provide a one-hour travel time through each. The HEC-2 variable **TIME** provides the cumulative travel time in hours based on the average cross-section velocity and channel reach length. The flood-wave velocity is generally 1.3 to 1.7 times faster than the average velocity (USACE, 1960). Therefore, the flood-wave travel time can be estimated by dividing the average velocity **TIME** by a factor of about 1.5. Table 1a. shows the **J4** input for the example problem. The section "HEC-1 Input for Storage Routing" describes the subdivision of a routing reach into steps.

The HEC-2 model must be modified for multiple-profile computations. If you are using a **QT** record to define discharge, this record is modified to define the discharges for the storage-discharge relation. The discharges should range from the lowest to the highest discharge expected in the inflow hydrograph. The program will assume that there is zero storage at zero discharge, that point is a given. The discharge values should be reasonably spaced because the result will be used to represent a curve with straight line segments between each pair of discharges. For flood routing, from ten to nineteen discharge values are suggested.

Following the **EJ** record, a set of title (**T1, etc.**) and job (**J1** and **J2**) records are required for each succeeding profile. The 1988 version of HEC-2 does not require three title records; one is sufficient. The **J1** record will define which field of the **QT** record to read (**INQ** in **J1.2**) and provide the appropriate starting water surface elevation for that discharge (**WSEL** in **J1.9**). The other input on the **J1** record is the same as the first profile's input. The **J2** record is required to indicate that this is a second, or subsequent, profile (**NPROF** in **J2.1**). While no additional input is required on the **J2**, suppressing the profile plot, (**J2.3** = -1) will reduce the output file size.

If you use computer program COED for editing the input file, the "Block Commands" are a convenient way to develop the title and job input data for the multiple profiles. The **ST**art command marks the beginning of the "Block", which would be the first title record. While editing the file in full-screen mode, locate the cursor at the start of the first title record and press the **F9** key. This will give you the **E>** prompt and allow you to enter one command (i.e, **ST**). The **EN**d command marks the end of the block, which would be the end of the **J2** record. Again, locate the cursor at the ending point for the block, enter: **F9**, and then enter: **EN**. The **DU**plicate command copies the defined block. The duplicate command has a parameter **n** which allows you to duplicate the block **n** times. Locate the cursor at the end of the file, press: **F9**, and then enter: **DU #** (where # = the number of duplicates you want). Refer to pages 3-8 of the COED User's Manual for a description of the "Block Commands".

## 2.2 HEC-2 Data Considerations for Storage Calculation

While the **J4** record is the only added HEC-2 input requirement for storage-discharge output, there are additional modeling considerations that affect how you create an HEC-2 model. The primary objective is to obtain the best estimate of water in storage, while defining the effective flow area for the water surface profile calculations. The steady flow water surface profile calculations do not consider storage area; therefore, any method that excludes the storage area is sufficient for the conveyance calculations. This section describes common modeling problems and provides a modeling approach for estimating storage in a routing reach.

**Bridges.** For flood-flow conditions, when all the flow passes under the bridge, there may be a significant transition between the floodplain flow area and the bridge flow area. The typical HEC-2 bridge modeling approach is to use the effective area option (X3.1 = 10) to control the flow to the bridge width (up to a controlling elevations defined on **X3** fields 9 and 10). The logic being that only the bridge opening is effectively conveying flow in the downstream direction. The overbank areas are storage zone and should not be included in the conveyance calculations for the sections on either side of the bridge. The shaded area in Figure 9 indicates the modeled boundary for ineffective flow at a bridge.

Using the effective flow option to block out ineffective area eliminates that area from the flow and storage computation. The use of high Manning's "n" values is the only HEC-2 option available to reduce conveyance and still include the area for volume calculations. A value of 100 is suggested. Remarks should be added to the input data to note that high "n" values were used to eliminated storage area from conveyance calculations. These remarks will help the reviewer and keep people from thinking that an input error was made.

