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COMPUTATION OF WATER SURFACE PROFILES USING HEC- RIVER ANALYSIS SYSTEM

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ABSTRACT

HEC-RAS, developed at the Hydrologic Engineering Centre (HEC), Davis, California, supports one-dimensional steady flow water surface profile calculations for a full network of natural and constructed channels. It is an improved version (Microsoft windows based) of HEC-2 and more convenient for the user with better graphics and input data preparation capabilities. It can also be used to analyse the effect of various obstructions along the river reach such as bridges, culverts, weirs, and structures in the flood plain. It is capable of assessing the change in water surface profiles due to channel improvements, levees, and ice cover. The program computes water surface profiles from one cross section to the next by solving the one-dimensional energy equation using standard step method.

Here, HEC-RAS has been used to analyse the water surface profiles of Malaprabha river system upto Khanapur for different combinations of discharges through various reaches of the river system. The river system is divided into 11 reaches and 41 cross sections have been measured and interpolated within these reaches. Discharge values have been assigned for different reaches according to the ratio of contributing area for each reach. The bridge across the river at Khanapur is reproduced in the modelling system to test its capabilities. Various return period floods have been allowed to pass through the river system to compute the individual water surface profiles.

1.0 INTRODUCTION

Information about the flow regime of any river under different discharge conditions is essential for the water resources engineers, planners, and managers. In order to know the depth of flow at different downstream reaches, water surface profiles are computed using the information on channel geometry and roughness coefficient of the river reach.

River training works modify the existing flow conditions. For example, construction of levees for the protection of a village or town increases the depth of flood flow. The human activities and encroachments in the flood plain affects the river environment. Construction of embankments along river reaches drastically changes the river regime which has to attain a new equilibrium state under changed conditions. For releasing water from a reservoir, knowledge of depth of flow at different downstream stations are required, to avoid damage to lives and properties.

As mentioned above, in many engineering applications, it is necessary to compute the flow conditions in channels having gradually varied flow. These computations, generally referred to as water surface profile calculations, determine the water surface elevations along the channel for a specified discharge. The water surface elevations are required for the planning, design, and operation of open channels so that the effects of engineering works and channel modifications on water levels may be assessed.

The continuity, momentum, and energy equations describe the relationships among various flow variables, such as the flow depth, discharge, and flow velocity. By solving these equations, it is possible to determine the flow conditions throughout a specified channel length. These analyses yield the change in flow depth in a given distance or compute the distance in which a specified change in flow depth will occur. The channel cross section, Manning's n, bottom slope, and the rate of discharge are usually known for these steady state flow computations.

By differentiating the energy equation for a channel section between two river sections, the governing equation for gradually varied flow can be expresses as;

$$dx/dy = (S_0 - S_f)/\left[1 - (\alpha B Q^2)\,(gA^3)\right]$$

where; S_f is the slope of the energy-grade line, S_0 is the slope of the channel bottom, α is the velocity head coefficient, B is the bottom width of the channel, Q is the discharge and A is the cross sectional area of the channel.

For the derivation of this governing equation, some assumptions are made. They are,

- the slope of the channel bottom is small
- channel is prismatic and there is no lateral inflow to or outflow from the channel
- pressure distribution at a channel section is hydrostatic

Several procedures to compute the water surface profiles have been developed. Some of the earlier procedures used varied flow functions developed by integrating the differential equation describing the gradually varied flow. Several graphical and mathematical methods were developed for the integration of this equation or for solving the energy equation between two sections. Some of these methods have been used in various general purpose computer programs for computing water surface profiles (Soil Conservation Service, 1976; US Geological Survey, 1976; US Army Corps of Engineers, 1982) Some of the generally used methods are listed below:

The most common and simple method is to calculate the profile reach by reach;

- Direct step method
- Standard step method

Methods in which numerical integration of differential equation for gradually varied flow is used;

- ↗ Single step methods: Euler method, Modified Euler method, Improved Euler method, Fourth order Runge-Kutta method, etc.
- ↗ Predictor-Corrector methods

HEC-2 or HEC-RAS, developed by Hydrologic Engineering Centre, US Army Corps of Engineers (1982), is based on standard step method. It is being widely used in many countries for water surface profile computations and proved to be very accurate and useful. This method uses river cross section data to define channel geometry; Manning's roughness coefficient to define flow characteristics along the main channel as well as for flood plain; and initial and boundary conditions to arrive at the profile characteristics for different reaches.

Other than the water surface profile computations, HEC-RAS is being used for many other applications such as planning of various river training works, river and flood plain encroachment studies, flood plain zoning, etc. It can also be used to prepare rating curves for different reaches of a river network, which can be useful during floods, for the planning and design of flood protection works along various reaches of the stream network.

2.0 HEC-RAS, RIVER ANALYSIS SYSTEM

HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of channels. The modelling system is intended for calculating water surface profiles for steady gradually varied flow. The basic computational procedure is based on the solution of one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilised in situations where water surface profile rapidly varies. These situations include mixed flow regime calculations (hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluence.

The effects of various obstructions such as bridges, culverts, weirs, and structures in the flood plain may be considered in the computation. The steady flow system is designed for application in flood plain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements, levees, and ice cover.

2.1 METHODOLOGY

Water surface profiles are computed from one cross section to the next by solving the energy equation with an iterative procedure called standard step method. The energy equation can be written as follows:

$$WS_2 + (\alpha_2 V_2^2 / 2g) = WS_1 + (\alpha_1 V_1^2 / 2g) + h_e \quad \text{-----------} \quad (1)$$

where, WS_1 and WS_2 = water surface elevations at cross sections

V_1 and V_2 = average velocities

α_1 and α_2 = velocity weighting coefficients

g = acceleration due to gravity

h_e = energy head loss

A diagram showing the terms of the energy equation is shown in Figure 1.

