Chapter 1

Introduction

1.1 Model Purpose and Philosophy

HEC-6 is a one-dimensional movable boundary open channel flow numerical model designed to simulate and predict changes in river profiles resulting from scour and/or deposition over moderate time periods (typically years, although applications to single flood events are possible). A continuous flow record is partitioned into a series of steady flows of variable discharges and durations. For each flow a water surface profile is calculated thereby providing energy slope, velocity, depth, etc. at each cross section. Potential sediment transport rates are then computed at each section. These rates, combined with the duration of the flow, permit a volumetric accounting of sediment within each reach. The amount of scour or deposition at each section is then computed and the cross section adjusted accordingly. The computations then proceed to the next flow in the sequence and the cycle is repeated beginning with the updated geometry. The sediment calculations are performed by grain size fraction thereby allowing the simulation of hydraulic sorting and armoring. Features of HEC-6 include: capability to analyze networks of streams, channel dredging, various levee and encroachment alternatives, and to use several methods for computation of sediment transport rates.

Separation of sediment deposition from the hydraulics of flow is valid in some circumstances; for example, deposition in deep reservoirs can usually be characterized as a progressive reduction in storage capacity if the material is rarely entrained once it is deposited. Prediction of sediment behavior in shallow reservoirs and most rivers, however, requires that the interactions between the flow hydraulics, sediment transport, channel roughness and related changes in boundary geometry be considered. HEC-6 is designed to incorporate these interactions into the simulation.

HEC-6 simulates the capability of a stream to transport sediment, given the yield from upstream sources. This computation of transport includes both bed and suspended load as described by Einstein's Bed-Load Function (1950)[1]. A reach of river with a bed composed of the same type of sediment material as that moving in the stream is termed an "alluvial" reach (Einstein 1950). Einstein recognized that an alluvial reach provides a record of the sediment that the stream has, and does, transport. That record is reflected in the materials that form the stream boundaries. Using the hydraulic properties of the flow and the characteristics of the sediment material (which can be determined by analyzing samples of the riverbed sediment particles), one can compute the rate of sediment transport. HEC-6 implements similar concepts to compute the movement of sediment materials for a temporal sequence of flows and, through volume conservation of bed material, changes in channel dimensions. The transport, deposition, and erosion of silts and clays may also be calculated. Effects of the creation and removal of an armor layer are also simulated.

[1] Although Einstein's Bed-Load Function is not included in this version of HEC-6, his concepts of particle movement and interchange have guided development of the algorithms used in HEC-6 to describe the dynamic interactions between bed material composition and bed material transport.

1.2 Applications of HEC-6

A dynamic balance exists between the sediment moving in a natural stream, the size and gradation of sediment material in the stream's boundaries and the flow hydraulics. When a reservoir is constructed, flood damage reduction measures are implemented, or a minimum depth of flow is maintained for navigation, that balance may be changed. HEC-6 can be used to predict the impact of making one or more of those changes on the river hydraulics, sediment transport rates, and channel geometry.

HEC-6 is designed to simulate long-term trends of scour and/or deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and/or stage, or from modifying the channel geometry (e.g., encroaching on the floodplains). HEC-6 can be used to evaluate deposition in reservoirs (both the volume and location of deposits), design channel contractions required to maintain navigation depths or decrease the volume of maintenance dredging, predict the influence that dredging has on the rate of deposition, estimate possible maximum scour during large flood events, and evaluate sedimentation in fixed channels. Some early applications of HEC-6 were described by Thomas and Prasuhn (1977) and more recent application advice is provided by HEC (1992). Guidelines for performing sedimentation studies is given in USACE (1989) and river hydraulics studies in USACE (1993).

1.3 Overview of Manual

This manual describes the fundamental concepts, numerical model limitations and capabilities, computational procedures, input requirements and output of HEC-6. A brief description of model capabilities and the organization of this manual is presented below.

Theoretical Basis For Movable Boundary Calculations (Chapter 2)

This chapter describes the theoretical basis for hydraulic and sediment computations used in the computer program HEC-6. It presents the general capabilities of the program and describes how the computations are performed.

General Input Requirements (Chapter 3)

This chapter describes the general data requirements of HEC-6. It describes the input data required for implementation of specific HEC-6 capabilities.

Program Output (Chapter 4)

This chapter provides information on the various output levels available for displaying the geometric, sediment, and hydrologic data; and for listing the initial and boundary conditions. It also describes how to save desired information at selected times during a simulation.

Modeling Guidelines (Chapter 5)

General modeling guidelines and additional information on how HEC-6 performs its computations are presented in this chapter.

Example Problems (Chapter 6)

This chapter gives example applications of HEC-6. It covers single river and network situations and some commonly used features of the program.

1.4 Summary of HEC-6 Capabilities

1.4.1 Geometry

A river system consisting of a main stem, tributaries and local inflow/outflow points can be simulated. Such a system in which tributary sediment transport is calculated is referred to in this document as a network model. Sediment transport is calculated by HEC-6 in primary rivers and tributaries. There will be upper limits on the number of network branches, number of cross sections, etc., due to computer memory limitations. As these may change among HEC-6 implementations on various computer systems, the user should check the header on the output file to determine the limits of the particular version being used.

1.4.2 Hydraulics

The one-dimensional energy equation (USACE 1959) is used by HEC-6 for water surface profile computations. Manning's equation and *n* values for overbank and channel areas may be specified by discharge or elevation. Manning's *n* for the channel can also be varied by Limerinos' (1970) method using the bed gradation of each cross section. Expansion and contraction losses are included in the determination of energy losses. The energy loss coefficients may be changed at any cross section.

