HEC-HMS as Instructional Tool

Gregory H. Nail, Ph.D., P.E.[1]

Abstract

The emergence of technical software has been a great help to practicing engineers in all fields. Once laborious calculations are now quickly handled by a myriad of software packages. This trend has become as established in the water resources field as any other. However, without exception, software must utilize the same fundamental theory as conventional methods. This paper details a water resources engineering application, showing how fundamental theory and technical software can be merged into an instructional tool. A runoff hydrograph is computed for a watershed for a synthetically generated storm event. NRCS (National Resource Conservation Service) techniques are utilized to obtain the runoff hydrograph, with all calculations performed manually or with spreadsheet. The same hydrograph is then obtained using the HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) software. Evidence from the literature indicates that this approach contributes toward developing appreciation for, and proper understanding of, technical software used by students.

Keywords: HEC-HMS, hydrograph, software, instructional, hydrology

INTRODUCTION

It is obvious that software has changed the face of engineering practice over the past few decades. The presence of software in professional practice has affected engineering education. Since the advent of widely available personal computers in the early 1980's, it has become commonplace to work with them in practice or education. Furthermore, during the 1990's a whole series of powerful engineering software began to appear. This trend took place at the same time more and more computing power became packaged on smaller and smaller platforms. Excepting the very young, individual engineers have their own personal experiences and are part of this history.

BACKGROUND

The literature is replete with commentary on the antithesis between technically advanced engineering software as compared against older manual analysis techniques. Criswell [1] stated that "experienced engineers are extremely concerned with the increasing problem of new engineers misusing software and not understanding basic behaviors well enough to produce practical and realistic preliminary designs." It is import to note that this observation was made 12 years ago, in 1994. He also points out that, in the case of Civil Engineering, "…practice is no more than two centuries removed from the period when the available analysis tools were very limited…" He concludes that use of classical solutions in the classroom is one way to help developing engineers deal with this trend.

Houghtalen and Robinson [2] made similar remarks. They offer a three-tier instructional approach of basic principles (theory), classical solutions, and exposure to engineering software. Also, they present survey results of students and practicing engineers – an evaluation of the three-tier approach. These results illustrate discrepancies

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between what engineers (both students and professionals) state is important versus the amount of time they think should be devoted to it in an educational setting.

Regarding the use of computers in technical education, Obiozor [7] observes that "the tendency is to take the computer's response as true, correct and infallible. It is not directly obvious to the student that the correctness of the computer is as good as the ability of the programmer to correctly model the situation or problem and translate it to a computer software." He goes on to conclude that "more must be done in the classrooms as we move into the 21st century to train future scientists and engineers on the models, assumptions, limitations and algorithms employed to develop these programs so that they are better prepared to use the software with a clearer understanding."

Despite these problems, it has been recognized by educators that the use of different media in the classroom can be shown to increase retention. Onc such documented study is that of Krone [6]. He presents a case study comparing two groups of students. The first group received instruction without the aid of any multi-media teaching aids. The second received instruction, in the same course material, with the aid of many different media. Results show that the academic performance of the two groups was the same, but the one with multi-media presentations had greater retention. However, he qualifies this conclusion by pointing out that multi-media aids alone will not have the intended results. The media must fit the subject material appropriately.

Huddleston [5], Rose [8], and Yousuf [10] each present suggestions on how to implement software into the instructional environment – without sacrificing basic principles or theory. The approach taken in this paper is similar to those taken by the above three authors. A relatively simple hydrologic problem will be solved using both the older hand-written method and the HEC-HMS software. The author hopes to stimulate thought and discussion regarding the benefits of introducing software in parallel with older methods.

HEC-HMS

HEC-HMS [3] is a software package developed by the U. S. Army Corps of Engineers to facilitate hydrologic computations. It has many features, has been extensively applied, and is widely accepted within the water resources field [9]. The model has been successfully applied to watersheds ranging in size from less than 1 sq. mi. to large river basins covering several hundred thousand sq. mi. It is a windows-based descendant of an earlier DOS version known as HEC-1. HEC-1 had its beginnings as far back as 1968. It is public domain and can be downloaded free of charge from the HEC (Hydrologic Engineering Center) web site at www.hec.usace.army.mil.

