DEVELOPMENT OF NUMERICAL MODEL FOR ALLUVIAL STREAMS WITH MULTI-CHANNEL CONFIGURATION

A DISSERTATION

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By

BINOD KUMAR SINHA

WATER RESOURCES DEVELOPMENT TRAINING CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE -247 667 (INDIA)

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CANDIDATE'S DECLARATION

I hereby declare that the dissertation titled **"Development of Numerical Model for Alluvial Streams with multi-channel configuration"** which is being submitted in partial fulfillment of the requirements for the award of Degree of Master of technology, Water Resources Development (civil) at Water Resources Development Training Centre (WRDTC), Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period of 16.07.2002 to the date of submission under the supervision and guidance of **Dr.Nayan Sharma,** Professor, WRDTC, IIT Roorkee,

I have not submitted the matter embodied in this dissertation previously for the award of any other degree.

Place: Roorkee

Dated: 23rd December , 2002

(Binod Kumar Sinha)

46th WRD (Civil).WTDTC, IIT, Roorkee

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

23.12.2002

(DR. NAYAN SHARMA)

PROFESSOR

W. R. D. T. C.,

I. I. T. ROORKEE, (INDIA)

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ABSTRACT

DEVELOPMENT OF NUMERICAL MODEL FOR ALLUVIAL STREAMS WITH MULTI-CHANNEL CONFIGURATION

The art of modeling an alluvial river of multi-channel configuration is still in a developing stage and a lot of ground yet remains to be covered. Unlike modeling approach for a single channel stream, the multi-channel model development entails dealing in complex problems of flow division around movable bars and islands, formation and deformation of islands and highly random nature of channel morphological changes. The dynamics of flow is further complicated in a natural stream due to wide differences in hydraulic properties and resistances of flow in the main channel and the subsidiary channels.

A number of contributions have been made for simulating flood routing, overland flow and related time-dependent transient flow problems by solving the gradually varied unsteady flow equations numerically however, invariably in all the existing models the solutions are obtained based on certain simplifications. These are:

(i) The geometric properties of all the irregular sections of a natural stream over the entire reach are averaged with respect to the flow depth to form a single representative cross-section. The cross-sectional areas and the top widths of the representative cross-section are then fitted by a polynomial.

(ii) The change in the volume of sediment per unit length at every time-step after sediment routing is distributed uniformly over the entire cross-section of the natural stream.

The above simplifications can work satisfactorily only when natural stream consists of single channel at all the stages of flow. However, in an alluvial stream of multi-channel configurations these simplifications can introduce serious error and the simulation results based on this cannot be relied upon.

The purpose herein is to **develop a numerical model for a multi-channel configuration of an alluvial river** with capability to simulate flow of water as well as aggradation/degradation in an active sediment transport regime. This model will be different from the conventional one-dimensional treatment of unsteady flow in natural stream wherein the flow is averaged across total cross-sectional area. This model treats the main flow channel and subsidiary channels as separate entity.

The technique is based on a modified form of Saint Venant's one-dimensional equations of unsteady flow (1) the equation of continuity for sediment, (2) the equation of continuity for sediment laden water, and (3) the equation of momentum for sediment laden water. **The three classic equations have been modified in such a way that all the geometric and hydraulic properties of all the channels at various stages of flow remain intact during the process of simulation.**

Also in the existing models, the bed erosion or deposition of sediment is uniformly distributed over the entire cross section. To improve upon the accuracy in the case of multi-channel configuration an endeavour has been made **to formulate suitable functional relationships to represent aggradation and degradation phenomena in a natural stream realistically.**

In order to arrive at a solution a suitable numerical scheme with **solution algorithm is also presented and a computer program has been developed.**

To facilitate the modeling endeavour with real life situation, the data of Brahmaputra River have been adopted for testing and simulation of numerical model. The large alluvial river like Brahmaputra is a perfect real life example of a stream with multi-channel configurations and it's complexities due to wide variations in the channel form and discharge poses many difficulties in modeling. To overcome these, certain steps have been taken which have been summarised in this work. Finally, the simulation results obtained from the model developed herein have been compared with the available observed data of Brahmaputra and discussion thereupon has been presented.

