Expanded Floodplain Information Study for The Wolf River Basin, Tennessee and Mississippi: A Computer Simulation

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Seemingly, every few weeks a flood of catastrophic proportions occurs somewhere within the U. S., recently in Houston, Texas, and Lake Charles, Louisiana, and just months ago on the Mississippi Delta and in Jackson, Mississippi. The apparent frequency and severity of such events are, to a degree, due to improved news media coverage and public awareness. On the other hand, though, such events are in reality occurring more frequently, and the impacts are becoming more substantial. Independently, decisions are made to modify upland, floodplain, and channel regimes. Singly, the impacts of such changes may be minor but in concert, sometimes devastating.

There is a real and continuous need for the provision of information on flood hazards and their possible economic and environmental consequences in river basins. Congress was aware of this need when it wrote Public Law 89-789, which states, in part:

> In recognition of the increasing use and development of the flood plains of the rivers of the United States and of the need for information on flood hazards to serve as a guide to such development, and as a basis for avoiding future flood hazards by regulation of use by States and political subdivisions thereof, and to assure that Federal departments and agencies may take proper cognizance of flood hazards, the Secretary of the Army, through the Chief of Engineers, is hereby authorized to compile and disseminate information on floods and flood damages. . . .

One of the ways the Corps of Engineers is responding to this mandate is through what are termed Expanded Floodplain Information studies, or more simply, XFPI studies. The general objectives of these studies are to develop computer simulation procedures for defining flood hazards and their associated economic and environmental consequences, both for current and likely future growth situations. The Wolf River XFPI study was one of the first of its kind. Its overall objectives were as noted above, the same as for all XFPI studies. Realizing, though, that simulation studies are themselves costly and time consuming, additional objectives were set for the Wolf River study, i.e., to systematize and streamline the process and to apply it comprehensively to a relatively large basin.

BASIN CHARACTERISTICS

The Wolf River basin lies in southwestern Tennessee and northwestern Mississippi. As shown in Figure 1, it is about 65