DEMONSTRATION PROBLEM

Problem Statement

The problem selected for instructional purposes describes a rural watershed near Dallas, TX. The storm recurrence interval and duration is specified. The student is asked to utilize National Resource Conservation Service (NRCS) techniques to estimate a runoff hydrograph for the watershed. The solution will be presented in summary form, followed by HEC-HMS analysis of the very same problem. The text by Wurbs and James [9] provides complete details.

The problem statement includes the following information regarding the watershed: area, hydraulic length, and average slope.

$$A = 8mi^2 \tag{1}$$

$$l = 22{,}892\,ft \tag{2}$$

$$Y = 0.5\,\% \tag{3}$$

The storm recurrence interval and duration of $T = 100yr$ and $t = 24hr$, respectively, is specified.

Conventional Solution

Runoff estimation using NRCS techniques proceeds through a series of steps, all of which can be done either by hand or with a spreadsheet. The first step involves developing a hytegraph for the synthetic storm, corresponding to the desired recurrence interval and duration. Next, a unit hydrograph must be developed. The unit hydrograph is utilized to distribute the incremental values of runoff into a series of hydrographs, the sum of which constitutes the storm runoff hydrograph at watershed outlet.

A hytegraph is a time series histogram depicting rainfall intensities or depths, at discreet time intervals, throughout a storm event. NRCS has developed a two-step method for converting total precipitation for any given storm into a hypothetical or synthetic hytegraph. The first step involves obtaining total precipitation for the storm. Secondly, this value is distributed into a hytegraph utilizing standardized NRCS rainfall distribution functions.

The Texas Department of Transportation hydraulic design documentation, referenced by Wurbs and James [9], includes the intensity-duration-frequency relationship shown in Equation 3. It expresses the mean rainfall intensity (in/hr) as a function of storm duration t (min) and three empirical coefficients a, b, and c.

$$i = \frac{a}{(t+b)^c} \tag{4}$$

The coefficients a, b, and c are 106, 8.3, and 0.762, respectively, for a 100-year recurrence interval [9]. The resulting mean intensity is 0.414 in/hr, corresponding to a total precipitation (over 24 hour duration) of 9.93 in. The total precipitation P is obtained by simply multiplying the mean intensity $i(in/hr)$ by the duration $t(hr)$. A convenient time interval is selected which will become the duration, d. The time series computations lend themselves to spreadsheet use, which is the way this problem was solved. The end result is total precipitation P distributed into a hytegraph via the NRCS rainfall distribution function, as shown in Figure 1.

Each cumulative value of precipitation is obtained by multiplying the total precipitation by the corresponding NRCS factor for that time interval, as shown in Equation 5.

$$\sum P_i = f_i P \tag{5}$$

The incremental precipitation can then be computed from the difference in cumulative precipitation, between current and last time step.

$$P_i = \sum P_i - \sum P_{i-1} \tag{6}$$

Equations 7-9 show that the cumulative volume runoff $\sum V_{R\,i}$ is a function of the cumulative precipitation $\sum P_i$, and initial abstraction, I_A, via the empirically derived curve number, CN. Initial abstraction refers to precipitation during the early part of a storm that does not contribute to runoff. It is the precipitation intercepted by exposed surfaces, trapped in puddles on the ground, or directly absorbed into the soil. The curve number is selected from values published by the NRCS. As one might expect, it depends on soil type, antecedent moisture condition, and land use, all parameters that affect runoff. The curve number for this particular watershed was estimated to be 80. Finally, values for incremental runoff corresponding to each time step can be determined as shown in Equation 9 – in a manner similar to Equation 6 above for incremental precipitation.

The hytegraph is shown in Figure 1. Note the symmetry of the histograms of Figure 1 about hour 12, caused by the NRCS Type II storm rainfall distribution factors. Also, the lack of runoff values during hours 1-4 depicts initial abstraction. Consequently, notice that the histograms during the latter part of the storm, from about hour 14 and thereafter, are nearly equal for precipitation and runoff. This is a graphical visualization of saturated conditions during the latter stages of the storm, when most precipitation is converted into runoff immediately after falling to the ground.

