A

MAJOR PROJECT REPORT

ON

COMPUTATION OF SEDIMENT DISTRIBUTION IN STORAGE RESERVOIRS

A thesis submitted in partial fulfillment of the requirement for the degree of

MASTER OF ENGINEERING

IN

HYDRAULICS AND FLOOD CONTROL ENGINEERING

Submitted By

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CERTIFICATE

This is to Certify that the Major Project Work entitled "**COMPUTATION OF SEDIMENT DISTRIBUTION IN STORAGE RESERVOIRS**" which is being submitted by **Mr. DILIP KUMAR,** in partial fulfillment for the award of the degree of **MASTER OF CIVIL ENGINEERING IN HYDRAULICS AND FLOOD CONTROL ENGINEERING** is a record of student's own work carried out by him under my supervision and guidance. The matter of this project has not been submitted by the student for the award of other Degree or Diploma.

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DATE:

(DILIP KUMAR)

ABSTRACT

The planning or design of a reservoir requires an analysis to determine how sediment deposits will be distributed in the reservoir. This is a difficult aspect of reservoir sedimentation because of the complex interaction between hydraulics of flow, reservoir operating policy, inflowing sediment load, and changes in the reservoir bed elevation. The traditional approach to analyzing the distribution of deposits has relied on empirical methods, all of which require a great deal of simplification from the actual physical problem. Firstly, an Empirical Area Reduction method is considered for analysis of sediment distribution. To know the new zero level at dam and sediment distribution in reservoir, using Empirical Area Reduction method, a computer program in C++ has been developed. For graphical presentation, Microsoft excel has been used. Software 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. In present thesis work Software HEC-6 has been used to compute sediment distribution in reservoir. HEC-6 has several advantages over Empirical Area Reduction method provided the requisite data are available. Lastly, the result obtained from these methods has been compared.

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LIST OF SYMBOLS

a_i	Incremental area.
a_0	Relative reservoir area at new zero depth.
A	Reservoir surface area.
A_j	Area of subsection
A_0	Total reservoir area at zero depth.
A_t	Total area of cross section
A_1	Downstream area of the flow normal to the cross sections
A_2	Upstream area of the flow normal to the cross sections
A(pH)	Reservoir area
B	Ccoefficient of consolidation for silts or clay
B_o	Width of movable bed
C_L	Loss coefficient for expansion or contraction
d	Grain diameter
D	Water depth
D_e	The minimum water depth for negligible sediment transport (i.e., equilibrium depth) for grain size d
Dy	Incremental depth.
F_{CL}	Fraction of clay in the deposit
F_{SA}	Fraction of sand in the deposit
F_{SL}	Faction of silt in the deposit
g	Acceleration of gravity
G	Average sediment discharge rate during time step Δt
h	A function of one of four types of theoretical design curves.
h_e	Energy loss
h'	A function of particular reservoir and its anticipated storage.
H	Total depth of reservoir at normal water surface.
K	Constant of proportionality for converting relative sediment area to actual area for a given reservoir, and
K'_t	Length-weighted subsection conveyance
L_j	Length of the jth strip between subsections
n	Manning's roughness coefficient
NSS	Total number of subsections across each cross section

P_d	**Porosity of deposits**
P_j	**Wetted perimeter of subsection**
P_i	**Incremental wetted perimeter**
q	**Water discharge per unit width of flow**
Q	**Water discharge**
R_j	**Hydraulic radius of subsection**
R_1	**Downstream hydraulic radius.**
R_2	**Upstream hydraulic radius.**
S	**Total sediment to be deposited in the reservoir.**
SG	**Specific gravity of sediment particles**
t	**Time**
T	**Accumulated time in years**
v_0	**Relative reservoir volume at new zero depth.**
V_0	**Total reservoir volume at new zero depth.**
$V(pH)$	**Reservoir capacity.**
V_1	**Average velocity (total discharge ÷ total flow area) at downstream end of reach**
V_2	**Average velocity (total discharge ÷ total flow area) at upstream end of reach**
W	**Width of an incremental area.**
W_t	**Total water surface width**
WS_1	**Water surface elevations at downstream end of reach**
WS_2	**Water surface elevations at upstream end of reach**
y_o	**The zero elevation at the dam after the sediment inflow period.**
Y	**Unit weight of water**
Y_s	**Unit weight of sediment**
Y_{SA}	**Unit weight of sand**
Y_{CL}	**Unit weight of clay**
Y_{SL}	**Unit weight of silt**
ρ_s	**Density of sand grains**
ρ_f	**Density of water**
α	**Velocity distribution factor**
α_1	**Velocity distribution coefficients for flow at downstream end of reach.**
α_2	**Velocity distribution coefficients for flow at upstream end of reach.**

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 General

When a barrier is constructed across some river in the form of a dam, water gets stored in the upstream side of the dam and a pool of water, generally called a dam reservoir or an impounding reservoir, is formed. Reservoirs interrupt the flow of water and, therefore the sediment. The reservoir causes a change in the upstream hydraulics of flow depth, velocity, etc. by forcing the energy gradient to approach zero. This results in reduction of transport capacity of river and subsequent sediment deposition in the reservoir. The reservoir also alters the downstream flood hydrograph and reduces the sediment supply, which may lead to the degradation of the downstream channel.

Life of reservoir is usually taken as the period through which the capacity occupied by sediment does not prevent the reservoir from serving its intended primary purpose. But even after this period it may be left with storage capacity of considerable economic value. It may then be able to serve a lesser command area or generate lesser amount of energy but remain economically efficient. It may then be put to use by itself or in conjunction with other system, but when all feasible methods of utilizing the reservoir prove economically inefficient, it may be viewed as totally useless.

Generally, the practice in India has been to adopt 100 years as the life of reservoir and to provide a silt storage space (dead storage) equal to the estimated total volume of silt deposition during its entire life.

1.2 Methods for Computation of Reservoir Life

Different methods are available to estimate life of reservoir. Use of these methods is entirely based upon availability of data. Two methods have been taken for analysis.

1.2.1 Empirical area reduction method

Empirical Area Reduction method has been developed based on data collection by actual reservoir. This method is entirely an empirical approach. Detailed about this method has been explained in subsequent chapter.

1.2.2 Use of Software HEC-6

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. HEC-6 can be used to evaluate deposition in reservoirs, both the volume and location of deposits. After knowing the sediment distribution in reservoir, life of reservoir can be estimated.

1.3 Scope of Work

The computation of sediment distribution in reservoir is a difficult aspect of reservoir sedimentation. Keeping in view the importance of sediment distribution in reservoir and its effect on modifying the capacity elevation curve present study is aimed to obtain the following:

(a) To obtain the data on live projects for carrying out reservoir-sedimentation studies.

(b) To obtain the sediment distribution in the reservoir by Empirical Area Reduction method and subsequently compute its anticipated life.

(c) To obtain the sediment distribution in reservoir using HEC-6 Software and then compute the life of reservoir.

(d) Compare the values obtain from these two methods.

CHAPTER 2
REVIEW OF LITERATURE

2.1 General

Methods for predicting sediment distribution in reservoir has been described in this chapter. Different terms used while calculating life of reservoir has also been elaborated as and when appeared different formula associated with these methods has been discussed.

2.2 Distribution of Sediment in Reservoir

Sediment distribution in reservoir is very important in planning our conservation structures and requires careful consideration at the design stage itself. This is a difficult aspect of reservoir sedimentation because of the complex interaction between hydraulics of flow, reservoir operating policy, inflow of sediment load, and changes in the reservoir bed elevation. The designer is interested to know how the sediment would accumulate at the dam during a given period for deciding the sill elevation of the outlets and the penstocks gate elevation etc. For the purposes of allocation of different storages, the pattern of sediment distribution needs special consideration in order to allow necessary storage for silt accumulation as silt is distributed throughout the reservoir. The pattern is also necessary in order to estimate the region where delta would be forming and consequent increase in back water levels after the reservoir comes into operation. The back water levels are important particularly if reach happens to be in a developing area.

2.2.1 Main channel deposition

Conceptually, deposition starts in the main channel. As flow enters a reservoir, the main channel fills at the upstream end until the elevation is at or above the former over bank elevations on either side. Flow then shifts laterally to one side or the other. During periods of high water elevation, deposition will move upstream. As the reservoir is drawn down, a channel is cut into the delta deposits and subsequent deposition moves material farther into the reservoir. The lateral location of the channel may shift from year to year, but the hydraulic characteristics will be similar to those of the natural channel existing prior to impounding the reservoir.

2.2.2 Sediment diameters

The diameter of sediment particles commonly transported by streams ranges over different sizes. Generally, the coarse material will settle first in the outer reaches of the reservoir followed by progressively finer fractions farther down toward the reservoir dam. Based on this depositional pattern, the reservoir is divided into three distinct regions: topset beds, foreset beds, and bottomset beds as shown in Fig.2.1. The top-set bed is located in the upper part of the reservoir and is largely composed of coarse material or bed load. While it may have a small effect on the reservoir storage capacity, it could increase upstream stages. The fore-set region represents the live storage capacity of the reservoir and comprises the wash load. The bottom-set region is located immediately upstream of the dam.

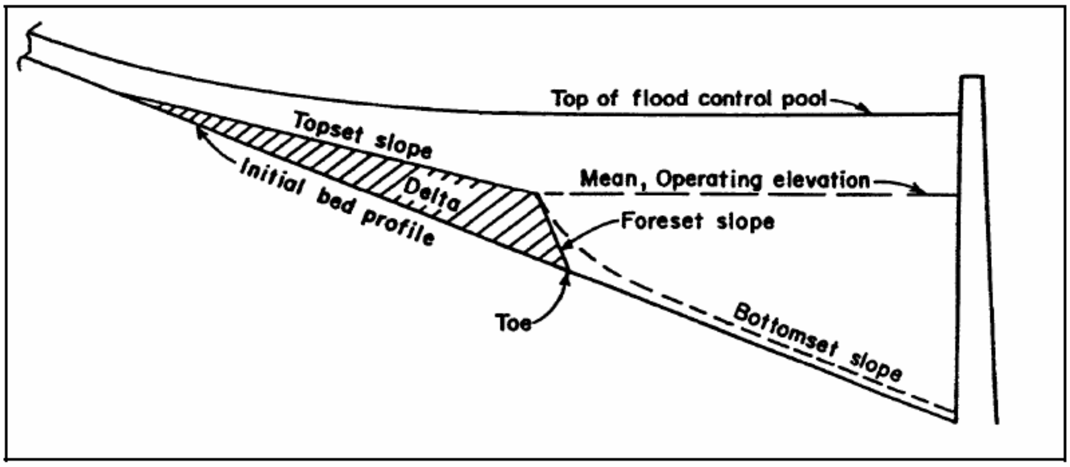

Fig 2.1 Pattern of Sediment Deposits in a Reservoir

2.2.3 Reservoir shape

Reservoir shape is an important factor in calculating the deposition profile. For example, flow entering a wide reservoir spreads out, thus reducing transport capacity, but the path of expanding flow does not necessarily follow the reservoir boundaries. It becomes a 2-dimensional problem to calculate the flow distribution across the reservoir in order to approximate transport capacity and, therefore, the resulting deposition pattern. On the other hand, flow entering a narrow reservoir has a more uniform distribution across the section resulting in hydraulic conditions that are better approximated by 1- dimensional hydraulic theory.

2.3 Classification of Reservoir into Different Type

From the sedimentation survey of several reservoirs in the United States, the distribution pattern of sediment has been classified into four standard types. These reservoirs vary in their capacity from 4920 ha-m to 36.9 ha-m and also vary in their catchments characteristics, location, sediment characteristics, and operation schedule, etc. The re-survey data indicate that a definite relationship exists between the reservoir shape and the percentage of sediment deposited at various depths throughout the reservoir.

The classification of reservoir is as follows:

M	Reservoir type	Standard classification
1-1.5	Gorge	IV
1.5-2.5	Hill	III
2.5-3.5	Flood plain-foot hill	II
3.5-4.5	Lake	I

Here 'M' is the reciprocal of the slope of the line obtained by plotting reservoir depths as ordinate and reservoir capacity as abscissa on log-log paper. It is first necessary to determine the type which fits a given reservoir. This is generally obtained by plotting the elevation-capacity relationship on log-log paper which gives a straight line and the slope of the line broadly indicates the type. Sometime the type may require suitable modification depending upon the other characteristics such as capacity-inflow ratio, characteristics of sediment, and reservoir operation. If a type III shaped reservoir is to be drawn down severely at frequent intervals or the sediment is predominantly clay, it should be classified as a type IV because a greater portion of the sediment is deposited near the bottom of type IV reservoir.

2.4 Empirical Area Reduction Method

Regarding the distribution pattern Borland and Milller [1] have suggested two methods in predicting the distribution pattern. The first is strictly mathematical and is called area-incremental method. The second method is mathematical procedure based on the observations of sediment distribution in several reservoirs and is known as Empirical Area Reduction Method.

The basic equation for developing Area Reduction Method can be expressed as:

$$S = \int_{0}^{y_0} A dy + \int_{y_0}^{H} K a dy \qquad (2.1)$$

where,

S=total sediment to be deposited in the reservoir.

0=original zero elevation at the dam.

y_o=the zero elevation at the dam after the sediment inflow period.

A=reservoir surface area.

dy=incremental depth.

H=total depth of reservoir at normal water surface.

K=constant of proportionality for converting relative sediment area to actual area for a given reservoir, and

a=relative sediment area.

By integration and simplification of equation 2.1, the following relationship can be developed:

$$\frac{1-v_0}{a_0} = \frac{S-V_0}{HA_0} \qquad (2.2)$$

where,

v_0 = relative reservoir volume at new zero depth.

a_0 = relative reservoir area at new zero depth.

V_0 = total reservoir volume at new zero depth.

H = original depth of reservoir, and

A_0 = total reservoir area at zero depth.

Then by defining two new terms:

$$h(p) = \frac{1-v(p)}{a(p)} \tag{2.3}$$

$$h^{'}(p) = \frac{S-V(pH)}{H \times A(pH)} \tag{2.4}$$

where,

h=a function of one of four types of theoretical design curves.

h' =a function of particular reservoir and its anticipated storage.

V(pH)= reservoir capacity.

A(pH)= reservoir area

2.4.1 Relative depth

Relative depth is calculated for each elevation. Relative depth is computed by dividing original depth (difference between the top elevation and bottom elevation) to the difference between corresponding elevation and bottom elevation.

2.4.2 Relative area

For different type of reservoir the formula used to calculate the relative area is as follows:

For type I,

$$a=5.07p^{1.85}(1-p)^{0.36} \tag{2.5a}$$

For type II,

$$a=2.487p^{0.57}(1-p)^{0.41} \tag{2.5b}$$

For type III,

$$a=16.967\,p^{-1.15}(1-p)^{2.32} \tag{2.5c}$$

For type IV,

$$a=1.486p^{-0.25}(1-p)^{1.34} \tag{2.5d}$$

2.4.3 Sediment area

Constant K is calculated by dividing relative area to the reservoir area at the new zero elevation. After multiplying the relative area to constant, K sediment area is obtained at desired elevations.

2.4.4 Steps in computation of life of reservoir

The following steps are required to compute the sediment deposition pattern and subsequently the life of reservoir:

(i) Obtain Area-Capacity curve for given data.

(ii) Compute the inflow of sediment into reservoir.

(iii) Draw depth-capacity relationship on log-log paper. Find the value of 'M' and then classify type of reservoir.

(iv) Compute the new zero-elevation at the dam site that corresponds to the elevation up to which sediment is filled adjacent to the dam.

(v) Fill the columns 1,2 and 3 using the data given, see Table 2.1

(vi) Compute the relative depth in column 4 (Table 2.1).

(vii) Compute the relative area in column 5 (Table 2.1) using equation 2.5.

(viii) Compute constant K_1 by dividing reservoir area by relative area both at new zero elevation. After multiplying the relative area to K_1 sediment area is obtained at other elevations and inserted in column 6 (Table 2.1).

(ix) Compute the sediment volumes in column 7 (Table 2.1) using trapezoidal rule.

(x) Accumulate the values in column 7 (Table 2.1) to complete column 8 (Table 2.1). If the accumulated total sediment volume does not agree with the total sediment inflow then a new value for K_2 is computed, as K_2 = (K_1 X Total sediment inflow)/ (Accumulated value of column 7).

(xi) Steps (viii) to (x) are repeated till accumulated sediment volume equals total sediment inflow in given period.

(xii) Compute column 9 (Table 2.1) as difference between column 2 (Table 2.1) and column 6 (Table 2.1) to get revised area.

(xiii) Compute column 10 (Table 2.1) as difference between column 3 (Table 2.1) and column 8 (Table 2.1) to get revised capacity.

(xiv) Plot revised capacity vs. elevation for ages. From there find the value of capacity at dead level.

(xv) Plot age vs. revised capacity at normal pool level and also capacity at dead storage, from this curve Life of Reservoir can be found.

Table 2.1 Sediment Deposition Computation

Elevation (m)	**Original Area(ha)**	**Original Capacity**	**Relative Depth**	**Ap Type**	**Sediment Area**	**Sediment Volume**	**Accumulated Sediment volume**	**Revised Area (ha)**	**Revised Capacity (ha- m)**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

2.5 HEC-6 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. 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. 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.

2.5.1 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. 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.

2.5.2 Summary of HEC-6 capabilities

Geometry

A river system consisting of a main stem, tributaries and local inflow/outflow points can be simulated. 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.

Hydraulics

The one-dimensional energy equation is used by HEC-6 for water surface profile computations. Manning's equation and n values for over bank and channel areas may be specified by discharge or elevation. 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.

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 method is used for deposition and Ariathurai and Krone's adaptation of Parthenaides' 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. Different methods are available in the program. 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.

2.5.3 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. 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:

i. Sediment transport in distributaries is not possible.

ii. Flow around islands; i.e., closed loops, cannot be directly accommodated.

iii. Only one junction or local inflow point is allowed between any two cross sections.

2.5.4 Theoretical basis for movable boundary calculations

HEC-6 processes a discharge hydrograph as a sequence of steady flows of variable durations. Using continuity of sediment, changes are calculated with respect to time and distance along the study reach for the following: total sediment load, volume and gradation of sediment that is scoured or deposited, armoring of the bed surface and the cross section elevations. In addition, sediment outflow at the downstream end of the study reach is calculated. The location and amount of material to be dredged can be obtained if desired.

Geometry

Geometry of the river system is represented by cross sections which are specified by coordinate points (stations and elevations) and the distances between cross sections. HEC-6 raises or lowers cross section elevations to reflect deposition and scour. The horizontal locations of the channel banks are considered fixed and the floodplains on each side of the channel are considered as having fixed ground locations; however, they will be moved vertically if they are within the movable bed limits specified by the user.

Hydraulics and hydrology

The water discharge hydrograph is approximated by a sequence of steady flow discharges, each of which continues for a specified period of time. Water surface profiles are calculated for each flow using the standard-step method to solve the energy and continuity equations. Friction loss is calculated by Manning's equation and expansion and contraction losses are calculated if the loss coefficients are specified. Hydraulic roughness is described by Manning's n values and can vary from cross section to cross section. At each cross section n values may vary vertically or with discharge. The downstream water surface elevation must be specified for subcritical water surface profile calculations. In the case of a reservoir the operating rule may be utilized, but if open river conditions exist, a stage-discharge rating curve is usually specified as the downstream boundary condition. A boundary condition or operating rule may be used at any location along the main stem or tributaries.

Sediment transport

Inflowing sediment loads are related to water discharge by sediment-discharge curves for the upstream boundaries of the main stem, tributaries and local inflow points. For realistic computation of stream behavior, particularly scour and stable conditions, the gradation of the material forming the stream bed must be measured. HEC-6 allows a different gradation at each cross section. If only deposition is expected, the gradation of material in the bed is less important.

Sediment gradations are classified by grain size using the American Geophysical Union scale. HEC-6 will compute transport potential for clay (particles less than 0.004 mm diameter), four classes of silt (0.004-0.0625 mm), five classes of sand (from very fine sand, 0.0625 mm, to very coarse sand, 2.0 mm), five classes of gravel (from very fine gravel, 2.0 mm, to very coarse gravel, 64 mm), two class of cobbles (from small, 64mm, to large cobbles, 256mm) and three classes of boulders (from small, 256mm, to large boulders, 2048mm).

Transport potential is calculated at each cross section using hydraulic information from the water surface profile calculation (e.g., width, depth, energy slope, and flow velocity) and the gradation of bed material. Sediment is routed downstream after the backwater computations are made for each successive discharge (time step).

2.5.5 Theoretical basis for hydraulic calculations

Equations for water surface profile calculations

The hydraulic parameters needed to calculate sediment transport potential are velocity, depth, width and energy slope - all of which are obtained from water surface profile calculations. The one dimensional energy equation (Equation 2-6) is solved using the standard step method and the hydraulic parameters are calculated at each cross section for each successive discharge. Figure 2-2 shows a representation of the terms in the energy equation.

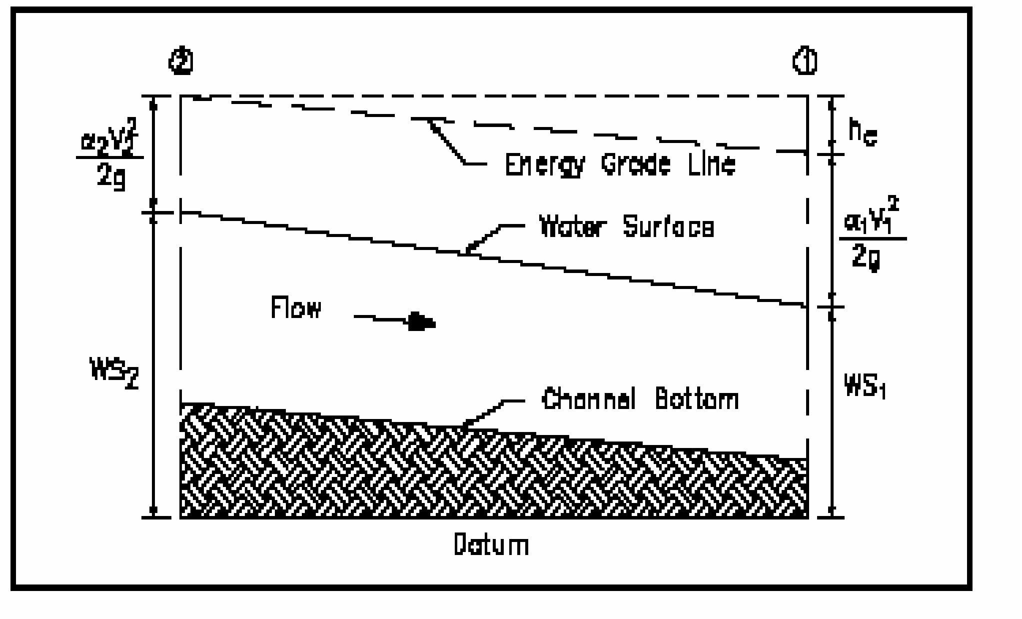

Fig. 2.2 Explanatory Terms of Energy Equation

$$WS_2 + \frac{\alpha_2 V_2^2}{2.g} = WS_1 + \frac{\alpha_1 V_1^2}{2.g} + h_e \qquad (2.6)$$

where:

g = acceleration of gravity

$\mathbf{h_e}$ = energy loss

$\mathbf{V_1}$, $\mathbf{V_2}$ = average velocities (total discharge ÷ total flow area) at ends of reach

$\mathbf{WS_1}$, $\mathbf{WS_2}$ = water surface elevations at ends of reach

α_1, $\boldsymbol{\alpha_2}$ = velocity distribution coefficients for flow at ends of reach.