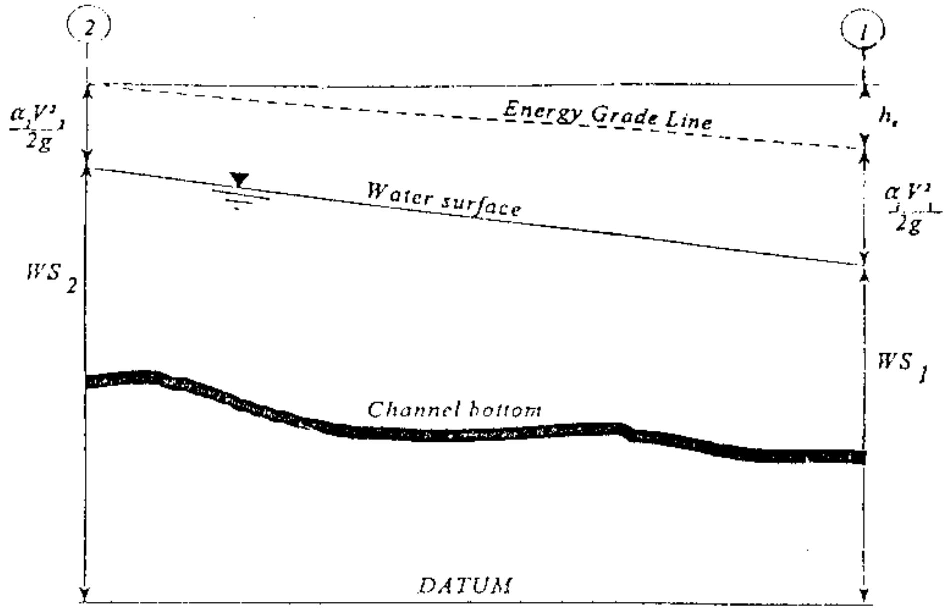

Figure 1 Representation of Terms in the Energy Equation

The energy head loss (h_e) between two cross sections is comprised of friction losses and contraction or expansion losses. The equation for the energy head loss is as follows:

$$h_e = L\bar{S}_f + C\left|\alpha_2 V_2^2/2g - \alpha_1 V_1^2/2g\right| \quad \text{------------------- (2)}$$

where, L = discharge weighted reach length

S_f = representative friction slope between two sections

C = expansion or contraction loss coefficient

The unknown water surface elevation at a cross section is determined by an iterative solution of equations 1 and 2. The computational procedure is as follows:

1. Assume a water surface elevation at the upstream cross section (or downstream cross section if a super critical profile is being calculated).
2. Based on the assumed water surface elevation, determine the corresponding total conveyance and velocity head.
3. With values from step 2, compute S_f and solve equation 2 for h_e.
4. With values from step 2 and 3, solve equation 1 for WS_2.
5. Compare the computed value of WS_2 with the value assumed in step 1; repeat steps 1 through 5 until the values agree to within 0.01 feet (0.003 m), or the user defined tolerance.

The criterion used to assume water surface elevations in the iterative procedure varies from trial to trial. The first trial water surface is based on projecting the previous cross section's water depth onto the current cross section. The second trial water surface elevation is set to the assumed water surface elevation plus 70% of the error from the first trial (computed water surface - assumed water surface). The third and subsequent trials are generally based on a 'Secant' method of projecting the rate of change of the difference between computed and assumed elevations for the previous two trials.

For a sub-critical profile, a preliminary check for proper flow regime involves checking the Froude number. The program calculates the Froude number of the balanced water surface for both the main channel and the entire cross section. If either of these two Froude numbers are greater than 0.94, then the program will check the flow regime by calculating a more accurate estimate of critical depth using the minimum specific energy method. A Froude number of 0.94 is used instead of 1, because the calculation of Froude number in irregular channels is not accurate.

For a super critical profile, critical depth is automatically calculated for every cross section, which enables a direct comparison between balanced and critical elevations.

Stream junctions can be modelled in two different ways in HEC-RAS. The default method is an energy based solution. This method solves for water surfaces across the junction by performing standard step backwater and forewater calculations through the junction. The method does not account for the angle of any of the tributary flows.

When the angle of the tributary plays an important role in influencing the water surface around the junction, a momentum based method can be used. This is a one-dimensional formulation of the momentum equation, but the angles of the tributaries are used to evaluate the forces associated with the tributary flows.

A series of program options are available in HEC-RAS to restrict flow to the effective flow areas of cross sections. Among these capabilities are options for ineffective flow areas, levees, and blocked obstructions.

3.0 DATA REQUIREMENTS

The main objective of the HEC-RAS program is to compute water surface elevations at all locations of interest for given flow values. The data needed to perform these computations are divided into geometric data and steady flow data.

3.1 GEOMETRIC DATA

The basic geometric data consists of the connectivity of the river system (river system schematic); cross section data; reach lengths; energy loss coefficients (friction losses, contraction and expansion losses); and stream junction information. If hydraulic structures (bridges, culverts, etc.) are present in the river system, the details and characteristics of those are also to be given.

The River System Schematic : The river system schematic is required for any geometric data set within the HEC-RAS system. The schematic defines how the various river reaches are connected, as well as establishing a naming convention for referencing all the other data.

Each river reach on the schematic is given a unique identifier. As other data are entered, the data are referenced to a specific reach of the schematic. The reach identifier defines which reach the cross section is situated, while the river station identifier defines where that cross section is located within the reach, with respect to the other cross sections for that reach.

The connectivity of reaches is very important in order for the model to understand how the computations should proceed from one reach to the next. It is required to draw each reach from upstream to downstream, in what is considered to be the positive flow direction. The connection of reaches are considered junctions. Junctions should only be established at locations where two or more streams come together or split apart.