$$\sum V_{R\,i} = \frac{\left(\sum P_i - 0.2S\right)^2}{\left(\sum P_i + 0.8S\right)} \qquad \text{for} \qquad P_i \geq I_A \tag{7}$$

$$\sum V_{R\,i} = 0 \qquad \text{for} \qquad P_i \leq I_A \tag{8}$$

$$I_A = 0.2S \qquad \text{where} \qquad S = \frac{1000}{CN} - 10 \tag{9}$$

$$V_{R\,i} = \sum V_{R\,i} - \sum V_{R\,i-1} \tag{10}$$

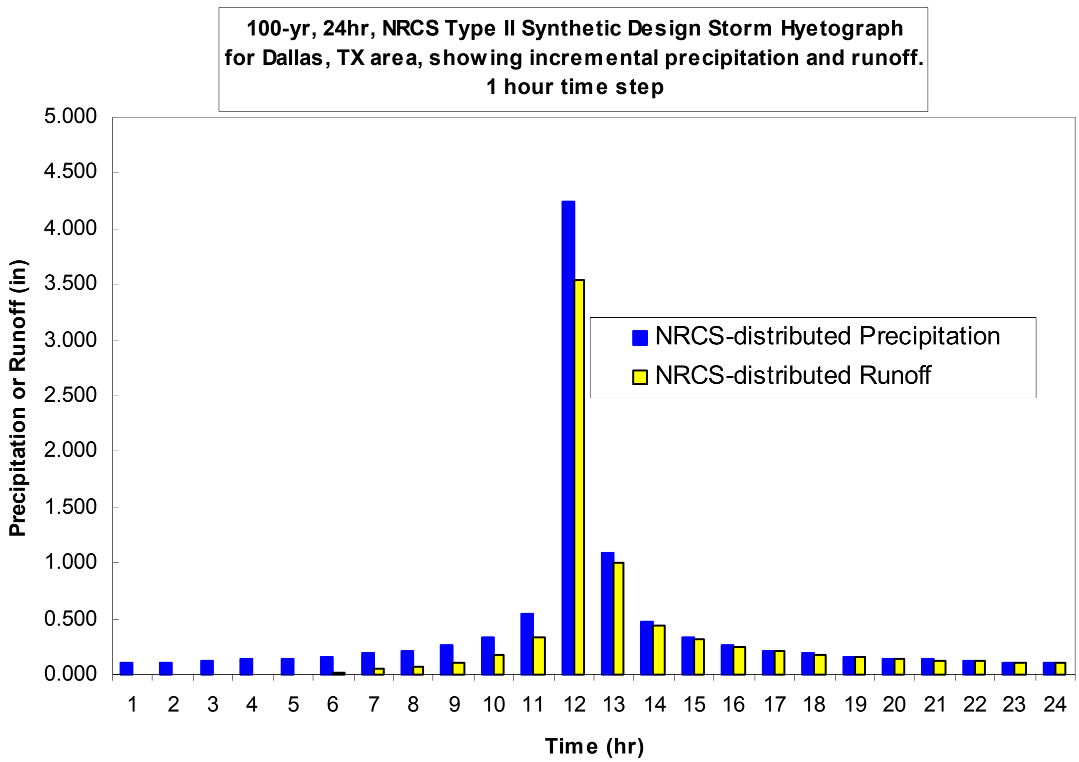

Figure 1

The next step in the solution calls for generation of a unit hydrograph. It will be used to transform the incremental runoff volumes into individual hydrographs – which sum together to form the storm runoff hydrograph. A unit hydrograph is defined in terms of a given watershed. For any given watershed it is the hydrograph resulting from a volume runoff of 1 in. (in standard units). For this reason a unit hydrograph is often referred to as a dimensionless unit hydrograph. Various techniques exist to accomplish this. The NRCS has developed a dimensionless unit hydrograph that is triangular in shape. Although crude, it is effective and is widely used and accepted. Equations 11-14 describe the NRCS dimensionless triangular unit hydrograph. The result of Equations 11 and 12 is peak discharge, Q_P, in cubic feet per second (cfs) when A is in square miles and T_P is in hours. For this particular case Q_P equals 645.4 cfs and T_P equals 6.0 hr.

$$Q_P = \frac{484A}{T_P} \tag{11}$$

$$T_P = \frac{d}{2} + t_L \tag{12}$$

The triangular unit hydrograph is composed of two linear functions, one for the rising limb and the other for the falling limb – as described by Equations 13 and 14. Note that in Equations 13 and 14 t is the time axis of the NRCS unit hydrograph.

$$Q = \frac{t}{T_P} Q_P \qquad \text{for} \qquad t \le T_P \tag{13}$$

$$Q = -\frac{Q_P}{1.667T_P} t + \frac{2.667}{1.667} Q_P \qquad \text{for} \qquad t \ge T_P \tag{14}$$