Hydraulic losses

Friction losses

River geometry is specified by cross sections and reaches lengths, friction losses are calculated. The energy loss term, $\mathbf{h_e}$, in Equation 2-6 is composed of friction loss, $\mathbf{h_f}$, and form losses, **h₀**, as shown in Equation 2-7. Only contraction and expansion losses are considered in the geometric form loss term.

$$h_e = h_f + h_0 \tag{2.7}$$

To approximate the transverse distribution of flow, the river is divided into strips having similar hydraulic properties in the direction of flow. Each cross section is subdivided into portions that are referred to as subsections. Friction, $\mathbf{h_f}$, loss is calculated as shown below

$$h_f = \left[\frac{Q}{K'_t}\right]^2 \tag{2.8}$$

in which:

$$K'_t = \sum_{j=1}^{NSS}\left[\frac{1.49}{n_j}\right]\frac{\frac{(A_2 + A_1)}{2}\left[\frac{R_2 + R_1}{2}\right]_j^{2/3}}{\sqrt{L_j}} \tag{2.9}$$

where:

$\mathbf{A_1}$, $\mathbf{A_2}$ = downstream and upstream area, respectively, of the flow normal to the cross sections

NSS = total number of subsections across each cross section

$\mathbf{K'_t}$ = length-weighted subsection conveyance

$\mathbf{L_j}$ = length of the jth strip between subsections

n = Manning's roughness coefficient

Q = water discharge

$\mathbf{R_1}$, $\mathbf{R_2}$ = downstream and upstream hydraulic radius, respectively.

Other losses

Energy losses due to contractions and expansions are computed by the following equation:

$$h_0 = C_L\left[\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right] \tag{2.10}$$

where:

$\mathbf{C_L}$ = loss coefficient for expansion or contraction

If the quantity within the absolute value notation is negative, flow is contracting and **C_L** is the coefficient of contraction; if it is positive, flow is expanding and **C_L** is the coefficient of expansion.

Computation of hydraulic elements

Each cross section is defined by coordinates (X,Y) as shown in Figure 2-3. For convenience of assigning n values, reach lengths, etc., each cross section is divided into subsections, usually consisting of a main channel, with left and right over banks.

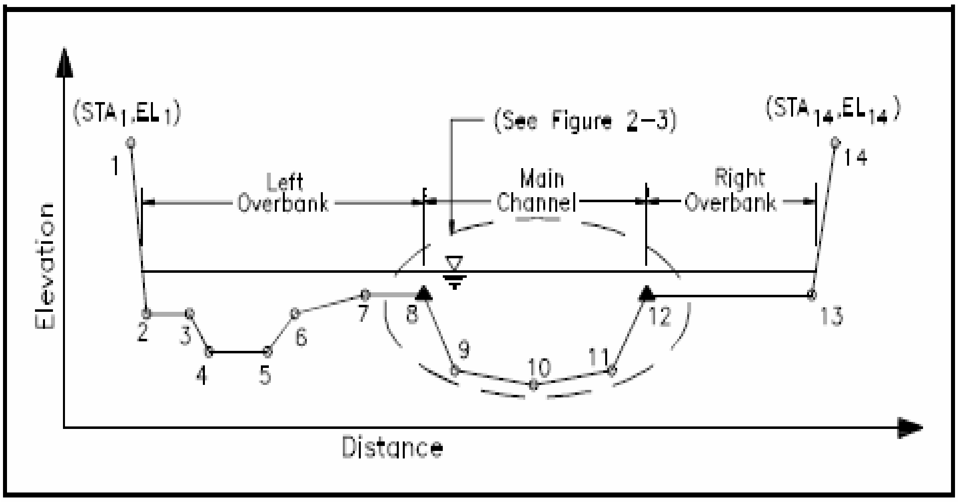

Fig. 2.3 Typical Representation of a Cross Section

Subsection area

The area of each subsection is computed by summing incremental areas below the water surface between consecutive coordinates of the cross section. Figure 2-4 illustrates the technique with a subsection of Figure 2-3 where STCHL and STCHR are the lateral boundaries of the subsection.

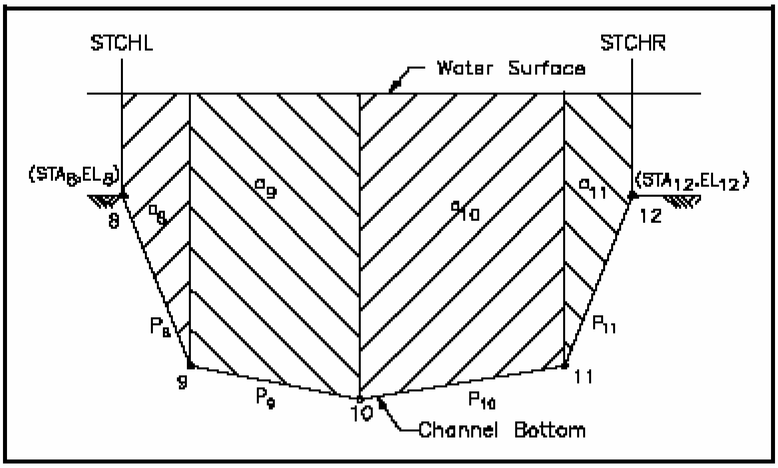

Fig. 2.4 Incremental Area in Channel Subsection

The area of the channel subsection is:

$$A_j = a_8 + a_9 + a_{10} + a_{11} \tag{2.11}$$

where:

a$_i$ = incremental area.

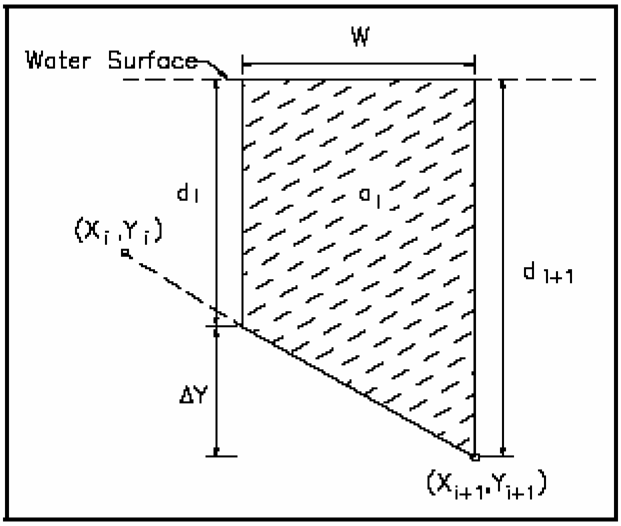

Fig. 2.5 Incremental Area

The equation for an incremental area, **a**$_i$, is:

$$a_i = \frac{(d_i + d_{i+1})W}{2} \qquad (2.12)$$

where:

d_i, d_{i+1} = the left and right depth of each incremental area, respectively.

W = width of an incremental area.

Normally, **d_i**, **d_{i+1}** and **W** are defined by two consecutive cross section coordinate points, as shown in Figure 2-5. However at the first and last increments in each subsection, a subsection station defines one side of the incremental area. If the subsection station does not coincide with an **X** coordinate, straight line interpolation is used to compute the length of either, **d_i**, **d_{i+1}**, or both.

Wetted perimeter

The wetted perimeter, **P**, is computed as the length of the cross section below the water surface. In the case of Figure 2-4, this is:

$$P = P_8 + P_9 + P_{10} + P_{11} \qquad (2.13)$$

where:

P_i = incremental wetted perimeter.

The equation for the wetted perimeter of the incremental area in Figure 2-5 is:

$$P_i = \sqrt{\left(\Delta Y^2 + W^2\right)} \qquad (2.14)$$

where:

ΔY and **W** are as shown in Figure 2-5.

Note that only the distance between coordinate points is considered in **p_i**, not the depths **d_i** and **d_{i+1}**. In other words, friction due to shear forces between subsections is not considered.

Hydraulic radius

The hydraulic radius, **R**, is calculated for each subsection, **j**, by:

$$R_j = \frac{A_j}{P_j} \qquad (2.15)$$

where:

$\mathbf{A_j}$ = area of subsection

$\mathbf{P_j}$ = wetted perimeter of subsection

$\mathbf{R_j}$ = hydraulic radius of subsection.

Conveyance

The conveyance, $\mathbf{K_j}$, is computed for each subsection, **j**, by:

$$K_j = \frac{1.49}{n_j} A_j R_j^{2/3} \tag{2.16}$$

where, system of unit is fps.

The total conveyance, $\mathbf{K_t}$, in the cross section is:

$$K_t = \sum_{j=1}^{NSS} K_j \tag{2.17}$$

where:

NSS = total number of subsections.

Velocity distribution factor, α

α is an energy correction factor to account for the transverse distribution of velocity across the floodplains and channel. Large values of α (>2) will occur if the depth of flow on the overbanks is shallow, the conveyance is small, and the area is large. α is computed as follows:

$$\alpha = \frac{\sum_{j-1}^{NSS} \left| \frac{K_j^3}{A_j^2} \right|}{\left[\frac{K_t^3}{A_t^2} \right]} \tag{2.18}$$

Effective depth and width

The sediment transport capacity for non-rectangular sections is calculated using a weighted depth, **EFD**, called the effective depth. The corresponding effective width, **EFW**, is calculated from the effective depth to preserve $A(D^{2/3})$ for the cross section.

$$EFD = \frac{\sum_{i=1}^{i_t} D_{avg}.a_i.D_{avg}^{2/3}}{\sum_{i=1}^{i_t} a_i.D_{avg}^{2/3}} \tag{2.19}$$

$$EFW = \frac{\sum_{i=1}^{i_t} a_i.D_{avg}^{2/3}}{EFD^{5/3}} \tag{2.20}$$

where:

a_i = flow area of each trapezoidal element

D_{avg} = average water depth of each trapezoidal element

i_t = the total number of trapezoidal elements in a subsection

The sediment transport computation is based upon hydraulics of the main channel only; therefore, the hydraulic elements are from the geometry within the channel limits only.

Critical depth calculations

To assess if the backwater profiles remain above critical depth, the critical section factor, **CRT**, is computed using Equation 2-21, and compared with the computed section factor at each cross section.

$$CRT = \frac{Q}{\sqrt{\frac{g}{\alpha}}} \tag{2.21}$$

A computed section factor, **ZSQ**, is calculated for comparison to **CRT**.

$$ZSQ = A_t\sqrt{\frac{A_t}{W_t}} \tag{2.22}$$

where:

A_t = total area of cross section

W_t = total water surface width

If **CRT** is less than **ZSQ**, subcritical flow exists and computations continue. Otherwise, critical depth is calculated by tracing the specific energy curve to the elevation of minimum total energy and the resulting water surface elevation is compared with the water surface elevation calculated by Equation 2-6 to decide if flow is supercritical. If supercritical flow is indicated, flow depth is determined as described in the following section.

Supercritical flow

In the standard step method for water surface profile computations, calculations proceed from downstream to upstream based upon the reach's starting water surface elevation. At each cross section, HEC-6 examines the appropriate hydraulic parameters to determine if the reach is a subcritical or supercritical flow reach. If flow is subcritical, computations proceed upstream in the manner described in previous Section. If it is supercritical, HEC-6 approximates the channel geometry using the effective depth and width as described in previous Section and determines the water surface elevation based upon the supercritical normal depth. If a subcritical reach is eventually encountered, the downstream cross section of the reach is assumed to be at critical depth and backwater computations proceed upstream for assumed subcritical flow conditions. Note that for subcritical flow, M1 and M2 curves are possible in HEC-6 but under supercritical flow, S1 and S2 curves are not computed because only supercritical normal flow depths are calculated. An example of such a series of profiles is shown in Figure 2-6.

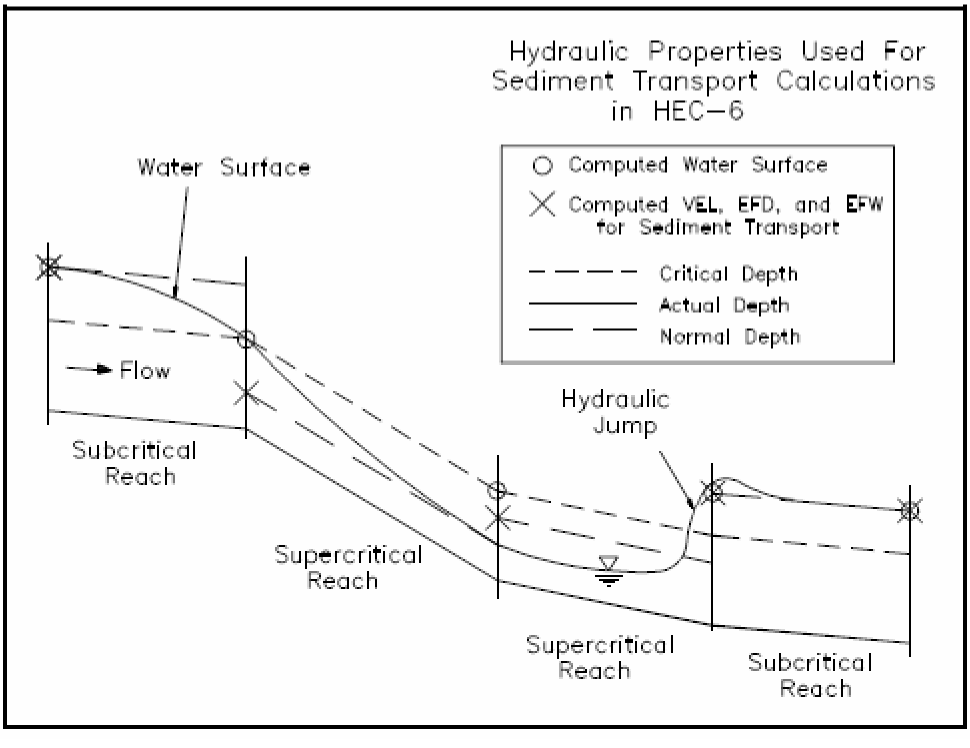

Fig. 2.6 Examples of Subcritical, Critical, and Supercritical Flow

Convergence equations

Three major steps are used to converge computational trials in computing the upstream cross section water surface elevation. Figure 2-7 demonstrates the sequence of successive trials to converge the standard step method.

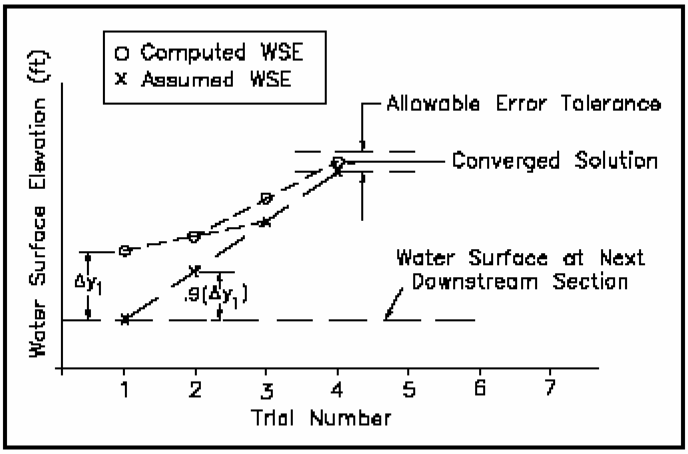

Fig. 2.7 Convergence of Assumed and Computed Water Surface Elevations

Computational Procedure:

Trial 1: Based on the previous water surface elevation.

Trial 2: Assumed change is ninety percent of ΔY_1

Trial 3: Trial 1 and 2 elevations assumed are connected with a straight line and the computed Trial 1 and 2 solutions are also connected with a straight line. The intersection of these lines becomes Trial 3's assumed value.

Trial 4, etc.: This process continues until the assumed and computed values of water surface elevation are within the allowable error tolerance. If they are, the computed water surface elevation becomes the converged solution.

Oscillation between positive and negative "error" is permitted. A note is printed in the event a solution is "forced" (after 20 trials) even though the "error" is greater than the allowable error. In this case, the last computed water surface elevation is used.

Hydraulic roughness

Boundary roughness of an alluvial stream is closely related to sediment transport and the movement of bed material. Energy losses for water surface profile calculations must include the effects of all losses: grain roughness of the movable bed, drag losses from bed forms such as ripples and dunes, bank irregularities, vegetation, contraction/expansion losses, bend losses, and junction losses. All these losses except the contraction/expansion losses are embodied in a single roughness parameter, Manning's n.

2.5.6 Theoretical basis for sediment calculations

Sediment transport rates are calculated for each flow in the hydrograph for each grain size. The transport potential is calculated for each grain size class in the bed as though that size comprised 100% of the bed material. Transport potential is then multiplied by the fraction of each size class present in the bed at that time to yield the transport capacity for that size class. These fractions often change significantly during a time step, therefore an iteration technique is used to permit these changes to affect the transport capacity. The basis for adjusting bed elevations for scour or deposition is the Exner equation.

Equation for continuity of sediment material

Control volume

Each cross section represents a control volume. The control volume width is usually equal to the movable bed width and its depth extends from the water surface to the top of bedrock or other geological control beneath the bed surface. In areas where no bedrock exists, an arbitrary limit (called the "model bottom") is assigned (see Figure 2-8). The control volume for cross section 2 is represented by the heavy dashed lines. The control volumes for cross sections 1 and 3 join that for cross section 2, etc.

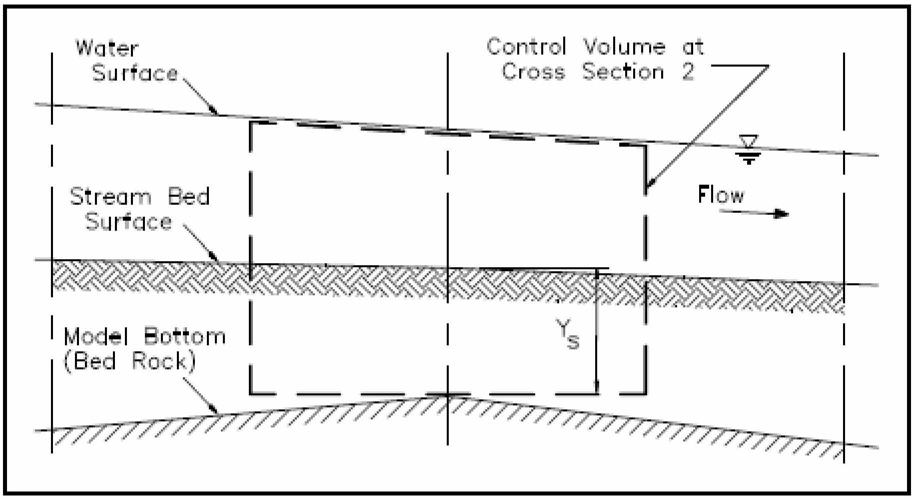

Fig. 2.8 Control Volume for Bed Material

The sediment continuity equation is written for this control volume; however, the energy equation is written between cross sections. Because descriptions of both sediment continuity and conservation of energy should enclose the same space; and because the averaging of two cross sections tends to smooth numerical results, the shape of the control volume is conceptually deformed. The amount of sediment in the stream bed, using an average end area approximation, is:

$$V_{sed} = B_0 . Y_s . \frac{L_u + L_d}{2} \tag{2.23}$$

where:

B$_o$ = width of the movable bed

L$_u$, L$_d$ = length of the upstream and downstream reach, respectively, used in control volume computation

V$_{sed}$ = volume of sediment in control volume

Y$_s$ = depth of sediment in control volume.

For a water depth, **D**, the volume of fluid in the water column is:

$$V_f = B_0 . Y_s . \frac{L_u + L_d}{2} \tag{2.24}$$

B$_o$ and **D** are hydraulic parameters, width and depth, which are calculated by averaging over the same space used in solving the energy equation. The solution of the continuity of sediment equation assumes that the initial concentration of suspended bed material is negligible. That is, all bed material is contained in the sediment reservoir at the start of the computation interval and is returned to the sediment reservoir at the end of the computation interval. Therefore, no initial concentration of bed material load need be specified in the control volume. The hydraulic parameters, bed material gradation and calculated transport capacity are assumed to be uniform throughout the control volume. The inflowing sediment load is assumed to be mixed uniformly with sediment existing in the control volume. HEC-6 assumes instantaneous diffusion of all grain size classes on a control volume basis.

Concepts of the control volume

The control volume concept employed in HEC-6 represents the alluvium of a natural river. Over time, the river will exchange sediment with its boundaries both vertically and laterally, changing its shape by forming channels, natural levees, meanders, islands, and other plan forms. HEC-6, however, only models vertical sediment exchange with the bed the width and depth of which is user defined.