<u>Cross Section Geometry</u> : Boundary geometry for the analysis of flow in natural streams is specified in terms of ground surface profiles (cross sections) and the measured distances between them (reach lengths). Cross sections are located at intervals along a stream to characterise the flow carrying capability of the stream and its adjacent flood plain. They should extend across the entire floodplain and should be perpendicular to the anticipated flow lines.

Cross sections are required at representative locations throughout a stream reach at locations where changes occur in discharge, slope, shape, or roughness; at locations where levees begin or end; and at bridges or control structures such as weirs. Where abrupt changes occur, several cross sections should be used to describe the change regardless of the distance.

Each cross section in an HEC-RAS data set is identified by a reach and river station label. The cross section is described by entering the station and elevation (X-Y data) from left to right, with respect to looking in the downstream direction. End points of a cross section that are too low (below computed water surface elevation) will automatically be extended vertically. The program adds additional wetted perimeter for any water that comes into contact with the extended walls.

Other data that are required for each cross section consist of downstream reach lengths; roughness coefficients; and expansion and contraction coefficients.

The measured distance between cross sections are referred to as reach lengths. The reach lengths for the left overbank, right overbank, and channel are specified on the cross section data editor. Often these three lengths will be of similar value. There are, however, conditions where they will differ significantly, such as at river bends, or where the channel meanders and the overbanks are straight.

Selection of an appropriate value of Manning's n is very significant to the accuracy of the computed water surface profiles. The value of Manning's n is highly variable and depends on a number of factors including; surface roughness, vegetation, channel irregularities, channel alignment, scour and deposition, obstructions, size and shape of channel, stage and discharge, seasonal change, temperature, and suspended material and bedload.

Contraction or expansion of flow due to changes in the cross section is a common cause of energy loss within a reach. Whenever this occurs, the loss is computed from the contraction and expansion coefficients specified on the cross section data editor. Where the change in river cross section is small, contraction and expansion coefficients are typically on the order of 0.1 and 0.3 respectively. When the change in cross section is abrupt such as at bridges, 0.3 and 0.5 are often used as the contraction and expansion coefficients. The coefficients of contraction and expansion around bridges and culverts may be as high as 0.6 and 0.8, respectively.

Stream Junction Data : Stream junctions are defined as locations where two or more streams come together or split apart. Junction data consists of reach length across the junction and tributary angles (only if momentum equation is selected). Reach lengths across the junction are entered in the junction data editor. This allows for the lengths across very complicated confluence to be accommodated. The cross sections that bound a junction should be placed as close together as possible which will minimise the error in the calculation of energy losses across the junction.

3.2 STEADY FLOW DATA

Steady flow data are required in order to perform a steady water surface profile calculation. Steady flow data consist of; flow regime, boundary conditions, and peak discharge information.

Flow Regime : Profile computations begin at a cross section with known or assumed starting conditions and proceed upstream for sub-critical flow or downstream for supercritical flow. The flow regime (sub-critical, supercritical, or mixed flow regime) is specified on the Steady Flow Analysis window of the program interface. Sub-critical profiles computed by the program are constrained to critical depth or above, and supercritical profiles are constrained to critical depth or below. In case where the flow regime will pass from sub-critical to supercritical or supercritical to sub-critical, the program should be run in a mixed flow regime mode.

Boundary Conditions : Boundary conditions are necessary to establish the starting water surface at the ends of the river system. A starting water surface is necessary in order for the program to begin the calculations. In a sub-critical flow regime, boundary conditions are only necessary at the downstream ends of the river system. If a supercritical flow regime is going to be calculated, boundary conditions are only necessary at the upstream ends of the river system. If a mixed flow regime is going to be made, then boundary conditions must be entered at all ends of the river system. The boundary conditions editor contains a table listing every reach. Each reach has an upstream and downstream boundary condition. Connections to junctions are considered as internal boundary conditions. These are automatically listed in the table, based on how the river system was defined in the geometric data editor. There are four types of boundary conditions available to the user:

1. Known water surface elevations can be entered as boundary condition for each of the profiles to be computed
2. If critical depth is selected as the boundary condition, the program will calculate critical depth for each profiles and use that as boundary condition.
3. If normal depth is selected as the boundary condition, the user is required to give an energy slope that will be used in calculating normal depth.
4. When rating curve is selected as the boundary condition, the user has to enter an elevation versus flow rating curve.

Discharge Information : Discharge information is required at each cross section in order to compute the water surface profile. Discharge data are entered from upstream to downstream for each reach. At least one flow value must be given for each reach in the river system. Once a flow value is entered at the upstream end of a reach, it is assumed that the flow remains constant until another flow value is encountered with the same reach. The flow rate can be changed at any cross section within a reach. However, the flow rate cannot be changed in the middle of a bridge, culvert, or a stream junction. Flow data must be entered for the total number of profiles that are requested to be computed.

3.3 OPTIONAL CAPABILITIES OF HEC-RAS

Multiple Profile Analysis : HEC-RAS can compute upto 15 profiles, for the same geometric data, within a single execution of the steady flow computations. When more than one profile is required, the flow data and boundary conditions should be established for each profile. Once a multiple profile computation is made, the output can be viewed in a graphical or tabular mode, for any single or combination of profiles.

Multiple Plan Analysis : The HEC-RAS system has the ability to compute a series of water surface profiles for a number of different characterisations of the river system. Modifications can be made to the geometry and/or flow data, and then saved in separate files. Plans are then formulated by selecting a particular geometry file and a particular flow file. The multiple plan option is useful when a comparison of existing conditions and future channel modifications are to be analysed. This option can also be used to perform a design of a specific geometric feature, such as sizing of a bridge opening.

Optional Friction Loss Equations : The friction loss between adjacent cross sections is computed as the product of the representative rate of friction loss (friction slope) and the weighted reach length. The program allows the user to select from the following previously defined friction loss equations:

- Average conveyance
- Average friction slope

- ↗ Geometric mean friction slope
- ↗ Harmonic mean friction slope

Any of the above friction loss equations will produce satisfactory estimates provided that reach lengths are not too long. The advantage sought in alternative friction loss formulations is to be able to maximise reach lengths without sacrificing profile accuracy.