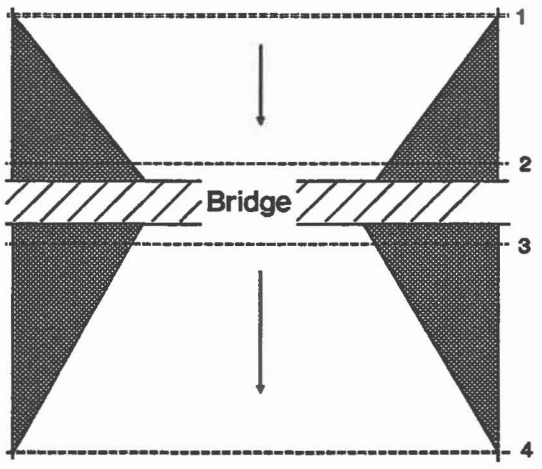


**Figure 9**
**Storage Area in the Vicinity of Bridges**

If a bridge acts as a sever choke, explicit routing through the resulting detention storage should be represented in the HEC-1 model. In this case, the bridge would be acting as a dam and the upstream area would be treated as a reservoir. The routing steps (**NSTPS**) would be one for the "reservoir" reach.

**Storage Area.** Bridges are an obvious example where storage zones are not included in the conveyance calculation. However, there are other modeling situations where portions of cross sections may not include storage area. To be complete, all flow area should be included in the cross sections. High Manning's "n" values can then be used to "block" storage areas out for conveyance calculations. The **NH** record allows the user to define "n" values across the cross section as a function of cross-section stations. The **NH** record can "block" any portion of a cross section by setting "n" equal to 100 for that portion.

**Example Input.** The following tables show portions of an HEC-2 input data set with examples of the added input for storage-outflow computation. Table 1a. shows the use of the **J4** record to define two routing reaches. The section numbers are input in downstream then upstream order, and they must equal a section number given on an **X1**. The reaches, however, are requested in an upstream to downstream order for HEC-1 routing. The **QT** input shows the range of flow values to be utilized. Table 2 shows the resulting storage-discharge data.

## Table 1a
## HEC-2 Input Showing J4 Data

```
T1       EXAMPLE DATA SET DEMONSTRATING MULTIPLE PROFILES FOR STORAGE DATA
T2       Discharge values set from low channel flow up to 1% Chance flood
T3       Unnamed Creek
T4       Data extracted from a Flood Insurance Study
J1            2                 0.0007                                  550
J2     1             -1
*
*  J4 input defines 2 reaches, one from 71000 to 85450, and one
*  from 60830 to 71000  (NOTE:  The upstream reach is first)
*
J4 71000   84520   60830   71000
*
NC   .07     .08    .045      .1      .3
QT    14    2000    4000    6000    8000   10000   12500   17500   20000   25000
QT 30000   35000   40000   50000   70000
X1 60830      25    1122    1270     400     150     330
GR 579.9    1000   574.9    1074   556.7    1122   552.4    1169   549.6    1171
GR 543.1    1180   536.2    1200   551.3    1236   553.7    1249   556.9    1270
GR 556.4    1300     556    1345   555.6    1400   556.2    1500   557.1    1600
GR 556.4    1700     557    1800   555.7    1900     600    1900     600    1900
GR   600    1900     600    1900     600    1900     600    1900     600    1900
X1 62300      21    1682    1905    1000    1750    1470
GR 575.0  1000.0   570.8  1068.0   570.4  1088.0   568.4  1121.0   557.2  1588.0
GR 554.0  1598.0   554.0  1630.0   557.3  1662.0   558.5  1682.0   554.2  1700.0
GR 555.5  1790.0   552.9  1800.0   543.0  1827.0   543.1  1878.0   545.6  1881.0
GR 560.1  1905.0   559.4  2600.0   560.8  3271.0   563.7  3275.0   574.0  3500.0
GR 577.6  3586.0
```

Table 1b shows the use of the NH record to set high Manning's "n" values for the overbank area, instead of the traditional use of the Effective Flow Option (X3.1 = 10). This allows the overbank area to be included in volume computations while effectively eliminating the conveyance of the overbanks. The output should be carefully reviewed to ensure that the bridge hydraulics are properly modeled for all flow conditions, given the wide range of flows used to compute the storage outflow relationship. Table 1c shows the multiple profile input.