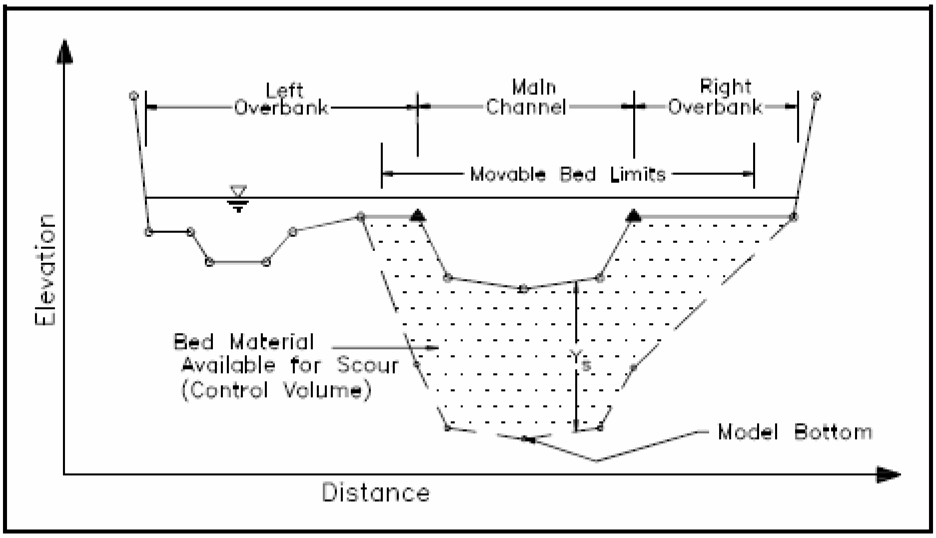

Fig. 2.9 Sediment Material in the Streambed

HEC-6 accounts for two sediment sources; the sediment in the inflowing water and the bed sediment. Transport theory for sand and larger sizes relates the transport rate to the gradation of sediment particles on the bed surface and the flow hydraulics. Armor calculations require the gradation of material beneath the bed surface. The depth to bedrock or some other material that might prevent degradation should also be identified to limit the scour process. These requirements are addressed in HEC-6 by separately computing the bed surface gradation and the sub-surface gradation. The coordinates connected by the solid line in Figure 2-9 define the initial cross section shape at the beginning of a simulation. For scour conditions, the difference between the inflowing sediment load and the reach's transport capacity is converted to a scour volume. After each time step, the coordinates within the "movable bed" are lowered by an amount which, when multiplied by the movable bed width and the representative reach length, equals the required scour volume. If a model bottom elevation is not specified in the initial conditions, a default value of 10 ft is used, which then becomes the maximum depth of bed material available for scour.

Exner equation

The above description of the processes of scour and deposition must be converted into numerical algorithms for computer simulation. The basis for simulating vertical movement of the bed is the continuity equation for sediment material (the Exner equation), which is expressed as below:

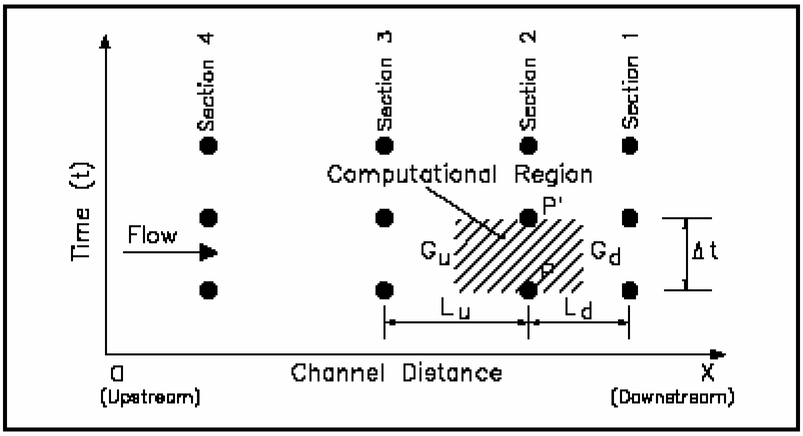

Fig. 2.10 Computation Grid

$$\frac{\partial G}{\partial X} + B_0 . \frac{\partial Y_s}{\partial t} = 0 \qquad (2.25)$$

where:

B_o = width of movable bed

t = time

G = average sediment discharge (ft^3/sec) rate during time step Δt

x = distance along the channel

Y_s = depth of sediment in control volume.

Equations 2-26 and 2-27 represents the Exner Equation expressed in finite difference form for point P using the terms shown in Figure 2-9.

$$\frac{G_d - G_u}{0.5(L_d + L_u)} + \frac{B_{sp}(Y'_{sp} - Y_{sp})}{\Delta t} = 0 \tag{2.26}$$

$$Y'_{sp} = Y_{sp} - \frac{\Delta t}{(0.5)B_{sp}} . \frac{G_d - G_u}{L_d + L_u} \tag{2.27}$$

where:

B_{sp} = width of movable bed at point P

G_u, G_d = sediment loads at the upstream and downstream cross sections, respectively

L_u, L_d = upstream and downstream reach lengths, respectively, between cross sections

Y_{sp}, Y'_{sp} = depth of sediment before and after time step, respectively, at point P

0.5 = the "volume shape factor" which weights the upstream and downstream reach lengths

Δ**t** = computational time step

The initial depth of bed material at point P defines the initial value of **Y_{sp}**. The sediment load, **G_u**, is the amount of sediment, by grain size, entering the control volume from the upstream control volume. For the upstream-most reach, this is the inflowing load boundary condition provided by the user. The sediment leaving the control volume, **G_d**, becomes the **G_u** for the next downstream control volume. The sediment load, **G_d**, is calculated by considering the transport capacity at point P, the sediment inflow, availability of material in the bed, and armoring. The difference between **G_d** and **G_u** is the amount of material deposited or scoured in the reach labelled as "computational region" on Figure 2-10, and is converted to a change in bed elevation using Equation 2-27. The transport potential of each grain size is calculated for the hydraulic conditions at the beginning of the time interval and is not recalculated during that interval. Therefore, it is important that each time interval be short enough so that changes in bed elevation due to scour or deposition during that time interval do not significantly influence the transport potential by the end of the time interval. Fractions of a day are typical time steps for large water discharges and several days or even months may be satisfactory for low flows.

Determination of the active and inactive layers

HEC-6 implements the concept of an active and an inactive bed layer. The active layer is assumed to be continually mixed by the flow, but it can have a surface of slow moving particles that shield the finer particles from being entrained in the flow. Two different processes are simulated: (1) Mixing that occurs between the bed sediment particles and the fluid-sediment mixture due to the energy in the moving fluid and, (2) Mixing that occurs between the active layer and the inactive layer due to the movement of the bed surface. The mixing mechanisms are attributed to large scale turbulence and bed shear stress from the moving water. The mixing depth (termed "equilibrium depth") is expressed as a function of flow intensity (unit discharge), energy slope, and particle size.

Equilibrium depth

The minimum energy hydraulic condition at which a particular grain size will just be stationary on the bed surface can be calculated by combining Manning's, Strickler's, and Einstein's equations, respectively:

$$V = \frac{1.49}{n} R^{2/3} S_t^{1/2} \tag{2.28}$$

$$n = \frac{d^{1/6}}{29.3} \tag{2.29}$$

$$\psi = \frac{\rho_s - \rho_f}{\rho_f} . \frac{d}{DS_f} \tag{2.30}$$

where:

d = grain diameter in feet

D = water depth in feet

V = water velocity in feet/sec

ρ_s = density of sand grains

ρ_f = density of water

ψ = transport intensity from Einstein's bed load function, related to the inverse of Shield's parameter

S_f = friction slope

For negligible transport, ψ equals 30 or greater. Solving Equation 2.30 in terms of **S_f** for a specific gravity of sand of 2.65 and with ψ set at 30 yields:

$$S_f = \frac{d}{18.18D} \tag{2.31}$$

Combining this with the Manning and Strickler equations, in which **R** has been replaced with **D**, and multiplying velocity by depth to get unit discharge yields:

$$q = \frac{(1.49)(29.3)D^{5/3}}{d^{1/6}}\left[\frac{d}{18.18D}\right]^{1/2}$$

$$= 10.21.D^{7/6}.D^{1/3} \tag{2.32}$$

where:

q = water discharge per unit width of flow in feet^2/sec

The equilibrium depth for a given grain size and unit discharge is therefore:

$$D_e = D = \left[\frac{q}{10.21d^{1/3}}\right]^{6/7} \tag{2.33}$$

where:

D_e = the minimum water depth for negligible sediment transport (i.e., equilibrium depth) for grain size **d**

Bed elevation change

When scour or deposition occurs during a time step, HEC-6 adjusts cross section elevations within the movable bed portion of the cross section. For deposition, the streambed portion is moved vertically. Scour occurs only if it is within the movable bed and below the water surface. Once the scour or deposition limits are determined, the volume of scour or deposition is divided by the effective width and length of the control volume to obtain the bed elevation change. The vertical components of the cross section coordinate within these scour/deposition limits are then adjusted as shown in Figures 2-11 and 2-12.

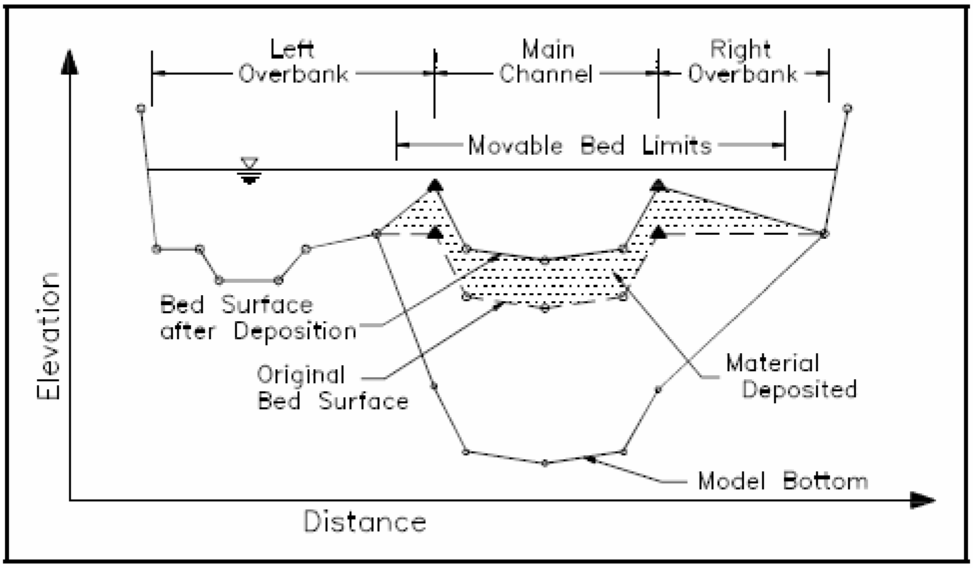

Fig. 2.11 Cross Section Shape Due to Deposition

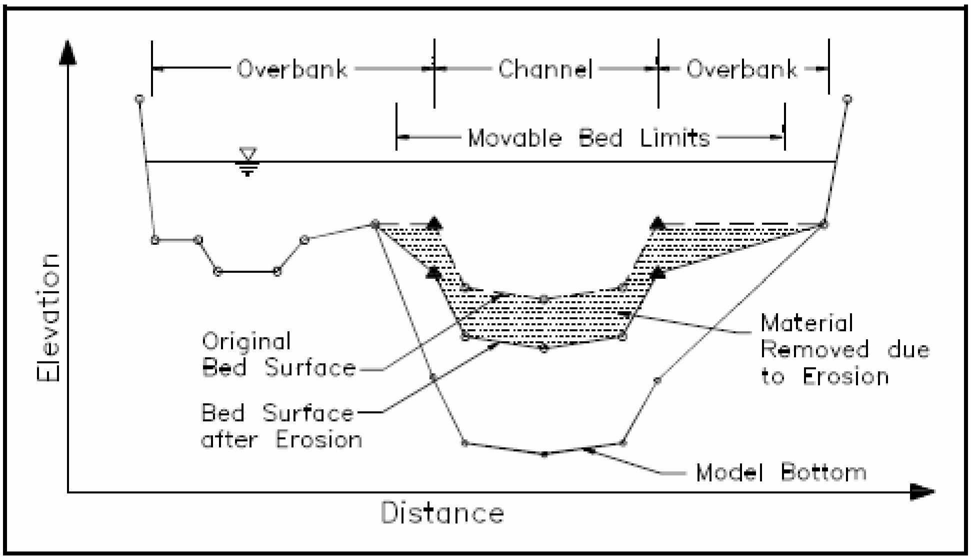

Fig. 2.12 Cross Section Shape Due to Erosion

Hard bottom channel

The special condition of a hard channel bottom (as with a concrete channel) can be approximated by specifying zero sediment depth in the bed sediment reservoir. This is accomplished by specifying the model bottom, **EMB**, equal to the initial thalweg elevation, less a small amount. No sediment is contributed to the flow of sediment at that cross section.

Unit weight of deposits

Initial unit weight

Unit weight is the weight per unit volume of a deposit expressed as dry weight.

$$Y_s = (1 - P_d).SG.Y \tag{2.34}$$

where:

P_d = porosity of deposits

SG = specific gravity of sediment particles

Y = unit weight of water

Y_s = unit weight of sediment

Composite unit weight

When dealing with mixtures of particle sizes, the composite unit weight, Y_{SC}, of the mixture is computed using Colby's equation [21]:

$$Y_{SC} = \frac{1}{\left[\frac{F_{SA}}{Y_{SA}} + \frac{F_{SL}}{Y_{SL}} + \frac{F_{CL}}{Y_{CL}}\right]} \tag{2.35}$$

where:

Y_{SA}, Y_{SL}, Y_{CL} = unit weight of sand, silt, and clay, respectively

F_{SA}, F_{SL}, F_{CL} = fraction of sand, silt, and clay, respectively, in the deposit

Consolidated unit weight

Compaction of deposited sediments is caused by the grains reorienting and squeezing out the water trapped in the pores. The equation for consolidation is [21] :

$$Y = Y_1 + B . \log_{10} T \tag{2.36}$$

where:

B = coefficient of consolidation for silts or clay

T = accumulated time in years

Y**1** = initial unit weight of the sediment deposit, usually after one year of consolidation

The average consolidated unit weight over a time period **T** requires integration over time. This is computed using the following relationship developed by Miller [1].

$$Y_{ave} = Y_1 + B.\left[\frac{T}{T-1}\right].\log_{10} T - 0.434\,B \qquad (2.37)$$

These unit weights are used to convert sediment weight to volume for computation of the bed elevation change.

Sediment particle properties

Four basic sediment properties are important in sediment transport prediction: size, shape factor, specific gravity, and fall velocity.

The particle shape factor, **SF**, is defined by:

$$SF = \frac{c}{\sqrt{a.b}} \qquad (2.38)$$

where:

a, b, c = the lengths of the longest, intermediate, and shortest, respectively, mutually perpendicular axes of a sediment particle

The particle shape factor is 1.0 for a perfect sphere and can be as low as 0.1 for very irregularly shaped particles. HEC-6 uses a shape factor default of 0.667 but it can be user specified. If a "sedimentation diameter" is used, which is determined by the particle's fall velocity characteristics, the particle shape factor of 1.0 should be used. If the actual sieve diameter is used, the actual shape factor should be used.

Specific gravity of a particle is governed by its mineral makeup. In natural river systems the bed material is dominated by quartz which has a specific gravity of 2.65. HEC-6 uses 2.65 as a default; however, values of specific gravities for sand, silt, and clay may be input.

Two techniques for calculating particle fall velocity are available in HEC-6. The first is based upon the fall velocities determined by Toffaleti and is similar to Rubey's method [21]. This method assumes 0.9 as the shape factor. The second, which takes into consideration the particle shape factor, utilizes the procedure described in ICWR, and is described in detail by Williams [22]. The second method is the default.

2.5.7 General input requirements

Input data are grouped into the three categories of geometry, sediment and hydrology. Details about input data are given below.

Geometric data

Geometric data includes cross sections, reach lengths and n values. In addition, the movable bed portion of each cross section and the depth of sediment material in the bed are defined.

Cross sections

Cross sections are specified for the initial conditions. Calculations are made directly from coordinate points (stations, elevations), not from tables or curves of hydraulic elements. **GR** records are used to input elevation station coordinates to provide a description of the shape of a cross section. Elevations may be positive, zero or negative. Cross section identification numbers, entered in field 1 of the **X1** record for each cross section, must be positive and should increase in the upstream direction. Each cross section may be subdivided into three parts called subsections - the left overbank, main channel and right overbank as shown in Figure 2.13. Each subsection must have a reach length. It extends from the previous (downstream) section to the present cross section

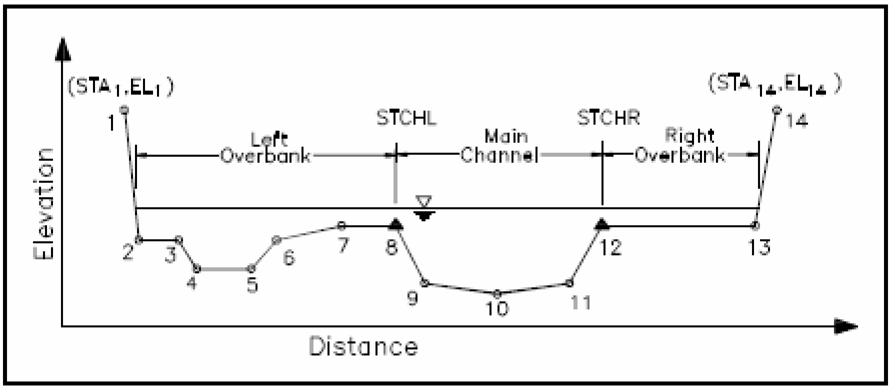

Fig. 2.13 Cross section Subsection

Manning's n values

A Manning's n value is required for each subsection of a cross section. It is not possible to automatically change n values with respect to time. Static or fixed n values are entered using the **NC** record. The n values may vary with either discharge or elevation in the main channel and overbank areas by using **NV** records.

Movable bed

Each cross section is divided into movable and fixed-bed portions. The **H** (or **HD**) record is used to define the movable bed limits, **XSM** and **XFM**, which can extend beyond the channel bank station. Scour and deposition will cause the movable bed to fall or rise by changing the cross section elevations within the movable bed at the end of each time step (see Fig. 2.14).

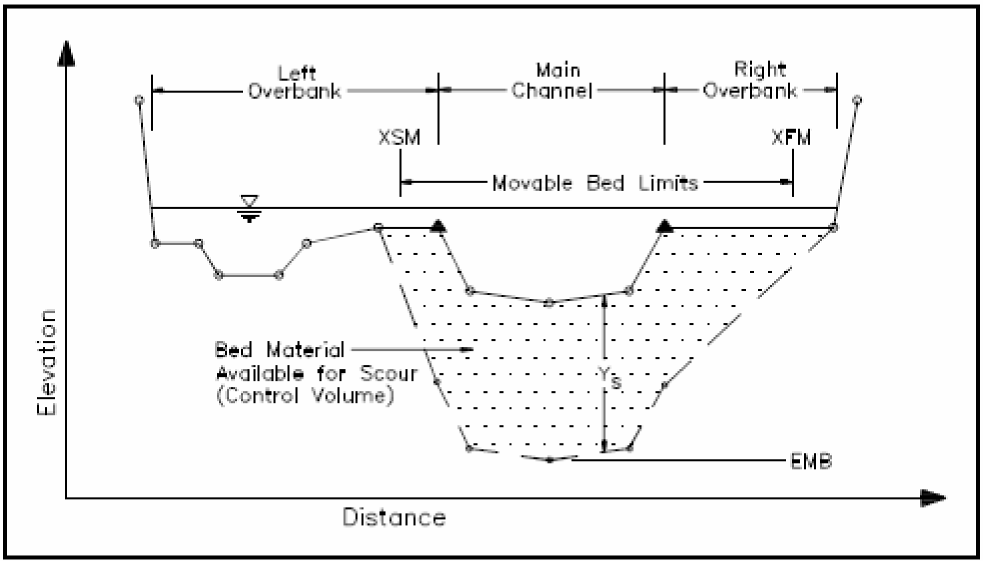

Fig. 2.14 Sediment Material in the Stream Bed

Sediment data

Sediment data is specified on records **I** through **PF**. This data includes fluid and sediment properties, the inflowing sediment load data, and the gradation of material in the stream bed. The transport capacity relationship(s) and unit weights of deposited material are also input in this section. The grain sizes of sediment particles commonly transported by rivers may range over several orders of magnitude. Small sizes behave much differently from large sizes. Therefore, it is necessary to classify sediment material into groups for application of different transport theories. The three basic classes considered by HEC-6 are clay, silt, and sands-boulders. The groups are identified and subdivided based on the American Geophysical Union (AGU) classification scale as shown in Table 2.2. HEC-6 accounts for 20 different sizes of material including one size for clay, four silt sizes, five sand sizes, five gravel, two cobble sizes, and three boulder sizes. The representative size of each class is the geometric mean size, which is the square root of the class ranges multiplied together.

Table 2.2 Grain Size Classification of Sediment Material

Class Size Number Used in HEC-6	Sediment Material	Grain Diameter(mm)
	Clay	
1	Clay	0.002-0.004
	Silt	
1	Very Fine Silt	0.004-0.008
2	Fine Silt	0.008-0.016
3	Medium Silt	0.016-0.032
4	Coarser Silt	0.032-0.0625
	Sands-Boulders	
1	Very Fine Sand(VFS)	0.0625-0.125
2	Fine Sand(FS)	0.125-0.25
3	Medium Sand(MS)	0.25-0.50
4	Coarse Sand(CS)	0.50-1.0
5	Very Coarser Sand(VCS)	1-2
6	Very Fine Gravel(VFG)	2-4
7	Fine Gravel(FG)	4-8
8	Medium Gravel(MG)	8-16
9	Coarse Gravel(CG)	16-32
10	Very Coarse Gravel(VCG)	32-64
11	Small Cobbles(SC)	64-128
12	Large Cobbles(LC)	128-256
13	Small Boulders(SB)	256-512
14	Medium Boulders(MB)	512-1024
15	Large Boulders(LB)	1024-2048

Inflowing sediment load

The aggradations or degradation of a stream bed profile depends upon the amount and size of sediment inflow relative to the transport capacity of the stream. The inflowing sediment supplies entering the upstream boundaries of the geometric model and at local inflow points are called inflowing sediment loads and are expressed in tons/day. The sediment load should include both bed and suspended load (total load) and is expressed as a function of water discharge in cfs vs. sediment load in tons/day. Data is entered on the **LT** and **LF** records as a table of sediment load by grain size class for a range of water discharges. The discharge entered on the **LQ** record should encompass the full range found in the computational hydrograph. A complete sediment load table is required for every inflow into the network. This includes the inflow to each stream segment as well as all local inflows.

Sediment material in the stream bed

The gradation of sediment material in the stream bed (the subsurface gradation) is specified as a function of percent finer vs. grain size on the **PF** records. Cross section numbers are used in field 1 of the **PF** records to identify the subsurface gradation location within the geometric data set. Subsurface gradations are linearly interpolated for those cross sections for which **PF** records have not been specified.

Sediment properties

Five basic properties are considered: grain size, specific gravity, grain shape factor, unit weight of deposits and fall velocity. The grain size classifications shown in Table 2.2 are predefined in HEC-6. The specific gravity of bed material has a default value of 2.65 and the grain shape factor has a default value of 0.667.