Cross Section Interpolation : Occasionally, it is necessary to supplement surveyed cross section data by interpolating cross sections in between two surveyed sections. Interpolated cross section are often required when the change in velocity head is too large to accurately determine the change in the energy gradient. When cross sections are spaced too far apart, the program may end up defaulting to critical depth. The HEC-RAS program has the ability to generate cross sections by interpolating the geometry between two user entered cross section.

Mixed Flow Regime Calculations : The HEC-RAS program has the ability to perform sub-critical, supercritical, or mixed flow regime calculations. The specific force equation is used to determine which flow regime is controlling, as well as locating any hydraulic jumps. The equation for specific force is derived from the momentum equation.

Flow Distribution Calculations : The general cross section output shows the distribution of flow in three subdivisions of the cross section; left overbank, main channel, and the right overbank. Additional output showing the distribution of flow for multiple subdivisions of the left and right overbanks, as well as the main channel, can be obtained from the HEC-RAS. The computations for the flow distribution are performed after the program has calculated a water surface elevation and energy by the normal methodology.

4.0 STUDY AREA

Malaprabha, which is a sub-basin of Krishna river originates from Kankumbi at an altitude of about 793 m in Belgaum district of Karnataka. Initially the river flows in an easterly direction and then towards north direction and joins the Krishna at an elevation of about 488 m, after about 300 km from its source. The total geographical area of the Malaprabha basin is 115449 km^2.

The catchment area upto Khanapur gauging station, which is the present study area, is 520 km^2. This area lies between 74°20' and 74°30' East longitudes and 15°20' and 15°40' North latitudes. Figure 2 shows the Malaprabha river upto Khanapur. This catchment is the major source of water for the Naviluteertha dam which situated at about 40 kms. downstream of Khanapur. This dam impounds about 1377 MCM water and provides water for irrigation for about 2.17 lakh ha. land.

Geologically, Malaprabha basin comprises of tertiary basalt, which covers the major part of the basin (96 %); and sedimentary formations of Pre-Cambrian age, which is confined to the south-east part of the catchment.

The soils of this basin can be grouped into two as; red loamy soils, which covers a major part of the basin (80%), especially in the upstream region; and medium black soil, which can be seen in the downstream portions. These black soils are usually clayey in texture with low permeability. Generally the soil thickness within the basin varies between 0.5 m to 10 m.

A major portion of the basin is covered by forests (63 % of the total catchment area), which can be seen along western and south-western parts of the study area. Agricultural lands constitute about 17 % of the total area, in the northern part of the basin. The sloppy area of the catchment are covered by shrubs, which occupies 19 % of the area.