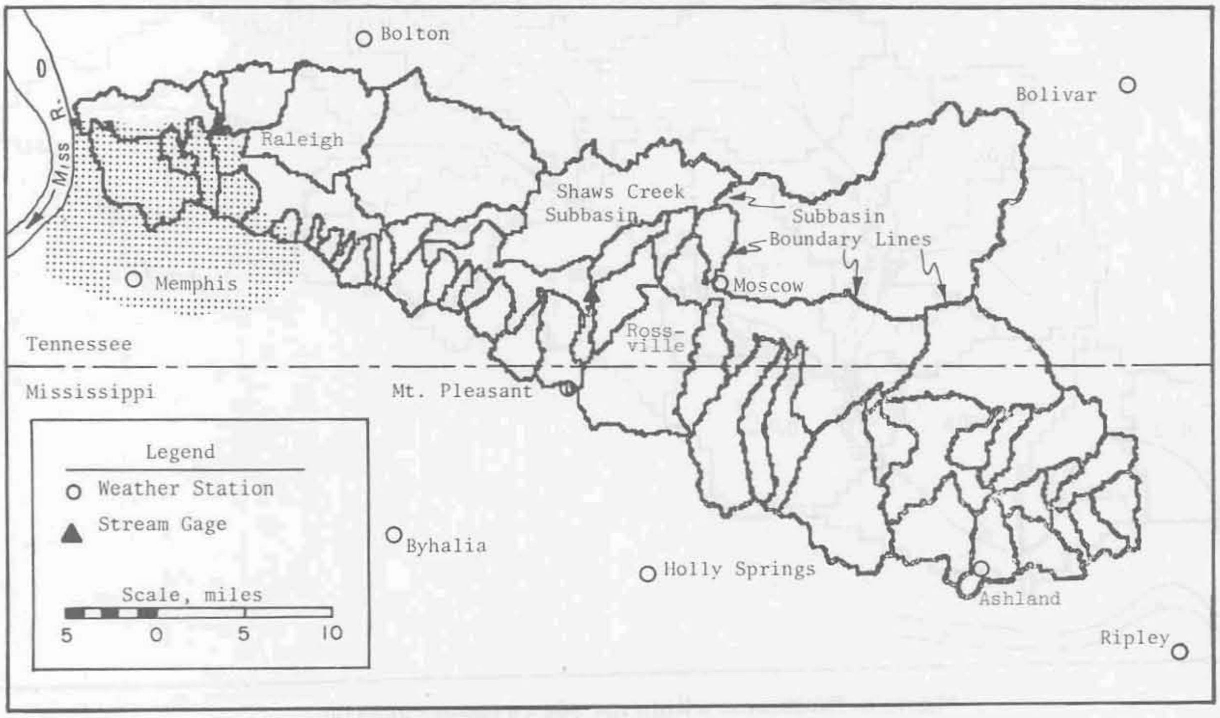


Figure 1. Map of the Wolf River Basin

miles in length, ranges from about 10 to 15 miles in width, and is 817 square miles in area. Generally, the area is hilly, although the floodplain of the Wolf River itself is broad and flat; the total relief difference from the mouth of the river to the highest point in the watershed is about 450 ft.

The western end of the basin, which includes large portions of the city of Memphis, Tennessee, is highly urbanized, but the eastern 80 percent is rural, comprised almost entirely of agricultural and forest lands. Urbanization has, and continues to, spread rapidly toward the east from Memphis.

There are in excess of 400 miles of stream channels within the basin. The Wolf River is about 95 miles in length; it drains from east to west, passes through the city of Memphis in its lower reaches, and empties into the Mississippi River. The 100-year discharge of the Wolf River is estimated to be 50,000 cfs. The lower 22 miles have been channelized and some floodwalls and levees exist in this area. There are also several small Soil Conservation Service (SCS) reservoirs in the central and eastern portions of the basin.

AVAILABLE DATA

Channel and overbank roughness values were obtained by U. S. Army Engineer Waterways Experiment Station (WES) personnel during field inspections of the basin. All other data were obtained from other agencies.

Precipitation records from nine National Weather Service (NWS) stations within or in the proximity of the basin were used (see Figure 1). Locations of recording gages included Memphis and Bolivar, Tennessee, and Byhalia, Holly Springs, and Ripley, Mississippi. Nonrecording gages were located at Boltan and Moscow, Tennessee, and Mt. Pleasant and Ashland, Mississippi.

A Corps stream gaging station is operated at Raleigh, Tennessee; the gage is at river mile 10.6 and reflects a drainage area of 772 square miles. This is a nonrecording station with records dating from 1936. A U. S. Geological Survey (USGS) recording gage existed at Rossville, Tennessee, from 1929 to 1972; this gage was at river mile 43.9 and reflected a drainage area of 511 square miles.

Cross-section data were obtained by the Memphis Engineer District (MD) and the SCS. All data were compiled by the MD and placed on magnetic tapes. Included were 207 sections at bridges and other hydraulic structures and 436 natural ground sections. Topographic data were available from USGS 1:24,000 quad sheets and from MD and SCS ground surveys.

Three types of digital areal data were made available from the SCS regional office in Ft. Worth, Texas, for the entire basin: present and future land use, slope, and soils. These data were in the format of 21.33-acre grids approximately 1056 ft by 879 ft in size. Land use was coded in 22 classes, slope in 8 classes, and soils by series. In addition, present land use was mapped for Shelby County by the Memphis and Shelby County Office of Planning and Development (MSCOPD). These data were delineated on 1:12,000 areal photomosaics for the most western 220 square miles of the basin. The MSCOPD used 44 land use classes of the Tennessee State Planning Office (TSPO) coding system.