The NRCS lab time, t_L, is expressed in Equation 12. For this particular watershed the lag time is estimated to be 5.5 hr. Figure 2 shows the unit hydrograph.

$$t_L = \frac{l^{0.8}(1000 - 9CN)^{0.7}}{1900CN^{0.7}Y^{0.5}} \tag{15}$$

The NRCS unit hydrograph is utilized to transform the incremental runoff values, V_{Ri}, computed above, to a storm runoff hydrograph. This is accomplished by multiplying each incremental runoff value, V_{Ri}, from Equation 10 with each discharge value from Equations 13-14. This is done so that each incremental runoff value is converted into its own hydrograph. The sum of these hydrographs is the storm runoff hydrograph. Computation of these values takes the form of a multi-banded matrix, when loaded into a spreadsheet. Summing discharges across the rows, from left to right, results in the storm runoff hydrograph. The end result is the storm runoff hydrograph, shown in Figure 3, as indicated by the red line and symbols.

HEC-HMS Solution

The HEC-HMS software can be used to very quickly and efficiently analyze the problem above. Figure 4 shows the main dialog box within HEC-HMS. The underlying organizational scheme can be seen from this graphic. Note the three labels above the three windows where the words *Basin Model*, *Meteorological Model*, and *Control Specifications* appear. Data for a HEC-HMS run is divided into three categories along these lines. Each of the three labels represents three files, which are bound together in a *project* file.

Physical characteristics of the basin are entered in a dialog box accessible from the window in Figure 4. Clicking on the basin 1 label activates the basin editor (not shown). The basin editor is the place where the basin model is defined. A pull-down menu is set to *SCS Curve Number*[2], consistent with the NRCS techniques used above. Additional entries are required for watershed area ($A = 8$ sq mi), SCS (NRCS) curve number ($CN = 80$), lag time, t_L, of 330 minutes (5.5 hr).

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[2] The Soil Conservation Service (SCS), originally begun in 1935, was replaced with the NRCS in 1994. However, the SCS acronym still appears within dialog boxes of HEC-HMS.

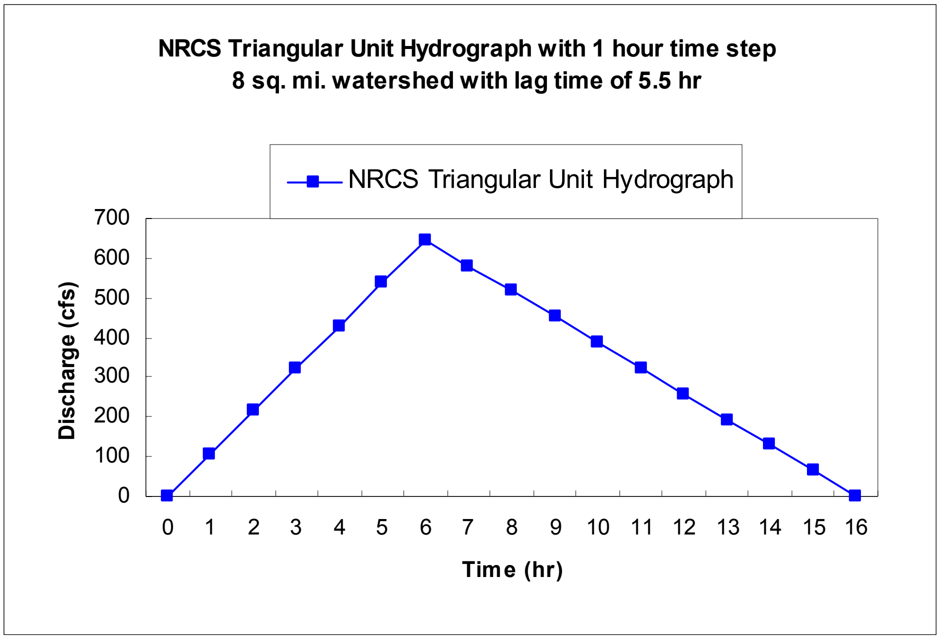
NRCS Triangular Unit Hydrograph with 1 hour time step
8 sq. mi. watershed with lag time of 5.5 hr
NRCS Triangular Unit Hydrograph
Discharge (cfs)
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Time (hr)