## Table 1b
## HEC-2 Input Showing NH Input to Control Effective Area

```
X1 64880     30.0  1800.0  2045.0  1270.0  1290.0  1330.0     0.      0.      0.
GR 592.8    500.0   581.5   800.0   571.6   800.0   565.5  1000.0   571.3  1200.0
GR 564.3   1400.0   562.8  1600.0   560.9  1800.0   558.4  1928.0   556.6  1951.0
GR 543.9   1991.0   556.7  2025.0   560.0  2045.0   562.8  2200.0   566.0  2450.0
GR 554.0   2469.0   553.8  2484.0   553.9  2500.0   565.4  2520.0   565.9  2600.0
GR 564.5   2800.0   564.6  3000.0   566.5  3200.0   566.1  3400.0   570.4  3600.0
GR 572.4   3800.0   571.4  4000.0   574.6  4200.0   579.7  4400.0   589.6  4600.0
*
*  Overbank Manning's n values set to 100 to eliminate overbank conveyance
*  instead of using effective area option (X3.1 = 10)
*
NH      3     100.    1800    .045    2045    100.    4600
X1 64960      0.      0.      0.      80.0    80.0    80.0    0.      0.      0.
SB  1.25     1.20    2.50               3       2    3486    6.16     544     544
X1 65000      0.      0.      0.      40.0    40.0    40.0    0.      0.      0.
X2                       1   567.7   570.8
BT  24.0    500.0   593.4      0.   600.0   588.0      0.   800.0   578.8      0.
BT1000.0    573.3      0.  1200.0   571.5      0.  1400.0   571.6      0.  1600.0
BT 571.3      0.  1760.0   571.3      0.  2099.0   571.4      0.  2224.0   571.4
BT    0.   2421.0   571.3      0.  2529.0   571.1      0.  2573.0   571.1      0.
BT2600.0    571.3      0.  2800.0   570.9      0.  3000.0   570.8      0.  3200.0
BT 571.0      0.  3400.0   571.2      0.  3600.0   571.0      0.  3800.0   571.7
BT    0.   4000.0   572.9      0.  4200.0   576.0      0.  4400.0   581.0      0.
BT4600.0    589.3      0.
*
*     NC to reset "n" values to appropriate values for cross section
*
NC   .10     .08    .050
X1 65140     30.0  2060.0  2388.0   140.0   140.0   140.0     0.      0.      0.
GR 600.0    500.0   590.0   660.0   580.0   790.0   575.0   850.0   570.0   950.0
GR 565.0   1240.0   559.6  2060.0   551.2  2093.0   544.5  2100.0   545.8  2140.0
GR 548.6   2143.0   553.5  2166.0   554.2  2200.0   560.3  2388.0   569.3  2420.0
GR 568.1   2850.0   554.1  2881.0   554.4  2891.0   569.7  2904.0   569.9  2910.0
GR 568.7   2947.0   563.0  2954.0   565.0  3450.0   570.0  3590.0   575.0  3830.0
GR 575.0   4130.0   575.0  4500.0   580.0  4600.0   590.0  4820.0   600.0  5150.0

* * * Cross sections missing, next section is end of reach 1 * * *

X1 71000      15    1450  1683.2    1300    1200    1270
GR 600.0   960.0   595.0    1000   563.0    1450   556.7    1460   556.7    1495
GR 560.7    1511   560.7    1640   571.0  1683.2   571.5    1712   572.2    1783
GR 572.7    2200   570.9    2300   570.0    2430   570.0    2690   600.0    2710
```