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LIST OF SYMBOLS

A = the cross-sectional area of the channel

A_{mc}= flow area of main channel

A_{sc}= flow area of subsidiary channels

A_c = the volume of deposition of sediment on unit length of channel bed

A_d = the volume of sediment suspended in the water over the cross section per unit length of channel

A_w = the volume of water per unit length of cross section of channel

A_x^y = $(\frac{\partial A}{\partial x})_y$, a term which represents a departure from a prismatis channel

B = the top width ,which is defined as the width at the water surface,

c = celerity of a gravity wave

cs = the mean sediment concentration on a volume basis

D_l = the dynamic contribution of the lateral discharge, given as $\frac{q_l V_l}{gA}$

d_{50} = sediment particle diameter of which 50% is finer

f = Darcy's friction factor

g = the gravity acceleration

h = the flow stage

L = the length of the reach

n = the Manning's roughness coefficient

P= wetted perimeter

p= the volume of sediment ina unit volume of bed sediment layer

Q= the flow discharge

Q_{mc}= flow in main channel

Q_{sc}= flow in subsidiary channel

q_{in}= the initial flow discharge

Q_s= the sediment discharge

Q_w= the water discharge

q_l= the lateral inflow to the channel

q_s= the lateral sediment inflow to the channel

q_w= the lateral water inflow to the channel

$R =$ Hydraulic radius

$S_f =$ the energy slope or friction slope

$S_o =$ the bed slope

$T =$ $\partial A / \partial y$

$t =$ time

$\tau_o =$ ambient shear

$\tau_c =$ critical shear

$V, u =$ the mean flow velocity

$V_l =$ the velocity component of of lateral inflow in x-direction

$u_* =$ shear velocity given by $\sqrt{\frac{\tau_o}{\rho_f}}$

$u_{*c} =$ critical shear velocity given by $\sqrt{\frac{\tau_c}{\rho_f}}$

$y =$ the depth of flow

$z =$ the mean bed elevation

$xx =$ the distance of river bed points from left reference line

$zz =$ the corresponding elevations of the river bed points

$\gamma =$ the unit weight of the sediment laden water

$\Delta A_c =$ the net deposited volume of sediment in Δt per unit length of channel bed

$\Delta h =$ the flow surface elevation

$\Delta t =$ the time increment

$\Delta x =$ the space increment

$\Delta z =$ the elevation variation of the channel bed

ρ or ρ_f =the density of sediment laden water, which is given by

$$\rho_w + c_s(\rho_s - \rho_w)$$

$\rho_s =$ density of sediment

$\rho_w =$ density of water

$$\theta = \frac{\Delta t}{\Delta x}$$

$\phi_T =$ total discharge of sediment

The meaning of other symbols is given as and when they appear.

CHAPTER - 1

INTRODUCTION

1.1 GENERAL

A river with multi-channel configuration occurs in high energy environments with large and variable discharges carrying heavy sediment loads on steeper gradients. These streams may consist of a random pattern of multi-thread channel network due to appearance of braid bars within the overall waterway of the river. Engineers are greatly interested in accurately predicting the behaviour of river under various flows and sediment loads so that better information can be obtained for the planning and design of river control structures, flood protection measures and other water diversion structures.

1.2 SIMULATION OF WATER AND SEDIMENT FLOW

In general, the gradually varied unsteady flow movement in open channels can be simulated by a mathematical model derived from the unsteady flow equations of continuity and momentum, which are expressed as one-dimensional nonlinear partial differential equations Chen(1973)[8]. Theoretical analysis of the nonlinear partial differential equations is so complicated that analytical solution is very difficult to obtain. The simulation of flow of water and sediment in a braided stream is further complicated due to its complex channel plan form. The difficulties arise primarily in the representation of braided waterway of stream configuration for solution of the governing equations and also in predicting the total sediment transport and distribution with reasonable accuracy Sharma (29)[28].

1.3 SEDIMENT DISTRIBUTION FUNCTION

The erosion and/or deposition on a channel cross section is a two dimensional process. The one dimensional mathematical model can only compute cross sectional area changes but not specifically in cross sectional shapes. Hence, need for Sediment Distribution Function.

1.4 NEED FOR NUMERICAL MODEL

To simulate unsteady flow, we need to solve the governing equations i.e. unsteady flow equations of Saint Venant in conjunction with the sediment continuity equation for the alluvial streams .As these equations are not amenable to analytical solution , they are solved by numerical technique[8]. The numerical solution scheme can be either explicit or implicit. However, the implicit schemes are superior from the standpoint of numerical stability[27]. Again, the numerical solution procedure can be coupled or uncoupled. In the coupled procedure all the three basic equations are solved simultaneously. In case of uncoupled procedure, water continuity and momentum equations are solved first and then the solution is obtained for sediment continuity equation using the flow variables yielded from water routing phase. The accuracy of the solution will be influenced by the sizes of time step and space depending upon the numerical procedure adopted. Smaller time step and space size gives better result. Thus to obtain an acceptably accurate solution with practicable size of time step and space; we need a good numerical model which can be employed to solve real life problems in field[8, 27, 29].

