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Simulation in Hydraulics and Hydrology

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38.1 Introduction

During the past three decades, computer models have become ubiquitous in hydraulics and hydrology. These models have been of invaluable help in hydrologic and hydraulic analysis and design. In this chapter several models are briefly introduced and four models (TR-20, HEC-HMS, HEC-RAS and XP-SWMM) are illustrated in depth.

Many of these models are quite complex. Books such as that by Hoggan [1989] have been written to explain and illustrate them. It is not possible to discuss these models in the depth required to illustrate their full capabilities. Consequently the approach taken in this section is to give synoptic descriptions of more important uses of the models. The detailed illustrations of TR-20, HEC-HMS, HEC-RAS, and XP-SWMM are given to demonstrate their characteristics and utility.

38.2 Some Commonly Used Models

Name:	Storm Water Management Model (SWMM) PC and Main Frame versions
Source:	Center for Exposure Assessment Modeling (CEAM) U.S. Environmental Protection Agency Office of Research and Development

Environmental Research Laboratory
College Station Road
Athens, GA 30613–0801
(706) 546–3549

User's Manual:

Huber, W.C. and Dickinson, R.E. 1988. *Storm Water Management Model*
(SWMM), Version 4, User's Manual.
EPA/600/3–88/001a
NTS accession No. PB88 236 641
Roesner, R.A., Aldrich, J.A., and Dickinson, R.E. Storm Water Management Model (SWMM), Version 4, User's manual Part B, Extran Addendum, 1989.
EPA/600/3–88/0001b
NTIS accession no. PB88 236 658

Availability of user's manuals:

National Technical Information Service (NTIS)
5825 Port Royal Road
Springfield, Virginia 22161
(703) 487–4650

or:

Dr. Wayne Huber
Oregon State University
Department of Civil Engineering
Apperson Hall 202
Corvallis, OR 973331–2302
(503) 737–6150

SWMM is a comprehensive simulation model of urban runoff quantity and quality including surface and subsurface runoff, snow melt, routing through the drainage network, storage, and treatment. Single event and continuous simulation can be performed. Basins may have storm sewers, combined sewers, and natural drainage. The model can be used for planning and design purposes. In the planning mode, continuous simulation is used on a coarse schematization of the catchment, and statistical analyses of the hydrographs and pollutographs are produced. In the design mode simulation is performed at shorter time steps using a more detailed schematization of the catchment and specific rainfall events.

The model consists of an executive block, four computational blocks (Runoff, Transport, EXTRAN, and Storage/Treatment), and five service blocks (Statistics, Graph, Combine, Rain, and Temp). The EXECUTIVE block performs a number of control tasks such as an assignment of logical units and files, sequencing of computational blocks and error messages. The RUNOFF block generates runoff given the hydrologic characteristics of the catchment, the rainfall, and/or the snowmelt hyetographs and the antecedent conditions of the basin. The runoff quality simulation is based on conceptual buildup and washoff relationships (see Chapter 33). The TRANSPORT block routes the flows and pollutants through the drainage system. It also generates dry-weather flow and infiltration into the sewer system. As kinematic wave routing is used (see Chapter 30, Section 30.9), backwater effects are not modeled. The EXTENDED TRANSPORT block (EXTRAN) simulates gradually varied unsteady flow using an explicit finite difference form of the Saint Venant Equations (see Chapter 30, Eqs. [30.50] and [30.51]). EXTRAN can handle backwater effects, conduit pressurization, and closed and looped networks. EXTRAN is limited to quantity simulation and consequently does not perform quality simulation. The STORAGE/TREATMENT block routes flows and up to three different pollutants through storage and a treatment plant with up to five units or processes. The STATISTICS block calculates certain statistics such as moments of event data and produces tables of magnitude, return period, and frequency. The COMBINE block combines the output of SWMM runs from the same or different blocks to model larger areas. The RAIN block reads National

Weather Service rainfall data and therefore can be used to read long precipitation records and can perform storm event analysis. The TEMP block reads temperature, evaporation, and wind speed data that can be obtained from the National Weather Service data base.

Name: Flood Damage Analysis System (HEC-FDA)

Source: U.S. Army Corps of Engineers
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616
(916) 440–2105
www.hec.usace.army.mil

The User's Manual can be downloaded from the Website.

The HEC-FDA program provides the capability to perform plan formulation and evaluation for flood damage reduction studies. It includes risk-based analysis methods that follow Federal and Corps of Engineers policy regulations (ER 1105–2–100 and ER 1105–2–101). Plans are compared to the condition without flood protection by computing expected annual damage for each plan. Computations and display of results are consistent with technical procedures described in EM 1110–2–1619. HEC-FDA will only run on computers using Windows 95/98 or Windows NT.

Name: Modular Three-Dimensional Finite-Difference
Groundwater Flow Model (MODFLOW)
PC and Main Frame Versions

Source: U.S. Geological Survey
437 National Center
12201 Sunrise Valley Drive
Reston, VA 22092
(703) 648–5695

User's manual:
McDonald, M.G. and Harbaugh, A.V.
U.S. Geological Survey Open-File Report
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center
Box 25425
Denver, CO 80225
(303) 236–7476

Source code and processing programs:
International Groundwater Modeling Center (IGWMC)
Institute for Groundwater Research and Education
Colorado School of Mines
Golden, CO 80401 — 1887
Phone (303) 273–3103
Fax (303) 273–3278

or:

Scientific Software Group
P.O. Box 23041
Washington, D.C. 20026–3041
Phone (703) 620–9214
Fax (703) 620–6793

or:

Geraghty & Miller
Software Modeling Group
10700 Parkridge Boulevard, Suite 600
Reston, VA 20091
Phone (703) 758–1200
Fax (703) 7581201

MODFLOW is a finite-difference groundwater model that simulates flow in three dimensions. The modular structure of the program consists of a main program and a series of highly independent subroutines called *modules*. The modules are grouped into *packages*. Each package deals with a specific feature of the hydrologic system which is to be simulated, such as flow from rivers or flow into drains, or with a specific method of solving linear equations that describe the flow system, such as strongly implicit procedure or slice-successive overrelaxation.

Groundwater flow within the aquifer is simulated using a block-centered finite-difference approach. Layers can be simulated as confined, unconfined, or a combination of the two. Flow associated with external entities, such as wells, areal recharge, evapotranspiration, drains and streams, can also be simulated. The finite-difference equations can be solved using either the strongly implicit procedure or slice-successive overrelaxation.

Application of the computer program to solve groundwater flow problems requires knowledge of the following hydrogeologic conditions: (1) hydraulic properties of the aquifer, (2) the shape and physical boundaries of the aquifer system, (3) flow conditions at the boundaries, and (4) initial conditions of groundwater flow and water levels.

The accuracy of the calibrated mathematical model is dependent on the assumptions and approximations in the finite-difference numerical solutions and the distribution and quality of data. Hydraulic properties of the aquifer deposits (estimated by model calibration) can be used to define the flow system and evaluate impacts that would be produced by changes in stress, such as pumping. However, three main limitations that constrain the validity of the model are:

1. The inability of the numerical model to simulate all the complexities of the natural flow system. The assumptions used for construction of the model affect the output and are simple compared to the natural conditions.
2. The distribution of field data; for example, water level or lithologic data may not be areally or vertically extensive enough to define the system adequately.
3. The model is probably not unique. Many combinations of aquifer properties and recharge-discharge distributions can produce the same results, especially because the model is usually calibrated for a predevelopment (steady state) condition. For example, a proportionate change in total sources and sinks of water with respect to transmissivity would result in the same steady state model solution.

Name: HEC-6 Scour and Deposition in Rivers and Reservoirs
PC and Main Frame versions

Source: Hydrologic Engineering Center
U.S. Army Corps of Engineers
609 Second Street
Davis, CA 95616–4687
(916) 756–1104

User's manual:

U.S. Army Corps of Engineers. 1993. *HEC-6: Scour and Deposition in Rivers and Reservoirs – User's Manual.*

Hydrologic Engineering Center. 1987. *COED: Corps of Engineers Editor User's Manual.*

Thomas, W.A., Gee, D.M., and MacArthur, R.C. 1981. Guidelines for the Calibration and Application of Computer Program HEC-6.

Availability of user's manuals:
National Technical Information Service
5825 Port Royal Road
Springfield, Virginia 22161
(703) 487–4650
(703) 321–8547

HEC-6 is a member in the series of numerical models developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center for studies of hydraulic or hydrologic problems. It is a one-dimensional model of a river or reservoir where entrainment, deposition, or transport of sediment occur. It is intended for use in the analysis of long-term river or reservoir response to changes in flow or sediment conditions. In HEC-6, models change as a sequence of steady states; the hydraulic and sediment parameters of each may vary during the sequence. It can be applied to analyze problems arising in or from stream networks, channel dredging, levee design, and reservoir deposition.

The hydraulic model is essentially identical to that used in HEC-RAS (see the description of HEC-RAS for more details), in which water-surface profiles are computed by using the standard step method and with flow resistance modeled with Manning's equation. Although flow resistance due to bed forms is not separately considered, Manning's n can be specified as a function of discharge. In a "fixed bed" mode, the sediment transport model can be turned off, and HEC-6 can be used as a limited form of HEC-RAS without capabilities for special problems such as bridges or islands. The input format of HEC-6 is very similar to the format of HEC-2, which is the program for computing water-surface profiles which preceded HEC-RAS.

The sediment transport model is based on the Exner equation (see Chapter 35, Eq. [35.29]). It treats graded sediments, ranging from clays and silts to boulders up to 2048 mm in diameter, by dividing both inflow and bed sediments up to 20 size classes. Several standard transport formulas for sand and gravel sizes are available and provision for a user-developed formula is included. Additional features include the modeling of armoring, clay and silt transport, and cohesive sediment scour. Because it is a one-dimensional model, it does not model bank erosion, meanders, or non-uniform transport at a given cross section.

38.3 TR-20 Program

The TR-20 computer program was developed by the Natural Resources Conservation Service (1982) to assist in the hydrologic evaluation of storm events for water resource projects. TR-20 is a single-event model that computes direct runoff resulting from synthetic or natural rainfall events. There is no provision for recovery of initial abstraction or infiltration during periods without rainfall. The program develops runoff hydrographs from excess precipitation and routes the flow through stream channels and reservoirs. It combines the routed hydrograph with those from tributaries and computes the peak discharges, their times of occurrence, and the water elevations at any desired reach or structure. Up to nine different rainstorm distributions over a watershed under various combinations of land treatment, flood control structures, diversions, and channel modifications may be used in the analyses. Such analyses can be performed on as many as 200 reaches and 99 structures in any one continuous run (NRCS, 1982). The program can be obtained from National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161, (703) 487-4600.

Summary of TR-20 Input Structure

The input requirements of TR-20 are few. If data from actual rainfall events are not used, the depth of precipitation is the only required meteorological input. For each subarea, the drainage area, runoff curve number and time of concentration are required; the antecedent soil moisture (AMC) condition (i.e., I, II, or III) can be specified, although the NRCS now recommends only AMC II, the so-called average runoff condition (NRCS, 1986). For each channel reach, the length is defined; the channel cross section is defined by the discharge and end area data at different elevations; a routing coefficient, which is defined by the discharge and end area data at different elevations; a routing coefficient, which is optional, may also be specified. If the channel-routing coefficient is not given as input, it will be computed by using a modified Att-Kin (attenuation-kinematic) procedure.

The modified Att-Kin routing procedure is described in TR-66 (NRCS, 1982). It uses storage and kinematic models to attenuate and translate natural flood waves. For each channel reach, the Att-Kin procedure routes an inflow hydrograph through the reach using a storage model. With the storage and kinematic models, flows are routed as a linear combination so that the outflow hydrograph satisfies the conservation of mass at the time to peak of the outflow hydrograph. Used separately, the storage routing provides only attenuation without translation; the kinematic routing provides only translation and distortion without attenuation of the peak (NRCS, 1982).

For each structure it is necessary to describe the outflow characteristics with an elevation-discharge-storage relationship. The time increment for all computations and any baseflow in a channel reach must be specified.

Input Structure

The input for a TR-20 consists of the following four general statement types: Job Control, Tabular Data, Standard Control statements, and Executive Control statements.

Job Control

The Job Control statements are the JOB statement, two TITLE statements, ENDATA statement, ENDCMP statement, and ENDJOB statement. The JOB and two TITLE statements *must* appear first and second, respectively, in a run and the ENDJOB statement must appear last. The ENDATA statement separates the standard control and the tabular data from the executive control statements. The ENDCMP statement is used to signify the end of a pass through a watershed or a sub-watershed thereby allowing conditions to be changed by the user before further processing.