## Table 1c
## HEC-2 Input Showing Multiple Profile Computation

```
* * * Remaining Cross sections missing * * *
EJ
T1      PROFILE 2
*  Only 1 Title Record required for 1988 version of HEC-2
*  Profiles started with Energy Slope, WSEL to start the slope-area search.
*
J1            3                 0.0007                          555
J2     2             -1
T1  PROFILE 3
J1            4                 0.0007                          557
J2     3             -1
T1  PROFILE 4
J1            5                 0.0007                          558
J2     4             -1
T1  PROFILE 5
J1            6                 0.0007                          559
J2     5             -1
T1  PROFILE 6
J1            7                 0.0007                          560
J2     6             -1
T1  PROFILE 7
J1            8                 0.0007                          561
J2     7             -1
T1  PROFILE 8
J1            9                 0.0007                          562
J2     8             -1
T1  PROFILE 9
J1           10                 0.0007                          562
J2     9             -1
T1  PROFILE 10
J1           11                 0.0007                          563
J2    10             -1
T1  PROFILE 11
J1           12                 0.0007                          563
J2    11             -1
T1  PROFILE 12
J1           13                 0.0007                          564
J2    12             -1
T1  PROFILE 13
J1           14                 0.0007                          564
J2    13             -1
T1  PROFILE 14
J1           15                 0.0007                          565
J2    14             -1
*   Summary Tables do not have to be requested  with  J1.1 = 15
*   Three blank lines are no longer required
ER
```

The complete data set was processed with HEC-2 to generate the storage-outflow function. The storage data are written to **TAPE7**, which is listed in the following table.

## Table 2
## HEC-2 TAPE7 Output File

```
KK RCH 1
KM      REACH EXTENDS FROM X-SECT.  71000.000 TO X-SECT.  84520.000
RS
SV     0     152     248     385     555     740     987    1451    1656    2036
SV  2401    2761    3117    3743    4934
SQ     0    2000    4000    6000    8000   10000   12500   17500   20000   25000
SQ 30000   35000   40000   50000   70000
KK RCH 2
KM      REACH EXTENDS FROM X-SECT.  60830.000 TO X-SECT.  71000.000
RS
SV     0     177     359     499     658     840    1065    1538    1773    2223
SV  2701    3198    3697    4612    6412
SQ     0    2000    4000    6000    8000   10000   12500   17500   20000   25000
SQ 30000   35000   40000   50000   70000
```

The TAPE7 file should be copied into a file named for use with HEC-1. The DOS "Rename" command or the "Copy" command could be used, for example:

***COPY TAPE7 ROUTING.DAT***

## 2.3 HEC-2 Model for Modified Conditions

The previous sections describe developing storage data for a model of a river reach, which may reflect existing conditions. For many studies, similar analysis are required for a modified condition. There may be an interest in the routing effects for the modified condition as compared to existing conditions. Examples include floodway determination and channel modifications for flood damage reduction. The following presents an HEC-2 option to produce an input data file that reflects user defined modifications to the cross sections. This file can be conveniently used, following the previously described procedures, to develop storage data for a modified reach.

The 1988 version of HEC-2 has an option to write a scratch file (**TAPE16**) of modified input data. The file will contain input data from **NC** through **EJ** records. The modified cross-section data will be in **GR** format. The TAPE16 file can then be edited, following the procedures described in "HEC-2 Input for Storage Function Output," to develop a storage model for the modified reach.

The TAPE16 file is requested by encoding a negative value for the **IBW** variable on the 8th field of the **J2** record. Variable **IBW** is used for the channel improvement option to define the appropriate field of **CI** records to be read for that profile. However, the TAPE16 option is not limited to channel improvements. Cross-section changes caused by: **X4** added points, cross-section elevation and width adjustments (**X1** fields 8 and 9), Method 1 and 2 encroachments (**X3** or **ET** records), and sediment elevation adjustment (**ELSED** on **X3.2**) are also reflected in the modified geometry. If the channel improvement option is not used, simply input a -1 for the **IBW** variable on the profile for which you want to generate the TAPE16 file. The HEC-2 User's Manual Supplement pages 13 and 14 show the input and resulting TAPE16 output file.

The following sections describe the application of HEC-1 to route hydrographs with the storage data created in HEC-2.