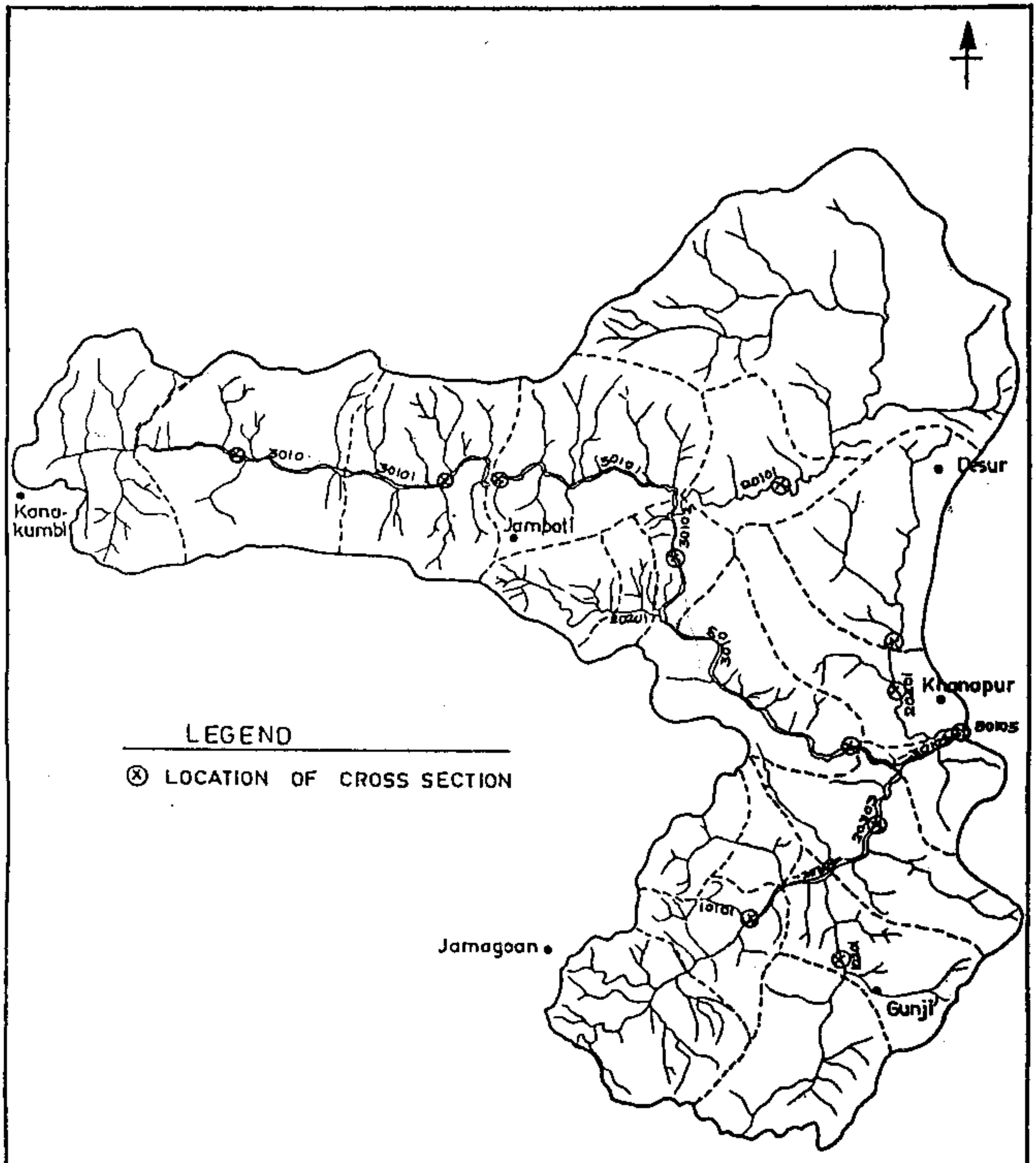

Fig. 2: Malaprabha River Upto Khanapur

The climate of the Malaprabha basin is influenced by the south-west monsoon, which extends from mid June to September. The monsoon rainfall accounts for 91 % of the total rainfall in the basin. The average annual rainfall of the basin is 2259 mm. The temperature in the basin varies between 19.2 °C to 29.5 °C. The mean evaporation in the catchment is 1496.9 mm. Normally the climate over the basin is humid. The discharge from the basin is measured at Khanapur gauge-discharge site, by WRDO, using a float type recording gauge. The average annual discharge at Khanapur is 8953.6 cumecs. About 77 % of this flow occurs in the month of July and August.

5.0 MODEL APPLICATION

For developing a hydraulic model using HEC-RAS, it is necessary to establish a new project and to supply geometric and flow input data. Geometric data consists of establishing the connectivity of the river system (River System Schematic), entering cross-section data, defining all the junction information, adding hydraulic structure data (bridges, culverts, etc.), and cross section interpolation. The flow input data consists of discharges at individual reaches and other flow coefficients.

The preliminary step in inputting geometric data is drawing of river system schematic on the geometric data window on the HEC-RAS program. River system schematic adopted for the present study is given in Figure 3.

Cross section data represent the geometric boundary of the stream. Typical cross sections at representative locations were measured along the stream as X-Z co-ordinates. X co-ordinates have been measured from a reference point located on the left side of the extreme left cross sectional point (looking downstream) and Z co-ordinates were measured upwards starting at a reference point located below the lowest cross sectional point. The river system is divided into 11 reaches and for each of these reaches, typical cross sectional measurements have been made. Slight modifications were made to these cross sections to arrive at the co-ordinates of cross sections for other stations in each reach. Distance between one cross section and the next downstream cross section is termed as the reach length. Reach lengths are defined for the left overbank, main channel, and the right overbank. A total number of 41 stations were identified and the cross sectional details were fed into the model for the 11 reaches.

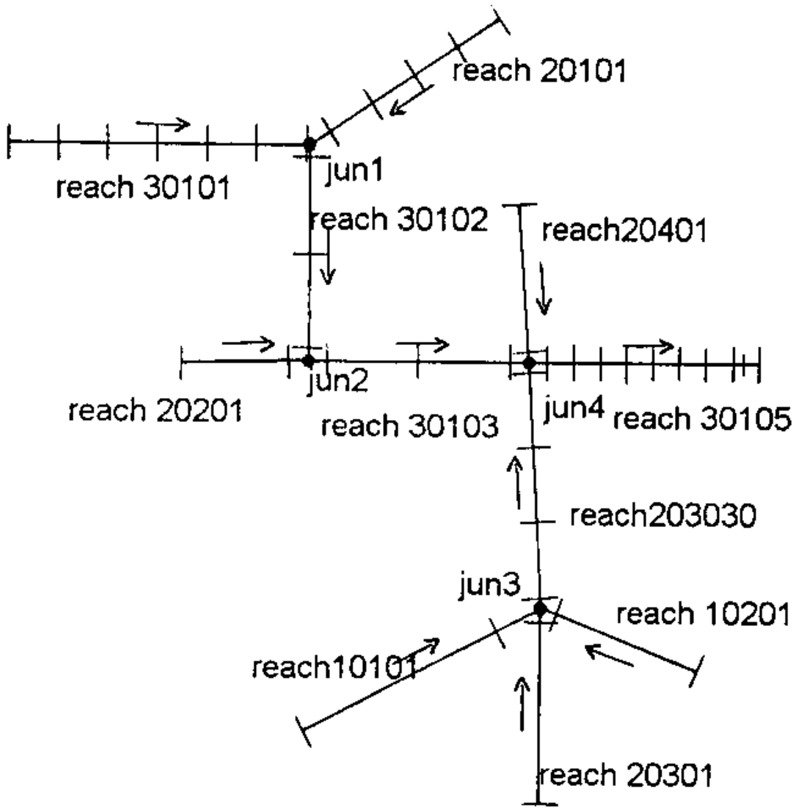

Fig. 3: River System Schematic of Malaprabha for Model Application

Manning's n value has been derived on the basis of the values given by Chow (1964), and Barns (1987). Three different n values were assigned to each cross section, for channel, left overbank, and right overbank. The n values for the channel varies between 0.05-0.075, and for the overbanks between 0.07-0.09. Expansion coefficient has been assumed as 0.1 and contraction coefficient between 0.3-0.4.

Four stream junctions are defined for the river system by providing data for reach lengths across the junction, tributary angles, and modelling approach. In most cases, the amount of energy loss due to the angle of the tributary flow is not significant. Hence energy equation is selected for the modelling of junctions.

In order to compute the water surface profiles, discharge values were calculated for different return periods. Gauge-Discharge data at Khanapur gauging site for 21 years from 1973 to 1993 have been analysed to get the different return period flow values by frequency analysis using the PWM based GEV, EV-1 and Wakeby distributions. The values obtained from EV-1 distribution were considered for the computation of water surface profiles at Khanapur. The estimated peak flow values for different return periods are tabulated in Table.1.