Input data are entered according to the specifications in a blank form. Each line of data on the form is a record entered into the computer file. The 80 columns across the top of the form represent the 80 positions on a record. Each statement is used to perform a specific operation. The order of records determines the sequence in which the operations are performed.

A name appears in columns 4 through 9 of all lines except those containing tabular data. These names identify the type of operation performed or type of data entered. A number corresponding to the name in columns 4 through 9 is placed in columns 2 and 11. The digit in column 11 is the operation number and identifies the type of operation, which must be entered unless it is a blank.

Tabular Data

The tabular data serve as support data for the problem description. These data precede both the Standard and Executive Control and have six possible tables:

1. *Routing coefficient table*: the relationship between the streamflow routing coefficient and velocity.
2. *Dimensionless hydrograph table*: the dimensionless curvilinear unit hydrograph ordinates as a function of dimensionless time.
3. Cumulative rainfall tables.
4. *Stream cross-section data tables*: a tabular data summary of the water surface elevation-discharge-cross sectional end area relationship.
5. *Structure data table*: a tabular summary of the water surface elevation-discharge-reservoir storage relationship.
6. *Read-discharge hydrograph data table;* a hydrograph that is entered directly into the program as data.

For example, the data needed to support a cumulative rainfall table include a rainfall table number, time increment, runoff coefficient (if desired), and the cumulative rainfall values for the modeled rainfall event. The cumulative rainfall values used in the following examples are the SCS Type II distribution.

TABLE 38.1 Output Options for TR-20

Output Option	A "1" in Column	Produces the following printout
PEAK	61	Peak discharge and corresponding time of peak and elevation (maximum storage elevation for a structure)
HYD	63	Discharge hydrograph ordinates.
ELEV	65	Stage hydrograph ordinates (reach elevations for a cross section and water surface elevation for structures).
VOL	67	Volume of water under the hydrograph in inches depth, acre-feet, and ft^3/sec-hours.
SUM	71	Requests the results of the subroutine be inserted in the summary tables at the end of the job.

Standard Control Operations

Standard Control consists of the following six subroutine operations. There can be up to 600 Standard Control statements for each TR-20 program.

1. RUNOFF: an instruction to develop a subbasin runoff hydrograph
2. RESVOR: an instruction to route a hydrograph through a structure or reservoir
3. REACH: an instruction to route a hydrograph through a channel reach
4. ADDHYD: an instruction to combine two hydrographs
5. SAVMOV: an instruction to move a hydrograph from one computer memory storage location to another
6. DIVERT: an instruction for a hydrograph to be separated into two parts.

As an example, the data needed to support the standard RUNOFF control operation are the area, curve number, and time of concentration. The operations are indicated on the input lines in columns 2, 4–9, and 11. The number 6 is placed in column 2 to indicate standard control. The name of the subroutine operation is placed in columns 4–9. The operation number, which is placed after the operation name (e.g., 1 for RUNOFF, 6 for DIVERT), is placed in column 11.

Column 61, 63, 65, 67, 69, and 71 of standard control records are used to specify the output. The individual output options are selected by placing a 1 in the appropriate column. If either the column is left blank or a zero is inserted, the corresponding option will not be selected. Table 38.1 summarizes the output options. If only a summary table is desired, it is convenient to place SUMMARY in columns 51–57 in the JOB statement and leave all the output options on the standard control records blank.

Executive Control

The Executive Control has two functions: (1) to execute the Standard Control statements, and (2) to provide additional data necessary for processing. The Executive Control consists of six types of statements. They are LIST, BASFLO, INCREM, COMPUT, ENDCMP, and ENDJOB. The Executive Control statements are placed after the Standard Control statements and tabular data to which they pertain.

The Standard Control is used to describe the physical characteristics of the watershed. The Executive Control is used to prescribe the hydrologic conditions of the watershed including the baseflow. The performance for the Executive Control is directed by the COMPUT statement. Its purpose is to describe the rainfall and the part of the watershed over which that rainfall is to occur (NRCS, 1982).

For the examples discussed in this section, the INCREM, COMPUT, ENDCMP, and ENDJOB will be the only executive control statements required to fulfill the operations requested.

Preparation of Input Data

Preparation of input data can be divided into the following requirements and functions:

1. Prepare a schematic drawing that conveniently identifies the locations, drainage areas, curve numbers (CN), times of concentration (t_c), and reach lengths for the watershed. It should display all alternate structure systems together with the routing and evaluation reaches through which they are to be analyzed.

2. Establish a Standard Control list for the watershed.
3. List the tabular data to support the requirements of the Standard Control list. This may consist of structure data, stream cross section data, cumulative rainfall data, and the dimensionless hydrograph table.
4. Establish the Executive Control statements that describe each storm and alternative situation that is to be analyzed through the Standard Control list.

Calculations

For a large watershed it may be necessary to divide the watershed into subbasins. Each subbasin is determined by finding the different outlet points or design points within the watershed, then finding the area contributing to those points.

1. *Area*. The area of each subbasin in square miles (mi^2).
2. *Curve number*. The curve number (CN) for each subbasin.
3. *Time of concentration*. Following the curve number, the time of concentration (t_c) is specified for each subbasin.

Forms for Input Data

Blank forms for the TR-20 data are found in NRCS (1982). The example problems therein demonstrate how the forms are completed. The process is straightforward because of the instructions given and the preselected columns for the data. The output options are shown in Table 38.1.

Examples

A 188.5-acre basin in modeled to determine the discharge and required storage as a result of development. The first example models a subbasin with existing conditions. The third example incorporates the entire basin to determine the peak discharge at the outlet. The area is located in Indianapolis and is shown in Fig. 38.1.

Example 38.1

Referring to Fig. 38.1, drainage area 1 is modeled to determine the runoff for present conditions. This area is a small part of the total drainage area of the watershed in Fig. 38.1.

Hydrological Input Data

The cumulative rainfall data used is the SCS Type II rainfall distribution. The intensity-duration-frequency tables for Indianapolis, Indiana, are used with the 6-hour rainfall depth for the 10-year event to generate the surface-runoff hydrograph for the subbasins. The SCS 24-hour distribution was scaled to give a 6-hr hyetograph. The point rainfall depth is 3.23 in./hr.

Calculations

Area. The area of subbasin 1 is 13.5 acres or 0.021 mi.^{2}

Curve number. There are two different land uses for this subbasin; therefore both areas must be calculated and a composite curve number determined for the respective area. An open area of 7.6 acres has a CN of 74. The other land use is commercial with 5.9 acres and a CN of 94. The product of curve number and area is 1117. The sum of the product of the curve numbers and areas is then divided by the total area of the drainage area 1 to find an overall composite CN of 83.

Time of concentration. The time of concentration is computed by assuming 300 ft. of sheet flow, 350 ft. of shallow concentrated flow over unpaved surface, and channel flow length of 1150 ft. The channel flow is computed to the lake, not the watershed boundary. The time is 0.24 hr.

Computer Input

The following section demonstrates where, for this example, the information is input to the computer. The following discussion is based on the input file shown in Fig. 38.2.

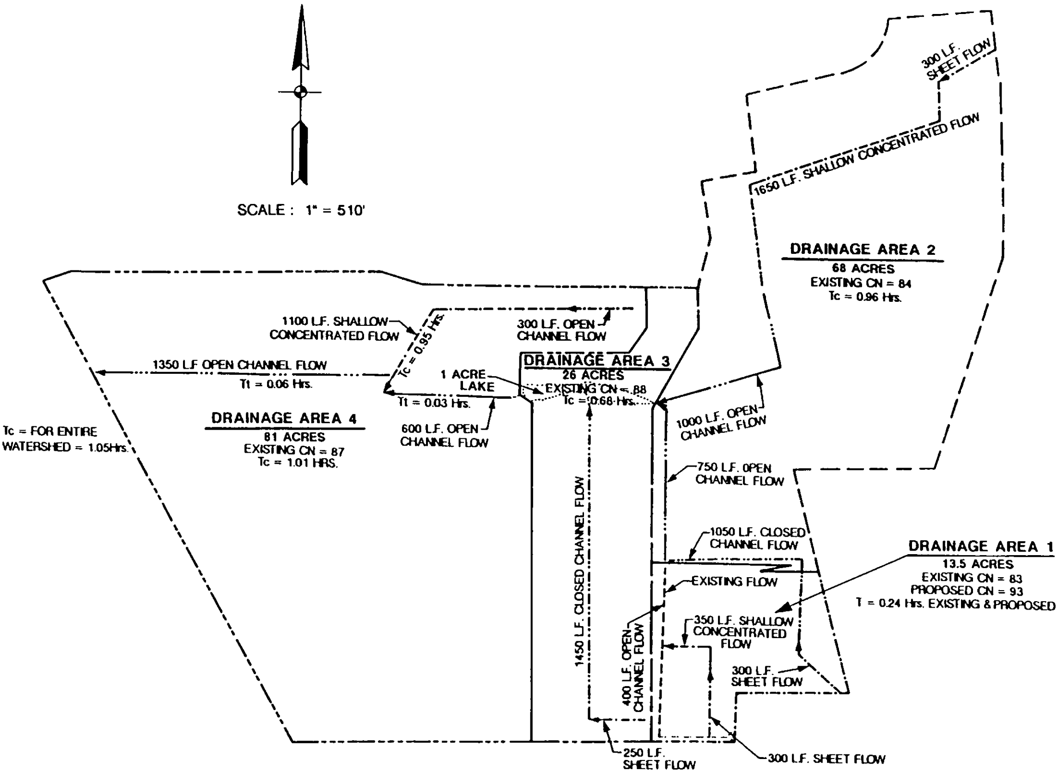


FIGURE 38.1 Location map.

```
JOB TR 20                 NOPLOTS
TITLE       EXAMPLE 1 DRAINAGE AREA 1
TITLE       EXISTING CONDITIONS
5 RAINFL 7                0.05
8           0             0.0125   0.25    0.04           0.06
8           0.08          0.1      0.13    0.165          0.22
8           0.64          0.78     0.835   0.87           0.895
8           0.92          0.94     0.96    0.98           0.99
8           1             1.0      1.0     1.0            1.0
9 ENDTBL
6 RUNOFF 1  1    1 0.021        83      0.24           1 1 0   1 0 1   AREA 1
 ENDATA
7 INCREM 6        0.1
7 COMPUT 7  1     10.0             3.23    6.              7 2     1 1   10-YR
 ENDCMP 1
 ENDJOB 2
```

FIGURE 38.2 Input for Example 38.1.

1. The first input is the JOB and TITLE. For this example NOPLOTS is entered in columns 61–67, which indicates that cross section discharge-area plots are not desired. Two TITLE statements are used to describe the problem and the rainfall information.
2. Next the cumulative rainfall table is used to describe the rainfall event. The statement describing this operation is RAINFL. There are six standard rainfall distributions which may be used and these are preloaded into TR-20. The user need not input these tables, but use only the proper rain table identification number on the COMPUT statement, in column 11. The user may override any of these tables by entering a new RAINFL table and entering 7, 8, or 9 in column 11. For this example a 7 is placed in column 11 indicating that a rainfall table will be specified by the user. Rainfall depths in inches can also be used. If these are used, the data code in column 2 needs to be changed to 8. The rainfall table of SCS Type II distribution is placed in the proper columns below the RAINFL statement as shown in Fig. 38.2. The time increment used for this example is 0.05 hr, determined by the number of cumulative rainfall points and the storm duration. The number of rainfall increments is 20, so that each increment is 0.05 of the total. This number, 0.05 is entered into columns 25–36. The 6-hour storm duration is entered on the COMPUT statement.
3. For this example, the runoff from area 1 is computed with the RUNOFF statement with the proper codes, described previously. This is the only standard control statement needed for this example. ENDATA indicates that the input information for the runoff is complete. Comments in columns 73 through 80 are helpful reminders.
4. The Executive Control statement is then used to indicate which computations are desired. This runoff from area 1 is computed for the 10-year rainfall. The INCREM statement causes all the hydrographs generated within the TR-20 program to have a time increment of 0.1 hours, as specified in columns 25–36, unless the main time increment is changed by a subsequent INCREM statement. The 7 in column 61 refers the COMPUT to rainfall table 7, the cumulative rainfall table. The AMC number is given in column 63 for each COMPUT (computation). For this example the AMC is 2. The starting time, rainfall depth, and rainfall duration are given for each recurrence interval. In this example, the starting time is 0.0, the rainfall depth is 3.23 in., and the duration is 6 hr. These values are placed in their corresponding columns. A COMPUT and an ENDCMP statement are necessary for each recurrence interval. ENDJOB is then used to signify that all the information has been given and the calculations are to begin. The Executive Control data are shown on Fig.38.2.