# Chapter 3

# HEC-1 Model for Modified Puls Routing

The **TAPE7** file will contain the routing data (**KK** to **SQ** records) for each routing reach defined on the **J4** record of the HEC-2 computer run. The file should be renamed to reflect the name of the routing reach. If the file is not renamed, a subsequent HEC-2 computer run could overwrite the file. The reach data are inserted in the HEC-1 data set at the appropriate reach locations. The **RS** record must be completed before running HEC-1.

## 3.1 HEC-1 Input for Storage Routing

The HEC-2 generated TAPE7 output file must be edited to develop the HEC-1 hydrograph routing model. First the title (**ID** records) and job data are required. For this example, the time interval (30 minutes) and the duration of the simulation (50 periods) are on the **IT** record, see Table 3a. Additionally, the starting date and time are required if HECDSS is used to store hydrograph data. The current date was used. The optional **ZW** record defines the pathname parts to write the computed hydrograph to a DSS file.

Next the inflow hydrograph is required. One of two options would likely be used: (1) Read in a known hydrograph on **QI** records, or (2) Compute a hydrograph from precipitation and unit hydrograph data. The latter option was used in this example because only peak discharge data were available. The rainfall data are on the **PB** record for storm total and **PI** record for distribution. The **IN** record was used to define rainfall data on an hourly time interval (IN.1 = 60). The storm total was adjusted to develop a hydrograph with a peak discharge equal to 50,000 cfs, the one-percent chance flood discharge. The hydrograph was based on the drainage area (**BA** record) and the SCS unit hydrograph method (**LS** and **UD** records). The following table shows the HEC-1 input for the hydrograph computations.

Following the HEC-1 input to define the inflow hydrograph, routing data (TAPE7) is input to route the computed inflow hydrograph. The remaining data set, Table 3b, shows the TAPE7 portion of the data after editing. Again the optional **ZW** records will write the routing results to the DSS file. For this example, both the storage (C=STOR) and outflow hydrograph (C=FLOW) will be written to the DSS file.

The additional input is primarily on the **RS** record. The first field is the number of steps in the routing reach. Because the storage reaches were selected to have approximately one hour travel time in each reach, and a 30 minute time step was used in the routing, two steps were used for routing (RS.1 = 2). The second field reflects starting conditions based on flow (RS.2 = FLOW). The

## Table 3a
## HEC-1 Input for Hydrograph Computation

```
ID      MODIFIED PULS ROUTING EXAMPLE WITH HEC-2 STORAGE DATA
ID      First cycle with constant discharge storage values
ID
IT    30 25MAY90    1200      50
KK  STA1
KM      GENERATE RUNOFF HYDROGRAPH FOR ROUTING
ZW A=MODPULS B=REACH1 C=FLOW F=INFLOW
PB   5.4
IN    60
PI    .5      .8       1     1.5       1      .6      .2
BA   100
LS            80
UD   1.5
```

third field indicates that inflow equals outflow at the start of the routing computations (RS.3 = -1). If there is a known starting base flow in the stream, that discharge value would be input on the third field. The second routing reach data are the same as the first. The last input item is the ZZ record to indicate end of run.

## Table 3b
## HEC-1 Input for the Routing Reaches

```
KK RCH 1
KM      REACH EXTENDS FROM X-SECT.  71000.000 TO X-SECT.  84520.000
ZW           B=REACH1 C=STOR F=RIVER
RS     2    FLOW      -1
SV     0     152     248     385     555     740     987    1451    1656    2036
SV  2401    2761    3117    3743    4934
SQ     0    2000    4000    6000    8000   10000   12500   17500   20000   25000
SQ 30000   35000   40000   50000   70000
ZW           B=REACH1 C=FLOW F=OUTFLOW
KK RCH 2
KM      REACH EXTENDS FROM X-SECT.  60830.000 TO X-SECT.  71000.000
ZW           B=REACH2 C=FLOW F=OUTFLOW
ZW           B=REACH2 C=STOR F=RIVER
RS     2    FLOW      -1
SV     0     177     359     499     658     840    1065    1538    1773    2223
SV  2701    3198    3697    4612    6412
SQ     0    2000    4000    6000    8000   10000   12500   17500   20000   25000
SQ 30000   35000   40000   50000   70000

ZZ
```

## 3.2 HEC-1 Output for Storage Routing

The HEC-1 program provides a printed output file that shows the results for each computation. For our example, the computation of a runoff hydrograph, the routing through reach 1, and the routing through reach 2 are tabulated in the output file. The output tables provide discharge values for each time interval, 30-minutes in this example. From these tables, the routing effect on the peak discharge can be determined for each routing reach.