Table 1: Discharge (in cumecs) at Khanapur for Different Return Periods

Return Period (years)	**Discharge (cumecs)**
2	341.658
5	425.341
10	643.085
50	907.345
100	1019.062
200	1130.372
500	1277.224
1000	1388.212

For the computation of water surface profiles, 5 year, 10 year, 50 year, 100 year, and 200 year return period discharge values were selected. Each of these discharge values have been distributed to different reaches using the discharge ratios calculated using RAINFLO model (NIH, TR-179, 1991-92). At a particular time, the discharge values assigned for different reaches/stations are given in Table 2. This alongwith the coefficients constitute the flow input data for HEC-RAS.

Table 2: Discharge (in Cumecs) at Different Reaches for Different Return Periods

Station/Reach	**T_5**	**T_{10}**	**T_{50}**	**T_{100}**	**T_{200}**
7/30101	60.93	92.10	130.36	145.94	162.95
12/20101	60.93	92.10	130.36	145.94	162.95
15/30102	121.86	184.20	259.30	291.88	324.48
17/20201	36.84	55.26	77.93	87.85	97.48
20/30103	158.70	239.46	336.95	379.74	421.68
22/10101	36.84	55.26	77.93	87.85	97.48
24/20301	36.84	55.26	77.93	87.85	97.48
26/10201	36.84	55.26	77.93	87.85	97.48
30/203030	110.52	165.78	233.79	263.55	292.45
32/20401	36.84	55.26	77.93	87.85	97.48
41/30105	425.34	643.09	907.35	1019.06	1130.37

Boundary conditions are necessary to establish the starting water surface at the ends of the river system. A starting water surface is necessary in order for the programme to begin the calculations. For the present study, the flow through the river system is assumed as sub-critical flow. In sub-critical flow conditions, four types of boundary conditions can be specified at the downstream end of the river system, viz. known water surface elevation, critical depth, normal depth, and rating curve. Normal depth is taken as the boundary condition for the present study. For this condition, the value of average energy slope at the downstream end of the river system is the input to the program, and is calculated as 0.003.

HEC-RAS computes energy losses caused by structures such as bridges and culverts in three parts. One part consists of losses that occur in the reach immediately downstream from the structure where an expansion of flow takes place. The second part is the losses at the structure itself, and the third part consists of loss that occur in the reach immediately upstream of the structure where the flow is contracting.

In the present application, the bridge at Khanapur has been simulated between stations 33 and 34 on reach 30105. Data pertaining to the bridge deck, abutments, and piers have been supplied.

After establishing a project, inputting the necessary geometric and flow data, and providing the required boundary conditions as described in previous paragraphs, hydraulic calculations have been performed for computing steady water surface profiles for five selected discharge values.

6.0 RESULTS AND DISCUSSIONS

6.1 RESULTS

Model outputs/results are in the form of water surface profiles, cross sectional plots and cross sectional and profile tables. It is seen from the results that the model is capable of simulating the flow profiles for different flow conditions. Slight variations are due to the approximations made in the selection of Manning's roughness coefficients, contraction and expansion coefficients, and inadequate number of cross sections in a reach.

HEC-RAS provides the user with a large amount of hydraulic information in the form of model output, for any particular station/cross section, reach, and profile. Some sample outputs for different reaches of Malaprabha river is given in succeeding pages.

Table 3 gives the details of flow properties within the bridge at Khanapur, for both upstream and downstream sides.

Table 3: Bridge Output for Profile 3 (T_{50}) for the D/S reach of the river

Plan: Malaprabha Reach: reach 30105 Riv Sta: 33.5 Profile: 3 (T_{50})

E.G. US. (m)	643.77	**Element**	**Inside BR US**	**Inside BR DS**
W.S. US. (m)	643.56	**E.G. Elev (m)**	643.27	642.13
Q Total (m3/s)	907.00	**W.S. Elev (m)**	642.82	641.64
Q Bridge (m3/s)	907.00	**Crit W.S. (m)**	640.54	639.57
Q Weir (m3/s)		**Max Chl Dpth (m)**	6.32	6.64
Weir Sta Lft (m)		**Vel Total (m/s)**	2.96	3.10
Weir Sta Rgt (m)		**Flow Area (m2)**	306.92	292.62
Weir Submerg		**Froude # Chl**	0.43	0.46
Weir Max Depth (m)		**Specif Force (m3)**	1099.83	1074.89
Min Top Rd (m)	646.50	**Hydr Depth (m)**	4.80	4.62
Min El Prs (m)	644.50	**W.P. Total (m)**	124.13	123.58
Delta EG (m)	3.37	**Conv. Total (m3/s)**	11224.1	10397.1
Delta WS (m)	3.79	**Top Width (m)**	63.96	63.40

The model output includes the flow details at an individual station and for each of the river reaches. It includes the flow velocity, water surface elevation, flow area, top width, flow distribution along channel and overbanks, etc. This will help the planners and designers in preparing project plans and for flood plain management. Table 4 gives the hydraulic properties of flow at a station/cross section for an individual profile. Table 5 provides the distribution of flow within the channel and its overbanks. Table 6 gives the flow properties at different stations in a river reach for different discharges.