Figure 2

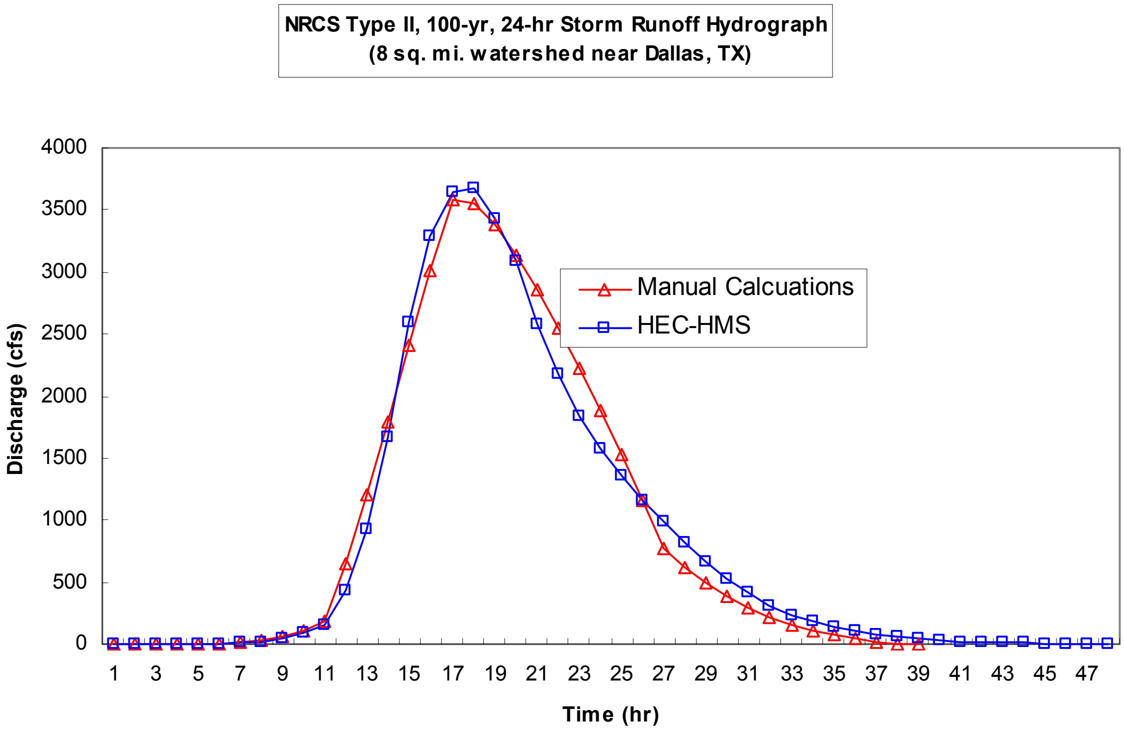

Figure 3

All of these entries are accommodated by three tabs from within the basin editor labeled *Loss Rate, Transform,* and *Base Flow Method*. These tabs access displays equipped to receive data describing the ground surface conditions, desired method to convert volume runoff to hydrograph, and accounting of pre-existing base flow, respectively. An entry is requested for percent surface impervious. For brevity and simplicity, this particular problem has no specified initial loss, and no significant portion of the watershed is assumed impervious. Baseflow is also requested. Again, for brevity and simplicity, no baseflow was included for this particular problem. This entry specifies that the NRCS unit hydrograph method, as outlined above, is the desired method to transform the incremental volume runoff values into a storm runoff hydrograph. HEC-HMS is equipped to employ a number of other methods.

Clicking on the Met 1 label activates the meteorological model editor (not shown). The SCS (NRCS) hypothetical storm has been selected on a pull-down menu. HEC-HMS is equipped to employ other methods to obtain a hyetograph from a total precipitation value – including statistical techniques that require additional data. A Type II storm has been selected in the pull-down menu and the total precipitation of 9.93 in. has been entered. Recall that the total precipitation value was obtained by multiplying the average intensity obtained from Equation 4 above by the storm duration of 24 hr.

Clicking on the Control 1 lable activates the run control editor (not shown). A 48-hour period has been entered using a time step of 1 hour. These data could have been different. In order to facilitate comparison with the manual calculation, a 1 hour time interval (time step) was preserved.