Figure 10 shows the three computed hydrographs for the example. The figure was created with DSS-DSPLAY. The primary reason for writing the computed results to a DSS file is to obtain graphical displays of the computed results.

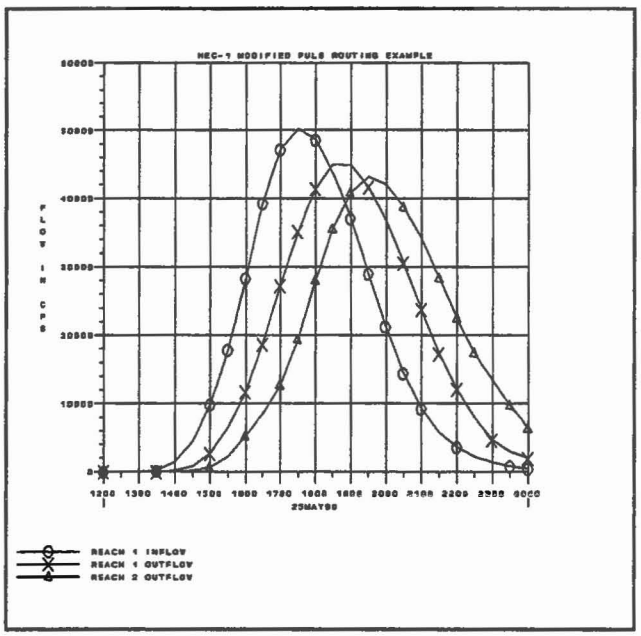


**Figure 10**
**HEC-1 Routed Hydrographs**

A second way of displaying the routing results is the combination of inflow, outflow, and storage use over time. For cases where the reach is divided into steps, the actual routing is sequentially performed with each division (step) of the routing storage. Only the results for the final step are shown in the graphical display. Figure 11 shows the routing results from the first reach.

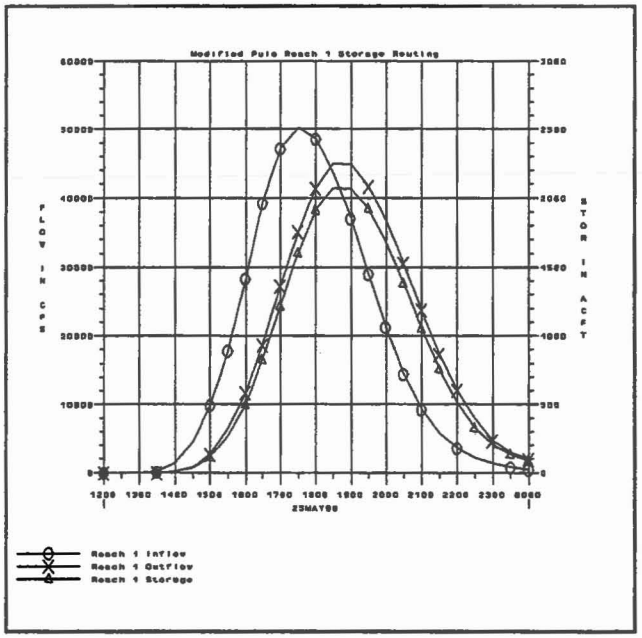


**Figure 11**
**HEC-1 Storage Routing for Reach 1**

The HEC-1 routing results show the decrease in peak discharge as the flood hydrograph moves through the two reaches. This information can be returned to the HEC-2 profile calculations. The HEC-2 data file is edited to include **QT** records at those locations where the discharge changes. For this example, that would only be two locations; however, for large studies these modifications could be extensive. The Corps' Chicago District has a utility program to perform automated transfer of HEC-1 flows into the corresponding HEC-2 data set. The following table shows the Summary output from HEC-1 which provides the peak discharge information that can be used to modify the HEC-2 flow values in the study reach.

