Session 3251

A Drainage Module for Environmental Engineering

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Abstract

This study consists of a learning module for undergraduate environmental or civil engineering students. The module is separated into two. The first half of the module is structured around three illustrative examples. A state of the art computer program, "Flood Hydrograph Package" (HEC-1), developed by the US Army Corps of Engineers, is used in all of the three examples. This program is used in engineering practice to determine watershed flooding characteristics of both rural and urban sites. The use of this program is given in the first half of the module with instructions on how to prepare the input for the three illustrative examples and the output is interpreted. A listing of the program input and output is also given in the module.

In the second half of the module, a stream flooding problem is given. As in the first half of the module, illustrative examples are used as a teaching guide. The US Army Corps of Engineers' Computer Program River Analysis System (HEC-RAS) is used to solve these flooding examples. HEC-RAS is user-friendly and computationally efficient. It uses the latest user interface technology for data entry, graphics, and display of program results. Complete help screens are available for almost every program feature and option. HEC-RAS is for steady, gradually varied flow in natural or man-made channels.

This module has been tested on groups of Civil Engineering Juniors and Seniors at Cooper Union. The seniors were taking advanced courses in hydrology and open channel flow and the juniors were taking their first course in Water Resource Engineering. These students were given the drainage module and asked to use the module to determine the flooding potential of their system.

The module was also beta tested at Florida International University and Case Western Reserve University by both engineering faculty and engineering students. The beta tests at these schools were similar to the alpha tests conducted at Cooper Union.

Introduction

The study of hydraulics and hydrology is a necessary part of civil and environmental engineering. There are a number of textbooks[1 2 3] available to the undergraduate student in these areas of engineering science. But it is difficult to find an introductory text that will cover both hydraulic and hydrologic engineering in a clear and concise manner. Presently, computer modeling is widely used in the environmental and civil engineering profession. A number of these programs are used to determine flooding potential of streams, roads, parking areas, etc. The U.S. Army Corps of Engineers has encouraged the use of two such programs: "Flood Hydrography Package (HEC-1)[4]," and "River Analysis System (HEC-RAS)[5]." It is virtually impossible to find the instructions on the use of these programs in an introductory course in Water Resource Engineering. This has placed an added burden in teaching hydraulics and hydrology to the undergraduate engineering students.

Approximately a decade ago, the course in Water Resource Engineering (hydraulics and hydrology is introduced to junior civil engineering students in this course) at Cooper Union was revised to include a three hour laboratory and problem solving weekly session. In order to incorporate the use of the latest techniques in this course, projects in urban storm water runoff and flooding were assigned. The HEC-1 program and HEC-2 program was used to determine drainage in the students' projects. HEC-RAS is basically the windows version of HEC-2. It was clear from the beginning that the students needed more than an introduction to the use of these two programs to be able to conduct watershed runoff and backwater curve computations. Longer and longer periods of time were necessary to instruct the students in the use of these necessary tools. This took valuable time away from the laboratory hydraulic experiments conducted as part of the required course. At this time, the module was developed as a learning aid in the proper use of both programs: HEC-1 and HEC-RAS. This module also includes instructions on basic hydraulic and hydrologic principles.

The module was alpha and beta tested. The module was first alpha tested at Cooper Union on senior and graduate civil engineering students. These students were taking advanced hydrology and open channel flow hydraulics. The module was revised after reviewing the questionnaires given to the students. The module was then tested on two separate classes of junior civil engineering students taking their first course in water resource engineering. The module was beta tested on engineering faculty and students at Florida International University (FIU), and at Case Western Reserve University (CWRU).

This paper will be separated into the following sections: a description of the module, drainage using HEC-1 Module, drainage using HEC-RAS Module, evaluation of the module (both alpha and beta testing), and implementation.

Drainage Using HEC-1 Module

A module was developed during the summer of 1995 to assist an undergraduate student in conducting a drainage study. The module was expanded during the fourth year of the Gateway project to include multiple watersheds. Advanced modeling concepts were also included, such as multiple storm events and diagraming the sub-watershed hydrologic characteristics. The same site was used for continuity purposes. This module directs the student step-by-step in the use of the HEC-1 program. We assume that the student has taken a first course in Water Resource Engineering, where hydrologic and hydraulic engineering techniques are discussed. A typical rural watershed was selected as a site to determine hydrologic characteristics for the input model parameters.