Hydrologic data

Hydrologic data is specified on records **Q** through **W**. The hydrologic data includes water discharges, temperatures, downstream water surface elevations and flow duration.

2.6 Concluding Remark

The philosophy used behind HEC-6 has been presented. The software HEC-6 has been used for sediment distribution computation. After knowing the sediment distribution at different level, than by using graphical procedure, the life of reservoir can be find out.

CHAPTER 3
SOURCE OF DATA

3.1 General

The data pertaining to sedimentation of a reservoir proposed on the Narmada River has been obtained and their details are described in terms of cross-sections of river upstream of reservoir, sediment inflow, reservoir characteristics and monthly water discharge at proposed dam site.

3.1 Cross Section Details

Cross-sectional details of the Narmada River have been taken in the upstream of the dam at 200 m intervals. The changes and corresponding elevations at their different cross-sections are enumerated as follows:

Site: Raghav Pur
Location: Dam Axis.

Distance (in m)	Level (in m)
0	661.4
36.79	656.42
46.12	653.53
92.48	638.76
108.18	627.64
138.84	610.95
179.58	606.18
185.2	605.31
231.56	605.22
250.97	605.89
277.92	607.42
322.37	610.18
324.28	610.35
370.64	623.64
393.76	631.08
417	636.36
463.36	642.83
465.16	643.05
509.72	648.49
536.55	657.8
548.41	660.68

Site: Raghav Pur
Location: 200 m Upstream.

Distance (in m)	Level (in m)
0	657.07
12.21	655.19
48.45	648.38
62.27	646.15
110.2	637.61
112.26	637.08

162.25	621.81
171.96	619.34
212.23	612.89
233.72	610.43
262.22	607.78
295.48	606.31
312.2	606
357.23	606.14
362.19	606.73
412.17	620.17
418.99	621.91
462.16	632.68
480.75	636.44
512.14	640.62
542.51	644.65
562.13	646.72
604.27	659.99
612.11	661.87

Site: Raghav Pur
Location: 400 m Upstream.

Distance (in m)	Level (in m)
0	664.47
20.68	662.54
31.93	661.34
75.42	654.01
107.82	648.35
118.9	646.33
162.39	637.9
194.96	628.2
205.87	625.3
249.36	619.5
282.1	616.72
292.85	615.93
336.33	614.2
369.23	612.02
379.82	611.16
423.3	607.94
456.37	606.84
466.79	606.57
510.28	606.55
543.51	612.48
553.76	615.94
597.25	624.76
630.64	627.43
640.74	627.72
684.22	626.92
717.78	632.48
727.71	635.38
754.4	647.29

Site: Raghav Pur
Location: 600 m Upstream.

Distance (in m)	Level (in m)
0	648.45
32.4	643.87
54.37	640.4
76.22	636.57
120.05	628.6
138.9	624.7
163.87	619.88
207.7	617.73
223.42	616.98
251.52	615.61
295.35	612.34
307.95	611.45
339.17	609.03
383	607.14
392.5	607.07
426.82	606.85
470.64	629.02
477.01	632.4
514.47	645.7
558.29	656.87
561.53	657.46
558.36	662.44

Site: Raghav Pur
Location: 800 m Upstream.

Distance (in m)	Level (in m)
0	668.36
10.74	669.39
39.13	670.54
76.4	664.29
87.35	662.29
135.57	652.2
142.06	651.18
183.79	643.62
207.73	641.57
232.02	639.22
273.39	636.15
280.24	635.92
328.46	633.1
339.05	631.9
376.68	627.5
404.71	623.05
424.9	620.87
470.37	617.25
473.13	617.05
521.35	614.24

536.03	613.52
596.57	611.86
601.69	610.33
617.79	609.59
666.01	607.27
667.35	607.24
714.24	607.2
733.01	607.67
762.46	613.76
798.68	623.97
810.68	625.76
858.9	629.76
864.34	630.8
880.06	636.02
888.93	638.46
899.51	641.59
910.09	644.72
920.68	647.86

Site: Raghav Pur
Location: 1000 m Upstream.

Distance (in m)	Level (in m)
0	672.65
24.57	669.23
38.17	666.38
73.05	659.33
103.17	652.96
121.54	649.2
168.17	639.22
170.3	638.81
218.52	629.43
233.16	627.62
267	624.88
298.16	622.56
315.49	621.36
363.16	617.93
363.98	617.87
412.47	614.48
428.15	613.36
460.95	611.06
493.15	608.8
509.44	607.72
557.93	607.28
558.15	607.28
606.41	607.3
623.14	615.23
654.9	635.85
688.14	648.19
703.39	652.76
731.57	655.46

Site: Raghav Pur
Location: 1200 m Upstream.

Distance (in m)	**Level (in m)**
0	675.31
15.81	674.41
22.27	673.34
70.99	662.78
76.9	661.58
126.17	650.98
131.53	649.89
181.35	639.56
186.16	638.41
236.53	629.05
240.79	628.68
291.71	625.19
295.42	624.93
346.89	621.4
350.05	621.18
402.07	617.59
404.68	617
457.25	613.76
459.32	613.61
512.43	609.88
513.94	609.78
567.6	607.96
568.57	608.01
622.78	619.5
623.2	619.6
677.83	633.01
677.96	633.04
732.46	643.83
733.14	644.05
787.1	661.73
788.32	661.71
789.06	661.68

Site: Raghav Pur
Location: 1400 m Upstream.

Distance (in m)	**Level (in m)**
0	674.72
12.28	673.26
35.96	668.9
79.81	660.13
95	657.46
123.65	651.62
167.5	643.43
177.73	641.48
211.35	633.88
255.2	627.45

260.45	627.06
299.05	624.18
342.9	621.23
343.18	621.21
386.75	618.12
425.9	615.3
430.6	615
474.45	611.89
508.63	610.48
518.3	610.08
562.14	610.34
591.35	612.89
605.99	614.16
649.84	616.84
674.08	618.86
693.69	621.46
737.54	624.2
756.8	624.99
781.39	627.77
825.24	646.9

Site: Raghav Pur
Location: 1600 m Upstream.

Distance (in m)	**Level (in m)**
0	671.46
30.36	673.1
69.04	671.368
107.72	668.51
146.4	663.43
185.08	659.02
223.76	652.79
262.44	646.08
301.12	639.24
339.8	633.1
378.48	627.85
417.16	624.94
455.83	622.07
494.51	619.2
533.19	616.35
571.87	613.57
610.55	610.79
649.23	611.1
687.91	611.34
726.59	611.54
765.27	612.64
803.95	614.35
842.63	615.47
881.31	616.21
919.99	616.95
958.67	617.72

997.35	618.68
1036.03	626.23
1074.71	633.78
1113.39	641.33
1152.07	648.88

Site: Raghav Pur
Location: 1800 m Upstream.

Distance (in m)	Level (in m)
0	639.75
7.35	637.75
46.03	630.29
84.71	625.74
123.39	621.74
162.07	618.35
200.75	610.6
239.43	610.53
278.11	610.67
316.79	610.81
355.47	610.92
394.15	614.05
432.83	617.24
471.5	620.45
510.19	626.07
548.87	631.7
587.54	637.25
626.22	642.81
647.66	645.66

Site: Raghav Pur
Location: 2000 m Upstream.

Distance (in m)	Level (in m)
0	651.85
21.06	650.13
59.74	638.85
98.42	614.12
137.1	611.42
175.78	611.43
214.46	611.44
253.14	612.43
291.82	616.62
330.5	620.72
369.18	624.43
407.86	628.01
446.54	631.59
485.22	635.17
523.9	638.85
562.58	643.61
601.26	648.56
613.52	649.55

3.2 Sediment Data

The time periods vs. their sediment inflow is given as below:

Periods	Sediment Volume (Ha-m)
25 years	6562
50 years	11998
75 years	16310
100 years	22809

Limitation of Sediment Data

Software HEC-6 required sediment data in a specified format. That format has been given in APPENDIX-C. Software HEC-6 required discharge vs. sediment inflow, grain size distribution of sediment and grain size distribution of bed material. Annual sediment inflows are given as well as average discharge. The sediment inflows for other discharges were interpolated linearly. The proportion of sand, silt and clay in sediment inflows and the gradation of bed material has been taken from other natural river with similar characteristics.

3.3 Reservoir Properties

FRL = 652 m
MWL = 652.53 m
MDDL = 640.92 m
Fetch Length = 5.75 km
Effective Fetch Length = 1.52 km

Variation or area and capacity with elevation for proposed reservoir is described as follows:

Elevation (in m)	Area (ha)	Capacity (ha-m)
652	3547.26	48694
650	3179.03	41971
648	2842.12	35953
646	2518.05	30597
644	2241.83	25839
642	1976.53	21624
640	1712.2	17938
638	1460.84	14768
636	1253.03	12057
634	1056.14	9751
632	912.19	7785
630	775.46	6099
628	646.97	4679
626	526.48	3508
624	423.71	2559
622	328.67	1808
620	250.04	1232
618	178.93	805
616	127.56	500
614	82.35	292

612	56.11	154
610	33.47	65
608	15	15
605	0	0

3.3 Hydrological Data

Monthly discharge(given in Mm^3) from the Narmada River at proposed dam site is given below:

Table 3.1 Monthly flows at Raghawpur Hydro-electric project

YEAR	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1977-78	177.41	360.48	776.66	346.48	81.08	49.71	27.10	27.17	23.77	16.47
1978-79	96.54	354.88	518.03	171.42	37.75	26.89	36.90	19.82	21.36	11.47
1979-80	17.47	85.90	188.17	37.30	17.86	9.58	8.94	8.29	5.01	3.03
1980-81	55.41	424.20	767.78	754.19	67.65	43.02	17.05	16.09	10.30	7.04
1981-82	32.11	231.38	367.51	122.57	51.10	16.53	14.82	14.30	13.60	6.19
1982-83	19.59	43.32	438.45	233.76	35.09	20.95	13.09	9.71	9.37	5.64
1983-84	14.74	163.78	389.21	479.92	131.57	31.30	22.09	47.74	24.25	11.74
1984-85	16.30	116.82	921.04	227.13	35.83	15.73	14.39	22.77	22.24	7.04
1985-86	11.99	358.87	954.59	170.47	48.35	22.16	17.46	13.37	19.83	12.45
1986-87	87.57	901.37	431.66	149.17	45.81	19.48	22.22	20.84	17.13	13.79
1987-88	25.68	164.05	421.18	981.00	145.19	50.76	26.08	21.49	14.52	11.06
1988-89	116.94	611.75	716.42	96.18	44.15	20.27	13.16	13.07	8.58	7.53
1989-90	52.11	140.79	394.47	132.83	29.20	12.80	14.31	11.40	9.02	5.34
1990-91	158.64	126.32	211.08	1040.90	171.52	35.25	23.62	18.52	10.13	8.38
1991-92	11.10	230.53	1223.06	127.06	30.96	16.79	14.45	12.36	8.84	5.32
1992-93	8.03	113.85	176.11	337.78	30.04	16.90	14.82	12.42	8.70	8.11
1993-94	26.88	156.27	284.11	604.66	104.61	24.37	17.00	15.25	10.73	7.62
1994-95	421.17	1298.83	1061.95	226.94	138.82	37.71	23.54	20.41	14.45	16.24
1995-96	13.76	264.79	637.45	344.78	35.11	22.12	31.56	33.67	17.19	11.15
1996-97	18.04	277.89	751.42	222.64	49.97	18.21	16.40	15.56	11.11	6.42
1997-98	103.15	206.75	546.41	344.36	75.86	123.25	147.94	179.37	62.14	31.93
1998-99	25.89	333.24	262.63	453.79	118.69	54.55	36.13	28.83	20.42	13.56
1999-00	22.02	103.95	1095.46	542.46	213.69	44.91	32.37	25.81	16.39	8.58
2000-1	38.87	164.87	346.94	74.66	29.88	15.48	11.56	12.08	7.62	7.58
2001-2	48.56	904.58	360.95	104.80	143.11	34.66	20.11	12.66	13.45	9.86
2002-3	26.50	19.99	345.56	332.80	34.39	22.18	19.36	16.36	16.73	12.12

Average
Flows
50 % De
Flows
75 % De
Flows
90 % De
Flows

CHAPTER 4

ANALYSIS OF DATA

4.1 General

The data given in chapter-3 have been analyses in the present chapter to get the distribution of sediments for different time period. Firstly, the data have been analyses with Empirical Area Reduction method. For Empirical Area Reduction method, a computer program has been developed in C++. For graphical presentations, Microsoft Excel has been used. After predicting the Life of Reservoir using Empirical Area Reduction method, Software HEC-6 has been used for sediment deposition computation and subsequently, in computation of Life of Reservoir. Lastly, results of these two methods have been discussed.

4.2 Empirical Area Reduction Method

Following steps has been taken to compute life of reservoir.

(i) For the data described in section 3.3, the area-elevation and capacity-elevation curves are plotted and shown in Fig.4.1 and Fig. 4.2 respectively.

(ii) Depth capacity relation has been plotted on log-log paper, as shown in Fig 4.3. From Fig 4.3, slope of the line is measured. The reciprocal of the slope ‘M’ is 2.6. Hence, reservoir is classified as Type-II.

(iii) The new zero elevation has been obtained in Tables 4.1 to 4.4 for 25 years, 50 years, 75 years and 100 years. A computer program, in C++ has been used to get these tables. The coding of the program is included at APPENDIX-A.

(iv) Reduced capacity after 25 years, 50 years, 75 years and 100 years at different level has been obtained from Tables 4.5 to 4.8. A computer program, in C++ has been used for this purpose. The coding of the program is included at APPENDIX-B. The revised capacity vs. elevation curve for 25 years, 50 years, 75 years and 100 years are shown in Fig. 4.8.

(v) Knowing the reduced capacity at FRL and dead level, Fig 4.9 has been prepared. From Fig. 4.9 life of reservoir can be computed as the time period by which dead storage becomes nil. The life of reservoir has been computed as 120 years.

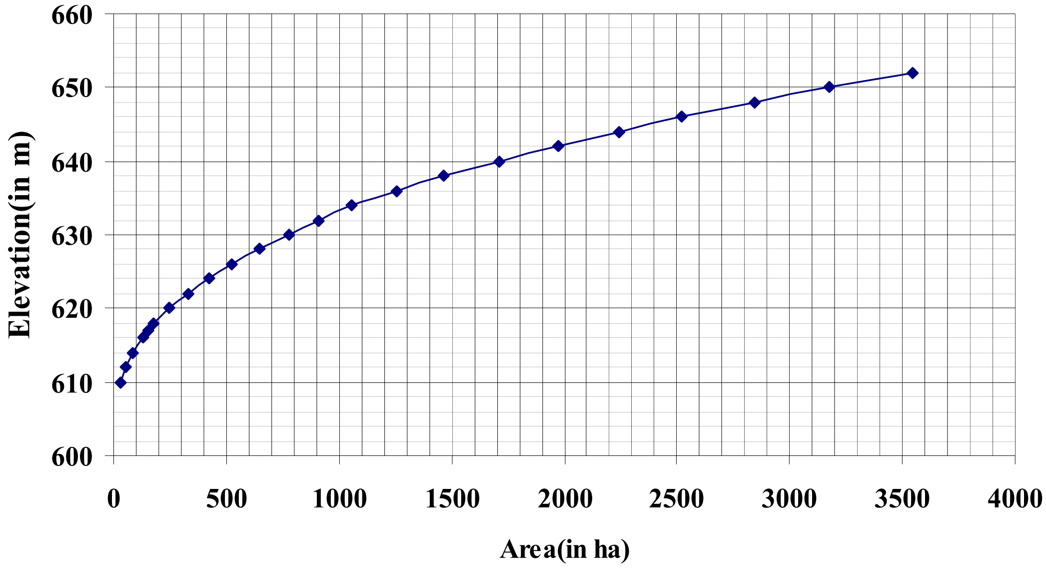

Fig 4.1 Area-elevation curve

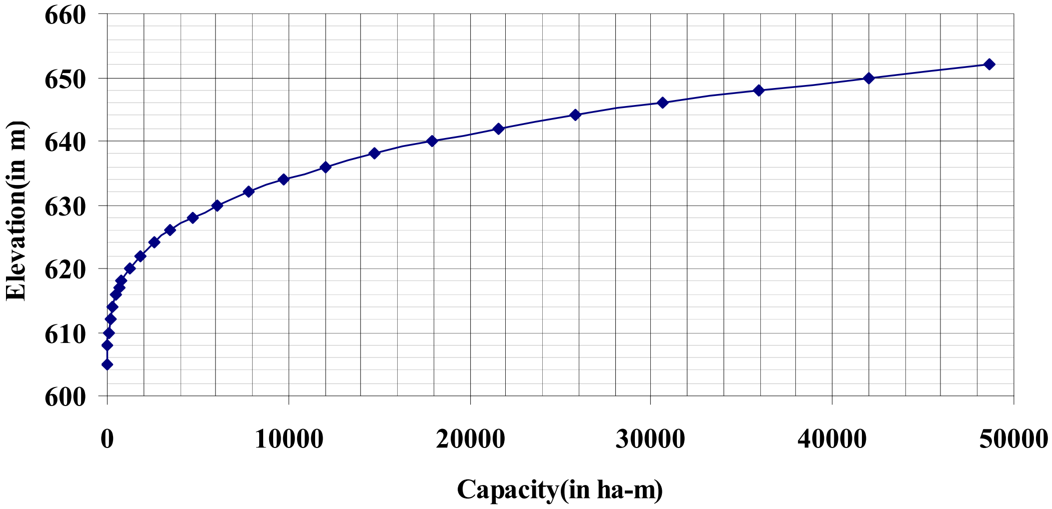

Fig 4.2 Capacity-elevation curve

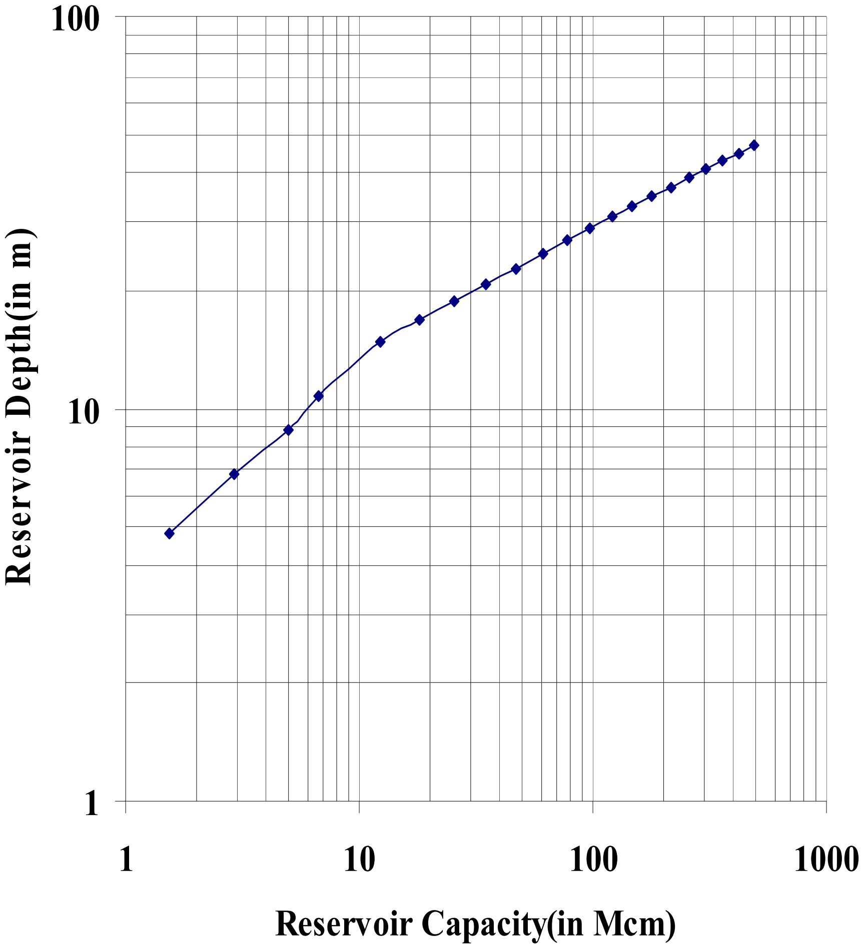

Fig 4.3 Reservoir depth vs. Capacity curve

Table 4.1 Determination of new zero elevation of sediment deposited at the Dam

Age: 25 years
Sediment, S =6562 ha-m

Elevation(m)	(p)	V(pH)	S-V(pH)	A(pH)	HA(pH)	h'(p)
605.2	0	0	6562	0	0	
606	0.017094017	0	6562	2.54	118.872	55.20223
608	0.05982906	18.06	6543.94	15.075	705.51	9.275474
610	0.102564103	65.4	6496.6	33.471	1566.4428	4.147359
612	0.145299145	154	6408	56.107	2625.8076	2.440392
614	0.188034188	291.6	6270.4	82.35	3853.98	1.626993
616	0.230769231	499.89	6062.11	127.56	5969.808	1.015461
618	0.273504274	804.93	5757.07	178.93	8373.924	0.6875
620	0.316239316	1231.9	5330.08	250.03	11701.404	0.455508
622	0.358974359	1808	4754	328.67	15381.756	0.309067
624	0.401709402	2559.2	4002.79	423.71	19829.628	0.201859
626	0.444444444	3507.5	3054.46	526.48	24639.264	0.123967
628	0.487179487	4678.9	1883.08	646.48	30255.264	0.06224
630	0.52991453	6099	463	775.46	36291.528	0.012758

Type: II
p_0 = 0.25(from Fig. 4.4)
H=652-605.2=46.8 m
$p_0 \times H$ =11.70
Bottom Elevation =605.2 m
Elevation of sediment deposited at dam=616.90