Sufficient data has now been entered into HEC-HMS to attempt a computer simulation. The basin model, meteorological model, and control specifications are each saved into separate files. Another dialog box is utilized to actually initiate the run. After the successful run, results can be viewed in a number of formats. One such view, which includes a lot of information in one place, is shown in Figure 9. The curve plotted in Figure 9 is the storm runoff hydrograph, and is identical with the curve labeled HEC-HMS in Figure 3. The hytegraph near the top of Figure 9 contains the same information as does the hytegraph of Figure 1.

Discussion

Note that the hydrographs of the manual computation and HEC-HMS, shown in Figure 3, are extremely close – but not identical. This occurs because the SCS unit hydrograph of HEC-HMS is not exactly triangular [HEC, 4]. Otherwise, the computation from HEC-HMS is identical with that obtained manually. Furthermore, a spreadsheet was utilized to do the manual calculations. This fact illustrates how pervasive computer software has become. Spreadsheet calculations are fundamental enough that they are not normally considered computer simulations in the strictest sense of the word. When allowing for the slightly different unit hydrograph algorithm in HEC-HMS, Figure 3 clearly demonstrates that the same results were obtained both manually and by computer simulation.

The problem selected for analysis is complex enough to be somewhat time-consuming, but not too difficult so as to be impossible without HEC-HMS. The problem is practical and well defined. The results can be directly compared with HEC-HMS. Therefore, the student has an opportunity to learn how the software is computing values – and can check the results. When performing this exercise, it is equally likely that, when discrepancies occur, the HEC-HMS model is producing erroneous results. All of these characteristics give HEC-HMS promise as an instructional tool.