Table 4: Cross Sectional Output for the Upstream Station

Plan: Malaprabha   Reach: reach 30101   Riv Sta: 7   Profile: 3 (T_{50})

W.S. Elev (m)	811.77	**Element**	**Left OB**	**Channel**	**Right OB**
Vel Head (m)	0.06	**Wt. n-Val.**	0.090	0.072	0.090
E.G. Elev (m)	811.83	**Reach Len. (m)**	3428.70	3428.70	3428.70
E.G. Slope (m/m)	0.001024	**Flow Area (m2)**	19.50	111.96	3.67
Q Total (m3/s)	130.00	**Flow (m3/s)**	6.37	122.95	0.69
Top Width (m)	56.66	**Top Width (m)**	22.08	25.00	9.58
Vel Total (m/s)	0.96	**Avg. Vel. (m/s)**	0.33	1.10	0.19
Max Chl Dpth (m)	5.27	**Hydr. Depth (m)**	0.88	4.48	0.38
Crit W.S. (m)		**Wetted Per. (m)**	22.15	28.82	9.61
Conv. Total (m3/s)	4062.9	**Conv. (m3/s)**	199.0	3842.4	21.5

Table 5: Flow Distribution Output for the Upstream River Station

Plan: Malaprabha   Reach: reach 30101   Riv Sta: 7   Profile: 3 (T_{50})

Left Sta (m)	**Right Sta (m)**	**%Q**	**Area (m2)**	**W.P. (m)**	**Conv. (m3/s)**	**Hydr D. (m)**	**Velocity (m/s)**
43.89	100.01	4.90	19.50	22.15	199.0	0.88	0.33
100.01	125.01	94.57	111.96	28.82	3842.4	4.48	1.10
125.01	182.88	0.53	3.67	9.61	21.5	0.38	0.19

Table 6: Profile Table for Profile No. 1, 3, & 5 (T_5, T_{50}, T_{200}) for the D/S Reach

Plan: Malaprabha Reach: reach 30105

River Sta.	Q Total (m3/s)	Min Ch El (m)	W.S. Elev (m)	Crit W.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m2)	Top Width (m)	Froude # Chl
41	425.00	646.50	650.75		651.08	0.004649	2.58	164.81	62.46	0.51
41	907.00	646.50	652.40		652.96	0.004468	3.31	273.70	68.20	0.53
41	1134.00	646.50	653.05		653.70	0.004410	3.56	318.37	70.14	0.53
40	425.00	645.50	649.42		649.69	0.003566	2.34	181.75	65.24	0.45
40	907.00	645.50	651.12		651.59	0.003550	3.05	297.27	70.35	0.47
40	1134.00	645.50	651.78		652.33	0.003552	3.29	344.32	72.33	0.48
39	425.00	644.00	648.20		648.48	0.003590	2.35	180.60	64.59	0.45
39	907.00	644.00	649.90		650.38	0.003604	3.08	294.75	69.69	0.48
39	1134.00	644.00	650.55		651.12	0.003625	3.33	340.84	71.64	0.49
38	425.00	642.50	646.97		647.25	0.003656	2.38	178.69	63.78	0.45
38	907.00	642.50	648.63		649.13	0.003785	3.14	289.02	68.87	0.49
38	1134.00	642.50	649.26		649.85	0.003852	3.41	332.94	70.76	0.50
37	425.00	641.00	645.53		645.87	0.004561	2.58	164.46	61.16	0.50
37	907.00	641.00	647.00		647.63	0.005194	3.49	259.63	67.00	0.57
37	1134.00	641.00	647.58		648.31	0.005300	3.80	298.63	68.73	0.58
36	425.00	639.50	643.20		643.73	0.009120	3.23	131.66	59.19	0.69
36	907.00	639.50	644.93		645.64	0.006566	3.76	241.41	66.77	0.63
36	1134.00	639.50	645.62		646.41	0.005963	3.93	288.26	68.84	0.61
35	425.00	638.00	641.93		642.15	0.002569	2.10	202.70	66.78	0.38
35	907.00	638.00	643.95		644.30	0.002314	2.64	343.45	72.83	0.39
35	1134.00	638.00	644.69		645.10	0.002309	2.85	398.55	75.06	0.39
34	425.00	636.50	641.59	638.60	641.69	0.000737	1.39	305.00	71.77	0.22
34	907.00	636.50	643.56	639.73	643.77	0.000993	2.01	452.74	80.70	0.26
34	1134.00	636.50	644.30	640.19	644.55	0.001047	2.23	514.44	86.92	0.28
33.5	Bridge									
33	425.00	635.00	638.28	637.39	638.64	0.005401	2.66	159.92	64.83	0.54
33	907.00	635.00	639.77	638.54	640.39	0.005403	3.49	260.15	69.31	0.57
33	1134.00	635.00	640.36	638.99	641.08	0.005401	3.77	301.01	71.06	0.58

Figure 4 shows the cross section at the bridge site showing details of bridge such as deck, piers, etc. and all the five profiles. Figure 5 shows the cross section at the upstream end of the Malaprabha at Kankumbi. Such plots can be visually checked for determining the effects of flood flow through the river.