NOTATION OF SYMBOLS
p= relative depth of reservoir
V(pH)= reservoir capacity in ha-m.
S= total sediment inflow in ha-m.
A(pH)= reservoir area in ha at a given elevation, and
h'(p)= a function of reservoir and its anticipated sediment storage expressed as follows

$$h'(p) = \frac{S - V(pH)}{HA(pH)}$$

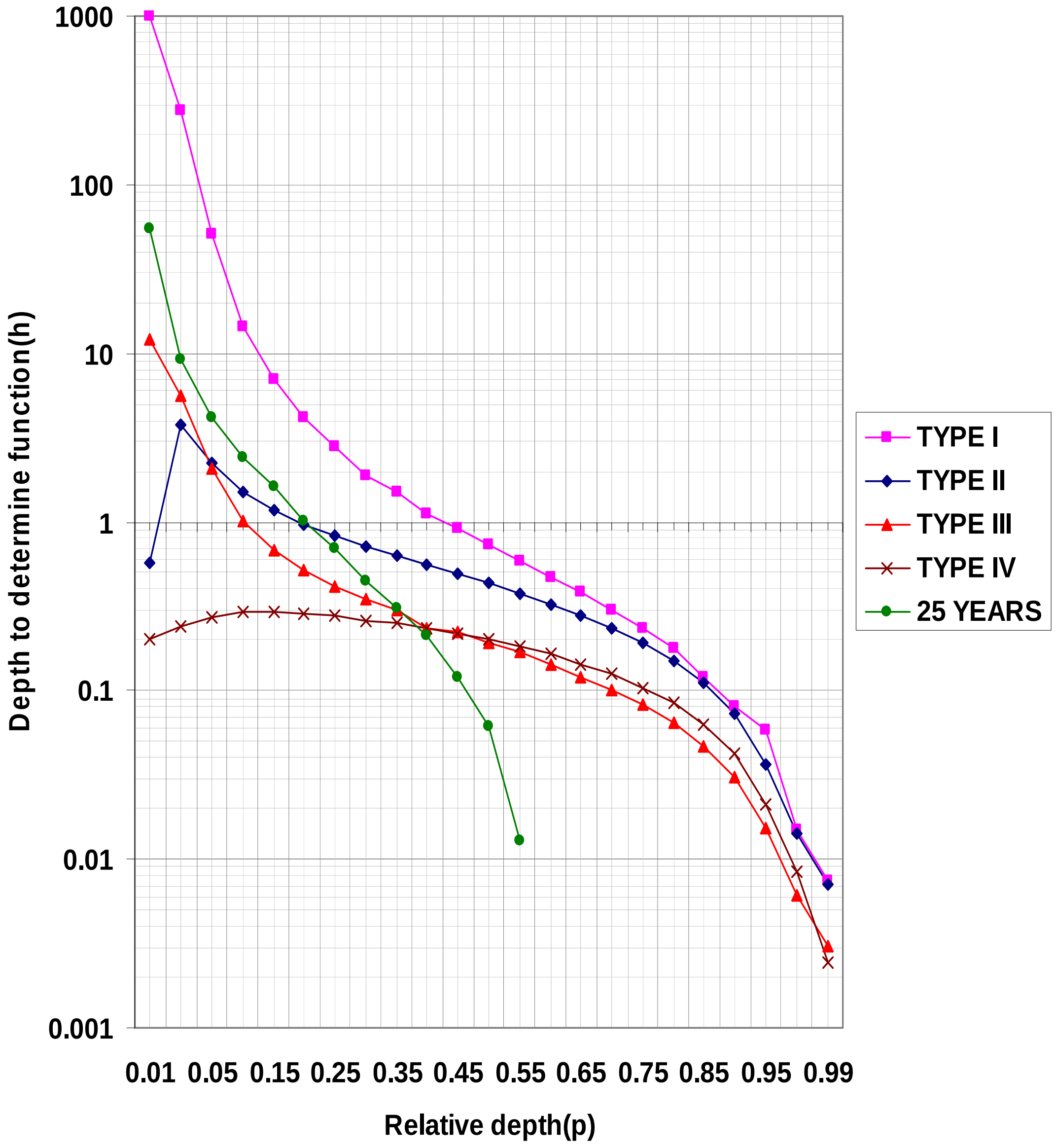

Fig. 4.4 Curve to find factor p_0 for 25 years

Table 4.2 Determination of new zero elevation of sediment deposited at the Dam

Age: 50 years
Sediment, S =11978 ha-m

Elevation(m)	(p)	V(pH)	S-V(pH)	A(pH)	HA(pH)	h'(p)
605.2	0	0	11978	0	0	
606	0.017094017	0	11978	2.54	118.872	100.7638
608	0.05982906	18.06	11959.94	15.075	705.51	16.95219
610	0.102564103	65.4	11912.6	33.471	1566.4428	7.604874
612	0.145299145	154	11824	56.107	2625.8076	4.502996
614	0.188034188	291.6	11686.4	82.35	3853.98	3.032294
616	0.230769231	499.89	11478.11	127.56	5969.808	1.922693
618	0.273504274	804.93	11173.07	178.93	8373.924	1.334269
620	0.316239316	1231.9	10746.08	250.03	11701.404	0.918358
622	0.358974359	1808	10170	328.67	15381.756	0.661173
624	0.401709402	2559.2	9418.79	423.71	19829.628	0.474986
626	0.444444444	3507.5	8470.46	526.48	24639.264	0.343779
628	0.487179487	4678.9	7299.08	646.48	30255.264	0.24125
630	0.52991453	6099	5879	775.46	36291.528	0.161994
632	0.572649573	7785	4193	912.19	42690.492	0.098219
634	0.615384615	9751	2227	1056.14	49427.352	0.045056

Type: II
p_0 = 0.37(from Fig. 4.5)
H=652-605.2=46.8 m
$p_0 \times H$ =17.32
Bottom Elevation =605.2 m
Elevation of sediment deposited at dam=622.52

NOTATION OF SYMBOLS
p= relative depth of reservoir
V(pH)= reservoir capacity in ha-m.
S= total sediment inflow in ha-m.
A(pH)= reservoir area in ha at a given elevation, and
$h'(p)$= a function of reservoir and its anticipated sediment storage expressed as follows

$$h'(p) = \frac{S - V(pH)}{HA(pH)}$$

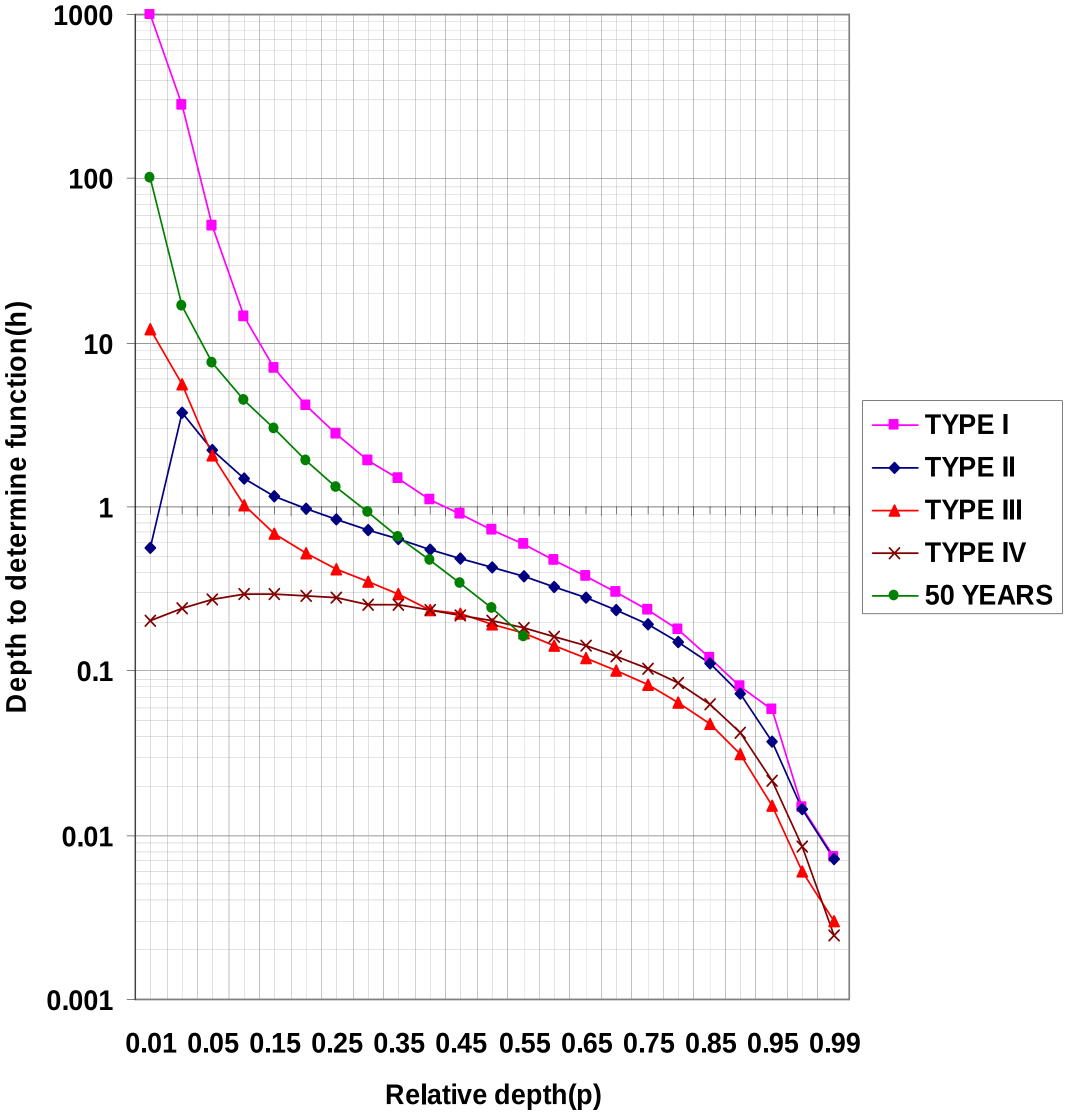

Fig. 4.5 Curve to find factor p_0 for 50 years

Table 4.3 Determination of new zero elevation of sediment deposited at the Dam

Age: 75 years
Sediment, S =16310 ha-m

Elevation(m)	(p)	V(pH)	S-V(pH)	A(pH)	HA(pH)	h'(p)
605.2	0	0	16310	0	0	
606	0.017094017	0	16310	2.54	118.872	137.2064
608	0.05982906	18.06	16291.94	15.075	705.51	23.09243
610	0.102564103	65.4	16244.6	33.471	1566.4428	10.37038
612	0.145299145	154	16156	56.107	2625.8076	6.152774
614	0.188034188	291.6	16018.4	82.35	3853.98	4.156327
616	0.230769231	499.89	15810.11	127.56	5969.808	2.648345
618	0.273504274	804.93	15505.07	178.93	8373.924	1.85159
620	0.316239316	1231.9	15078.08	250.03	11701.404	1.28857
622	0.358974359	1808	14502	328.67	15381.756	0.942805
624	0.401709402	2559.2	13750.79	423.71	19829.628	0.693447
626	0.444444444	3507.5	12802.46	526.48	24639.264	0.519596
628	0.487179487	4678.9	11631.08	646.48	30255.264	0.384432
630	0.52991453	6099	10211	775.46	36291.528	0.28136
632	0.572649573	7785	8525	912.19	42690.492	0.199693
634	0.615384615	9751	6559	1056.14	49427.352	0.1327
636	0.658119658	12057	4253	1253.03	58641.804	0.072525
638	0.700854701	14768	1542	1460.84	68367.312	0.022555

Type: II
p_0 = 0.46(from Fig. 4.6)
H=652-605.2=46.8 m
$p_0 \times H$ =21.53
Bottom Elevation =605.2 m
Elevation of sediment deposited at dam=626.73

NOTATION OF SYMBOLS
p= relative depth of reservoir
V(pH)= reservoir capacity in ha-m.
S= total sediment inflow in ha-m.
A(pH)= reservoir area in ha at a given elevation, and
$h'(p)$= a function of reservoir and its anticipated sediment storage expressed as follows

$$h'(p) = \frac{S - V(pH)}{HA(pH)}$$

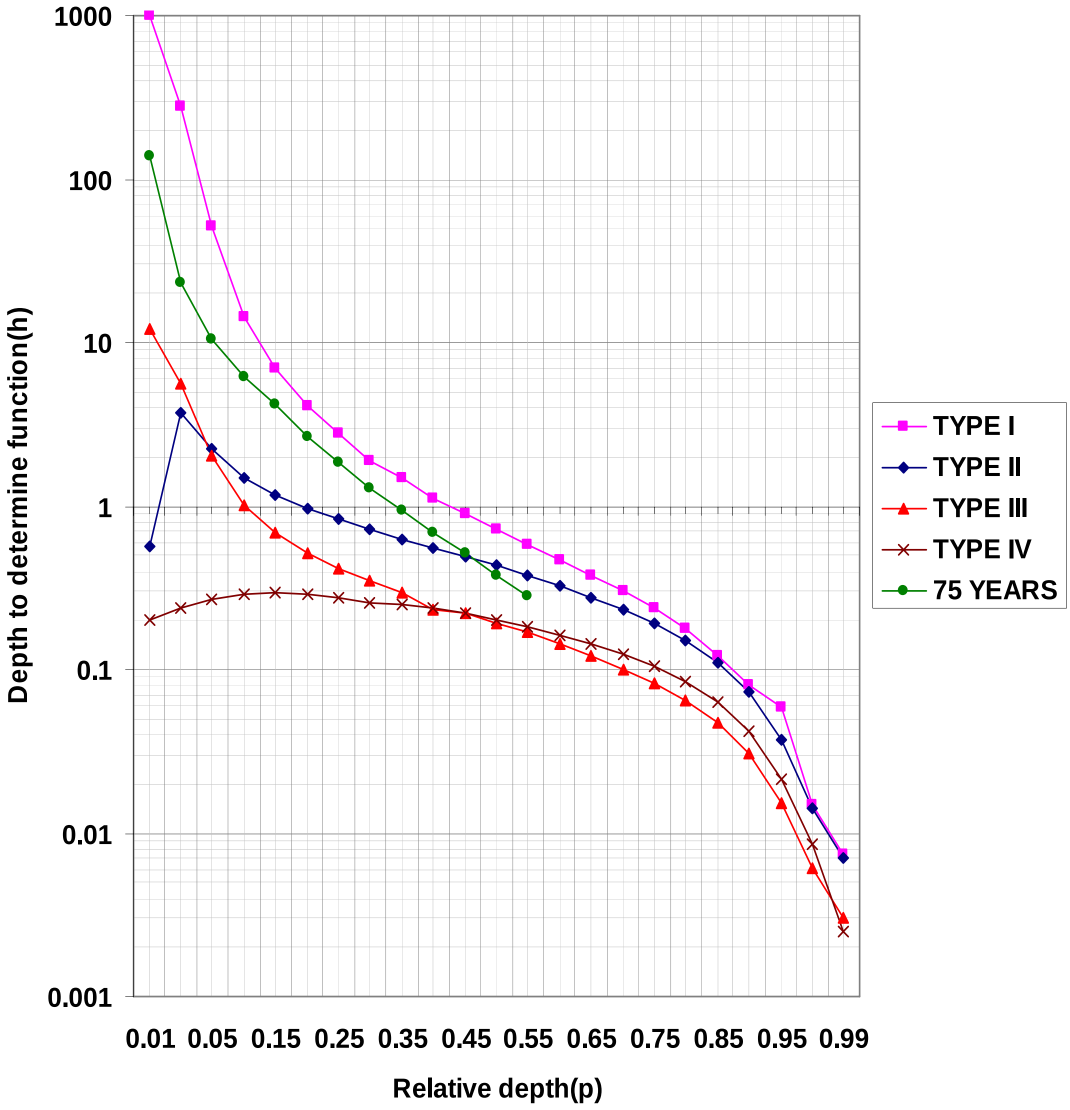

Fig. 4.6 Curve to find factor p_0 for 75 years

Table 4.4 Determination of new zero elevation of sediment deposited at the Dam

Age: 100 years
Sediment, S =22809 ha-m

Elevation(m)	(p)	V(pH)	S-V(pH)	A(pH)	HA(pH)	h'(p)
605.2	0	0	22809	0	0	
606	0.017094	0	22809	2.54	118.872	191.8787
608	0.059829	18.06	22790.94	15.075	705.51	32.30421
610	0.102564	65.4	22743.6	33.471	1566.4428	14.51927
612	0.145299	154	22655	56.107	2625.8076	8.627822
614	0.188034	291.6	22517.4	82.35	3853.98	5.842635
616	0.230769	499.89	22309.11	127.56	5969.808	3.73699
618	0.273504	804.93	22004.07	178.93	8373.924	2.627689
620	0.316239	1231.9	21577.08	250.03	11701.404	1.843974
622	0.358974	1808	21001	328.67	15381.756	1.365319
624	0.401709	2559.2	20249.79	423.71	19829.628	1.021189
626	0.444444	3507.5	19301.46	526.48	24639.264	0.783362
628	0.487179	4678.9	18130.08	646.48	30255.264	0.599237
630	0.529915	6099	16710	775.46	36291.528	0.460438
632	0.57265	7785	15024	912.19	42690.492	0.351928
634	0.615385	9751	13058	1056.14	49427.352	0.264186
636	0.65812	12057	10752	1253.03	58641.804	0.18335
638	0.700855	14768	8041	1460.84	68367.312	0.117615
640	0.74359	17938	4871	1712.2	80130.96	0.060788
642	0.786325	21624	1185	1976.53	92501.604	0.012811

Type: II
p_0 = 0.58(from Fig. 4.7)
H=652-605.2=46.8 m
p_0 x H =27.14
Bottom Elevation =605.2 m
Elevation of sediment deposited at dam=632.34

NOTATION OF SYMBOLS
p= relative depth of reservoir
V(pH)= reservoir capacity in ha-m.
S= total sediment inflow in ha-m.
A(pH)= reservoir area in ha at a given elevation, and
h'(p)= a function of reservoir and its anticipated sediment storage expressed as follows

$$h'(p) = \frac{S - V(pH)}{HA(pH)}$$

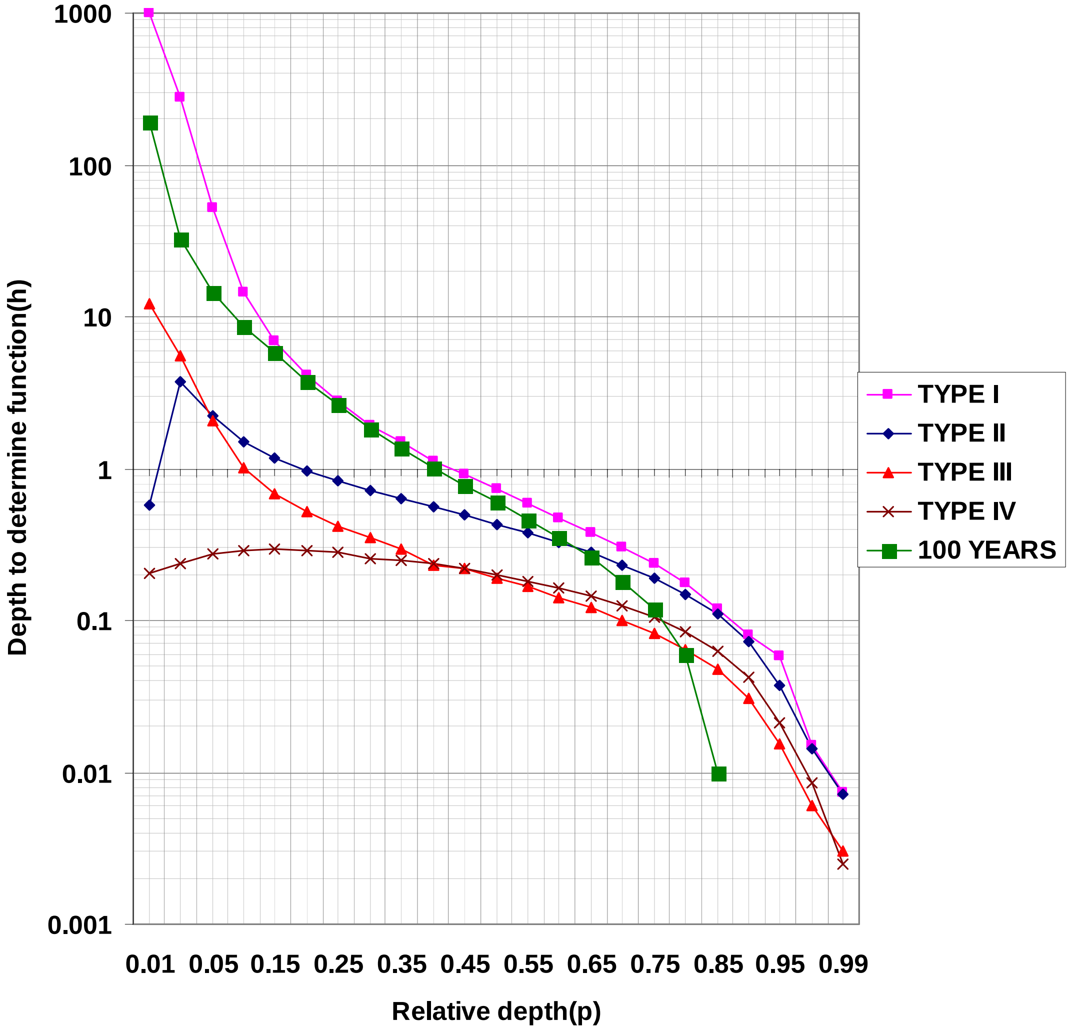

Fig. 4.7 Curve to find factor p_0 for 100 years

Table 4.5 Sediment deposition computations, age=25 years

Age : 25 years
Sediment:6562 ha-m

Elev.	Org area	Org cap.	Rel depth	Rel area	Sed area	Sed vol.	Acc SV	Rev area	Rev cap
652	3547.26	48694	1	0	0	102.79	6589.41	3547.3	42104.59
650	3179.03	41971	0.96	0.67	102.79	235.86	6486.62	3076.2	35484.38
648	2842.12	35953	0.91	0.86	133.07	285.97	6250.76	2709.1	29702.24
646	2518.05	30597	0.87	0.99	152.91	320.1	5964.78	2365.1	24632.22
644	2241.83	25839	0.83	1.08	167.19	344.95	5644.69	2074.6	20194.31
642	1976.53	21624	0.79	1.15	177.76	363.32	5299.74	1798.8	16324.26
640	1712.2	17938	0.74	1.2	185.55	376.66	4936.42	1526.6	13001.58
638	1460.84	14768	0.7	1.24	191.1	385.85	4559.76	1269.7	10208.24
636	1253.03	12057	0.66	1.26	194.75	391.46	4173.91	1058.3	7883.09
634	1056.14	9751	0.62	1.27	196.71	393.84	3782.45	859.43	5968.545
632	912.19	7785	0.57	1.28	197.14	393.26	3388.61	715.05	4396.39
630	775.46	6099	0.53	1.27	196.13	389.87	2995.35	579.33	3103.654
628	646.97	4679	0.49	1.25	193.74	383.73	2605.48	453.23	2073.52
626	526.48	3508	0.44	1.23	190	374.88	2221.75	336.48	1286.254
624	423.71	2559	0.4	1.2	184.89	363.27	1846.86	238.82	712.1391
622	328.67	1808	0.36	1.16	178.38	348.78	1483.59	150.29	324.4116
620	250.04	1232	0.32	1.1	170.4	331.21	1134.81	79.641	97.19405
618	178.93	805	0.27	1.04	160.81	142.53	803.593	18.116	1.407363
616.9	155.8	670	0.25	1.01	155.93	155.92	661.058	0	0
616	127.56	500	0.23	0.97	127.56	209.91	505.139	0	0
614	82.35	292	0.19	0.88	82.35	138.46	295.229	0	0
612	56.11	154	0.15	0.78	56.11	89.58	156.769	0	0
610	33.47	65	0.1	0.65	33.47	48.55	67.1891	0	0
608	15.08	18	0.06	0.49	15.08	17.62	18.6391	0	0
606	2.54	0	0.02	0.24	2.54	1.016	1.01911	0	0
605.2	0	0	0	0	0	0	0	0	0