The surface runoff in a river basin due to precipitation is simulated by the HEC-1 computer model. The river basin is represented by an interconnected system of hydrologic and hydraulic components. A component may represent a surface runoff entity, a stream, channel, or a reservoir. Streamflow hydrographs are the result of this modeling process.

The HEC-1 computer model has a large number of options, such as multiple basin watersheds, flood damage analysis, dam safety, etc. Here only a single watershed analysis is presented. The Soil Conservation Service (SCS) TR-55 approach to the determination of precipitation, interception/infiltration and unit hydrographs is used. This approach is commonly used for urban watersheds by the U.S. Army Corps of Engineers.

The reformatted input data is printed in the output for the user's convenience. Hydrographs are printed in tabular form and graphed in this module. Rainfall, losses and excesses are included in a table and plotted for runoff calculations. Separate values of losses and excess are printed for rainfall. For storage routings, storage and stage are printed/plotted along with discharge. The program produces hydrologic summaries of the computations throughout the river basin.

Three illustrative examples are given in this first half of the module. The first is a determination of the flood hydrograph for an actual site, Stickle Pond, New Jersey. The second example is to route this hydrograph through a reservoir/spillway. A multiple watershed is given in the third example. In all cases, the actual site conditions and the SCS technique are used to determine the input parameters to the HEC-1 computer model. The examples given are common drainage problems in the determination of flood peaks and reservoir/detention pond water level elevations for urban watersheds. These examples are divided as follows: the determination of the model input parameters, HEC-1 input parameters, HEC-1 output results, and interpretation of these results. Sub basins are considered in the third illustrative example.

Drainage Using HEC-RAS Module

In the second half of the module the student is instructed to solve a series of stream flooding examples. The illustrative examples range from the determination of backwater curves for a simple stream network to the solution of stream elevations with culvert and bridge crossings. In all of these examples, the computer program HEC-RAS is used to determine stream widths, elevations and flows.

This half of the module has an introduction where the basic elements of HEC-RAS are given, with a description of the mathematical and physical principles used and the special features of the program. This is followed by a presentation of the main elements of the program, data requirements, geometric data, boundary conditions, etc. Then each illustrative example is given with the procedure outlines and figures of the windows shown on the computer, as well as tables with data input. A complete set of the windows input data is given and, in some cases, blank windows are given to show how the data should be input to the program.

Each example has figures of cross sections, logitudinal and perspective views of the stream flows. The output is tabulated in a report at the end of each example, stream velocity, discharge, critical water surface elevation, etc.

The HEC-RAS model can handle a full network of channels, a branching system, or a single river reach. The steady flow component is capable of modeling subcritical, supercritical and mixed flow regime water surface profiles.

The solution of the one-dimensional energy equation is used as the basic computational procedure. The flow in natural and man-made channels is estimated by the use of the one-dimensional Manning equation. Energy losses are evaluated by friction and contraction/expansion coefficients (coefficient multiplied by the change in velocity head). Where the water surface profile is rapidly varied, the momentum equation is utilized. By the use of these equations, the program can handle hydraulic jumps, hydraulics of bridges, and evaluate profiles of stream functions.

The program can also be used to determine the effects of various obstructions such as bridges, culverts, rivers, and structures in the flood plain. Flood plain management and flood insurance studies to evaluate floodway enroachments may be evaluated by the steady flow system component of the program. Also, capabilities are available for assessing the change in watersurface profiles due to the channel improvements, levees, and ice cover.

Special features of the steady flow component include: multiple plan analysis; multiple profile components; and multiple bridge and/or culvert opening analysis.

The HEC-RAS computer model has a large number of options, such as mixed flow regime analysis, allowing analysis of both sub- and supercritical flow regimes in a single computer run, culvert and bridge routines allowing for multiple openings of different types and sizes, quasi 2-D velocity distributions, and x-y-z graphics of the river channel system.

HEC-RAS operates under the MS-Windows environment (version 3.1 or Windows 95) and provides state-of-the-art Graphical User Interface (GUI) graphics for both input and output.

These are four illustrative examples given in the HEC-RAS module:

1) Stream Network Analysis
   The flooding analysis of a stream network located in New Braintree, Massachusetts is given in the first example.