Output

The type and amount of output are controlled by input options on the JOB record and by the output options on the Standard Control records. For this example, by declaring NOPLOTS in columns 61–67 of the JOB record, plots are suppressed. The RUNOFF statement requested to have the peak discharge, volume of water under the hydrograph, and a summary table of the results, because a “1” was placed in columns 61, 67, and 71 in this statement. The output for this example is shown in Fig. 38.3.

Summary/Explanation

The table in Fig. 38.3 summarizes all of the information obtained. From this table it can be seen that, for a rainfall event with a 10-year recurrence interval, the amount of runoff from Area 1 is 1.64 in. for a 6-hour duration. The peak discharge occurs after 3.08 hours and has a flow rate of 30.72 cfs.

Example 38.2

Description

The runoff from area 1 is computed for developed conditions and a pond is added inside area 1. A stage-storage-discharge relationship is required for the structure, and the attenuation effects are evaluated. The hydrologic input data area the same as that which was used in Example 38.1. The input for example 38.2 is shown in Fig. 38.4.

```
EXECUTIVE CONTROL OPERATION INCREM                                                     RECORD ID
+                                MAIN TIME INCREMENT = .10 HOURS
EXECUTIVE CONTROL OPERATION COMPUT                                                     RECORD ID 10-YR
+                                              FROM XSECTION 1
+                                                                TO XSECTION 1
STARTING TIME = .00   RAIN DEPTH = 3.23   RAIN DURATION = 6.00   RAIN TABLE NO. = 7   ANT. MOIST. COND = 2
    ALTERNATE NO. = 1      STORM NO. = 1      MAIN TIME INCREMENT = .10 HOURS

OPERATION RUNOFF CROSS SECTION 1

PEAK TIME(HRS)                        PEAK DISCHARGE(CFS)            PEAK ELEVATION(FEET)
3.08                                        30.72                          (RUNOFF)
5.35                                         2.40                          (RUNOFF)

TIME
(HRS) FIRST HYDROGRAPH POINT = .00 HOURS TIME INCREMENT = .10 HOURS DRAINAGE AREA = .02 SQ.MI.
2.00    DISCHG        0        0     0.02     0.12     0.26    0.49    0.88    1.32    4.93     16.04

3.00    DISCHG    27.38    30.47    22.64    17.67    14.47    9.95    7.49    6.23    4.98      4.34

4.00    DISCHG     3.92     3.35     3.05     2.95     2.92    2.91    2.81    2.56    2.42      2.38

5.00    DISCHG     2.37     2.36     2.37     2.37     2.37    2.16    1.65    1.36    1.25      1.22

6.00    DISCHG      1.2     0.98     0.46     0.16     0.06    0.02    0.01       0


RUNOFF VOLUME ABOVE BASEFLOW = 1.64 WATERSHED IN., 22.18 CFS-HRS, 1.83 ACRE-FT; BASEFLOW = .00 CFS

EXECUTIVE CONTROL OPERATION ENDCMP                                                    RECORD ID
+                         COMPUTATIONS COMPLETED FOR PASS 1

EXECUTIVE CONTROL OPERATION ENDJOB                                                    RECORD ID

TR20 XEQ 12–05–01 05:28 EXAMPLE 1 - DRAINAGE AREA 1                               JOB 1 SUMMARY
   REV PC 09/83(.2) EXISTING CONDITIONS                                                  PAGE 1

SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL
INSTRUCTIONS IN THE ORDER PERFORMED (A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS) VALUES
INDICATES A FLAT TOP HYDROGRAPH A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.


                                                  MAIN          PRECIPITATION                        PEAK DISCHARGE
  SECTION/   STANDARD               RAIN  ANTEC   TIME                                RUNOFF
 STRUCTURE   CONTROL    DRAIN.  TABLE  MOIST  INCREM  BEGIN  AMOUNT  DURATION  AMOUNT  ELEV.  TIME  RATE   RATE
    ID       OPERATION   AREA      #    COND   (HR)    (HR)    (IN)     (HR)     (IN)   (FT)   (HR)  (CFS)  (CSM)

ALTERNATE 1                   STORM 1

XSECTION 1    RUNOFF     0.02      7      2     0.1      0     3.23       6       1.64    —     3.08  30.72  1463.1

  SUMMARY TABLE 3 - DISCHARGE (CFS) AT XSECTIONS AND STRUCTURES FOR ALL STORMS AND ALTERNATES

  XSECTION          DRAINAGE
  STRUCTURE           AREA        STORM NUMBERS……
  ID                 (SQ MI)                 1

  0 XSECTION 1          .02
  +________________________________________
   ALTERNATE 1                             30.72
  END OF 1 JOBS IN THIS RUN
```

FIGURE 38.3 Output from Example 38.1.

```
JOB TR-20 NOPLOTS
TITLE EXAMPLE 2 - DRAINAGE AREA 1
TITLE PROPOSED CONDITIONS
5 RAINFL 7           0.05
        8                0    0.0125     0.025      0.04        0.06
        8             0.08       0.1      0.13     0.165        0.22
        8             0.64      0.78     0.835      0.87       0.895
        8             0.92      0.94      0.96      0.98        0.99
        8              1.0       1.0       1.0       1.0         1.0
9 ENDTBL
3 STRUCT 01
        8                      780.5                 0                   0
        8                        781                 2               0.004
        8                      781.5                 4               0.014
        8                        782                 8               0.019
        8                      782.5                12               0.046
        8                        783                15                0.88
        8                      783.5                20                1.33
        8                        784                23                1.67
        8                      784.5                28                2.07
        8                        785                30                2.46
        8                      785.5              32.5                2.85
        8                        786                35                3.23
        8                      786.5                36                3.49
        8                        787                40                4.52
9 ENDTBL
6 RUNOFF 1 1        1 0.021       93.      0.24              1 1 0 1 0 1
6 RESVOR 2 01 1     2                                          1 0 0 1 0 1
  ENDATA
7 INCREM 6              0.1
7 COMPUT 7 1        01 0.0      3.23        6.                   7 2 1 1
  ENDCMP 1
  ENDJOB 2
```

FIGURE 38.4 Input for Example 38.2.

Calculations

Once the proposed pond is designed, the discharge and storage is computed at different elevations by the user. The discharge from the pond is controlled by the outlet structure. Table 38.2 shows the stage-storage-discharge relationship for the pond. For example, at elevation 783.0 feet, the discharge is 15.0 cfs and the storage is 0.88 acre-ft. This is an ungated control structure with headwater control.

The CN for the developed condition is 93 and the time of concentration is 0.24 hours.

1. The TITLE statement is adjusted to show the proper example problem number and description.
2. As mentioned previously, the same rainfall table will be used.
3. After the ENDTBL statement of the rainfall table, the structure table for the pond is added. The initial values for the stage-storage-discharge relationship must have the elevation of the invert of the outlet structure and 0.0 values for the discharge and storage. All data entered in this table must have decimal points and must increase between successive lines of data. The STRUCT table

TABLE 38.2 Stage-Storage-Discharge Relationship for Pond in Example 38.2

Stage	Discharge	Storage
780.5	0	0.0
781.0	2	0.004
781.5	4	0.014
782.0	8	0.019
782.5	12	0.046
783.0	15	0.88
783.5	20	1.33
784.0	23	1.67
784.5	28	2.07
785.0	30	2.46
785.5	32.5	2.85
786.0	35	3.23
786.5	36	3.49
787.0	40	4.52

must have a number placed in columns 16 and 17 of the first row of the STRUCT statement. This number, 01, should be the same as the structure number on the RESVOR standard control statement.

4. The RUNOFF Standard Control statement for area 1 is used to obtain the runoff from the 0.021 square miles. The CN and t_c for the developed conditions replace the numbers used in Example 38.1.
5. A RESVOR Standard Control statement is used to have the hydrograph calculated from area 1 routed through the pond structure. This is done by placing "01" (the pond structure number) in columns 19 and 20. The routed hydrograph is placed in a computer memory location by placing a number 1 through 7, not already used, in column 23. Therefore, a 2 is placed in column 23.
6. The INCREM and COMPUT Executive Control statements are the same as in Example 38.1. With these statements, the peak discharge rate and time will be computed, as well as the peak elevation in the pond. In order for the flow in pond to be analyzed, the last cross section must be specified as the pond structure. This is done by placing the cross section number of the culvert in columns 20 and 21 of the COMPUT statement. Again, ENDJOB is the last statement.

Output

The output format is the same as in Example 38.1 because the output options in columns 61–70 are the same, with the addition of the options chosen for the RESVOR statement. A condensed version of the output is shown on Fig. 38.5 and Table 38.3.

Summary

As in Example 38.1, the summary table on the last page of the output summarizes all of the information obtained. This table contains the developed runoff information for area 1 and for peak flow and elevation through the pond. The pond used to control the runoff from area 1 is checked to see if it is sufficient. The peak discharge elevation is 783.07 feet for the 10-year storm. This indicates that the pond does not overtop for the storm event modeled.

Example 38.3

Description

The entire watershed is analyzed to determine the amount of runoff from the 0.3 square miles. This example incorporates the same area as Example 38.1, but also includes the runoff from the three other subbasins under existing conditions from the entire watershed. The watershed is subdivided into 4 subbasins as shown on Fig. 38.1. Area 1 has been analyzed with and without the pond in the two previous examples. There is a 1-acre lake in the middle of the watershed, which takes in the runoff from

```
SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL
INSTRUCTIONS IN THE ORDER PERFORMED (A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS) VALUES INDICATES
A FLAT TOP HYDROGRAPH A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.)

                                                    MAIN          PRECIPITATION                        PEAK DISCHARGE
                                                           ------------------------------        ----------------------------------
 SECTION/      STANDARD              RAIN   ANTEC   TIME                                 RUNOFF
STRUCTURE      CONTROL     DRAIN.   TABLE   MOIST  INCREM   BEGIN   AMOUNT   DURATION    AMOUNT    ELEV.    TIME    RATE     RATE
   ID         OPERATION     AREA      #     COND    (HR)    (HR)     (IN)      (HR)       (IN)     (FT)     (HR)    (CFS)    (CSM)

ALTERNATE 1                   STORM 1

XSECTION    1  RUNOFF       0.02      7       2     0.10     .0      3.23      6.00       2.48      —       3.05    46.63   2220.4
STRUCTURE   1  RESVOR       0.02      7       2     0.10     .0      3.23      6.00       2.47    783.07    3.45    15.72    748.8
```

FIGURE 38.5 Output from Example 38.2.

TABLE 38.3 Summary of Example 38.2

Location	Peak Discharge (cfs)	Runoff Amount (in.)	Water Surface Elevation (ft)	Time to Peak (hr)
Area 1	46.63	2.48	—	3.05
Pond	15.72	2.47	783.07	3.45

TABLE 38.4 Stage-Storage-Discharge Relationship for the 1-Acre Lake in Example 38.3

Stage	Discharge	Storage
773.0	0.0	0.0
773.5	3.0	0.34
774.0	5.0	0.86
774.5	7.0	1.33
775.0	9.0	1.87
775.5	11.0	2.41
776.0	13.0	3.03
776.5	19.0	3.56
777.0	116.0	4.37
777.5	325.0	5.17
778.0	656.0	5.96

Areas 1, 2, and 3. The discharge from this lake is routed through a channel to the outlet of the watershed. Table 38.4 shows the stage-storage-discharge relationship for the 1-acre lake.

The hydrologic input data is the same as in the previous examples. This refers to the rainfall data for the SCS Type II distribution and the rainfall amount for a 10-year recurrence interval in Indianapolis. Another storm, the 100-year 12-hour event, was used to demonstrate how easy it is to add additional storms.

Calculations

Table 38.5 contains the information from the computation of the CN and t_c values. The longest t_c is for drainage area 4. The total time of concentration for the entire watershed is 1.05 hours.

Computer Input

The input file from Example 38.1 is edited to include the information for the additional subbasins. A reach is added by using the tabular control XSECTN and the corresponding codes. The STRUCT table is changed to reflect the 1-acre lake. The Standard Control statements, RUNOFF and ADDHYD, are needed for the additional subbasins. The area, CN, and t_c are described on each RUNOFF statement. COMPUT and ENDCMP statements are used to add the 100-year storm event values. The ADDHYD statement is used to combine two hydrographs computed from the respective RUNOFF statement. The ADDHYD is used because there are only two input hydrographs entries for each RUNOFF statement. The input is shown in Fig. 38.6.