SCOPE OF STUDY

In agreement with the MD, the funding agency for the study, general guidelines were established for conducting the hydrologic and hydraulic (H&H) analyses. The U. S. Army Engineer Hydrologic Engineering Center's "Water Surface Profiles" program HEC-2 was to be used for both deriving

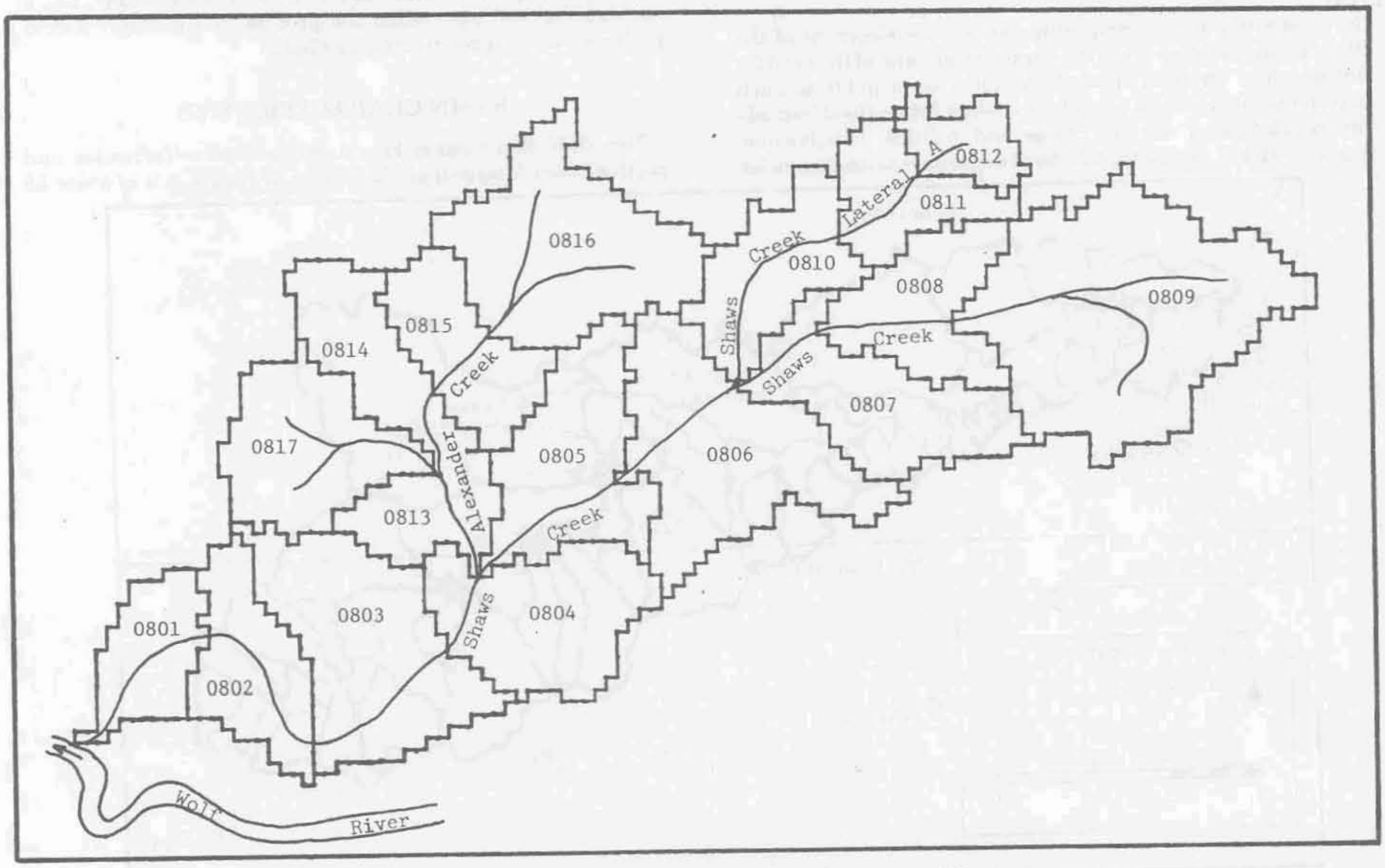


Figure 2. Minibasins within the Shaws Creek subbasin.