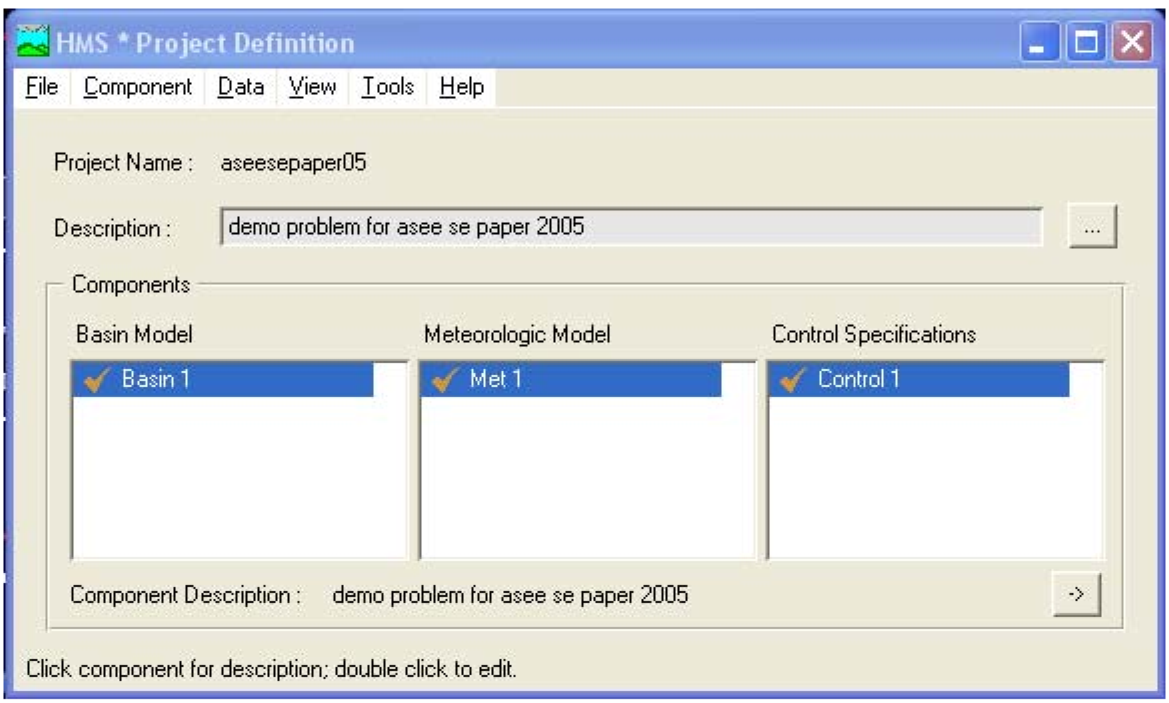

Figure 4

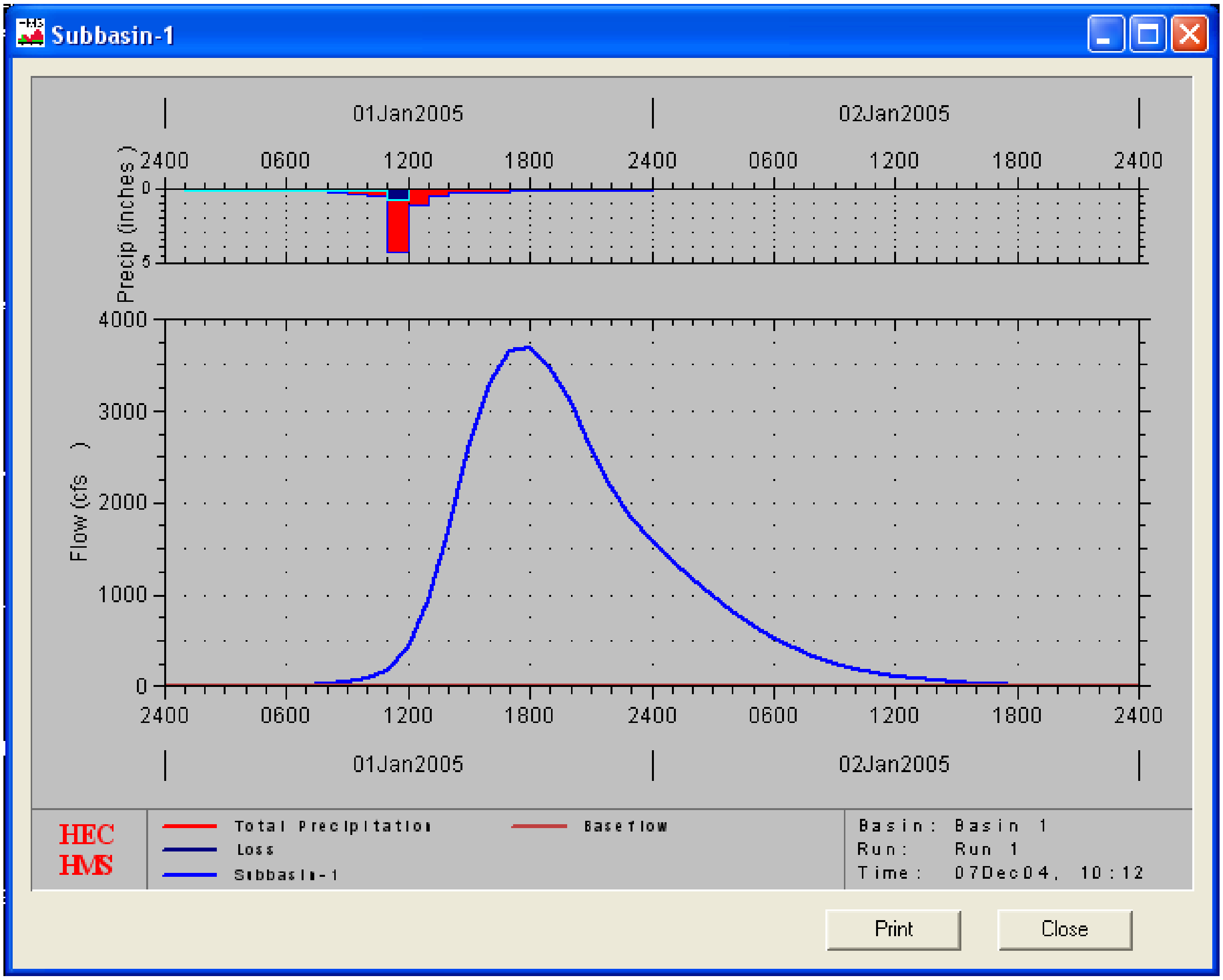

Figure 5

CONCLUSIONS

A demonstration problem has been presented which enables incorporation of technically advanced engineering software without sacrificing fundamentals. The hydrographs computed manually, and by HEC-HMS, are essentially identical, as shown in Figure 3. This comparison serves to reinforce the concepts learned by carrying out the manual calculation. The goal of taking this approach is to promote appreciation for and understanding of technical engineering software. The problem selected for this purpose is not technically challenging by industry standards. However, it is realistic, and complex enough to have value in an instructional environment. More features are available in HEC-HMS, and more manual calculations could have been made. These are beyond the scope of this paper, but could serve as the basis for a later paper.

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