For example, the hydrographs from areas 1, 2, and 3 are combined and routed through the 1-acre lake before adding runoff from area 4. Therefore, two ADDHYD statements are used to combine the hydrographs computed from the pond in area 1 and the runoff from area 2. Another ADDHYD statement is used to combine the previously obtained hydrographs with the hydrograph computed from area 3. The 1-acre pond in area 3 is then described by a RESVOR statement. This statement refers to STRUCT 02 for the stage-storage-discharge relationship. The runoff from all three subbasins is routed through the

TABLE 38.5 Curve Numbers and Times of Concentration for Example 38.3

Drainage Area	Area (acres)	Land Use	CN	Area * CN
		Drainage Area 2		
	36	Residential	86	3096
2	11	Commercial	94	1034
	21	Open Area	74	1554
Total	68			5684
		Composite curve number		84
		Drainage Area 3		
	19	Residential	86	1634
3	7	Commercial	94	658
	N/A	Open Area		
Total	26			2292
		Composite curve number		88
		Drainage Area 4		
	28	Residential	86	2408
4	37	Commercial	94	3478
	16	Open Area	74	1184
Total	81			7070
		Composite curve number		87

pond by placing a "1," the combined hydrograph number, in column 19 of the RESVOR statement. The discharge from the pond is then routed through a channel to the outlet of the watershed. The routing is described by a REACH statement which refers to XSECT 006. The XSECT is the stage-discharge and area relationship for the 2050-foot channel. The relationship is computed by using the channel cross section shown in Fig. 38.7. The RUNOFF statement is then used to describe the runoff from area 4. Finally, the hydrograph from the REACH and area 4 runoff are added together with the ADDHYD statement.

The Executive Control statements are the same as those used in the previous two example problems, except the last cross section number used must be placed in columns 20 and 21 and the additional COMPUT and ENDCMP. The COMPUT statements require the input of the initial and final cross sections that are to be analyzed. Because the ADDHYD was the last Standard Control statement, its cross section number (columns 14 and 15) is placed in columns 20 and 21 of the COMPUT statement.

Output

The type and amount of output can be controlled by input options on the JOB record and by the output options on the Standard Control records. All of the output options on the Standard Control statements were left blank because only a summary table is desired. To accomplish this, SUMMARY is placed in columns 51–57 of the JOB statement. The output is shown in Fig. 38.8.

Summary

From the summary table of the output shown in Fig. 38.8, it is determined that, for a 10-year storm, the peak discharge is 233 cfs, which occurs after 3.71 hours. For the 100-year 12-hour storm, the peak discharge is 361 cfs with a time to peak at 6.46 hours. Output from each subbasin can be inspected to determine the amount it contributes to the overall runoff from the watershed. The outflow from drainage areas 1, 2, and 3 are routed through the 1-acre pond and then through a channel. The reach had very little effect on the time to peak or the discharge. The channel would have to be much wider and longer for any attenuation to be realized. The results are also summarized below in Table 38.6.

```
JOB TR-20                                            SUMMARY         NO PLOTS
TITLE            EXAMPLE 3 - ENTIRE WATERSHED
TITLE            PROPOSD CONDITIONS
5       RAINFL   7                 0.05
8                    0             0.01     0.03     0.04    0.06
8                    0.08          0.10     0.13     0.17    0.22
8                    0.64          0.78     0.84     0.87    0.90
8                    0.92          0.94     0.96     0.98    0.99
8                    1.0           1.0      1.0      1.0     1.0
9       ENDTBL
2       XSECTN       6             1.0      770.0
8                                  759.0    0.0      0.0
8                                  760.0    15.09    5.0
8                                  761.0    51.53    12.0
8                                  762.0    110.34   21.0
8                                  763.0    194.31   32.0
8                                  764.0    306.33   45.0
8                                  765.0    372.72   71.0
8                                  766.0    670.69   121.0
8                                  767.0    1208.35  195.0
8                                  768.0    2034.72  293.0
8                                  769.0    2751.61  455.0
8                                  770.0    4579.98  723.0
9       ENDTBL
3       STRUCT       1
8                                  773.0    0.0      0
8                                  773.5    3.0      0.34
8                                  774.0    5.0      0.86
8                                  774.5    7.0      1.33
8                                  775.0    9.0      1.87
8                                  775.5    11.0     2.41
8                                  776.0    13.0     3.03
8                                  776.5    19.0     3.56
8                                  777.0    116.0    4.37
8                                  777.5    325.0    5.17
8                                  778.0    656.0    5.96
9       ENDTBL
6       RUNOFF   1   1         1   0.021    93       0.24                     AREA 1
6       RUNOFF   1   2         2   0.106    84       0.96                     AREA 2
6       RUNOFF   1   3         3   0.041    88       0.68                     AREA 3
6       ADDHYD   4   4   1  2  4
6       ADDHYD   4   5   3  4  1
6       RESVOR   2   01  1     2                                              LAKE
6       REACH    3   6   2     3   2050                                       REACH
6       RUNOFF   1   7         4   0.127    87       1.01                     AREA 4
6       ADDHYD   4   8   3  4  5
        ENDATA
7       INCREM   6                 0.1
7       COMPUT   7   1      8      0.00     3.23     6       7       2  1  1  10-YR
        ENDCMP   1
7       COMPUT   7   1      8      0.00     5.24     12      7       2  1  1  100-YR
        ENDCMP   1
        ENDJOB   2
```

FIGURE 38.6 Input from Example 38.3.

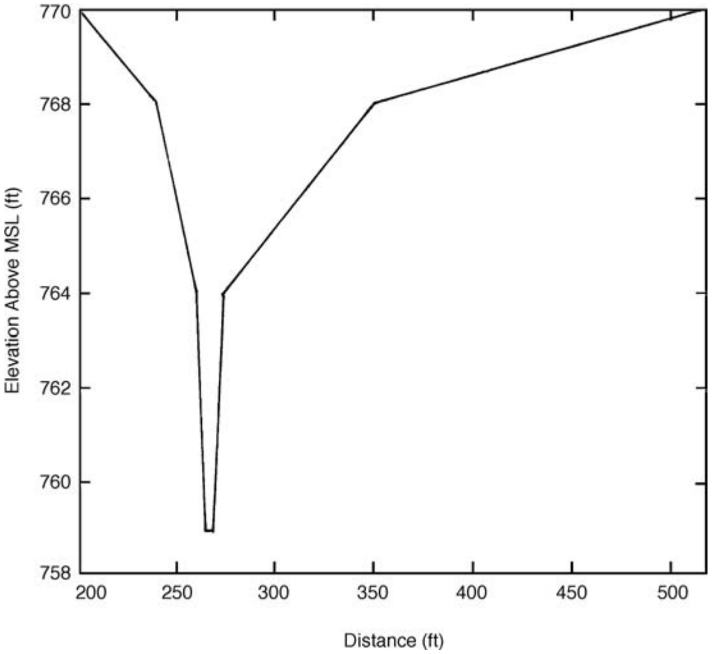


FIGURE 38.7 Cross section of reach through drainage area 4.

TABLE 38.6 Summary of Results for Example 38.3

	6-Hour Storm Event		12-Hour Storm Event	
Drainage Area	Time of Peak (hours)	Peak Discharge (cfs)	Time of Peak (hours)	Peak Discharge (cfs)
1	3.05	46.64	5.97	46.93
2	3.60	80.62	6.43	125.86
3	3.37	46.00	6.22	63.91
Reach	3.73	127.71	6.47	201.82
4	3.63	107.55	6.46	159.03
Outlet	3.71	232.79	6.46	360.85

38.4 The HEC-HMS Model

Uses of HEC-HMS

HEC-HMS is a precipitation-runoff simulation model developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) that is a "new generation" software to supercede the HEC-1 Flood Hydrograph Package. Similar to HEC-1, HEC-HMS can be used: (1) to estimate unit hydrographs, loss rates, and streamflow routing parameters from measured data and (2) to simulate streamflow from historical or design rainfall data. Several new capabilities are available in HEC-HMS that were not available in HEC-1: (1) continuous hydrograph simulation over long periods of time and (2) distributed runoff computation using a grid cell depiction of the watershed. Capabilities for snow accumulation and melt, flow-frequency curve analysis, reservoir spillway structures, and dam breach are under development for HEC-HMS but not yet incorporated.

HEC-HMS consists of a graphical user interface, integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities. The program features a completely integrated work environment including a database, data entry utilities, computation engine,

```
SUMMARY TABLE 1 - SELECTED RESULTS OF STANDARD AND EXECUTIVE CONTROL
INSTRUCTIONS IN THE ORDER PERFORMED (A STAR(*) AFTER THE PEAK DISCHARGE TIME AND RATE (CFS)
VALUES INDICATES A FLAT TOP HYDROGRAPH A QUESTION MARK(?) INDICATES A HYDROGRAPH WITH PEAK AS LAST POINT.)


                                                          MAIN
 SECTION/         STANDARD              RAIN    ANTEC     TIME          PRECIPITATION            RUNOFF          PEAK DISCHARGE
                                                                 ---------------------------            ------------------------------
STRUCTURE         CONTROL     DRAIN.   TABLE    MOIST    INCREM   BEGIN   AMOUNT   DURATION    AMOUNT   ELEV.    TIME    RATE    RATE
   ID            OPERATION     AREA      #      COND      (HR)    (HR)     (IN)      (HR)       (IN)    (FT)     (HR)   (CFS)   (CSM)

 ALTERNATE 1                      STORM 1

 XSECTION    1   RUNOFF        0.02      7       2         0.1      0      3.23        6        2.48             3.05    46.63  2220.4
 XSECTION    2   RUNOFF        0.11      7       2         0.1      0      3.23        6        1.71             3.6     80.62   760.6
 XSECTION    3   RUNOFF        0.04      7       2         0.1      0      3.23        6        2.02             3.37    46     1121.9
 XSECTION    4   ADDHYD        0.13      7       2         0.1      0      3.23        6        1.83             3.5     90.94   716
 XSECTION    5   ADDHYD        0.17      7       2         0.1      0      3.23        6        1.88             3.43   136.16   810.5

 STRUCTURE   1   RESVOR        0.17      7       2         0.1      0      3.23        6        1.87    777.04   3.61   130.97   779.6
 XSECTION    6   REACH         0.17      7       2         0.1      0      3.23        6        1.88    762.21   3.73   127.71   760.1
 XSECTION    7   RUNOFF        0.13      7       2         0.1      0      3.23        6        1.94             3.63   107.55   846.9
 XSECTION    8   ADDHYD        0.30      7       2         0.1      0      3.23        6        1.91             3.71   232.79   789.1

 ALTERNATE 1                   STORM 2

 XSECTION    1   RUNOFF        0.02      7       2         0.1      0      5.24       12        4.43             5.97    46.89  2232.7
 XSECTION    2   RUNOFF        0.11      7       2         0.1      0      5.24       12        3.49             6.43   125.86  1187.4
 XSECTION    3   RUNOFF        0.04      7       2         0.1      0      5.24       12        3.89             6.22    63.91  1558.8
 XSECTION    4   ADDHYD        0.13      7       2         0.1      0      5.24       12        3.65             6.4    143.16  1127.3
 XSECTION    5   ADDHYD        0.17      7       2         0.1      0      5.24       12        3.71             6.3    202.98  1208.2

 STRUCTURE   1   RESVOR        0.17      7       2         0.1      0      5.24       12        3.7     777.21   6.34   202.33  1204.3
 XSECTION    6   REACH         0.17      7       2         0.1      0      5.24       12        3.71    763.07   6.47   201.82  1201.3
 XSECTION    7   RUNOFF        0.13      7       2         0.1      0      5.24       12        3.79             6.46   159.03  1252.2
 XSECTION    8   ADDHYD        0.30      7       2         0.1      0      5.24       12        3.74             6.46   360.85  1223.2
```

FIGURE 38.8 Output from Example 38.3.

and results reporting tools. A graphical user interface allows the user seamless movement between different parts of the program. The HEC Data Storage System (DSS) [HEC, 1993] allows the transfer of data between HEC programs. The data are identified by unique labels called PATHNAMES, which are specified when the data are created or retrieved. For example, a hydrograph computed by HEC-HMS can be labeled and stored in DSS for later retrieval as input to HEC-RAS. The DSS program has several utility programs for manipulating data. HEC-HMS is an easier tool to develop a hydrologic model for first time users because of its graphical user interface. Those familiar with and who routinely use HEC-1 may be frustrated with the set-up and complexity of running design storm events with user defined cumulative rainfall distributions. The more complex the hydrologic model is, the more liable the program is to crashing. It is anticipated that these problems will be improved upon with each new release of HEC-HMS. The graphics and reporting facilities is a very valuable tool that saves time and makes the presentation of results easy to produce.