K1 is: 154.3

Table 4.6 Sediment deposition computations, age=50years

Age: 50 years
Sediment:11978 ha-m

Elev.	Org area	Org cap.	Rel depth	Rel area	Sed area	Sed vol.	Acc SV	Rev area	Rev cap
652	3547.3	48694	1	0	0	204.85	11987.87	3547.26	36706.13
650	3179	41971	0.96	0.666	204.9	470.04	11783.02	2974.18	30187.98
648	2842.1	35953	0.91	0.862	265.2	569.91	11312.98	2576.93	24640.02
646	2518.1	30597	0.87	0.99	304.7	637.91	10743.07	2213.33	19853.93
644	2241.8	25839	0.83	1.083	333.2	687.45	10105.16	1908.64	15733.84
642	1976.5	21624	0.79	1.151	354.3	724.05	9417.709	1622.27	12206.29
640	1712.2	17938	0.74	1.202	369.8	750.63	8693.662	1342.41	9244.338
638	1460.8	14768	0.7	1.238	380.8	768.95	7943.03	1079.99	6824.97
636	1253	12057	0.66	1.261	388.1	780.12	7174.079	864.924	4882.921
634	1056.1	9751	0.62	1.274	392	784.88	6393.957	664.125	3357.043
632	912.19	7785	0.57	1.277	392.9	783.73	5609.073	519.322	2175.927
630	775.46	6099	0.53	1.27	390.9	776.96	4825.348	384.603	1273.652
628	646.97	4679	0.49	1.255	386.1	764.73	4048.393	260.872	630.6075
626	526.48	3508	0.44	1.231	378.6	747.1	3283.658	147.843	224.342
624	423.71	2559	0.4	1.197	368.5	538.43	2536.559	55.2482	22.44059
622.5	360	2060	0.37	1.167	359.1	178.83	1998.133	0	0
622	328.67	1808	0.36	1.155	328.7	578.71	1819.301	0	0
620	250.04	1232	0.32	1.104	250	428.97	1240.591	0	0
618	178.93	805	0.27	1.042	178.9	306.49	811.6214	0	0
616	127.56	500	0.23	0.968	127.6	209.91	505.1314	0	0
614	82.35	292	0.19	0.88	82.35	138.46	295.2214	0	0
612	56.11	154	0.15	0.776	56.11	89.58	156.7614	0	0
610	33.47	65	0.1	0.649	33.47	48.55	67.18145	0	0
608	15.08	18	0.06	0.487	15.08	17.62	18.63145	0	0
606	2.54	0	0.02	0.243	2.54	1.016	1.011447	0	0
605.2	0	0	0	0	0	0	0	0	0

K1 is: 307.7

Table 4.7 Sediment deposition computations, age=75 years

Age: 75 years
Sediment: 16310 ha-m

Elev.	Org area	Org cap.	Rel depth	Rel area	Sed area	Sed vol.	Acc SV	Rev area	Rev cap
652	3547.3	48694	1	0	0	302.32	16356.59	3547.26	32337.41
650	3179	41971	0.96	0.67	302.32	693.68	16054.27	2876.71	25916.73
648	2842.1	35953	0.91	0.86	391.36	841.07	15360.59	2450.76	20592.41
646	2518.1	30597	0.87	0.99	449.71	941.42	14519.52	2068.34	16077.48
644	2241.8	25839	0.83	1.08	491.71	1014.5	13578.1	1750.12	12260.9
642	1976.5	21624	0.79	1.15	522.81	1068.5	12563.58	1453.72	9060.423
640	1712.2	17938	0.74	1.2	545.73	1107.8	11495.04	1166.47	6442.962
638	1460.8	14768	0.7	1.24	562.05	1134.8	10387.26	898.793	4380.737
636	1253	12057	0.66	1.26	572.76	1151.3	9252.454	680.267	2804.546
634	1056.1	9751	0.62	1.27	578.53	1158.3	8101.159	477.608	1649.841
632	912.19	7785	0.57	1.28	579.79	1156.6	6942.838	332.4	842.1623
630	775.46	6099	0.53	1.27	576.82	1146.6	5786.225	198.637	312.7753
628	646.97	4679	0.49	1.25	569.8	736.38	4639.604	77.1717	39.39645
626.7	562.6	3860	0.46	1.24	563.09	381.35	3903.223	0	0
626	526.48	3508	0.44	1.23	526.48	950.19	3521.872	0	0
624	423.71	2559	0.4	1.2	423.71	752.38	2571.682	0	0
622	328.67	1808	0.36	1.16	328.67	578.71	1819.302	0	0
620	250.04	1232	0.32	1.1	250.04	428.97	1240.592	0	0
618	178.93	805	0.27	1.04	178.93	306.49	811.6225	0	0
616	127.56	500	0.23	0.97	127.56	209.91	505.1325	0	0
614	82.35	292	0.19	0.88	82.35	138.46	295.2225	0	0
612	56.11	154	0.15	0.78	56.11	89.58	156.7625	0	0
610	33.47	65	0.1	0.65	33.47	48.55	67.18248	0	0
608	15.08	18	0.06	0.49	15.08	17.62	18.63248	0	0
606	2.54	0	0.02	0.24	2.54	1.016	1.012484	0	0
605.2	0	0	0	0	0	0	0	0	0

K1 is: 454.1

Table 4.8 Sediment deposition computations, age=100 years

Age: 100 years
Sediment: 22809 ha-m

Elev.	Org area	Org cap.	Rel depth	Rel area	Sed area	Sed vol.	Acc SV	Rev area	Rev cap
652	3547.3	48694	1	0	0	482.27	22820.96	3547.26	25873.04
650	3179	41971	0.96	0.666	482.27	1106.6	22338.69	2696.76	19632.31
648	2842.1	35953	0.91	0.862	624.32	1341.7	21232.1	2217.8	14720.9
646	2518.1	30597	0.87	0.99	717.39	1501.8	19890.39	1800.66	10706.61
644	2241.8	25839	0.83	1.083	784.4	1618.4	18388.6	1457.43	7450.404
642	1976.5	21624	0.79	1.151	834.01	1704.6	16770.18	1142.52	4853.819
640	1712.2	17938	0.74	1.202	870.57	1767.2	15065.6	841.631	2872.399
638	1460.8	14768	0.7	1.238	896.6	1810.3	13298.43	564.239	1469.569
636	1253	12057	0.66	1.261	913.7	1836.6	11488.13	339.334	568.8657
634	1056.1	9751	0.62	1.274	922.9	1533.8	9651.539	133.241	99.46054
632.3	925.1	7960	0.58	1.277	925.05	312.33	8117.741	0	0
632	912.19	7785	0.57	1.277	912.19	1687.7	7805.411	0	0
630	775.46	6099	0.53	1.27	775.46	1422.4	6117.761	0	0
628	646.97	4679	0.49	1.255	646.97	1173.5	4695.331	0	0
626	526.48	3508	0.44	1.231	526.48	950.19	3521.881	0	0
624	423.71	2559	0.4	1.197	423.71	752.38	2571.691	0	0
622	328.67	1808	0.36	1.155	328.67	578.71	1819.311	0	0
620	250.04	1232	0.32	1.104	250.04	428.97	1240.601	0	0
618	178.93	805	0.27	1.042	178.93	306.49	811.6306	0	0
616	127.56	500	0.23	0.968	127.56	209.91	505.1406	0	0
614	82.35	292	0.19	0.88	82.35	138.46	295.2306	0	0
612	56.11	154	0.15	0.776	56.11	89.58	156.7706	0	0
610	33.47	65	0.1	0.649	33.47	48.55	67.19058	0	0
608	15.08	18	0.06	0.487	15.08	17.62	18.64058	0	0
606	2.54	0	0.02	0.243	2.54	1.016	1.020585	0	0
605.2	0	0	0	0	0	0	0.004585	0	0

K1 is: 724.4

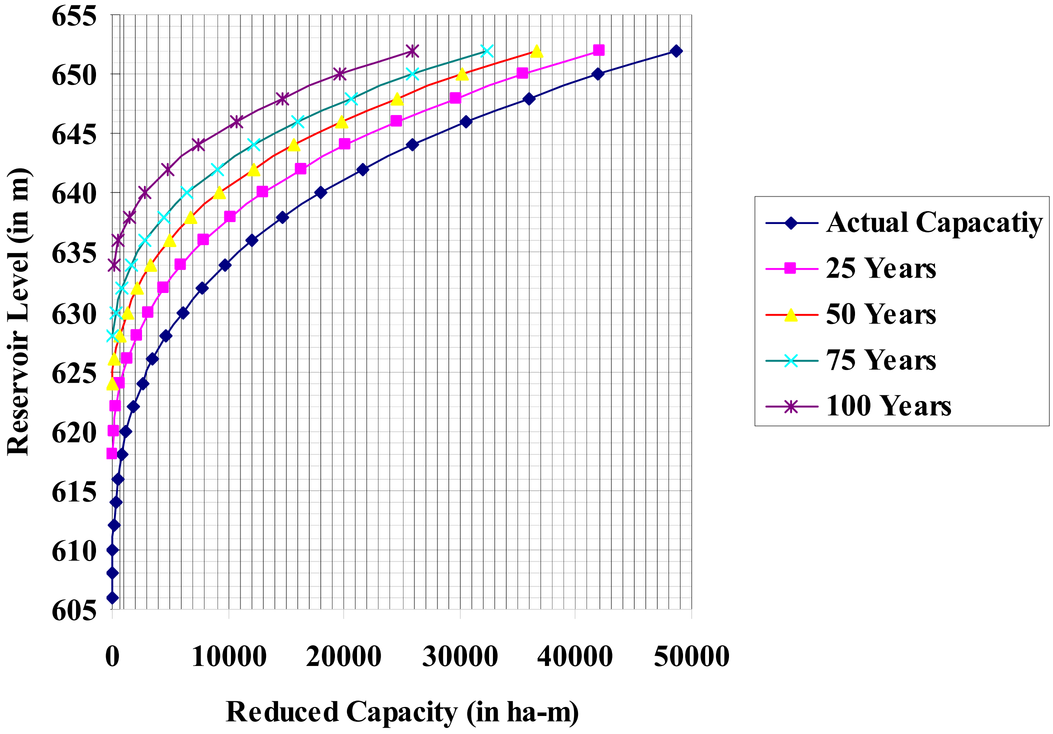

Figure 4.8 Reduced capacity curves for different ages

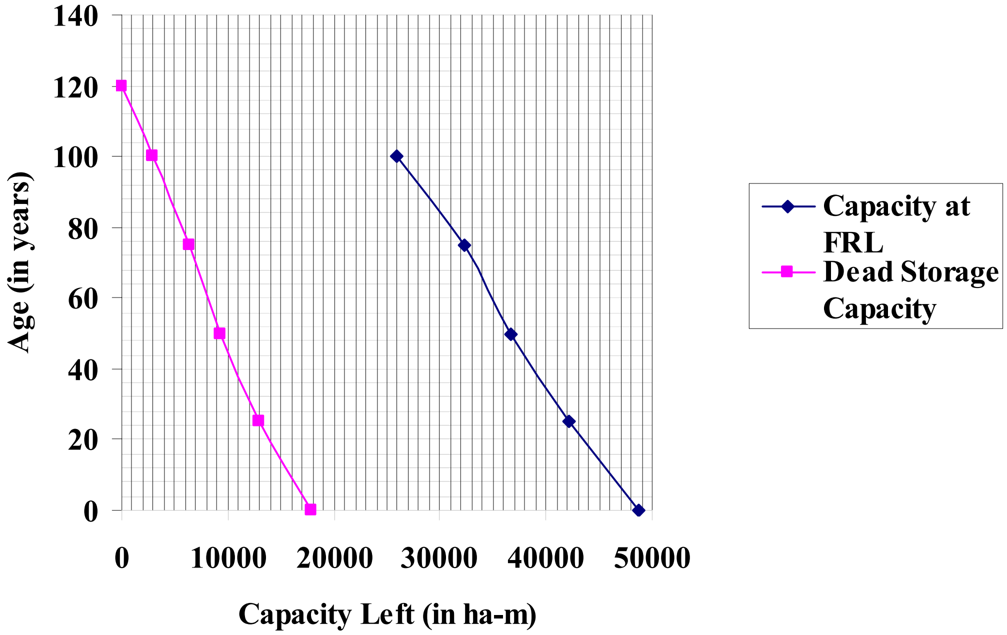

Figure 4.9 Capacity left vs. age in years

4.3 Analysis of Data by Software HEC-6

(i) From given data in Chapter 3, an approximate reservoir rule curve has been drawn as shown in Fig. 4.10.

(ii) All the required input data, were given to the Software HEC-6 as per the details available in Manual [15]. The detailed format of input data is shown in APPENDIX-C.

(iii) The output from HEC-6 for the above input data is included in APPENDIX-D.

(iv) Similar output file were obtained for different time period. From the output file the variation of longitudinal bed along the river in Upstream as well as revised area capacity curves have been obtained for different time period. See Table 4.9.

(v) Initial capacity vs. elevation curve given in the form of data and those computed from HEC-6 are compared in Fig.4.11. The both computation agrees at lower and higher elevations, however the departure is significant at intermediate elevation. This may be ascribed due to inherent assumptions involved in HEC-6 theory and also the gross assumptions involved in the interpolation of sediment data.

(vi) Also the reduced capacity of reservoir vs. elevation have been plotted for different durations, see Fig. 4.12. From Fig. 4.12, it is seen that the capacity of reservoir decreases suddenly in first 25 years and the rate of decrease has been slowed down afterwards. This may be ascribed due to reduction in trap-efficiency as the Capacity- Inflow ratio has gone down with time.

(vii) Bed profile as obtain from output file has also been plotted in Fig. 4.13 to 4.14 for different time periods. A close study of bed profiles show that distribution of sediment in reservoir is not uniform. It is like a sinusoidal curvature, however, the level of bed towards dam increases with increase in time period.

(viii) Knowing the reduced capacity at FRL and dead level, Fig 4.15 has been prepared. From Fig. 4.15 life of reservoir can be computed as the time period by which dead storage becomes nil. The life of reservoir has been computed as 95 years.

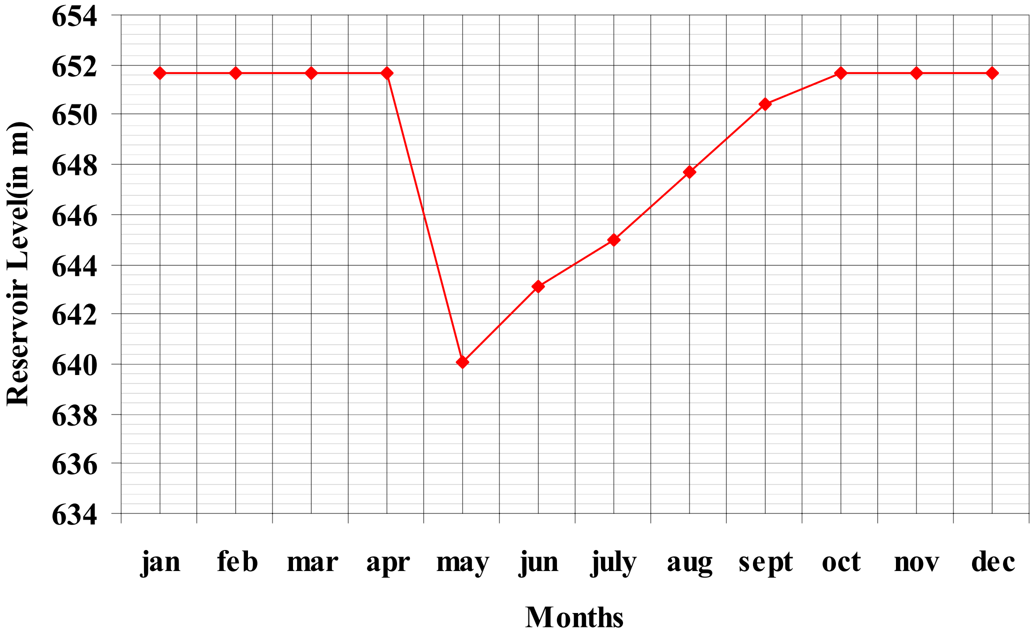

Figure 4.10 Reservoir Rule curve

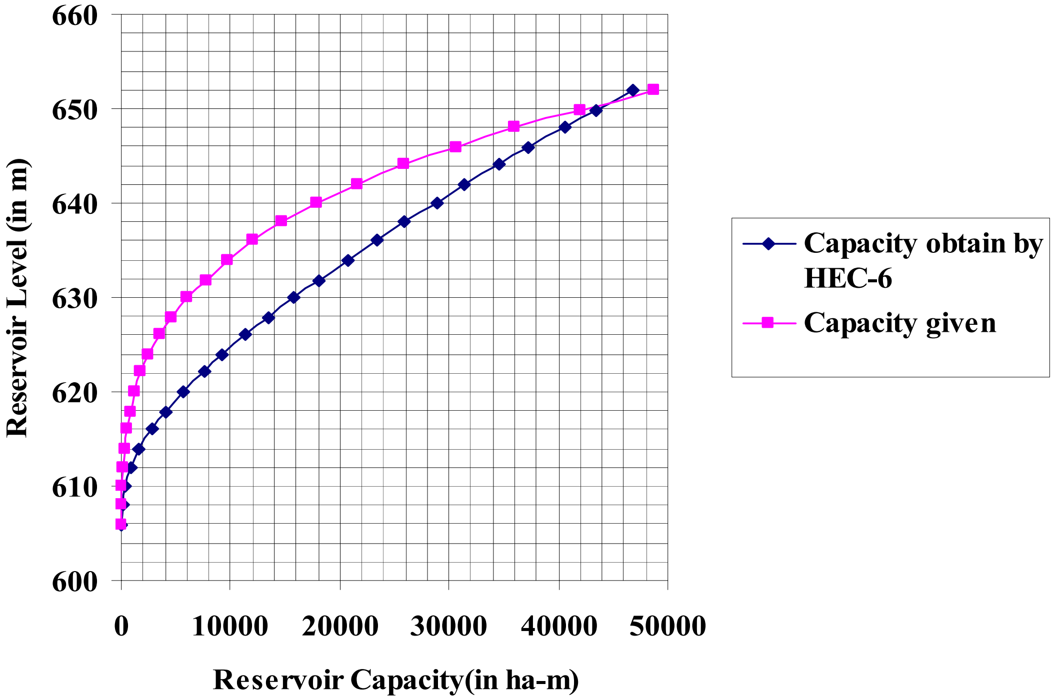

Figure 4.11 Comparison of Initial elevation capacity curve

Table 4.9 Sediment Deposition Computations by HEC-6

Level (in feet)	Initial Cap (ha-m)	Rev. Cap. After 25 yr.	Rev. Cap. After 50 yr.	Rev. Cap. After 75 yr.	Rev. Cap. After 90 yr.
1988	5.4274	0	0	0	0
1995	131.478765	0	0	0	0
2001	376.525875	189.79	0	0	0
2008	884.407165	477.32	140.24895	0	0
2014	1646.685495	879.9	241.506965	0	0
2021	2850.56916	1358.00949	373.57781	57.9745	0
2027	4080.751045	1551.0029	498.70405	119.415135	0
2034	5729.200445	1813.4917	658.61499	203.23146	70.50686
2041	7561.663375	2096.888325	833.57463	295.238225	92.524835
2047	9264.682815	2355.947995	997.445105	392.610715	115.887325
2054	11408.78952	2712.12112	1262.89431	534.45088	149.57421
2060	13387.05215	3071.73571	1529.39198	715.639695	189.58895
2067	15832.47824	3525.56503	1873.4398	963.06746	262.71083
2073	18018.36359	3968.49021	2223.95116	1199.38139	342.04955
2080	20667.16915	4569.513085	2707.93956	1509.72999	460.453215
2087	23425.07779	5227.64701	3237.72781	1863.64581	611.34727
2093	25877.69518	5832.444395	3723.11006	2207.360585	773.244145
2100	28843.85563	6627.657175	4324.93471	2655.195095	1000.22048
2106	31457.96284	7405.07055	4895.56414	3082.380815	1229.787165
2113	34579.07555	8439.175275	5666.31662	3690.31129	1586.663385
2119	37310.50095	9434.42475	6401.17424	4288.11473	1967.642195
2126	40558.38046	10726.38032	7341.92769	5059.39761	2476.57196
2132	43390.13874	11942.77167	8250.06739	5784.461245	2969.318205
2139	46755.21309	13489.60534	9441.49271	6718.442775	3622.703155