## Table 4
## HEC-1 Summary Printout for Example Routing

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

| OPERATION | STATION | PEAK FLOW | TIME OF PEAK | AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR | 24-HOUR | 72-HOUR | BASIN AREA | MAXIMUM STAGE | TIME OF MAX STAGE |
|---|---|---|---|---|---|---|---|---|---|
| HYDROGRAPH AT | STA1 | 50282. | 5.50 | 32297. | 8724. | 8546. | 100.00 | | |
| ROUTED TO | RCH 1 | 44981. | 6.50 | 31263. | 8724. | 8546. | 100.00 | | |
| ROUTED TO | RCH 2 | 43217. | 7.50 | 30318. | 8724. | 8546. | 100.00 | | |

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

-----DSS---ZCLOSE Unit: 71
Number of Records: 10
File Size: 6.6 Kbytes
Percent Inactive: .00

This example only reflects the routing of the estimated one-percent chance flood. The typical flood study would utilize an entire range of frequency-flow data to evaluate flood reduction measures. If the modeling is performed for a series of discharges, then a series of flood hydrographs would be required to simulate the routing effects for the entire range of floods. The HEC-1 multiplan-multiflood feature provides a convenient method for creating an array of hydrographs that can be used for routing through the study reach.

**The multiflood option** allows the user to analyze several different floods in the same computer run. The floods are computed as ratios of a base flood event (e.g., 0.5, 0.8, 1.0, 1.25, etc.) which may be either ratios of precipitation or runoff. The ratio hydrographs are computed for every component of the river basin. For ratios of runoff, the ratios are applied to the computed or direct-input hydrograph and no rainfall-runoff calculations are made for the individual ratios.

The **JR** record is the only added input required for the multiratio option. The first field indicates **PREC** for ratios of precipitation or **FLOW** for ratios of runoff, the second is the most likely choice for this application. The remaining fields provide the ratios to be applied, up to nine (9) values are allowed. In this example the one-percent chance flood is computed, so most of the ratios should be less than one to represent the smaller flood events. The following shows the modified HEC-1 input file with an example **JR** record.

### 3.3 Revised HEC-2 Model for Peak Discharge Profiles

The results from this application of HEC-1 will provide the routing affect on the six hydrographs computed by the flow ratios. If these hydrographs represent an array of percent chance floods, the water surface elevations for these floods can now be computed with HEC-2. From the HEC-1 routing, the estimated peak discharge is computed for the locations equivalent to the first cross section,

## Table 5
## HEC-1 Input for Multiflood Computation

```
ID      MODIFIED PULS ROUTING EXAMPLE WITH HEC-2 STORAGE DATA
ID      First cycle with constant discharge storage values
ID
IT    30 25MAY90    1200      50
*  *************** MULTIFLOOD RATIOS *******************
JR  FLOW      .3      .5      .7      .9       1     1.1
*
KK  STA1
KM      GENERATE RUNOFF HYDROGRAPH FOR ROUTING
ZW A=MODPULS B=REACH1 C=FLOW F=INFLOW
PB   5.4
IN    60
PI    .5      .8       1     1.5       1      .6      .2
BA   100
LS            80
UD   1.5
```

number 60830, and the middle section number 71000. Revised **QT** records can be placed in the HEC-2 data file to reflect the changing discharge over distance. The **QT** record changes the flow for the next cross section in the input sequence. The computed profiles would now reflect the routing affects of the river reach. If alternative channel characteristics or floodways are to be evaluated, The process would be repeated with the modified cross-sectional data. The section "HEC-2 Model for Modified Conditions" describes the HEC-2 option to preserve the modified cross-section data for storage routing and subsequent profile calculations.

# Chapter 4

# References


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