storage-outflow relations for flood routing and the computation of water surface elevations. The program employs standard step procedures except at structures where pressure and/or weir flow come into play. The program HEC-1, "Flood Hydrograph Package," was used to compute, route, and combine hydrographs. SCS runoff curve number and dimensionless hydrograph options were used because they incorporate objective, reproducible procedures and they function on the basis of quantitative inputs. The modified Puls method was used for both stream and reservoir routing. Neither the H&H models used nor the sequence in which they were employed (HEC-2, HEC-1, HEC-2) are uncommon to Corps studies. However, other requirements set forth by the MD made the study unique in scope.

As for most Corps Districts, the MD has a variety of H&H-related investigations simultaneously in progress. This was true at the time the Wolf River XFPI study was initiated; as a consequence, the MD requested that the scope be broadened to the extent that it would meet the requirements of ongoing or planned water quality, floodway, flood insurance, and basin survey studies. Consequently, ten different floods were simulated for both present and future land use conditions, these being for recurrence intervals of 1/3-, 1-, 3-, 5-, 10-, 25-, 50-, 100-, and 500-years as well as the standard project flood (SPF). Peak discharges and profiles were to be computed on the basis of associated 48-hr-duration synthetic storms derived with NWS[1,2] and Corps[3] methodologies. Furthermore, at any point in the basin, regardless of whether it was on the main stem, a primary tributary, or a secondary tributary, estimated peak discharge values were to reflect runoff resulting from synthetic storms corrected for the cumulative drainage area to that point. In essence then, a 10-year discharge for a 2-square-mile drainage area was to be associated with a 10-year 2-square-mile storm and a 50-year discharge for a 100-square-mile drainage area was to be that associated with a 50-year, 100-square-mile storm. Thus, simulation accuracies were to be maintained throughout the basin making the system equally applicable to small and large areas.

BASIN SUBDIVISION

In automating and streamlining the basin simulation process, methods used in subdividing a basin are key to success. The first step in subdivision involved the delineation of the drainage area associated with each major tributary of the Wolf River. The resultant areas, termed subbasins, varied from about 1 to 127 square miles in size. A total of 47 subbasins were delineated, and the boundary lines of each are shown in Figure 1. Each subbasin was assigned a unique two-digit code; e.g., Shaws Creek was designated 08.

Subbasins were then divided into smaller areas, termed minibasins, for runoff computations. Drainage patterns, bridge locations, and homogeneity of areal factors were prime considerations in the delineation of minibasin boundaries. Minibasin areas varied from about 1/2 to 10 square miles in area but generally ranged between 1 and 2 square miles. In addition to the subbasin designator, minibasins were assigned an additional two-digit code. The coding logic used was indicative of and could be used to reproduce minibasin runoff sequences within a subbasin.

For the Shaws Creek subbasin, which is shown in Figure 2, the following series of number sets serves to demonstrate this capability:

0801-0809, 0806-0812, 0804-0816, 0813-0817

The set 0801-0809, being first in the series, indicates that minibasins 0801 through 0809 lie along the main stem of Shaws Creek with minibasin 0801 at the mouth and 0809 at the head. The next set begins with the number 0806; this indicates two things—(a) this is a tributary to the main stem because 0806 is a main-stem minibasin, and (b) the tributary joins Shaws Creek at the top of minibasin 0806. The tributary, Shaws Creek Lateral A, has three associated minibasins, 0810 (the next number not included in the prior set) through 0812, with 0810 at the mouth. The third set is also a main-stem tributary, Alexander Creek, which joins Shaws Creek at the top of minibasin 0804. The main stem of Alexander Creek has four associated minibasins, 0813 through 0816. The last set shows that Alexander Creek has a tributary branching off at the top of minibasin 0813; one minibasin, 0817, includes the entire drainage area contributing to this second-order tributary.