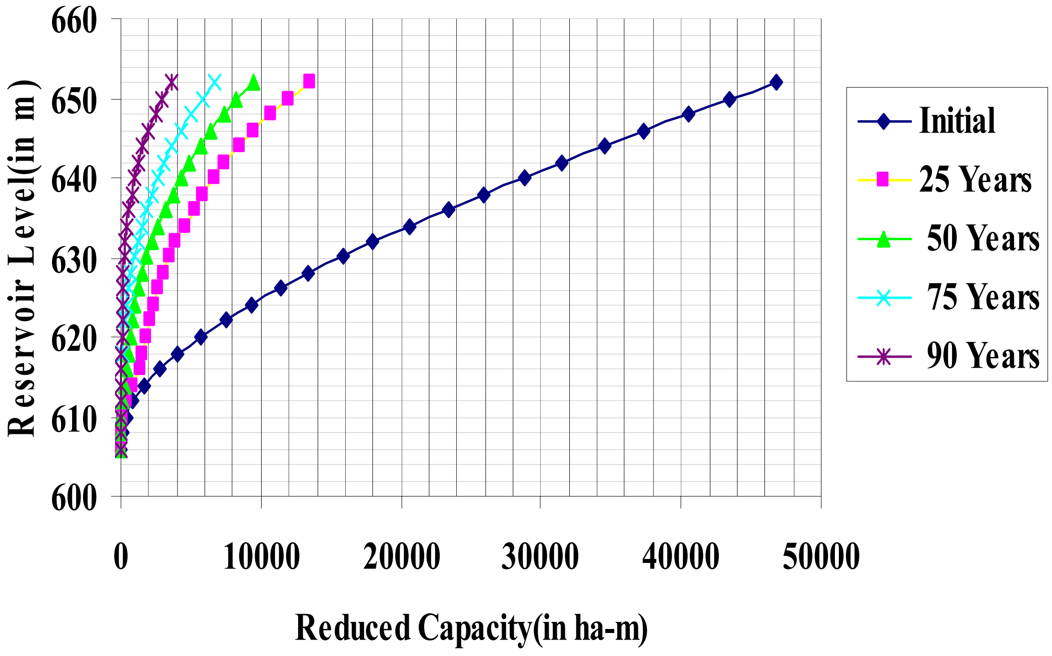

Figure 4.12 Reduced capacity curves for different ages

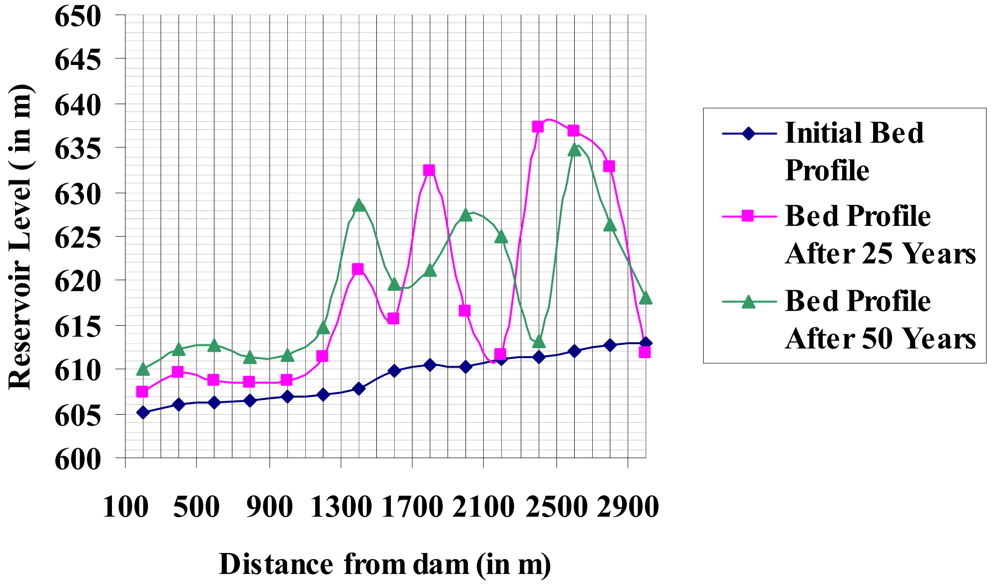

Figure 4.13 Curve which show change in bed profile after 25 and 50 years

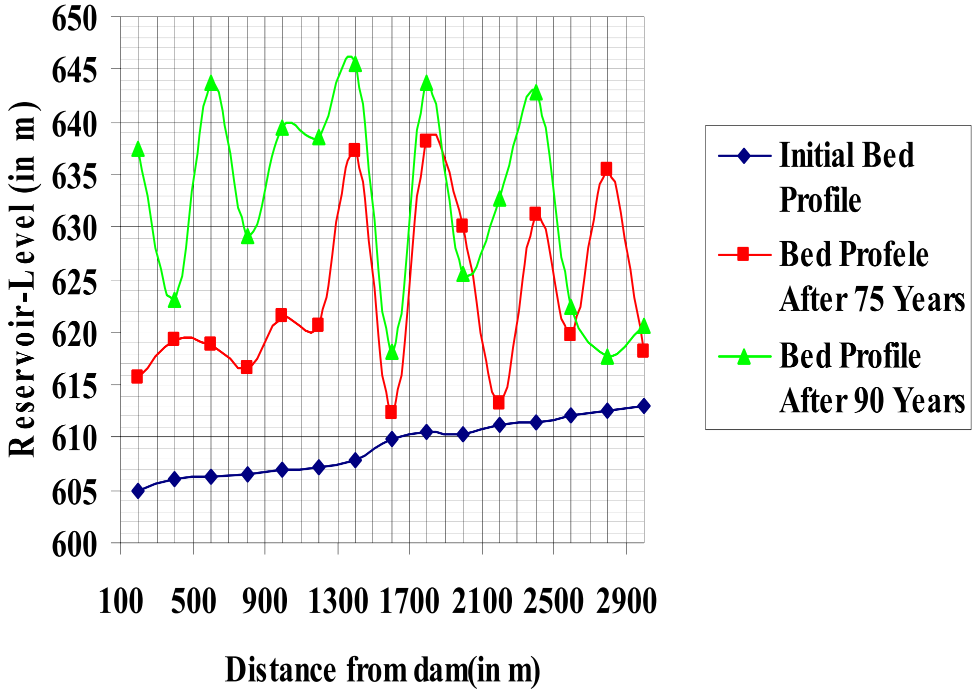

Figure 4.14 Curve which show change in bed profile after 75 and 90 years

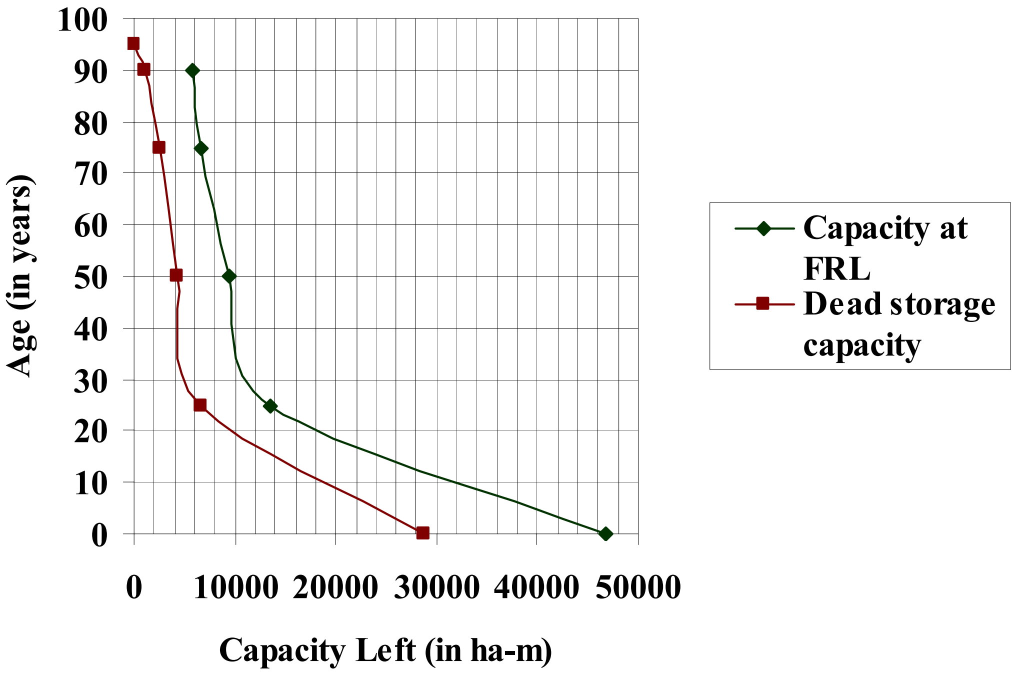

Figure 4.15 Capacity left vs. age

4.4 Concluding Remark

By using Empirical Area Reduction methods “Life of Reservoir” comes out to be 120 years while using Software HEC-6 it is 95 years. The variation may be due to following limitations imposed on Empirical Area Reduction method:

- Empirical Area Reduction method did not consider grain size distribution of sediment, which play very important role in sediment distribution.
- It did not consider variation of sediment with discharge. Since in monsoon period and in non-monsoon there is large variation of sediment with discharge, hence it plays an important role in sediment distribution.
- Also, it did not consider cross-sectional property of river, like coefficient of contraction, coefficient of expansion and Manning’s coefficient, these are very important to find energy losses and then water profile.

HEC-6 model used, here in, has several advantages over Empirical Area Reduction Method provided the requisite data are available as input to the software. Here, the complete sedimentation data were not available in true sense, hence the results obtained by two methods are expected to have the difference.

CHAPTER 5

CONCLUSIONS

The thesis work has been concluded as below:

1. The life of reservoir is mainly dependent upon sediment distribution in reservoir.
2. A software program has been made in C++ for Empirical Area Reduction method to calculation elevation of sediment deposited at dam.
3. Microsoft Excel sheet has been used for graphical calculation.
4. Life of reservoir has been calculated by Empirical Area Reduction method.
5. Software HEC-6 has been used to find sediment deposition in reservoir.
6. After determining sediment deposition in reservoir by software HEC-6, life of reservoir is obtained.

Scope of further work

While calculating sediment distribution in reservoir, there is a need to give emphasis on bed profile also. How bed profile changes and what is the nature of sediment distribution in reservoir that must be consider. To check the accuracy of software HEC-6, values obtained by using this software and value obtained from field must be compared.

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APPENDIX-A

1. A program for determination of elevation of sediment deposited at the dam.

```
#include<iostream.h>
#include<dos.h>
#include<graphics.h>
#include<stdio.h>
#include<conio.h>
void main()
{
float el[10],oc[10],oa[10],rd[10],sv[10],hamax[10],hp[10];
float sediment,height,bottomdepth;
int i,n;
char abc;
clrscr();
cout<<" Enter the no. of data : ";
cin>>n;
cout<<"\n Enter the elevations , original capacity , original area in
given sequence :\n\n";
for(i=0;i<n;i++)
cin>>el[i]>>abc>>oc[i]>>abc>>oa[i];
cout<<"\n Enter bottom depth : ";
cin>>bottomdepth;
cout<<"\n\n Enter the height:";
cin>>height;
for(i=0;i<n;i++)
rd[i]=(el[i]-bottomdepth)/height;
cout<<"\nenter the sediment:";
cin>>sediment;
for(i=0;i<n;i++)
{
sv[i]=sediment-oc[i]*1000000;
hamax[i]=height * oa[i]*1000;
if(i==0) hp[i]=0;
else
hp[i]=sv[i]/hamax[i];
}
clrscr();
printf("\n\n Direct Determination of elevation of sediment Deposited
at the Dam\n\n");
printf("\n Elevation(m)\t(p)\t V(pH)\t S-V(pH)\t A(pH)\t HA(pH)\t
h'(p)\n");
for(i=0;i<n;i++)
{
oc[i]*=1000000;
if(i==0)
printf("\n%8.2f%13.3f%11.3f%11.3f%11.3f       -
",el[i],rd[i],oc[i],sv[i],hamax[i]);
else
printf("\n%8.2f%13.3f%11.3f%11.3f%11.3f%11.3f",el[i],rd[i],oc[i],sv[i
],hamax[i],hp[i]);
}
getch();
}
```

APPENDIX-B

2. A program for sediment deposition computation (empirical area reduction method).

```
#include<iostream.h>
#include<iomanip.h>
#include<stdio.h>
#include<process.h>
#include<math.h>
#include<conio.h>

void main()
{
clrscr();
int i,j,n,age;
float cd,k1,k2,sum,sediment;
char abc;
int type;
float
el[20],oa[20],oc[20],rd[20],ra[20],sa[20],sv[20],asv[20],raa[20],rc[2
0];
cout<<" Enter the no. of data & age : ";
cin>>n>>age;
cout<<"\n Enter the elevations , original area , original capacity in
given sequence :\n\n";
for(i=0;i<n;i++)
cin>>el[i]>>abc>>oa[i]>>abc>>oc[i];
for(i=0;i<n;i++)
{
rd[i]=(el[i]-el[n-1])/(el[0]-el[n-1]);
}
cout<<"\n Enter the value of type(1,2,3,4)  ";
cin>>type;
for(i=0;i<n;i++)
{
      if(type==1)
      {
      ra[i]=5.074 * pow(rd[i],1.85) * pow((1-rd[i]),0.36);
      }
      else if(type==2)
      {
      ra[i]=2.487 * pow(rd[i],0.57) * pow((1-rd[i]),0.41);
      }
      else if(type==3)
      {
      ra[i]=16.967 * pow(rd[i],-1.15) * pow((1-rd[i]),2.32);
      }
      else if(type==4)
      {
      ra[i]=1.486 * pow(rd[i],-0.25) * pow((1-rd[i]),1.34);
      }
      else
      {
      cout<<" you have given the wrong number\n";
      exit(1);
      }
```

```
}

cout<<"\n Enter the value of critical depth : ";
cin>>cd;
i=0;
while(1)
{
if((el[i]-cd)==0)
 break;
else
 i++;
}
k1=oa[i]/ra[i];
for(j=0;j<n;j++)
{
  if(j<i)
     sa[j]=k1* ra[j];
  else if(j==i)
    sa[j]=oa[j];
  else
     sa[j]=0;
}
sv[0]=0;
sum=0;
for(j=1;j<n;j++)
{
if(j<=i)
sv[j]=((sa[j]+sa[j-1])*(el[j-1]-el[j]))/2;
else
sv[j]=0;

sum+=sv[j];
}
cout<<"\n Enter the value of sediment : ";
cin>>sediment;
clrscr();
if(sum<sediment)
{
k2=k1*sediment/sum;
for(j=0;j<n;j++)
{
  if(j<i)
     sa[j]=k2* ra[j];
  else if(j==i)
    sa[j]=oa[j];
  else
     sa[j]=0;
}
sv[0]=0;
sum=0;
for(j=1;j<n;j++)
{
if(j<=i)
sv[j]=((sa[j]+sa[j-1])*(el[j-1]-el[j]))/2;
else
sv[j]=0;

sum+=sv[j];
}
asv[0]=sum;
```

```
for(j=1;j<n;j++)
 {
  asv[j]=asv[j-1]-sv[j];
 }

}
else
{
asv[0]=sum;
for(j=1;j<n;j++)
asv[j]=asv[j-1]-sv[j];
}
for(j=i;j<n;j++)
asv[j]=0;
for(j=0;j<n;j++)
{
      if(j<i)
      {
      raa[j]=oa[j]-sa[j];
      rc[j]=oc[j]-asv[j];
      }
      else
      {
      raa[j]=0;
      rc[j]=0;
      }
}
cout<<"\n k1 is :"<<k1;
cout<<"\n k2 is :"<<k2;
cout<<"\n\t\t\t Sediment Diposition Computations\n\n";
cout<<"\t Age : "<<age<<" years\n\n"<<"\t Sediment : "<<sediment<<"
ha-m\n";
cout<<"\n Elev.    Org      Org   Rel      Rel    Sed      Sed
Acc     Rev      Rev ";
cout<<"\n          area     cap. depth    area    area     vol.    SV
area     cap \n";
for(int k=0;k<n;k++)
printf("\n%7.2f %8.2f %7.1f %5.3f %5.3f %8.3f %7.2f %8.2f %8.2f
%8.2f",el[k],oa[k],oc[k],rd[k],ra[k],sa[k],sv[k],asv[k],raa[k],rc[k])
;

getch();
}
```

APPENDIX-C

3. Input File for HEC-6 (for 1 year)

```
T1      HYDRAULIC AND GEOMETRIC OPTIONS.
T2      NO LOCAL INFLOWS
T3      NARMADA RIVER
NC    .1      .1     .04       .1      .3
X1   1.0      21       0  1798.8       0       0       0
GR 2169.   000.0  2153.1  120.67  2143.6  151.27   2095.  303.33
2058.  354.83
GR 2004.  455.39  1988.2  589.02  1985.4  607.45   1985.  759.52
1987.  823.18
GR 1992.  911.57  2001.4  1057.4  2001.9  1063.6   2045.  1215.7
2070.  1291.5
GR 2087.  1367.7  2108.5  1519.8  2109.2  1525.7   2127.  1671.9
2157.  1759.9
GR 2167.  1798.8
HD   1.0    10.0  354.83  1215.7
X1   2.0      13       0  2007.7   656.1   656.1   656.1
GR 2155.  000.00  2119.4  204.24  2089.6  368.20   2031.  564.00
2010.  696.14
GR 1993.  860.08  1988.7  969.17  1988.2  1171.7   2034.  1351.9
2087.  1577.0
GR 2114.  1779.4  2121.2  1843.8  2170.9  2007.7
HD   2.0    10.0  564.00  1351.9
X1   3.0      18       0  2474.0   656.1   656.1   656.1
GR 2179.  000.00  2169.2  104.70  2145.0  247.40   2127.  353.60
2119.  390.00
GR 2092.  532.60  2060.5  639.50  2050.5  675.25   2032.  817.90
2020.  960.50
GR 2007.  1211.0  1994.0  1388.4  1989.5  1531.0   1989.  1673.0
2049.  1959.0
GR 2058.  2069.0  2056.3  2244.0  2123.1  2474.0
HD   3.0    10.0  1211.0  1959.0
X1   4.0      12       0  1926.5   656.1   656.1   656.1
GR 2127.  000.00  2888.0  250.00  2033.2  537.50   2019.  825.00
1997.  1112.5
GR 1991.  1287.4  1990.5  1400.0  2063.2  1544.0   2074.  1565.0
2118.  1687.5
GR 2157.  1842.0  2172.8  1926.5
HD   4.0    10.0  537.50  1544.0
X1   5.0      12       0  3019.8   656.1   656.1   656.1
GR 2192.  000.00  2199.6  128.30  2111.1  602.80   2072.  1112.1
2036.  1393.7
GR 2024.  1551.9  1999.5  2026.3  1991.8  2188.9   1993.  2404.3
2052.  2659.0
GR 2069.  2835.0  2125.0  3019.8
HD   5.0    10.0  1393.7  2659.0
X1   6.0      10       0  2399.5   656.1   656.1   656.1
GR 2206.  000.00  2064.5  716.75  2015.5  1353.0   1993.  1671.0
1992.  1830.7
GR 1992.  1989.1  2017.9  2043.9  2116.1  2257.1   2141.  2307.2
2150.  2399.5
HD   6.0    10.0  1352.9  2043.9
```

```
X1   7.0       8       0  2588.1   656.1   656.1   656.1
GR 2215.  000.00  2212.1  51.900  2062.1  789.90   2025.  1319.0
1994.  1865.0
GR 2032.  2044.1  2112.5  2404.5  2170.3  2588.1
HD   7.0    10.0  1319.0  2044.1
X1   8.0      11       0   2706.8   656.1   656.1   656.1
GR 2213.  000.00  2208.3  40.280  2104.1  582.92   2057.  854.30
2001.  1700.0
GR 2002.  1843.8  2038.4  2275.3  2047.4  2419.1   2050.  2482.3
2059.  2562.9
GR 2122.  2706.8
HD   8.0    10.0  854.30  2562.9
X1   9.0      11       0  3778.8   656.1   656.1   656.1
GR 2202.  000.00  2207.8  99.580  2076.6  1114.5   2059.  1241.4
2003.  2002.6
GR 2006.  2383.2  2018.7  2764.0  2023.6  3017.6   2029.  3271.3
2054.  3398.2
GR 2128.  3778.8
HD   9.0    10.0  1114.5  3398.2
X1   10.       8       0  2124.3   656.1   656.1   656.1
GR 2098.  000.00  2091.8  24.110  2067.3  151.00   2028.  531.60
2002.  658.50
GR 2004.  1166.0  2035.1  1546.5  2117.8  2124.3
HD   10.    10.0  531.60  1546.5
X1  11.0       9       0  2012.4   656.1   656.1   656.1
GR 2138.  000.00  2132.4  69.100  2095.5  195.90   2014.  322.80
2005.  450.00
GR 2009.  830.30  2071.6  1464.6  2095.5  1718.4   2130.  2012.4
HD   11.    10.0  195.90  1718.4
X1  12.0       9       0  2012.4    656.1   656.1   656.1
GR 2140.  000.00  2134.0  69.100  2097.1  195.90   2015.  322.80
2006.  450.00
GR 2010.  830.30  2073.0  1464.6  2097.0  1718.4   2132.  2012.4
HD   12.    10.0  195.90  1718.4
X1  13.0       9       0  2012.4   656.1   656.1   656.1
GR 2142.  000.00  2135.6  69.100  2098.7  195.90   2016.  322.80
2008.  450.00
GR 2012.  830.30  2074.6  1464.6  2098.6  1718.4   2133.  2012.4
HD   13.    10.0  195.90  1718.4
X1  14.0       9       0  2012.4   656.1   656.1   656.1
GR 2144.  000.00  2137.2  69.100  2099.3  195.90   2018.  322.80
2010.  450.00
GR 2014.  830.30  2076.2  1464.6  2100.2  1718.4   2134.  2012.4
HD   14.    10.0  195.90  1718.4
X1  15.0       9       0  2012.4   656.1   656.1   656.1
GR 2144.  000.00  2137.2  69.100  2099.3  195.90   2018.  322.80
2010.  450.00
GR 2014.  830.30  2076.2  1464.6  2100.2  1718.4   2134.  2012.4
HD   15.    10.0  195.90  1718.4
EJ
T4      SEDIMENT MODEL INCLUDES SILT AND SAND. TOTAL SAND LOAD IS
SUBDIVIDED
T5      INTO 4 CLASSES VERY FINE, FINE, MEDIUM AND COARSE.
T6      TRANSPORT CAPACITY RELATION SHIP = YANG'S STREAMPOWER
T7      TWO BED GRADATION SIZES USED, ONE FOR MOST D/S SECTION OTHER
FOR MOST
T8      U/S SECTION ; MODEL VARIFIED BETWEEN EL =      TO   EL =
I1            50
I2CLAY         2
I2SPL          1    0.02    0.22    1.36     168     450
I2SPL          2    0.02    0.22    1.76     183       0
```

```
I3SILT         2       1       4
I4SAND         4       1       4
I5           0.5     0.5    0.25     0.5    0.25     0.5     0.5
LQ            50    1500    7500   20000
LT TOTAL     321    9645   48225  128600
LF  CLAY       0       0       0       0       0
LF SILT1       0       0       0       0       0
LF SILT2       0       0       0       0       0
LF SILT3    0.27    0.27    0.27    0.27    0.27
LF SILT4    0.27    0.27    0.27    0.27    0.27
LFVFSAND    0.27    0.27    0.27    0.27    0.27
LF FSAND    0.06    0.06    0.06    0.06    0.06
LF MSAND    0.06    0.06    0.06    0.06    0.06
LF CSAND    0.07    0.07    0.07    0.07    0.07
PFSECNO.       1     1.0     1.0     0.5    99.5    0.25    99.0
0.125    98.0
PFC.0625    95.0   0.032    87.0   0.016    46.0   0.008    20.0
0.004     8.0
PFC0.002     0.0
$HYD
$PRT
CP             1
PS           1.0    15.0
END
$VOL  X        0
VJ    24
VR  1988    1995    2001    2008    2014    2021    2027    2034
2041    2047
VR  2054    2060    2067    2073    2080    2087    2093    2100
2106    2113
VR  2119    2126    2132    2139
$PRT   A
*    A     FLOW 1 (1977-78),june
Q   2416
R  2110.
T     65
W    30.
*    A     FLOW 2  july
Q 4903.0
R  2116.
W    30.
*    A     FLOW 3  aug.
Q  10578
R  2125.
W    31.
*    B     FLOW 4  sep.
Q  4719.
R  2134.
W    31.
*    A     FLOW 5 oct.
Q    680
R  2138.
T     65
W    30.
*    A     FLOW 6  nov.
Q  368.0
R  2138.
W    30.
*    A     FLOW 7  dec.
Q   370.
R  2138.
```

```
W    30.
*    B     FLOW 8  jan.
Q   224.
R  2138.
W    30.
*    A     FLOW 9  feb.
Q    323
R  2138.
T     65
W    30.
*    A     FLOW 10  march
Q  224.0
R  2138.
W    30.
*    A     FLOW 11  april
Q    77.
R  2138.
W    30.
*    B     FLOW 12  may
Q    33.
R  2100.
W    30.

$PRT
CP            1
PS          1.0    15.0
END
$VOL  X
VJ    24
VR  1988    1995    2001    2008    2014    2021    2027    2034
2041    2047
VR  2054    2060    2067    2073    2080    2087    2093    2100
2106    2113
VR  2119    2126    2132    2139
$$END
```