Summary of HEC-HMS Input Structure

A project serves as a container for the different parts that together form the complete watershed model in HEC-HMS. The three components required for a hydrologic simulation are: (1) Basin Model, (2) Meteorologic Model, and (3) Control Specifications. A project file may contain more than one of these three components and is useful for running scenario analysis.

Each run of the model combines a basin model, meteorologic model, and control specifications. The user should be cautious, as some of these components may not be compatible with each other, depending on methods and time intervals chosen. Runs can be re-executed at any time to update results when data in a component is changed. The Run Manager is used to manage and execute runs, proportionally adjust flow or precipitation results, and save or start the basin model in differing states.

Basin Models

The physical representation of watershed or basins and rivers is configured in the basin model. Hydrologic elements are connected in a dendritic network to simulate runoff processes. Available elements are: (1) subbasin, (2) reach, (3) junction, (4) reservoir, (5) diversion, (6) source, and (7) sink. Computation proceeds from upstream elements in a downstream direction. Hydrologic elements are added to the model by dragging the appropriate icon from the element palette to the schematic in the Basin Model screen. Elements are connected to each other within the stream network from upstream to downstream elements. Elements may also be duplicated and deleted within the Basin Model Screen.

When developing a precipitation-runoff model using HEC-HMS, boundaries of the basin are initially identified. Most often, the basin is subdivided into smaller subbasins depending on the study objectives, drainage pattern, and other factors. Points where runoff information is needed are identified. The model can be structured to produce hydrographs at any desired location. As different areas of a large basin may have different hydrologic response characteristics, it is important to select an appropriate computational time interval and subdivide the watershed so that lumped parameters provide a reasonable depiction of the subbasins.

There are several methods that may be used in HEC-HMS to compute surface runoff. These are based on: (1) initial and constant excess precipitation, (2) SCS curve number, (3) gridded SCS curve number, (4) and Green and Ampt. The one-layer deficit and constant model can be used for simple continuous modeling. The five-layer soil moisture accounting model can be used for continuous modeling of complex infiltration and evapotranspiration environments.

Several methods are included for transforming excess precipitation into surface runoff. Unit hydrograph methods include the Clark, Snyder, and SCS technique. User-specified unit hydrograph ordinates can also be used. The modified Clark method, ModClark, is a linear quasi-distributed unit hydrograph method that can be used with gridded precipitation data. An implementation of the kinematic wave method with multiple planes and channels is also included.

A variety of hydrologic routing methods are included for simulating flow in open channels. Routing with no attenuation can be modeled with the lag method. The traditional Muskingum method is included.

TABLE 38.7 HEC-HMS Meteorologic Model Precipitation Methods

	Precipitation Method	Explanation
Historical Precipitation	User-specified hyetograph	Precipitation data analyzed outside of the program
	Gage weights	Uses Precipitation data from rainfall gages
	Inverse-distance gage weighting	Precipitation data from rainfall gages can be used to proceed when missing data is encountered
	Gridded precipitation method	Uses radar rainfall data
Synthetic Precipitation	Frequency storm	Uses statistical data from technical sources to produce balanced storm with given excedence probability
	Standard project storm	Implements regulations for precipitation when estimating the standard project flood
	SCS hypothetical storm	Implements the primary precipitation distributions for design analysis using Natural Resource Conservation Service (NRCS) criteria
	User-specified hyetograph	Used with a synthetic hyetograph resulting from analysis outside the program

The modified Puls method can be used to model a reach as a series of cascading level pools with a user-specified storage-outflow relationship. Channels with trapezoidal, rectangular, triangular, or circular cross sections can be modeled with the kinematic wave or Muskingum-Cunge method and an 8-point cross section.

Meteorologic Model

Meteorologic data analysis is performed by the meteorologic model and includes precipitation and evapotranspiration. Seven different historical and synthetic precipitation methods are included: (1) User Hyetograph, (2) User Gage Weighting, (3) Inverse-Distance Gage Weighting, (4) Gridded Precipitation, (5) Frequency Storm (6) Standard Project Storm – Eastern US, and (7) SCS Hypothetical Storm. These methods are summarized in Table 38.7. One evapotranspiration method is included in the model.

The four historical storm methods and the Gage Weights and User-Specified Hyetograph Methods for Synthetic Precipitation require entry of time-series precipitation data into the program. Time series data is stored in a project at a gage. Gage data has to be entered only once. The gages are owned by the project and can be shared by multiple basin or meteorologic models. The gage data is also stored in the DSS file created for the project and may be accessed by other projects.

An example of implementing time-series precipitation gage data in HEC-HMS would be using the Illinois State Water Survey (ISWS) Bulletin 70 rainfall depths with the Huff Rainfall Distributions. The Huff Rainfall Distribution for a 24-hour design storm event falling over an area of less than 10 square miles does not vary with different design frequency events. For this reason, the Huff 3rd Quartile Distribution may be entered as a precipitation gage using the cumulative storm percent precipitation data from 0–1 over the 24 hour design storm event duration. However, the Huff Rainfall Distributions are given in cumulative storm percent distributions rather than cumulative time series distributions that HEC-HMS accepts for precipitation gage data. Therefore, the cumulative storm percent distributions must be converted to time series precipitation distributions before being entered into HEC-HMS. The Huff Distributions in this example is specifically for northeastern Illinois (Huff and Angel).

Using the User-Specified Hyetograph precipitation method, this precipitation gage may be assigned to the subbasins in the model. When running the simulation, the precipitation may be weighted in the Run Manager to correspond to different design frequency events. The weighted precipitation is the depth of rainfall for a given design storm event.

Control Specifications

The control specifications set the starting date and time of a run as well as the ending date and time. The time interval, also called the computation step, is also included.

Preparation of Input Data

Preparation of input data can be divided into the following requirements and functions for using the SCS Methodology in HEC-HMS:

1. Prepare a schematic drawing that conveniently identifies the locations, drainage areas, curve numbers (CN), lag times (t_L), and reach lengths for the watershed. It should display all alternate structural systems together with the routing and evaluation reaches through which they are to be analyzed.
2. List the tabular data to support the requirements of the *Basin Model*. This may consist of structure data, stream cross section data, source or sink data and diversion data.
3. Establish the *Control Specifications* based on the time duration of the storm event to be simulated.
4. Develop a *Meteorological Model* to be used in the watershed analysis. This may require importing synthetic or historical rainfall data or developing synthetic rainfall distributions within HEC-HMS. The starting and ending time and date of the Meteorological Model, as well as the time interval, should be set in conjunction with the *Control Specifications*.

Calculations

For a large watershed it may be necessary to divide the watershed into subbasins. Each subbasin is determined by finding the different outlet points or design points within the watershed, then finding the area contributing to those points.

1. *Area*. The area of each subbasin in square miles (mi^2).
2. *Curve Number*. The curve number (CN) for each subbasin.
3. *Lag Time*. The lag time (t_L) is specified for each subbasin. Lag time (t_L) is 0.6 times the time of concentration (t_c).

The program is currently only set up to use English units.

HEC-GeoHMS Applications

HEC-GeoHMS has been developed as a geospatial hydrology tool kit for engineers and hydrologists with limited GIS experience. It combines the functionality of ArcInfo programs into a package that is easy to use with a specialized interface.

The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate subbasins and streams, construct inputs to hydrologic models, and assist with report preparation. Working with HEC-GeoHMS through its interfaces, menus, tools, buttons, and context-sensitive online help, in a windows environment, allows the user to effectively create hydrologic inputs that can be used directly with HEC-HMS. It is intended that these hydrologic inputs provide the user with an initial HEC-HMS model. The user can estimate hydrologic parameters from stream and watershed characteristics, gaged precipitation, and streamflow data. The user has full control in HEC-HMS to modify the hydrologic elements and their connectivity to more accurately represent field conditions.

HEC-HMS Example

A 60-acre basin in the Chicagoland area is modeled to determine the adequacy of a stormwater detention basin to which the area drains. This analysis will use SCS methodologies to determine the runoff hydrograph characteristics with the Illinois State Water Survey (ISWS) Bulletin 70 rainfall depths and the Huff rainfall distribution for the 100-year 24-hour design storm event. The 60-acre basin is composed of 40 acres of residential area and 20 acres of commercial area.

Hydrologic Input Data

The hydrologic parameters of the two subbasins within the 60-acre basin are given in Table 38.8.

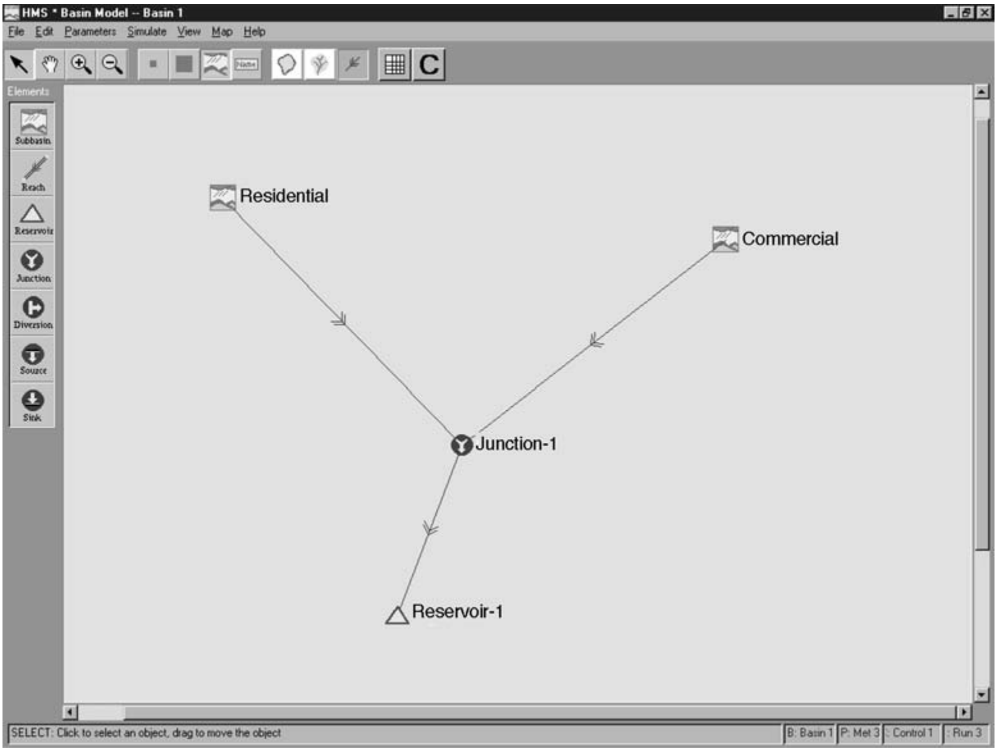
The stormwater detention basin and control structure were sized based on the DuPage County, Illinois stormwater detention requirements. The runoff from the developed area must be released at 0.1 cfs per acre. The elevation-storage-discharge relationship for the detention basin is given in Table 38.9.

TABLE 38.8 Hydrologic Model Subbasin Parameter

Subbasin Name	Area (acres)	Runoff Curve Number	Time of Concentration (minutes)
Commercial	20	94	15
Residential	40	83	45

TABLE 38.9 Stage-Storage-Elevation Relationship for Example Detention Basin

Elevation (ft)	Storage (ac-ft)	Outflow (cfs)
683	0.0	0.0
684	5.87	2.70
685	11.92	4.08
686	18.16	5.10
687	24.60	5.95



SELECT: Click to select an object, drag to move the object

B: Basin 1 | P: Met 3 | : Control 1 | : Run 3

FIGURE 38.9 HEC-HMS example problem basin schematic.

Using the subbasin hydrologic parameters and the stage-storage-elevation relationship for the stormwater detention pond, a basin model was constructed in HEC-HMS. The basin model schematic that is generated within HEC-HMS is shown as Fig. 38.9.

The pictured map icons represent the subbasins, the arrows represent the upstream and downstream orientation of the basin model, the circle junction icon represents the combination of the Residential and Commercial hydrographs and the triangle represents the reservoir routing of the combined hydrographs. By clicking on the icons, the data from Tables 38.8 and 38.9 can be added to the Basin Model.