For each discharge in a hydrograph, the downstream water surface elevation can be determined by either a user-specified rating curve or a time dependent water surface elevation. Internal boundary conditions can be imposed on the solution. The downstream rating curve can be changed at any time. Internal boundary conditions can also be changed at any time.

Flow conveyance limits, containment of the flow by levees, ineffective flow areas, and overtopping of levees are simulated in a manner similar to HEC-2. Split flow computations are not done and no special capability for computing energy losses through bridges is available. Supercritical flow, should it occur, is approximated by normal depth; therefore, sediment transport phenomena occurring in supercritical reaches are simplified in HEC-6.

HEC-6 can be executed in "fixed bed" mode, which is similar to an HEC-2 application, in that only water surface profiles are computed. Sediment information such as inflowing sediment load and bed gradations are not needed to run HEC-6 in fixed-bed mode.

1.4.3 Sediment

Sediment transport rates are calculated for grain sizes up to 2048 mm. Sediment sizes larger than 2048 mm, that may exist in the bed, are used for sorting computations but are not transported. For deposition and erosion of clay and silt sizes up to 0.0625 mm, Krone's (1962) method is used for deposition and Ariathurai and Krone's (1976) adaptation of Parthenaides' (1965) method is used for scour. The default procedure for clay and silt computations allows only deposition using a method based on settling velocity.

The sediment transport function for bed material load is selected by the user. Transport functions available in the program are the following:

a. Toffaleti's (1966) transport function
b. Madden's (1963) modification of Laursen's (1958) relationship
c. Yang's (1973) stream power for sands
d. DuBoys' transport function (Vanoni 1975)
e. Ackers-White (1973) transport function
f. Colby (1964) transport function
g. Toffaleti (1966) and Schoklitsch (1930) combination
h. Meyer-Peter and Müller (1948)
i. Toffaleti and Meyer-Peter and Müller combination
j. Madden's (1985, unpublished) modification of Laursen's (1958) relationship
k. Modification by Ariathurai and Krone (1976) of Parthenaides' (1965) method for scour and Krone's (1962) method for deposition of cohesive sediments
l. Copeland's (1990) modification of Laursen's relationship (Copeland and Thomas 1989)
m. User specification of transport coefficients based upon observed data

The above methods (except for method a.), utilize the Colby (1964) method for adjusting the sediment transport potential when the wash load concentration is high. Armoring and destruction of the armor layer are simulated based upon Gessler's (1970) approach. Deposition or scour is modeled by moving each cross section point within the movable bed (i.e., the area which is shifted vertically each time step due to sediment movement).

The movable bed limits may extend beyond the channel bank "limits". Deposition is allowed to occur in all wetted areas, even if the wetted areas are beyond the conveyance or movable bed limits. Scour occurs only within the movable bed limits. Sediment transport potential is based upon the hydraulic and sediment characteristics of the channel alone. Simulation of geological controls such as bedrock or a clay layer may be done by specifying a minimum elevation for the movable bed at any particular cross section.

The sediment boundary conditions (inflowing sediment load as a function of water discharge) for the main river channel, its tributaries and local inflow/outflow points can be changed with time. HEC-6 has the capability to simulate the diversion of water and sediment by grain size. A transmissive boundary condition is available at each downstream boundary; this boundary condition forces all sediment entering that section to pass it, resulting in no scour or deposition at that section.

1.4.4 General

Computed information includes the total sediment discharge passing each cross section and the volume of deposits (or scour) accumulated at each cross section from the beginning of the simulation. HEC-6 also has the ability to simulate the effects of dredging activities. Dredging can be initiated when a depth of deposition is exceeded or can occur on a periodic basis. Dredging can also be based upon a required minimum depth for navigation.

Should a river network of a main stem and tributaries be simulated, HEC-6 uses the same data that previous versions had used if each river and tributary segment were being analyzed independently. Control point data must be supplied to link the geometric segments together into a complete stream network. Data sets from earlier versions of HEC-6 that include local inflows can be used if all $TRIB records are replaced by $LOCAL records and a water temperature is entered for each local inflow point.

1.5 Theoretical Assumptions and Limitations

HEC-6 is a one-dimensional continuous simulation model that uses a sequence of steady flows to represent discharge hydrographs. There is no provision for simulating the development of meanders or specifying a lateral distribution of sediment load across a cross section. The cross section is subdivided into two parts with input data; that part which has a movable bed, and that which does not. The movable bed is constrained within the limits of the wetted perimeter and other limitations that are explained later. The entire wetted part of the cross section is normally moved uniformly up or down; an option is available, however, which causes the bed elevation to be adjusted in horizontal layers when deposition occurs. Bed forms are not simulated; however, *n* values can be input as functions of discharge, which indirectly permits consideration of the effects of bed forms if the user can determine those effects from measured data. Limerinos' (1970) method is available as an option for computation of bed roughness. Density and secondary currents are not simulated.

There are three restrictions on the description of a network system within which sediment transport can be calculated with HEC-6:

a. Sediment transport in distributaries is not possible.
b. Flow around islands; i.e., closed loops, cannot be directly accommodated.
c. Only one junction or local inflow point is allowed between any two cross sections.

1.6 Single Event Analysis

HEC-6 is designed to analyze long-term scour and/or deposition. Single flood event analyses must be performed with caution. HEC-6 bed material transport algorithms assume that equilibrium conditions are reached within each time step (with certain restrictions that will be explained later); however, the prototype is often influenced by unsteady non-equilibrium conditions during flood events. Equilibrium may not occur under these conditions because of the continuously changing hydraulic and sediment dynamics. If such situations predominate, single event analyses should be performed only on a qualitative basis. For gradually changing sediment and hydraulic conditions, such as for large rivers with slow rising and falling hydrographs, single event analyses may be performed with confidence.