In addition to subbasins and minibasins, the entire basin was subdivided into 656-ft-square grids. Finally, the floodplain areas of the basin were further subdivided into 164-ft-square grids.

H&H SIMULATION

A generalized flow chart of the H&H simulation procedures followed is shown in Figure 3. As previously noted, neither the major H&H models used nor the sequence in which they were employed (HEC-2, HEC-1, HEC-2) are uncommon to Corps studies. However, the data base systems, supporting programs, and modifications to HEC-1 are unique and result in a more rapid and flexible total simulation capability.

Data Bases

For H&H analyses, three data bases were used. One consisted of computer files of the cross-sectional field data provided by the MD. Basically, the data included were section identification, rod readings, stations associated with the rod readings, and codes associated with the rod readings to identify the type of readings made, e.g. center line of road, bridge deck, top of channel bank, bottom of channel, etc.

The second data base consisted of areal parameters associated with 656-ft-square grids referenced to a Universal Transverse Mercator (UTM) coordinate system. Within this data base, each 656-ft-square grid has associated with it: UTM coordinates; subbasin and minibasin codes; present land use, future land use, and slope classes; and soil series codes. The 21.33-acre gridded data received from the SCS (i.e. land use, soils, and slope) were rectified and transferred to the 656-ft-square grid data base using a computer software routine called SCSCON. Mapped data including subbasin, minibasin, and MSCOPD land use boundaries were digitized using a line follower. These digitized factors were then gridded with a program called FACGRD and added to the gridded SCS data with a program called GROW. With reference to present land use, the SCS data were overridden by SCOPD data within Shelby County. Some of the 44 TSPO land use classes were then combined to produce the 22 equivalent SCS land use classes.

The third data base included elevations at 164-ft grid spacings for all floodplain areas within the basin. Data were generated in two steps. First, contour lines and other elevation points on USGS topographic maps were digitized using a line follower. Line and point data were then processed to determine elevations of grid points with a program called ELEVGRD.

Supporting Programs

In addition to the software routines used in constructing the data bases discussed above, three major supporting programs were developed. These programs substantially streamlined the total simulation process by reducing interface problems between H&H packages or between the data bases and the H&H packages. A program called EXSEC was written to access the cross-section file. With a minimum of inputs, EXSEC outputs an HEC-2 input deck for an entire subbasin which is ordered, includes tributaries, and is nearly complete.

If desired, a set of preliminary discharge values for input into HEC-2 can be generated through a modified version of HEC's

HYDPAR program called HYDPAR2. HYDPAR2 accesses the 656-ft data base. The set of preliminary discharges is based on accumulated drainage areas, the number of discharges desired, and the general range of discharge values required. HYDPAR2 is also used to generate an HEC-1 deck (with the HEC-1 options selected) that is ordered and about 95-percent complete. In fact, the only data not included are storage-outflow cards (obtained from HEC-2), precipitation data, and rain gage assignments.

Final estimated water surface elevations are filed on magnetic tape. A computer program called FLOOD was developed which accesses the water surface elevation files and the 164-ft grid elevation data base. Coordinates of the line(s) delineating an event FLOOD are computed and automatically plotted for an areal view of the flood (i.e. area inundated).

HEC-1 Modifications

Modifications were made to HEC-1 to broaden and simplify its applications. Some modifications were rather simple. As an example, the number of time intervals was increased from 150 to 400; this allows for a single run capability for the entire basin. To avoid having to provide starting discharge values and curve number modifications for each minibasin to reflect antecedent wetness conditions, the program was altered to allow for these changes to be input only once for the entire basin. Another