2) Bridge Analysis
   In the second example, a bridge is placed across one of the tributaries in example one and the backwater curves are determined.

3) Curve Analysis
The flooding of the stream network given in example one is determined with the addition of a culvert in one of the tributaries.

4) Encroachment Analysis
In this last example, the backwater curves are determined for obstructions placed in one of the tributaries in the stream network in example one.

Evaluation

The module was alpha tested at Cooper Union. A group of senior and graduate civil engineering students were first given the module to test. The students were taking advanced courses in hydrology and open channel hydraulics. These students critiqued the module after conducting hydrologic (HEC-1) or open channel hydraulic flow (HEC-RAS) projects.

Their comments were incorporated into a revised module. The revised module was given to classes of junior civil engineering students taking their first course in water resource engineering. Again these students critiqued the module in a questionnaire. The module was tested on a total of 57 engineering students at Cooper Union.

In all classes, the students were assigned drainage projects in which the class was instructed to use the module. Each class was separated into groups of 3 to 5 students. Each group was given a different watershed site consisting of a reservoir or drainage pond. The assigned watersheds were different from the watershed used for the illustrative example in the module. The students were asked to determine the flooding potential for their watershed for a 100 year storm. The class was also given a disk containing the HEC-1 program.

After the watershed project, the class was assigned a stream flooding project. Each group of students was given topography for different stream networks with accompanying hydrologic soil properties, inflows and downstream controls. Each group was asked to determine the flood potential of their stream network using the second half of the module and the HEC-RAS program, which was given to each group on a disk.

The module was also beta tested at FIU and CWRU by both engineering faculty and engineering students. The beta tests at these schools were similar to the alpha tests (described above) conducted at Cooper Union. The critiqued material was incorporated into the module. This module is presently being used at Cooper Union in its civil engineering water resource engineering course.

Implementation

The module will be incorporated into CE 142, "Water Resource Engineering", a second semester junior level Civil Engineering course. There is a three hour weekly laboratory/ problem solving session scheduled for the Spring 1998 term. The module will be assigned to groups of 3 to 4 students by giving each group a watershed/river site. Each group will use this module to determine the runoff and flood characteristics of the site. These projects will be a required exercise for each student group and take about half a semester.

The three hour laboratory/problem solving session of CE142 will be revised. This laboratory/problem solving session will consist of:

1. Short lectures (20% of course)
2. Problem-solving in class using the module (60% of course)
3. Problem-solving on the Internet using the module (20% of course)

The short lectures will introduce the subject, such as, descriptive and quantitative hydrology, and open channel hydraulics in a rural stream environment. This will be followed by reading assignments and problem solving. All of these lectures and problems will be designed so the students will be prepared to use the module.

Each student group will be given a water shed site and reservoir in the tri-state area (NY, NJ, CT). In an open classroom, each group will be asked to determine runoff and routing characteristics of their watersheds.

The HEC-1 program will be an integral part of their solutions. The overflow from the reservoir will be directed into a natural stream where flooding will be determined by the use of the HEC-RAS program.

There will be tutoring sessions whenever necessary. The professor and student aids (graduate students familiar with HEC-1 and HEC-RAS) will be in the open classroom to guide the student.

Each student will have to continue their drainage project in a virtual classroom on the Internet. They will be able to ask questions and interact with the professor and/or student aid on the Internet.

There will be specific milestones set for the class (such as: determination of the hydraulic properties, time of concentration, precipitation characteristics, etc.), to assure that the students stay on schedule. A written report will be presented by each student group summarizing the terms' work. Each student will also present their work in front of the class. These presentations will be videoconferenced to FIU where the staff (Professor and students) will be able to interact with and ask questions of the Cooper Union students.

References

1. Linsky, R., Franzini, J., and Tchobanoglous; "Water Resource Engineering," McGraw-Hill, New York, 1992

2. Viessman, W., Lewis, G., and Knapp, J.; "Introduction to Hydrology," Harper and Row, New York, 1989

3. Hoggan, D.; "Computer Assisted Floodplain Hydrology and Hydraulics," McGraw-Hill, New York, 1989

4. "HEC-1 Flood Hydrograph Package;" U.S. Army Corps of Engineers, Davis, California, 1990

5. "HEC-RAS Analysis System;" U.S. Army Corps of Engineers, Davis, California, 1995

Biographical Information

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