TABLE 38.10 Huff 3rd Quartile Distribution for Hourly Precipitation Input

Hour	Cumulative Rainfall Distribution	Hour	Cumulative Rainfall Distribution
1	0.025	13	0.438
2	0.05	14	0.53
3	0.075	15	0.635
4	0.10	16	0.73
5	0.125	17	0.80
6	0.15	18	0.85
7	0.183	19	0.833
8	0.217	20	0.91
9	0.25	21	0.935
10	0.287	22	0.957
11	0.33	23	0.975
12	0.38	24	1.00

The next step is to specify a starting and ending date and time in the Control Specifications. A Control Specifications file with a starting date of 01/01/2001 and ending date of 01/03/2001 has been used for this example. The time for both the starting and ending date is 0:00.

The cumulative rainfall data to be used are the Bulletin 70 rainfall depths and Huff 3rd Quartile rainfall distributions. For the 60-acre basin in the Chicagoland area and the 100-year 24-hour design storm event, the corresponding storm code is 5 and the Sectional (zone) code is 2. This corresponds to a rainfall depth of 7.58 inches and the Huff 3rd Quartile distribution for areas less that 10 square miles. The Huff distribution is given in cumulative storm percent in increments of 5% of storm duration. This cumulative storm percent distribution must be converted to a cumulative time series distribution for input into HEC-HMS. This can be done with linear interpolation in a spreadsheet program, and the results of this analysis are given in Table 38.10. Note that the precipitation time increment chosen for this example problem is 1 hour.

This rainfall distribution is entered as a precipitation gage with an hourly time interval. The time window for the precipitation gage is set to match the time window for the Control Specifications. In this example, the precipitation start date is 01/01/2001. The distribution is left as a scaled distribution from 0–1, and the appropriate rainfall depth multiplier will be specified in the Run Manager later in the example.

Using the precipitation gage created for the Huff Rainfall Distribution and the subbasins from the Basin Model, a Meteorological Model is created for the 60-acre basin. In the Meteorological Model, User-Hyetograph is specified as the method and the precipitation gage created above is assigned to each subbasin.

Finally, a model run is created in Run Configuration by selecting a Basin Model, Meteorological Model and Control Specifications. Using the Run Manager, a total precipitation depth can be chosen to match a design storm event. In this example, we set the precipitation ratio to 7.58 inches.

Output

HEC-HMS produces both graphical and tabular output for viewing and report generation as well as detailed tabular output that is automatically stored in DSS. It also generates a run log that contains details of Errors and Warnings produced in the model computations. The tabular output for each location within the hydrologic model is shown in Fig. 38.10.

Tabular output is also available for each individual element of the hydrologic model. The tabular output for the stormwater detention basin called Reservoir-1 is shown in Fig. 38.11.

The output from each element of the hydrologic model may also be presented graphically in the form of a hydrograph. Figure 38.12 shows the graphical output for the Residential subbasin.

```
                    HMS   *   Summary of Results

              Project : Example        Run Name : Run 3

       Start of Run      : 01Jan01  0000   Basin Model    :  Basin 1
       End of Run        : 03Jan01  0000   Met. Model     :  Met 3
       Execution Time    : 09Jan02  0828   Control Specs  :  Control 1

                  Discharge                      Volume     Drainage
    Hydrologic      Peak          Time of          (ac        Area
     Element        (cfs)          Peak            ft)      (sq mi)

   Residential     28.229     01 Jan 01 1511     18.591      0.063
   Commercial      15.806     01 Jan 01 1500     11.441      0.031
   Junction-1      43.865     01 Jan 01 1503     30.031      0.094
   Reservoir-1     5.8520     02 Jan 01 0021     16.078      0.094
```

FIGURE 38.10 HEC-HMS tabular summary for the example problem.

```
                 HMS   *   Summary of Results for Reservoir-1

                 Project : Example        Run Name : Run 3

           Start of Run      : 01Jan01  0000   Basin Model    :  Basin 1
           End of Run        : 03Jan01  0000   Met. Model     :  Met 3
           Execution Time    : 09Jan02  0828   Control Specs  :  Control 1

   Computer Results

     Peak Inflow    : 43.865 (cfs)    Date/Time of Peak Inflow   : 01 Jan 01    1503
     Peak Outflow   : 5.8520 (cfs)    Date/Time of Peak Outflow  : 02 Jan 01    0021
     Total Inflow   : 6.01 (in)       Peak Storage               : 23.857 (ac-ft)
     Total Outflow  : 3.22 (in)       Peak Elevation             : 686.88 (ft)
```

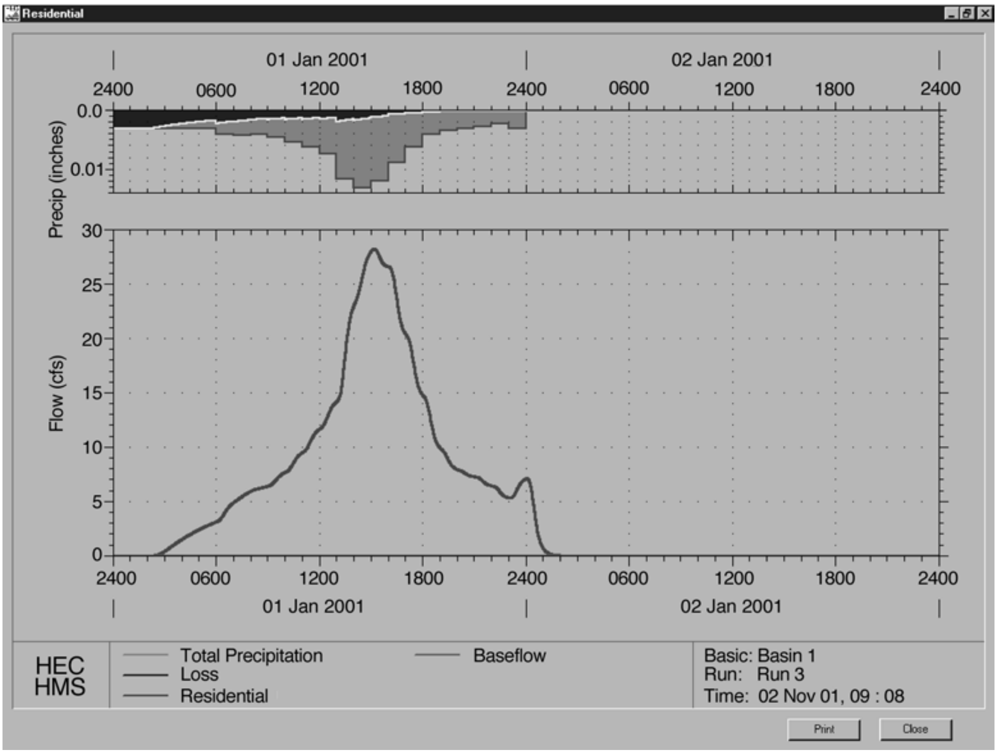
FIGURE 38.11 HEC-HMS tabular output for the stormwater detention basin.

The hydrographs for reservoirs within the HEC-HMS model show inflow and outflow hydrographs, elevation hydrographs and storage volume hydrographs. The graphical output for the stormwater detention facility is shown in Fig. 38.13.

38.5 The HEC-RAS Model

Uses of HEC-RAS

The U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) is a computer model enables one-dimensional steady and unsteady flow river hydraulic calculations. The HEC-RAS software supercedes the HEC-2 river hydraulics package, which was a one-dimensional, steady flow water surface profiles program. HEC-2 hydraulic models may be imported into HEC-RAS, although differences in the way HEC-RAS computes conveyance, losses at hydraulic structures and critical depth will cause results in the two programs to be slightly different. The HEC-RAS software is a significant advancement over HEC-2 in terms of both hydraulic engineering and computer science, but an imported HEC-2 hydraulic model should be carefully analyzed before using it for simulations in HEC-RAS.



Basic: Basin 1
Run: Run 3
Time: 02 Nov 01, 09 : 08

FIGURE 38.12 Graphical output for residential subbasin.

HEC-RAS consists of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The hydraulic analysis components will ultimately contain three one-dimensional components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; and (3) movable boundary sediment transport computations. All three of these components will use a common geometric data representation and common geometric and hydraulic computation routines.

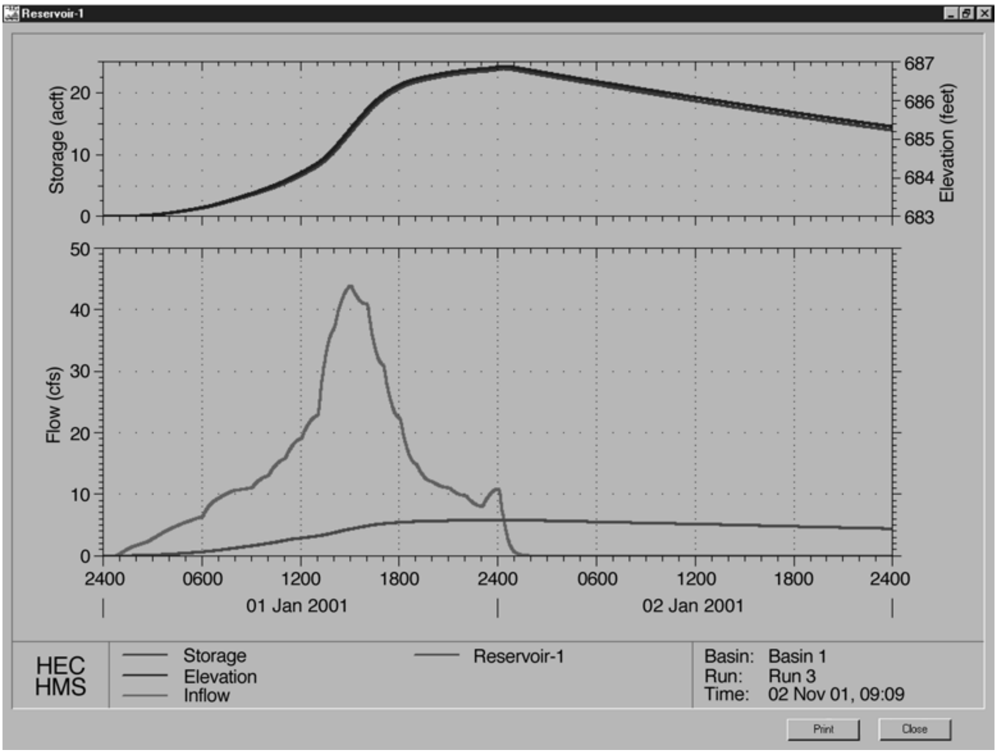
HEC-RAS Hydraulic Analysis Components

Steady Flow Water Surface Profiles

This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow based on the solution of the one-dimensional energy equation. The effects of various obstructions such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computations. The steady flow system is also designed for application in floodplain management to evaluate floodway encroachments. Special features of the steady flow component include: multiple plans analyses; multiple profile computations; multiple bridge and/or culvert opening analysis; and split flow optimization.

Unsteady Flow Simulation

This component of the HEC-RAS modeling system is capable of simulating one-dimensional unsteady flow through a full network of open channels. The hydraulic calculations for cross-sections, bridges, culverts, and other hydraulic structures that were developed for the steady flow component were incorporated into the unsteady flow module. The unsteady flow equation solver was adapted from Dr. Robert L. Barkau's UNET model (Barkau, 1992 and HEC, 2001).



Basin: Basin 1
Run: Run 3
Time: 02 Nov 01, 09:09

FIGURE 38.13 Graphical output for stormwater detention basin.

There are three components used in performing an unsteady flow analysis within HEC-RAS. These components are: (1) a geometric data pre-processor; (2) the unsteady flow simulator; and (3) an output post-processor. The pre-processor is used to process the geometric data into a series of hydraulic properties tables and rating curves, the unsteady flow simulation is performed by a modified version of UNET, and the post-processor is used to compute detailed hydraulic information for a set of user specified time lines during the unsteady flow simulation period.

Sediment Transport/Movable Boundary Computations

This component of the modeling system is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over time. The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring. The model will be designed to simulate long-term trends of scour and deposition in a stream channel that might result form modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. This system can be used to evaluate depositions in reservoirs, design channel contractions required to maintain navigation depths, predict the influence of dredging on the rate of deposition, estimate maximum possible scour during large flood events, and evaluate sedimentation in fixed channels.

HEC-RAS Hydraulic Model Structure

In HEC-RAS terminology, a *Project* is a set of data files associated with a particular river system. Steady flow analysis, unsteady flow analysis, and sediment transport computations may be performed as part of the project. The data files for a project are categorizes as follows: (1) plan data, (2) geometric data, (3) steady flow data, (4) unsteady flow data, (5) sediment data, and (6) hydraulic design data.