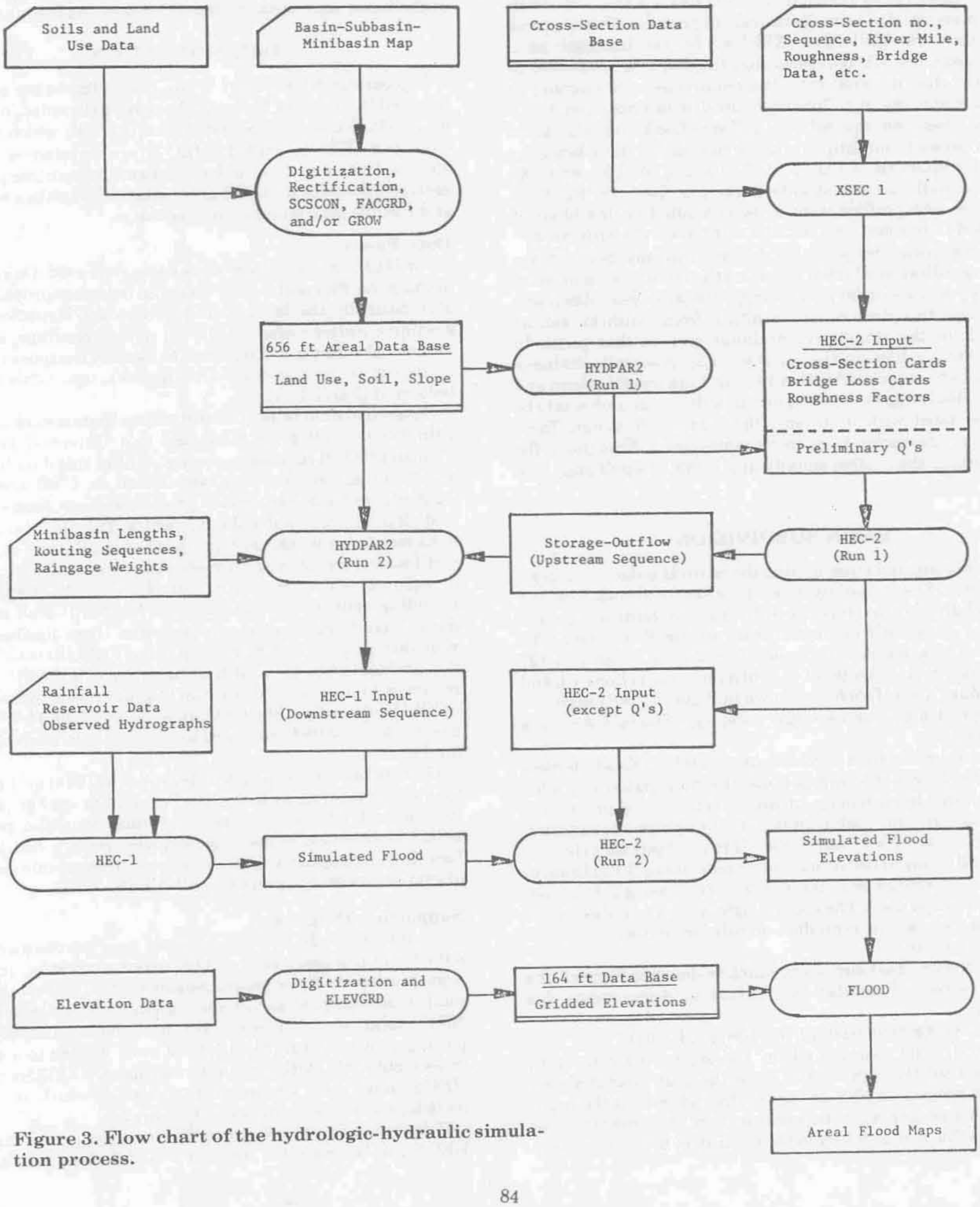
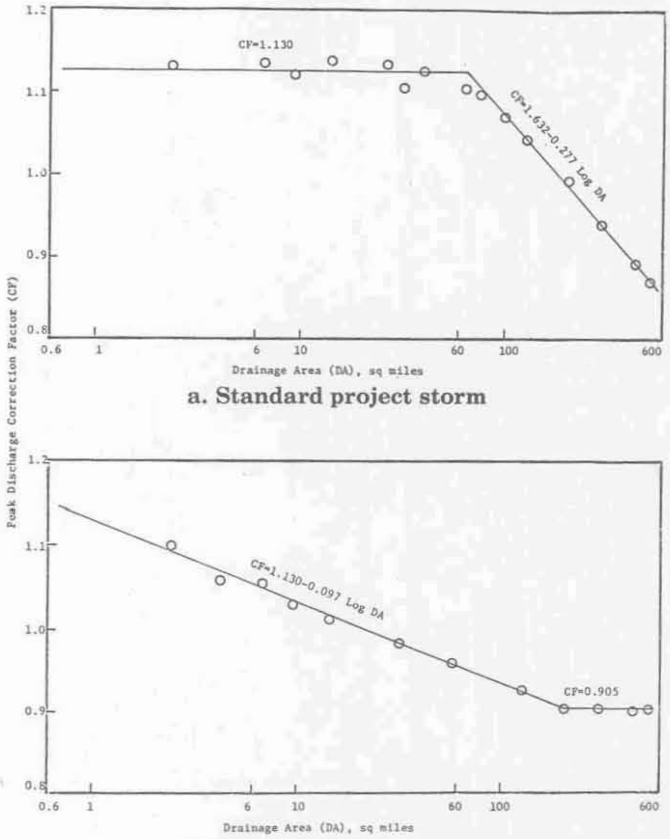