1.5 WORKS DONE SO FAR

This field has drawn a lot of attention from researchers and considerable amount of work has been done in the recent decades. However, the modeling of alluvial streams with multi-channel configuration still awaits comprehensive solution from modelers. Chen (1973)[8], for the first time formulated a model that included sediment transport for generalized use. Dass (1975)[13] developed multi-stream flow and compound stream flow models by adopting the uncoupled solution procedure to rout water and sediment in non-uniform channels. The HEC-6 model, developed by W. A. Thomas at Hydrologic Engineering Center, U.S.A. in 1977[33] simulates water and sediment in a stream using different options for sediment predictor. Sharma (1995)[29] developed model for braided alluvial channels. Several researchers (e.g.Chen, 1973; the Corps of Engineers, U.S.A. 1976) assumed a uniform distribution of bed changes[8, 20, and 21]. A detailed review of existing models are given in second chapter a uniform distribution of bed changes[8, 20, and 21]. A detailed review of existing models are given in second chapter.

1.6 GAPS IN THE EXISTING WORKS

In the course of development of models to simulate the flow of water and sediment in natural streams, some simplifications are made to overcome the complexities of solving the governing equations. Due to these simplifications, the existing models do not truly represent the prototype especially when it comes to modeling of a highly braided channel with multi-channel configuration. The deficiency lies due to the following simplifications Chen (1973), [8,9,12]:

(a) In most of the models the actual geometry of the natural stream are simplified with introducing a representative shape by fitting a polynomial to yield area, top width, etc. of flow as a function of depth of flow. The models do not distinguish between the main flow channel (thalweg) and the subsidiary channels, which are active only during the high stages of flow in an episodic manner. Though, some of the models do consider different values of rugosity coefficients for main channels and flood plains[32, 33]. However this is not enough.

(b) In almost all models the supplementary equation used to represent energy slope (s_f) are Manning's equation, Chezy's relation or similar type of empirical relations. Strictly speaking, these equations are applicable for steady condition in rigid bed only and the appropriate relations for flow resistance to be used in unsteady condition are yet to be evolved[29].

(c) Further the supplementary equation for sediment discharge predictor and the connected relations to evaluate flow resistance in mobile bed with changing bed forms need considerable work to be done. In real life situation, the bank of the stream may also be erodible. Hence their application in the real life problems needs in-depth studies[29].

(d) In case of streams with multi-channel configuration the diffluence, transition and confluence zones introduce complex fluvial forces which must be duly taken into account while dealing with hydrodynamics of the flow [29].

(e) A model developed on the assumption of uniform distribution of bed changes over the cross section of a stream is not adequate and this needs to be improved upon.

1.7 OBJECTIVES AND SCOPE OF THE PRESENT STUDY

Keeping the above points in mind, following objectives are decided for the present study:

1. **To develop a model to simulate water and sediment flow in a stream of multi-channel configuration taking the main channel and subsidiary channels as separate entity.**
2. **To formulate suitable functional relationships to represent aggradations and degradation phenomena for developing the model.**
3. **To explore the use of a suitable numerical scheme.**
4. **To adopt a suitable solution algorithm for the model.**
5. **To develop a computer software for solution, of the model.**
6. **To test the performance of the model with real life problem.**

1.8 WORK DONE IN THIS DISSERTATION AND THE OUTCOME

In accordance with the above objectives, a model has been developed which explicitly accounts for the waterway of the main channel and subsidiary channel separately in the governing equations of the mathematical model. The numerical scheme and the solution algorithm are so geared to take into account the necessary alterations due to change in all stages of flows.

Further, the model developed herein, considers the bed degradation phenomena across the channel cross-section in proportion to the effective inertial motion of the channel i.e. difference between shear velocity and the critical velocity. Thus the spatial distribution of bed changes due to degradation in the sub-channels and main channel has been done on a reasonably micro-level basis. Similarly the aggradation of the bed has been taken in the inverse proportion of the conveyance and the distribution of the bed deposition across the cross-section has been done accordingly.

The numerical model developed in this dissertation has been tested with the data of Brahmaputra River. These data have been obtained from Flood control Department, Govt. of Assam. The simulation results have displayed reasonably good agreement with the observed data. This model has therefore, good potential for its use in the real life problems.