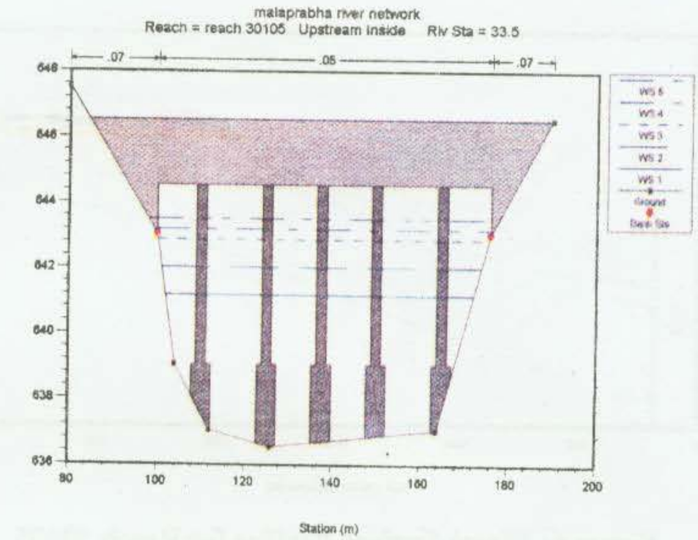

Figure 4: Cross Section at Bridge Showing the Profiles

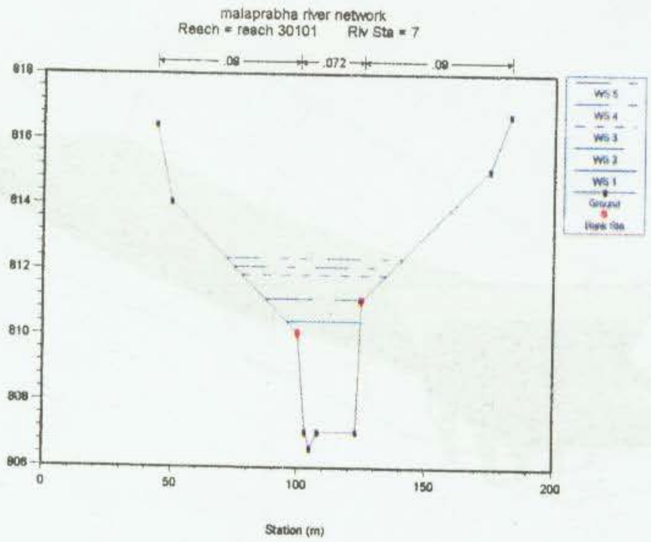

Figure 5: Cross Section at the Upstream End of the River With Profiles

Graphics produced by HEC-RAS are of high quality. Figure 6 gives the profiles for the downstream reach. Figure 7 shows the perspective view of all the 5 profiles for the downstream reach (30105).

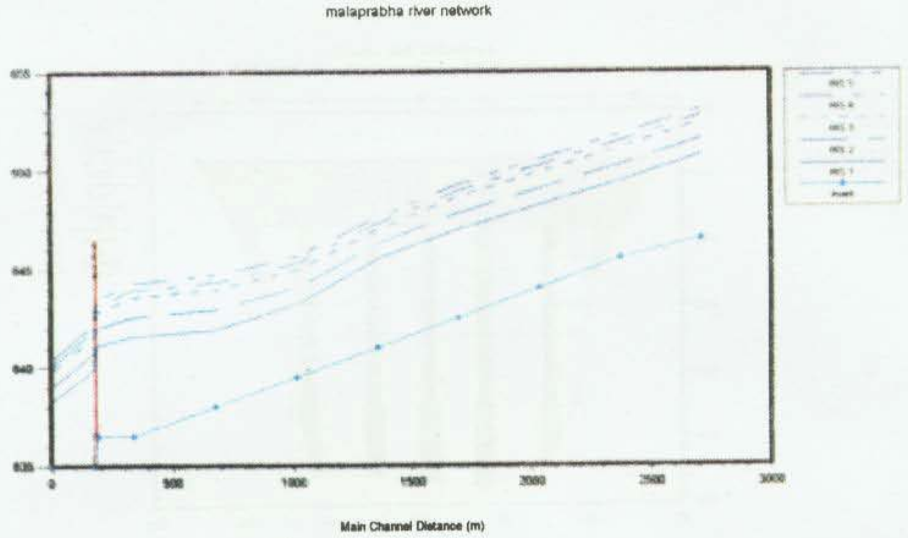

Figure 6: Water Surface Profiles for Reach 30105

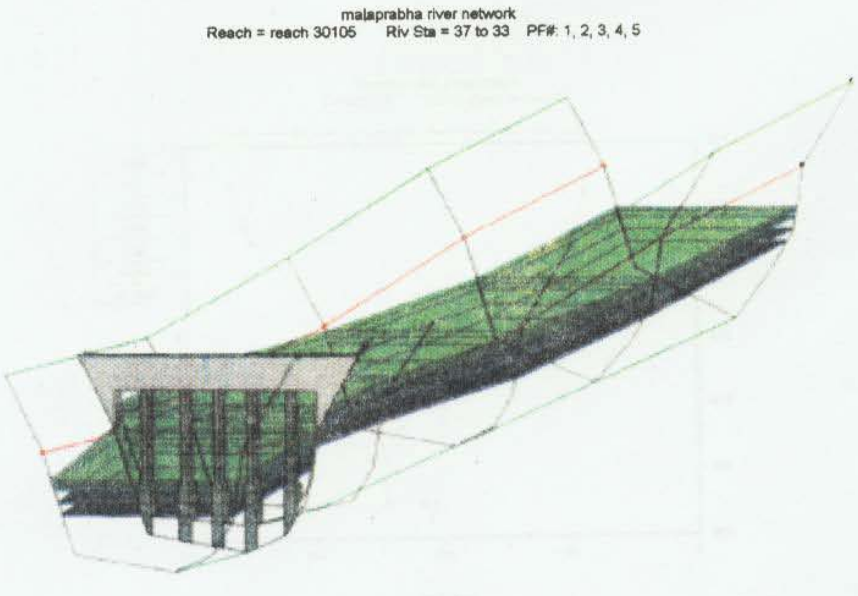

Figure 7: Perspective View of the Profiles for the Downstream Reach

6.2 LIMITATIONS

1. HEC-RAS is not designed to model very long reaches because of linearity reasons. Since the energy grade line between two cross sections is linearly interpolated, a longer reach will introduce errors in the computation of water surface profiles. Furthermore, interpolation of cross sections will be source of major error in a long reach. These systematic errors are additive in nature. However, by suitably incorporating measured cross sectons at locations where there is significant variations in the physical characteristics of the river reach, these errors can be reduced to some extent.

2. The assumption regarding steady flow condition throughout the river system is not practical. Hence routing techniques are preferred for modelling. HEC-RAS can be used (a) for an initial estimate of the water surface profiles; (b) when the river reach is not very long, enough cross sections are available and the flow characteristics will not change drastiacally; and (c) to assess the effects of channel improvement, encroachment, river trainning works, etc.

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