Figure 3. Flow chart of the hydrologic-hydraulic simulation process.



a. Standard project storm

b. Hypothetical event storms

Figure 4. Peak discharge correction factors to account for synthetic storm area effect

modification to HEC-1 allowed for punching discharge (QT) cards for input back into HEC-2 for final estimates of water surface elevations.

Earlier, it was noted that one of the MD requirements was that peak discharge values were to reflect runoff resulting from synthetic storms corrected for cumulative drainage areas. The details of how this was accomplished are beyond the scope of this paper. However, it was found that within the Wolf River basin, very strong correlations existed between peak discharges generated from storms associated with some arbitrary, but specific area (e.g. 2, 20, 200, or 800 square miles) and peak discharges associated with storm areas equal to actual drainage areas. Although the relations differed, this was true for both the standard project storm (SPS) and individual event storms. Furthermore, for event storms, relations were almost independent of recurrence interval.

Because of the facts noted above, it was possible to generate discharge hydrographs for the SPF and the recurrence interval floods of interest on the basis of single storm areas (200 square miles for the SPS and 20 square miles for event storms) and then correct peak discharge values for actual drainage area. Corrections were made within HEC-1 by incorporating the relations shown in Figure 4 in the program.

CONCLUSIONS

The initial development of the simulation system discussed above was not an easy task. It is believed, though, that a tool has been made available for the Wolf River basin that will be useful in the decades ahead. The areal and elevation data bases can be modified easily for incorporation of improved or updated data. The entire simulation methodology can then be run on a minibasin, subbasin, or basinwide basis to evaluate the impacts of these modified data on water surface profiles. Thus, the system can be continuously modified to reflect current and projected conditions.

The system can be used for planning purposes. For example, the impacts of proposed land use and channel modifications or the addition of hydraulic structures can be quickly and accurately evaluated. In fact, the potential impacts of channel modifications and additional reservoirs in one of the major subbasins are now being simulated.

The system is flexible to the point that it can be used for research. One example might be to determine the degree and extent of land use change required to significantly impact flow regimes. Another might involve a series of tests with continuously increasing grid size to establish optimum grid size, and thus minimize costs of data base development and operation.

Finally, methodologies developed for the basin simulation process are systematized and streamlined, are generally applicable to any basin, and are unique in their ability to model comprehensively basins up to 1000 square miles or more in area.

REFERENCES

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