1. Plan Data – A plan represents a specific set of geometric data and flow data – the two required elements to perform a hydraulic analysis. Once the geometric and flow data are entered into the project, plans can easily be formulated by matching geometric and flow data.
2. Geometric Data – Geometric data represents the physical elements of a stream system. Included in the geometric data are the connectivity of the river, channel cross-sections, reach lengths, energy loss coefficients, stream junction information, and hydraulic structure data.
3. Steady Flow Data – Steady flow data consisting of flow regime, boundary conditions, and peak discharge information, are required to perform a steady flow analysis.
4. Unsteady Flow Data – The user is required to enter boundary conditions at all of the external boundaries of the system, as well as any desired internal locations, and set the initial flow and storage area conditions in the system at the beginning of the simulation period. The boundary conditions can be input manually by the user or imported from a HEC-DSS file.
5. Sediment Data – The sediment transport capabilities of HEC-RAS are currently under development. This feature is scheduled to be available in future releases of the program.
6. Hydraulic Design Data – This option allows the user to perform a series of channel modifications and evaluate the hydraulics of these modifications. These data can be used to determine if a channel modification will cause further scour of the channel bed and banks.

HEC GeoRas Applications

HEC-RAS has the ability to import three-dimensional river schematic and cross section data created in a GIS or CADD system. The HEC has developed an ArcView GIS extension called GeoRAS, that was designed to process geospatial data for use with HEC-RAS. The GeoRAS software allows a user to write geometric data to a file in the required format for HEC-RAS. Additionally, the users can read the HEC-RAS results into GeoRAS and perform the flood inundation mapping.

HEC-RAS Example

A trapezoidal channel is modeled to determine the head loss through a 36-inch Reinforced Concrete Pipe (RCP) at a road crossing at design flow-rates of 50 and 100 cfs.

A simple HEC-RAS example schematic is shown in Fig. 38.14.

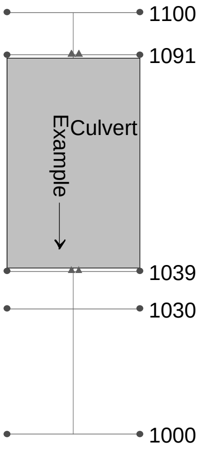


FIGURE 38.14 HEC-RAS sample schematic.

Hydraulic Input Data

Figure 38.14 shows the HEC-RAS Geometric Data for the example channel. The channel is trapezoidal and the culvert is a 36-in. RCP culvert with a length of 50 ft. The overtopping elevation of the roadway is at an elevation of 605.0 ft. The single vertical line represents the stream centerline and the horizontal lines with attached numbers represent cross-section locations that are entered into the HEC-RAS hydraulic model. The dots on the end of the cross-sections represent the channel banks. In this simple example, the channel cross-sections were not extended beyond the channel banks. The direction arrow indicates the orientation of the stream. The channel slope was assumed to be 1% and a Manning's n value of 0.027 was used for a grassed channel. The cross-section station numbers represent stream length in feet, starting from 1000 at the downstream end. However, left, right, and overbank lengths are specified at each cross-section. Manning's n values, channel bank stations, cross-section coordinates, ineffective flow areas and levees are also specified for each cross-section. The trapezoidal channel cross-section is shown in Fig. 38.15.

A culvert analysis in HEC-RAS requires four cross-sections. The first cross-section should be located sufficiently downstream of the structure so that flow is not affected by the structure. In the case of this example, the cross-section is located 40 ft downstream of the culvert opening. The second cross-section (1039) should be located immediately downstream of the culvert opening, and in this example

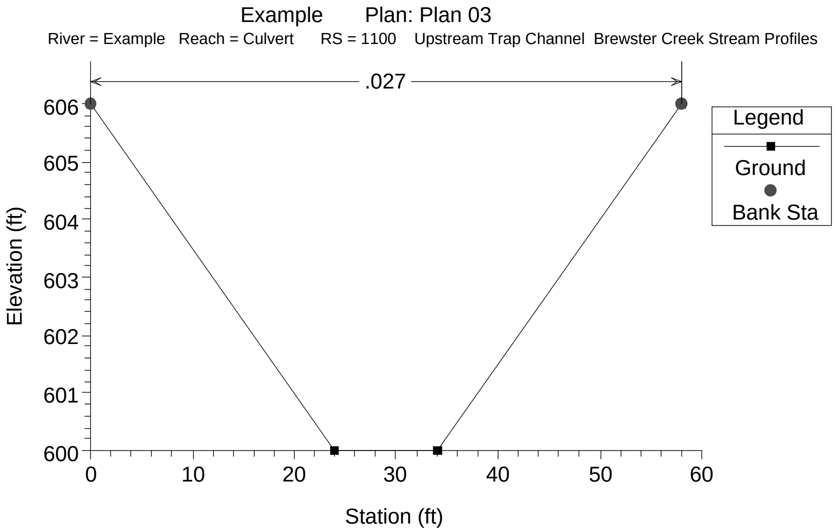


FIGURE 38.15 HEC-RAS example trapezoidal channel cross-section plot.

cross-section 1039 is located 1 ft downstream of the culvert. This cross-section should represent the effective flow area just at the culvert width. The third cross-section (1091) is located on the upstream side of the culvert, and it also should represent the effective flow area as the width of the culvert. In order to model only the effective flow areas at the second and third cross-sections, the ineffective flow area option should be used. The fourth cross-section (1100) is located upstream where the flow lines are approximately parallel and the cross-section is fully effective. These cross-section locations were arbitrarily chosen for this simple example. When using HEC-RAS to analyze bridges and culverts, special attention should be paid to the locations of these 4 cross-sections. Reference is given in the HEC-RAS User's Manual to the proper selection of cross-section locations.

The culvert cross sections with the ineffective flow areas at cross-sections 1039 and 1091 are shown in Fig. 38.16.

Once the geometry of the reach is completed, a downstream boundary condition and design flowrates must be specified. For this example, we have assumed a critical depth downstream boundary condition and a design flowrates of 100 and 50 cfs.

HEC-RAS Output

HEC-RAS allows for the output of results in both tabular and graphical formats. The tabular output for this hydraulic analysis is shown in Table 38.11.

This table shows that the head loss through the culvert for design flowrates of 100 cfs and 50 cfs is 2.75 feet and 2.16 ft, respectively. For the design flowrate of 100 cfs, the water surface elevation at the upstream cross-section (1091) is greater than the roadway elevation of 605.0 feet, which indicates that the roadway overtops for this design flowrate.

Another way to view the results in HEC-RAS is through the graphical interface. The graphical profile plot of the trapezoidal channel and culvert is shown in Fig. 38.17.

The stationing and stream length in feet from cross-section 1000 are given on the X-axis, while elevation is given on the Y-axis. The shaded area is the fill above the culvert and the opening below that is the culvert opening. The water surface profiles for the 100 cfs and 50 cfs design flowrates are given as the WS PF 4 and WS PF 2 lines in Fig. 38.18. Note that the 100 cfs water surface profile confirms that the roadway overtops at this design flowrate.

Each cross-section may also be viewed individually with resultant water surface elevations. Figure 38.18 shows cross-section 1039 with the two design flowrate elevations at this location.

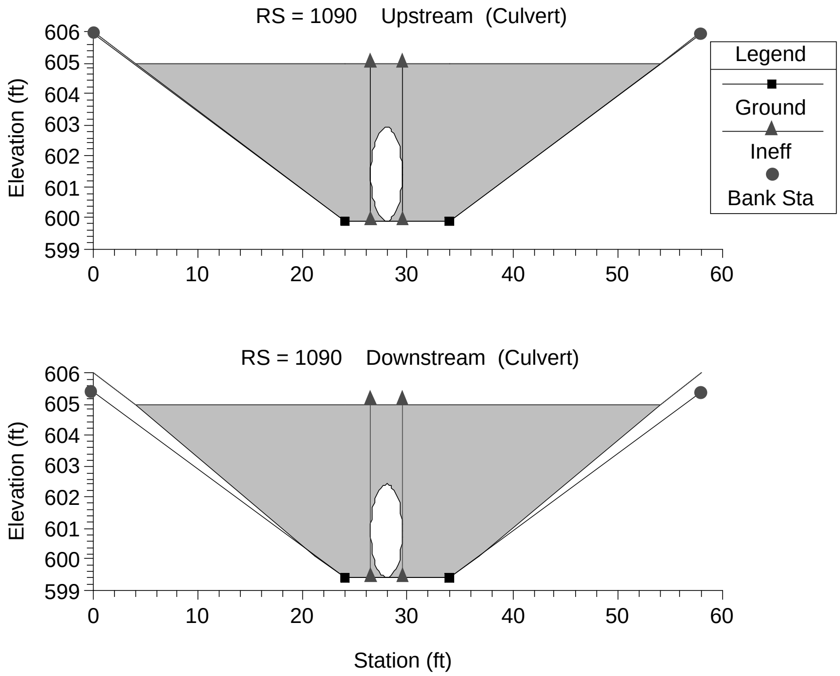


FIGURE 38.16 HEC-RAS example culvert plot.

TABLE 38.11 HEC-RAS Sample Tabular Output

	River Sta	Q Total (cfs)	Min Ch El (ft)	W. S. Elev (ft)	Crit W.S. (ft)	e.g., Elev (ft)	e.g., Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
Culvert	1100	50.00	600.00	603.95		603.95	0.000025	0.49	101.89	41.60	0.06
Culvert	1100	100.00	600.00	605.41		605.41	0.000025	0.58	170.99	53.25	0.06
Culvert	1091	50.00	599.90	603.61	601.95	603.92	0.001163	4.50	11.12	39.66	0.41
Culvert	1091	100.00	599.90	605.41	603.15	605.41	0.000023	0.57	176.36	54.05	0.06
Culvert	1090	Culvert									
Culvert	1039	50.00	599.40	601.45	601.45	602.48	0.008418	8.14	6.14	26.38	1.00
Culvert	1039	100.00	599.40	602.66	602.66	604.28	0.007148	10.23	9.78	36.07	1.00
Culvert	1000	50.00	599.00	599.87	599.82	600.15	0.010006	4.27	11.72	16.96	0.90
Culvert	1000	100.00	599.00	600.26	600.22	600.69	0.010010	5.25	19.04	20.11	0.95

The hatched area reflects ineffective flow areas just downstream of the culvert opening. Again, the ineffective flow areas must be determined on a case-by-case basis for each hydraulic structure. The HEC-RAS User's Manual gives a detailed description of modeling culverts and bridge openings.

38.6 XP-SWMM

Uses of XP-SWMM

Capabilities

The XP-SWMM model is comprehensive unsteady flow model that can be used for the simulation of urban runoff quantity and quality in either storm or combined sewer systems. It is a relatively sophisticated

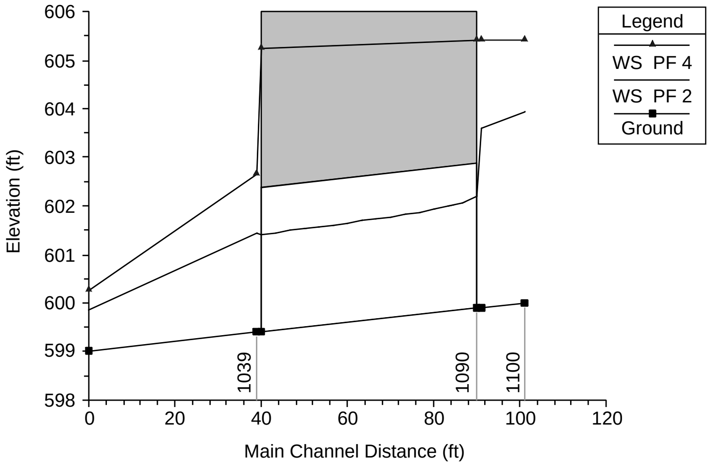


FIGURE 38.17 HEC-RAS profile graphical output.

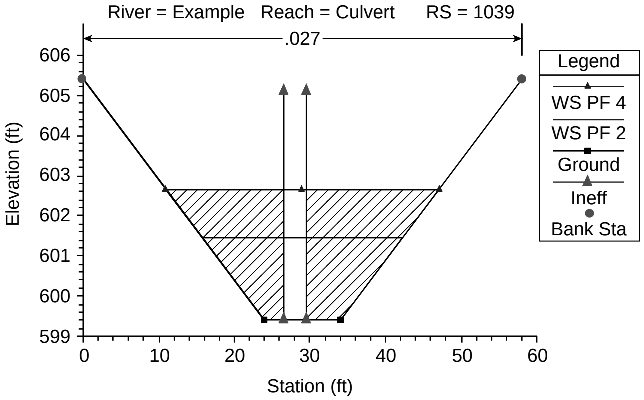


FIGURE 38.18 HEC-RAS cross section graphical Output.

hydrologic, hydraulic and water quality simulation program that utilizes the Storm Water Management Model (SWMM), developed under the sponsorship of the U.S. Environmental Protection Agency (USEPA), with an XP graphical interface. Also, many improvements to the USEPA's SWMM Version 4.3 have been incorporated into the latest version of XP-SWMM (Version 8.0). These improvements include many enhancements to the water quality capabilities of XP-SWMM, a new hydraulics solution algorithm and unsteady flow water quality routing. XP-SWMM can be used in drainage systems that are hydraulically complex, systems in which flow or stage data are available for calibration, or systems in which water quality is to be simulated.