APPENDIX-D

4. Output File after running input file

```
 *  OUTPUT FILE: n1
 *    Version: 4.2   -  May 2004          *   * HYDROLOGIC

 *  INPUT FILE: 1year new1.txt                         *     *
***************************************************
***********************************
 *  SCOUR AND DEPOSITION IN RIVERS AND RESERVOIRS  *     *  U.S. ARMY
CORPS OF ENGINEERS   *
 *       Version: 4.2    -  May 2004               *     *
HYDROLOGIC ENGINEERING CENTER  *
 *  INPUT FILE: new1.txt                          *     *  609 SECOND
STREET             *
 *  OUTPUT FILE: n1                                *     *  DAVIS,
CALIFORNIA 95616-4687   *
 *  RUN DATE: 06 AUG 05    RUN TIME: 16:21:19      *     *  (530)
756-1104                *
 ***************************************************
***********************************

                        X     X  XXXXXXX   XXXXX           XXXXX
                        X     X  X        X     X         X     X
                        X     X  X        X               X
                        XXXXXXX  XXXX     X        XXXXX  XXXXXX
                        X     X  X        X               X     X
                        X     X  X        X     X         X     X
                        X     X  XXXXXXX   XXXXX           XXXXX


*********************************************************************
*
          *  MAXIMUM LIMITS FOR THIS VERSION ARE:
*
          *       10  Stream Segments (Main Stem + Tributaries)
*
          *      500  Cross Sections
*
          *      200  Elevation/Station Points per Cross Section
*
          *       20  Grain Sizes
*
          *       20  Control Points
*

*********************************************************************
*

 T1      HYDRAULIC AND GEOMETRIC OPTIONS.
 T2      NO LOCAL INFLOWS
 T3      NARMADA RIVER
```

```
 N values...  Left   Channel   Right    Contraction    Expansion
            0.1000   0.0400   0.1000       1.0000     0.0000

 SECTION NO.     1.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     2.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     3.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     4.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     5.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     6.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     7.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     8.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.     9.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    10.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    11.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    12.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    13.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    14.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 SECTION NO.    15.000
 ...DEPTH of the Bed Sediment Control Volume =   10.00 ft.

 NO. OF CROSS SECTIONS IN STREAM SEGMENT= 15
 NO. OF INPUT DATA MESSAGES =   0

 TOTAL NO. OF CROSS SECTIONS IN THE NETWORK =  15
 TOTAL NO. OF STREAM SEGMENTS IN THE NETWORK=   1
 END OF GEOMETRIC DATA


=====================================================================
=========================================

 T4      SEDIMENT MODEL INCLUDES SILT AND SAND. TOTAL SAND LOAD IS
SUBDIVIDED
```

```
 T5     INTO 4 CLASSES VERY FINE, FINE, MEDIUM AND COARSE.
 T6     TRANSPORT CAPACITY RELATION SHIP = YANG'S STREAMPOWER
 T7     TWO BED GRADATION SIZES USED, ONE FOR MOST D/S SECTION OTHER
FOR MOST
 T8     U/S SECTION ; MODEL VARIFIED BETWEEN EL =     TO   EL =

        HYDRAULIC AND GEOMETRIC OPTIONS.
        NO LOCAL INFLOWS
        NARMADA RIVER

 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - -
 SEDIMENT PROPERITES AND PARAMETERS

        SPI     IBG    MNQ      SPGF      ACGR     NFALL    IBSHER
 I1     50.       0       1     1.000    32.174         2         1
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - -
 CLAY IS PRESENT.

        MTCL    SPGC      PUCD      UWCL      CCCD
 I2      2     2.650    78.000    30.000    16.000


   DEPOSITION COEFFICIENTS BY LAYER
                        DEPOSITION
                        THRESHOLD
                          SHEAR
               LAYER      STRESS
                NO.      lb/sq.ft

   ACTIVE LAYER  1      0.0200
 INACTIVE LAYER  2      0.0200

   EROSION COEFFICIENTS BY LAYER
                      PARTICLE   MASS       MASS       SLOPE OF
SLOPE OF
                      EROSION    EROSION    EROSION    PARTICLE
MASS
                      SHEAR      SHEAR      RATE       EROSION
EROSION
               LAYER  STRESS     STRESS                LINE=ER1
LINE=ER2
                NO    lb/sq.ft   lb/sq.ft.  lb/sf/hr   1/hr
1/hr

   ACTIVE LAYER  1      0.2200     1.3600   168.0000   147.3684
450.0000
 INACTIVE LAYER  2      0.2200     1.7600   183.0000   118.8312
0.0000
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - -
 SILT IS PRESENT

        MTCL   IASL   LASL    SGSL    PUSDLB    UWSDLB    CCSDLB
 I3      2      1      4     2.650    82.000    65.000     5.700

   DEPOSITION COEFFICIENTS BY LAYER
                        DEPOSITION
                        THRESHOLD
                          SHEAR
```

```
               LAYER      STRESS
                NO.      lb/sq.ft

   ACTIVE LAYER  1      0.0200
 INACTIVE LAYER  2      0.0200

   EROSION COEFFICIENTS BY LAYER
                      PARTICLE   MASS       MASS       SLOPE OF
SLOPE OF
                      EROSION    EROSION    EROSION    PARTICLE
MASS
                      SHEAR      SHEAR      RATE       EROSION
EROSION
               LAYER  STRESS     STRESS                LINE=ER1
LINE=ER2
                NO    lb/sq.ft   lb/sq.ft.  lb/sf/hr   1/hr
1/hr

   ACTIVE LAYER  1      0.2200     1.3600   168.0000   147.3684
450.0000
 INACTIVE LAYER  2      0.2200     1.7600   183.0000   118.8312
0.0000
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - -
  SANDS - BOULDERS ARE PRESENT

        MTC     IASA     LASA     SPGS        GSF       BSAE       PSI
UWDLB
 I4      4        1        4     2.650     0.667     0.500    30.000
93.000

 USING TRANSPORT CAPACITY RELATIONSHIP #  4, YANG
 GRAIN SIZES UTILIZED (mean diameter - mm)
 --------------------------------------------------------------------
--
     CLAY.............    0.003  |  VERY FINE SAND....    0.088
     VERY FINE SILT....   0.006  |  FINE SAND.........    0.177
     FINE SILT.........   0.011  |  MEDIUM SAND.......    0.354
     MEDIUM SILT.......   0.023  |  COARSE SAND.......    0.707
     COARSE SILT.......   0.045  |
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - -
 COEFFICIENTS FOR COMPUTATION SCHEME WERE SPECIFIED
         DBI      DBN      XID      XIN      XIU      UBI      UBN
JSL
 I5    0.500    0.500    0.250    0.500    0.250    0.500    0.500
1
 - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - -

 SEDIMENT LOAD TABLE FOR STREAM SEGMENT #   1
           LOAD BY GRAIN SIZE CLASS (tons/day)
 ------------------------------------------------------------
     FLOW | 50.0000    | 1500.00    | 7500.00    | 20000.0    |
           ----------- ----------- ----------- -----------
     CLAY |0.100000E-19|0.100000E-19|0.100000E-19|0.100000E-19|
  VF SILT |0.100000E-19|0.100000E-19|0.100000E-19|0.100000E-19|
  F  SILT |0.100000E-19|0.100000E-19|0.100000E-19|0.100000E-19|
  M  SILT | 86.6700    | 2604.15    | 13020.8    | 34722.0    |
  C  SILT | 86.6700    | 2604.15    | 13020.8    | 34722.0    |
  VF SAND | 86.6700    | 2604.15    | 13020.8    | 34722.0    |
```

```
  F  SAND | 19.2600    | 578.700    | 2893.50    | 7716.00    |
  M  SAND | 19.2600    | 578.700    | 2893.50    | 7716.00    |
  C  SAND | 22.4700    | 675.150    | 3375.75    | 9002.00    |
           ------------ ------------ ------------ ------------
    TOTAL | 321.000    | 9645.00    | 48225.0    | 128600.    |
 --------------------------------------------------------------

 REACH GEOMETRY FOR STREAM SEGMENT  1
 ------------------------------------
    CROSS        REACH    MOVABLE      INITIAL BED-ELEVATIONS
ACCUMULATED CHANNEL DISTANCE
    SECTION      LENGTH     BED    LEFT SIDE  THALWEG  RIGHT SIDE
FROM DOWNSTREAM
      NO.         (ft)     WIDTH      (ft)      (ft)      (ft)
(ft)       (miles)
 --------------------------------------------------------------------
---------------------------
                 0.000
      1.000                924.520  2058.000  1985.000  2045.000
0.000        0.000
               656.100
      2.000                998.350  2031.000  1988.200  2034.000
656.100         0.124
               656.100
      3.000                928.250  2007.000  1989.000  2049.000
1312.200        0.249
               656.100
      4.000               1160.750  2033.200  1990.500  2063.200
1968.300        0.373
               656.100
      5.000               1494.100  2036.000  1991.800  2052.000
2624.400        0.497
               656.100
      6.000               1115.625  2015.500  1992.000  2017.900
3280.500        0.621
               656.100
      7.000               1169.850  2025.000  1994.000  2032.000
3936.600        0.746
               656.100
      8.000               1916.240  2057.000  2001.000  2059.000
4592.700        0.870
               656.100
      9.000               2981.460  2076.600  2003.000  2054.000
5248.800        0.994
               656.100
     10.000               1494.100  2028.000  2002.000  2035.100
5904.900        1.118
               656.100
     11.000               1732.900  2095.500  2005.000  2095.500
6561.000        1.243
               656.100
     12.000               1732.900  2097.100  2006.000  2097.000
7217.100        1.367
               656.100
     13.000               1732.900  2098.700  2008.000  2098.600
7873.200        1.491
               656.100
     14.000               1732.900  2099.300  2010.000  2100.200
8529.300        1.615
               656.100
```

```
     15.000              1732.900  2099.300  2010.000  2100.200
9185.400        1.740

 BED MATERIAL GRADATION
 ----------------------
      SECNO    SAE   DMAX   DXPI    XPI  TOTAL       BED MATERIAL
FRACTIONS
                     (ft)   (ft)          BED            per grain
size
 --------------------------------------------------------------------
--------------
      1.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                               | VF SILT  0.120 | F
SAND  0.010 |
                                               | F  SILT  0.260 | M
SAND  0.005 |
                                               | M  SILT  0.410 | C
SAND  0.005 |
                                               | C  SILT  0.080 |


      2.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                               | VF SILT  0.120 | F
SAND  0.010 |
                                               | F  SILT  0.260 | M
SAND  0.005 |
                                               | M  SILT  0.410 | C
SAND  0.005 |
                                               | C  SILT  0.080 |

      3.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                               | VF SILT  0.120 | F
SAND  0.010 |
                                               | F  SILT  0.260 | M
SAND  0.005 |
                                               | M  SILT  0.410 | C
SAND  0.005 |
                                               | C  SILT  0.080 |

      4.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                               | VF SILT  0.120 | F
SAND  0.010 |
                                               | F  SILT  0.260 | M
SAND  0.005 |
                                               | M  SILT  0.410 | C
SAND  0.005 |
                                               | C  SILT  0.080 |

      5.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                               | VF SILT  0.120 | F
SAND  0.010 |
                                               | F  SILT  0.260 | M
SAND  0.005 |
                                               | M  SILT  0.410 | C
SAND  0.005 |
                                               | C  SILT  0.080 |
```

```
     6.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                              | VF SILT  0.120 | F
SAND  0.010 |
                                              | F  SILT  0.260 | M
SAND  0.005 |
                                              | M  SILT  0.410 | C
SAND  0.005 |
                                              | C  SILT  0.080 |

     7.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                              | VF SILT  0.120 | F
SAND  0.010 |
                                              | F  SILT  0.260 | M
SAND  0.005 |
                                              | M  SILT  0.410 | C
SAND  0.005 |
                                              | C  SILT  0.080 |

     8.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                              | VF SILT  0.120 | F
SAND  0.010 |
                                              | F  SILT  0.260 | M
SAND  0.005 |
                                              | M  SILT  0.410 | C
SAND  0.005 |
                                              | C  SILT  0.080 |

     9.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                              | VF SILT  0.120 | F
SAND  0.010 |
                                              | F  SILT  0.260 | M
SAND  0.005 |
                                              | M  SILT  0.410 | C
SAND  0.005 |
                                              | C  SILT  0.080 |

    10.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                              | VF SILT  0.120 | F
SAND  0.010 |
                                              | F  SILT  0.260 | M
SAND  0.005 |
                                              | M  SILT  0.410 | C
SAND  0.005 |
                                              | C  SILT  0.080 |

    11.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                              | VF SILT  0.120 | F
SAND  0.010 |
                                              | F  SILT  0.260 | M
SAND  0.005 |
                                              | M  SILT  0.410 | C
SAND  0.005 |
                                              | C  SILT  0.080 |
```

```
     12.000  1.000  0.003  0.003  1.000  1.000 |    CLAY  0.080 | VF
SAND  0.030 |
                                               | VF SILT  0.120 | F
SAND  0.010 |
                                               | F  SILT  0.260 | M
                                               | M  SILT  0.410 | C
SAND  0.005 |
                                               | C  SILT  0.080 |


======================================================================
=====================

 $HYD
 BEGIN COMPUTATIONS.

 ---------------------------------------------------------------------
----------------------
 $PRT
 ...Selective Printout Option
      - Print at the following cross sections
 CP            1
 PS           1.0     15.0
 END

 ---------------------------------------------------------------------
----------------------
 $VOL  X        0

 STREAM SEGMENT #  1: HYDRAULIC AND GEOMETRIC OPTIONS.

                    SUMMARY TABLE:  MASS AND VOLUME OF SEDIMENT
 ---------------------------------------------------------------------
------------------------------------------
   SECTION      SEDIMENT THROUGH SECTION (tons)          SEDIMENT
DEPOSITED IN REACH in cu. yds
                TOTAL      SAND      SILT      CLAY     TOTAL
CUMULATIVE   SAND      SILT      CLAY

     INFLOW         0.        0.        0.        0.        0.

     15.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
     14.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
     13.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
     12.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
     11.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
     10.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      9.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      8.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      7.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      6.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
```

```
      5.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      4.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      3.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      2.000         0.        0.        0.        0.        0.
0.        0.        0.        0.
      1.000         0.        0.        0.        0.        0.
0.        0.        0.        0.

              ELEV       SURFACE     VOLUME        VOLUME
                          AREA       AC-FT         CY
 SECTION NO.     1.000
             2139.00        0.00        0.00        0.00
SECTION NO.    15.000
             1988.00        18.92        44.02       70980.60
             1995.00       271.55      1065.94     1719721.63
             2001.00       387.10      3052.56     4924622.47
             2008.00       803.61      7169.91    11567439.92
             2014.00      1244.31     13349.72    21537447.82
             2021.00      1539.51     23109.61    37283531.74
             2027.00      1781.75     33082.72    53373397.62
             2034.00      2024.30     46446.76    74934036.26
             2041.00      2218.39     61302.58    98901295.67
             2047.00      2383.87     75108.90   121175747.52
             2054.00      2580.96     92491.22   149219127.18
             2060.00      2759.85    108529.03   175093383.75
             2067.00      2900.52    128354.12   207077937.78
             2073.00      3005.13    146075.15   235667758.09
             2080.00      3130.80    167549.05   270312416.42
             2087.00      3257.32    189907.40   306383972.68
             2093.00      3371.04    209790.83   338462471.92
             2100.00      3493.26    233837.52   377257855.61
             2106.00      3570.45    255030.13   411448503.17
             2113.00      3657.35    280333.02   452270500.39
             2119.00      3724.34    302476.75   487995791.53
             2126.00      3796.72    328807.37   530475837.02
             2132.00      3855.51    351764.40   567513290.01
             2139.00      3943.60    379045.13   611526151.34


======================================================================
=====================
 TIME STEP #       1
 *    A     FLOW 1 (1977-78),june

 TABLE SA-1. TRAP EFFICIENCY ON STREAM SEGMENT #  1
             HYDRAULIC AND GEOMETRIC OPTIONS.
             ACCUMULATED AC-FT ENTERING AND LEAVING THIS STREAM
SEGMENT

**********************************************************************
**************************************************
     TIME       ENTRY *             CLAY              *
SILT              *             SAND              *
     DAYS       POINT *    INFLOW   OUTFLOW  TRAP EFF *    INFLOW
OUTFLOW  TRAP EFF *    INFLOW   OUTFLOW  TRAP EFF *
    30.00      15.000 *      0.00                    *    177.77
*    105.84                *
```

```
    TOTAL=      1.000 *      0.00      0.00      0.35 *    177.77
0.00      1.00 *    105.84      0.00      1.00 *

**********************************************************************
************************************************

======================================================================
=====================
 TIME STEP #       2
 *    A     FLOW 2  july
 TABLE SA-1. TRAP EFFICIENCY ON STREAM SEGMENT #  1
             HYDRAULIC AND GEOMETRIC OPTIONS.
             ACCUMULATED AC-FT ENTERING AND LEAVING THIS STREAM
SEGMENT

**********************************************************************
*************************************************
     TIME       ENTRY *             CLAY              *
SILT              *             SAND              *
     DAYS       POINT *    INFLOW   OUTFLOW  TRAP EFF *    INFLOW
OUTFLOW  TRAP EFF *    INFLOW   OUTFLOW  TRAP EFF *
    60.00      15.000 *      0.00                     *    538.53
*    320.63                *
=13.19      0.99 *   1058.98      0.00      1.00 *

**********************************************************************
*************************************************

 = OUTFLOW  TRAP EFF *    INFLOW   OUTFLOW  TRAP EFF *
   212.00      15.000 *      0.00                     *   1805.87
*   1075.18                *
    TOTAL=      1.000 *      0.00      0.04********** *   1805.87
13.19      0.99 *   1075.18      0.00      1.00 *

**********************************************************************
*************************************************


     12.000    105012.        0.   104876.      136.   129528.
4698146.        0.   129514.      14.
     11.000     73363.        0.    73227.      136.    36068.
4734214.        0.    36067.       1.
     10.000     62156.        0.    62044.      112.    12802.
4747017.        0.    12744.      58.
      9.000     51295.        0.    51203.       92.    12404.
4759420.        0.    12355.      49.
      8.000     37196.        0.    37119.       77.    16087.
4775507.        0.    16050.      37.
      7.000     31308.        0.    31243.       66.     6725.
4782232.        0.     6697.      28.
      6.000     28734.        0.    28676.       58.     2944.
4785176.        0.     2925.      19.
      5.000     26515.        0.    26463.       53.     2536.
4787713.        0.     2523.      14.
      4.000     24535.        0.    24487.       48.     2263.
4789975.        0.     2252.      11.
      3.000     22298.        0.    22255.       44.     2555.
4792530.        0.     2544.      11.
      2.000     19764.        0.    19724.       40.     2893.
4795423.        0.     2884.       9.
```

```
     1.000     18707.         0.    18669.       38.     1207.
4796630.        0.     1202.        5.

             ELEV      SURFACE       VOLUME         VOLUME
                         AREA        AC-FT          CY
 SECTION NO.     1.000
            2139.00        0.00         0.00         0.00

 SECTION NO.    15.000
            1988.00        18.72        42.52     68617.82
            1995.00       269.81      1045.61   1686962.53
            2001.00       385.60      3022.33   4875938.04
            2008.00       755.97      7025.42  11334302.88
            2014.00      1054.44     12535.05  20223126.45
            2021.00      1320.83     20802.26  33560862.36
            2027.00      1600.80     29633.87  47809223.64
            2034.00      1828.58     41687.08  67254955.28
            2041.00      2082.81     55457.14  89470853.55
            2047.00      2245.43     68447.62 110428751.97
            2054.00      2436.81     84840.15 136875337.46
            2060.00      2611.65    100000.01 161333393.22
            2067.00      2746.32    118766.86 191610458.97
            2073.00      2845.61    135547.02 218682506.06
            2080.00      2964.45    155880.88 251487675.94
            2087.00      3083.72    177049.13 285639143.74
            2093.00      3190.86    195870.94 316005037.16
            2100.00      3310.92    218640.03 352739206.85
            2106.00      3402.67    238780.58 385232609.32
            2113.00      3507.13    262971.72 424261027.75
            2119.00      3583.61    284243.14 458578799.43
            2126.00      3664.06    309620.51 499521127.61
            2132.00      3728.12    331797.22 535299423.33
            2139.00      3824.77    358204.25 577902755.72

 ---------------------------------------------------------------------
----------------------
 $$END

       0   DATA ERRORS DETECTED.

 TOTAL NO. OF TIME STEPS READ =        12
 TOTAL NO. OF WS PROFILES =            12
 ITERATIONS IN EXNER EQ =            9000

 COMPUTATIONS COMPLETED
 RUN TIME =  0 HOURS,  0 MINUTES &  1.00 SECONDS
```