The hydrologic simulation capabilities of XP-SWMM allow the use of historical rainfall events or design storm events, either of which may be input directly to the model or imported from programs outside of XP-SWMM. The hydraulic simulation capabilities of XP-SWMM include flow routing for both open and closed conduits in dendritic and looped networks. The model is capable of performing dynamic routing of stormwater flows through the stormwater drainage system to the outfall points of the receiving water system. Water quality characteristics of urban stormwater may also be simulated by XP-SWMM within the hydrologic and hydraulic simulation, although many applications of XP-SWMM are for water quantity purposes only.

XP-SWMM Model Structure

The XP-SWMM model is constructed of the following three “blocks” which are linked together to mathematically simulate all aspects of an urban drainage system: (1) Runoff Block, (2) Transport Block, and (3) EXTended TRANsport (EXTRAN) Block. Within the XP-SWMM graphical user interface, drainage networks are composed of links and nodes that may be dragged from the menu bar onto the screen. The nodes may represent watershed areas, manholes, level-pool reservoirs, and outfalls within the stormwater drainage system. The links may represent storm sewers of varying cross-sections, overland flow, trapezoidal or natural channels, pumps, orifices, weirs, or user-defined rating curves.

Stormwater Runoff from the drainage area is generated within the Runoff Block. The runoff may be routed through the drainage network by any of the three blocks in SWMM (Runoff, Transport, and EXTRAN), although it is recommended that routing be done in the EXTRAN Block for all drainage systems except the most simple. This text will assume that all routing of stormwater flows by the reader will be done in the EXTRAN Block. The stormwater runoff enters the EXTRAN Block at nodes shared by the Runoff Block and the EXTRAN Block. An interface file specified in each block transfers flow and water quality information between the two blocks.

The XP-SWMM model also has the ability to create and store databases of information that may be referenced within the model. This reduces data redundancy and associated problems of updating at many places when changes are made.

Runoff Block

The Runoff Block is the input source to the SWMM model. It generates surface runoff based on arbitrary rainfall and snowmelt hyetographs, antecedent moisture conditions, land use, and topography. The Runoff Block simulates the quantity and quality of the runoff from a watershed and generates hydrographs and pollutographs that may be analyzed or used as input to the EXTRAN Block. Each watershed is represented by a node in the XP-SWMM model and may be composed of up to five different subcatchments, each with unique runoff routing, rainfall hyetographs, water quality data, and infiltration characteristics.

There are several methods which may be used by the Runoff Block within XP-SWMM to compute surface runoff hydrographs. These are based on: (1) SCS Hydrology, (2) Unit Hydrograph Method, (3) Laurenson’s Method, and the (4) Kinematic Wave routing methodology. Infiltration for the three latter runoff methodologies may be simulated using the Horton or Green and Ampt methodology.

EXTRAN Block

Hydrographs and pollutographs generated within the Runoff Block are transferred to the EXTRAN Block via the interface file. The EXTRAN Block performs dynamic routing of stormwater flows from the input nodes, through the major storm drainage system, and to the outfall points of the drainage network. Within the EXTRAN Block, the nodes represent level-pool reservoirs, outfall points, and junctions of the stormwater drainage system. The links may represent pipes of various cross-section, open channels, orifices, weirs, pumps, or user-defined rating curves.

The EXTRAN Block will simulate flow in branched or looped networks, backwater due to tidal conditions, free-surface flow, pressure or surcharged flow, flow reversals, flow transfers by weirs, orifices and pumping facilities, and pond or lake storage. The EXTRAN Block uses a combination of implicit and explicit finite difference formulations for solving the St. Venant equations for gradually varied one-dimensional flow. Flow conditions violating the assumptions of gradually varied flow are solved using a combination of the kinematic wave and full dynamic equations in the conduit of interest.

Water Quality Simulation

Water quality processes are represented in all three of the core blocks of XP-SWMM (Runoff Block, Transport Block, and EXTRAN Block). Up to 10 water quality constituents may be modeled, and concentrations are transferred between blocks via the interface file. For most XP-SWMM applications,

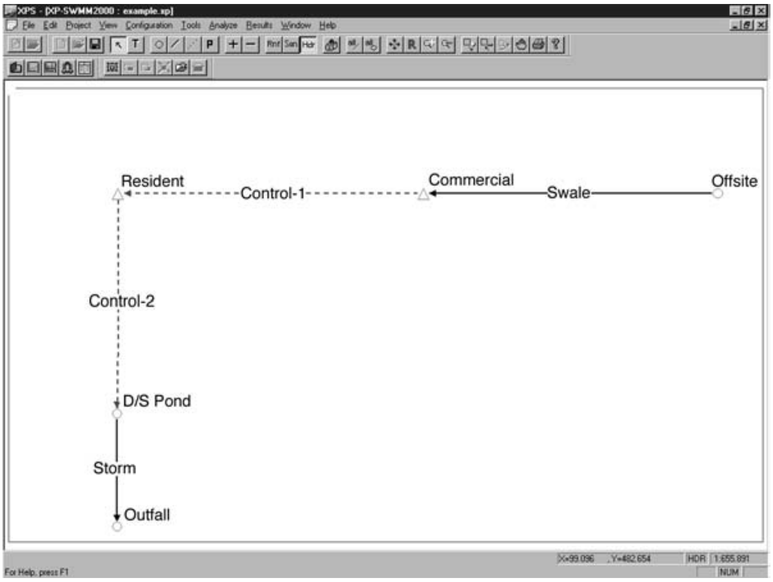


FIGURE 38.19 Sample XP-SWMM model schematic.

the Runoff Block is the origin of water quality constituents. The Runoff Block attempts to simulate the buildup of pollutants on the watershed and the overland transport of these pollutants into the drainage system. The mechanisms of urban runoff quality involve factors such as wind, erosion, traffic, atmospheric fallout, land surface activities, street cleaning, and many other complex processes. XP-SWMM attempts to consider many of these factors; however the difficulties of modeling urban runoff quality are well documented and cannot be completely overcome by XP-SWMM.

Water quality can be simulated in three different ways in the Runoff Block: (1) Buildup and Washoff, (2) Rating Curve, and (3) Event Mean Concentration. The Buildup and Washoff method simulates buildup of dust and dirt on the watershed as well as the subsequent washoff using exponential functions. The second method is the use of a rating curve of concentration vs. flow rate. The third method for simulating water quality is using the event mean concentration (EMC). The Runoff Block can also include water quality constituents in rainfall, catchbasin flushing, and erosion of solids using the Universal Soil Loss Equation.

Pollutants generated by the Runoff Block enter the drainage system as a pollutograph at the nodes, which are shared by the Runoff and EXTRAN Block (the same way hydrographs enter the system). Pollutographs may also be generated and enter the drainage system in the EXTRAN Block by simulating dry weather flow for simulation of combined sewer systems. Once in the sewer network, each pollutant is individually routed through conduits in the EXTRAN Block by assuming complete mixing within the conduit in the manner of a continually stirred tank reactor (CSTR). With this assumption, the concentration of the pollutant leaving the pipe is equal to the concentration in the pipe. All subsequent calculations are thus based on a mass balance, with pollutants being added or removed based on the concentration in the conduit. These calculations include scour, deposition, and decay of each pollutant.

XP-SWMM Example Problem

A simple XP-SWMM example watershed is shown in the following schematic (Fig. 38.19).

RUNOFF Block

The watershed will be analyzed using the National Resource Conservation Service (NRCS) TR-55 methodologies and Illinois State Water Survey (ISWS) Bulletin 70 rainfall depths and the Huff 3rd Quartile design rainfall distribution. The watershed is broken into three subbasins as shown in Table 38.12.

TABLE 38.12 Hydrologic Model Subbasin Parameters

Subbasin Name	Area (acres)	Runoff Curve Number	Time of Concentration (minutes)
Offsite	150	72	240
Commercial	20	94	15
Residential	40	83	45

This information is entered into the Runoff Block of the XP-SWMM model at the appropriate node. A hydrograph will be generated at these three "active" nodes in the Runoff Block based on this information in Table 38.12 using the NRCS methodology. In this example, the Huff 3rd Quartile design rainfall distribution and ISWS Bulletin 70 100-year 24-hour rainfall depth are entered in the Global Data database and are referenced at each node in the Runoff Block. A starting and ending date and time must be selected for a model run. For this example, the time period selected is July 18, 2001 to July 21, 2001.

EXTRAN Block

This watershed consists of farmland in the headwaters and commercial and residential development in the downstream areas. The offsite area drains via open swale to the commercial area. A cross-section, length, channel roughness, channel slope, bank stations, and upstream and downstream inverts of the swale are entered into this link to route the offsite flow to the commercial area. The commercial area drains into a stormwater detention basin, which drains to a residential area that is also served by a stormwater detention basin. The storm sewers within the commercial and residential area have been omitted from this example, for it can be reasonably assumed that all of the runoff in these areas drains to the detention basins via storm sewers and overland flow routes with little attenuation. These runoff processes can be simulated in the Runoff Block.

The stormwater detention basins for the commercial and residential areas are represented by a triangle in XP-SWMM. An elevation-area relationship is entered at the commercial and residential nodes in the EXTRAN Block. The control structure for each detention basin, represented by a dashed multi-conduit in the EXTRAN block, is composed of an orifice and an overflow weir. The relevant hydraulic properties (elevation, area, discharge coefficient, length) of the weir and orifice are explicitly entered into each multi-conduit. The residential detention basin drains into a storm sewer. Pipe size and shape, roughness, length, slope, rim, and invert elevations are entered for each storm sewer. The downstream side of this storm sewer is considered the outfall of the system. Several options exist for outfall conditions, but this example will use a critical depth assumption.

Results

XP-SWMM presents results in tabular and graphical formats. Tabular output of numerous hydrologic and hydraulic input parameters and results may be specified within XP-SWMM. This output can easily be imported into spreadsheets for further analysis or graphing. However, the graphical capabilities of XP-SWMM allow for the user to view discharge hydrographs of all links and stage hydrographs of all nodes within XP-SWMM in the EXTRAN Block. Furthermore, runoff discharge hydrographs at each node may also be viewed in the Runoff Block.

Figure 38.20 shows the discharge hydrograph of the orifice in the control structure for the residential development. The upstream elevation represents the water surface elevation in the residential stormwater detention basin. The downstream elevation represents the water surface elevation downstream of the residential stormwater detention basin control structure. In this example, the tailwater effect on the orifice from the downstream node can be clearly seen by the sharp drop in the hydrograph as the downstream water surface elevation rises.

This graph may also be exported from XP-SWMM in a tabular format that can be imported into spreadsheet programs for further analysis. XP-SWMM also produces an output file for each model run that gives details of the hydrologic and hydraulic simulation.

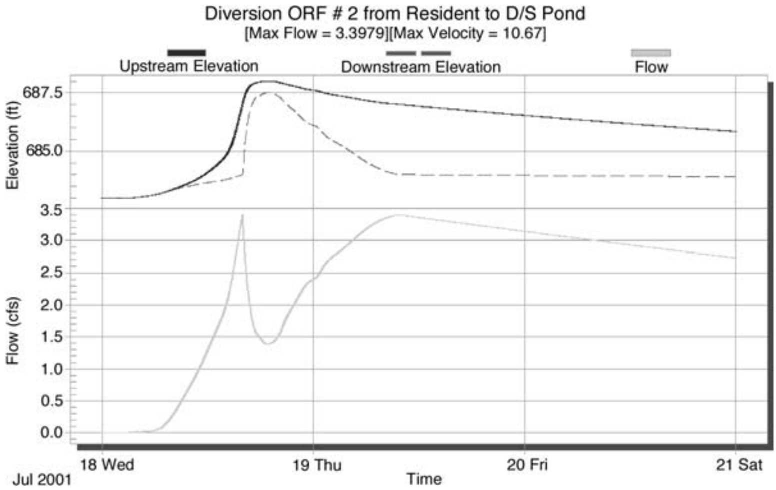


FIGURE 38.20 XP-SWMM graphical output.

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Further Information

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