The dissertation has been organized as under. Chapter-2 presents a review of existing literature and models. Chapter-3 gives details of Development of Numerical Model. Chapter-4 consists of solution procedure, a solution algorithm and Development of Computer Software. The Chapter-5 deals with the Testing of the Model and discussion on results. Summary and Conclusions has been dealt in Chapter-6.The Source code of software, Figures, Tables and Plots of results has been given in Appendices.

REVIEW OF LITERATURE

2.1 GENERAL

A number of researchers worked on the development of alluvial river models during last two or three decades. Most of these models are based on the unsteady flow equations of water and sediment and adopted mostly the uncoupled solution procedure. The mathematical models have been developed by De Vries.(1971),Chen(1973)[8,9],the U.S. Corps of Engineers ("Guidelines" 1981)[32,33],Holly(1989) et al[12] to simulate the flow of sediment laden water and aggradation/ degradation in alluvial rivers. A review of the models pertaining to natural alluvial stream is presented in the following Para.

2.2 DELFT HYDRAULIC LABORATORY MODEL

DE Varies (1973) developed a mathematical model combining continuity and momentum equations along with Chezy's equations for alluvial streams. The equations are as follows:

$$(U-\frac{gQ}{bU^2})\frac{\partial U}{\partial x}+g\frac{\partial z}{\partial x}=\frac{gU|U|}{c^2h} \qquad (2.1)$$

The sediment continuity for streams of constant width is written as:

$$\partial z/_{\partial t}+(1/_{p})\partial G/_{\partial x} \qquad (2.2)$$

Terms need to be specified.

$$G=MU^N \qquad (2.3)$$

Where M and N are constants.

In this model, the two dependent variables U(x, t) and Z(x, t) are computed in two separate steps. In this model, Cunge et al (1980) commented that computational time step cannot be chosen arbitrarily. This model is true for coarse sediment only.

2.3 CHEN'S MODEL

Chen (1973)[8,9] formulated a model based on Saint Venant's continuity and momentum equations of unsteady flow of sediment-laden water. This model is capable of flood and sediment routing in a gradually varied flow channel[11]. He used sediment load functions from Einstein's Bed load function as well as Toffaleti's function[17]. Chen for the first time formulated a mathematical model that included sediment transport for generalized use. His works have proved to be a landmark in the field of open channel modeling for sediment-laden flow.

2.4 DASS MODEL

Dass(1975)[13] developed multi-stream flow and compound stream flow models by adopting the uncoupled solution procedure to rout water and sediment in non-uniform channels with the capability to simulate bed level changes. The governing equations adopted by Dass are:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}+\frac{\partial A_d}{\partial t}-q=0$$

$$\frac{\partial Q_s}{\partial x}+p\frac{\partial A_d}{\partial t}+\frac{\partial A_s}{\partial t}-q_s=0$$

$$\frac{\partial Q}{\partial t}+\frac{\partial(\beta QV)}{\partial x}+gA\frac{\partial y}{\partial x}+gAS_f-M_c=0$$

However, the validation of the model has been done in a hypothetical channel case.

2.5 HEC-6 MODEL[32]

This model has been developed by W.A.Thomas at Hydrologic Engineering Centre, U.S.A. in 1977.There are five different options provided for the transport of sediment, viz Lausen's equation, Toffaleti's equation ,Yang's stream power function ,Duboy's equation and Q_t=f(Q,S).The flow equation is the Manning's equation. For numerical solution ,uncoupled explicit finite difference scheme is used. Simulation of reservoir sedimentation was reported to be successful.

2.6 FLUVIAL MODEL (1978 and 1984)[4,5,6,7]

Chang and Hill of San Diego State University developed this model in 1976.The same equations of St. Venant are solved. In the case of aggradation, the deposition is made starting from the lowest point in horizontal layers. A four point implicit finite difference schemes with uncoupled solution procedure is used to solve the equations. Channel width adjustments are used to reflect lateral migration. Manning's equation is used to represent resistance to flow.

He also developed FLUVIAL 11 Model in 1984 which employs a space-time domain in which space domain is represented by the discrete cross-sections along the river reach and the time domain is represented by discrete time steps. The model uses the concept enunciated by Langbein and Leopold that the equilibrium channel represents a state of balance with a minimum rate of energy expenditure along the channel. Chang has considered the bank erodibility or coefficient of bank erosion to predict the bank changes. Fluvial 11 is undoubtedly a promising model for channel changes prediction. However the adoption of empirical bank erodibility factor appears to have constrained its universal applicability and may require considerable calibration efforts. This model cannot be applicable for a river of multi-channel configuration.

2.7 MIKE 11 (version 2.1)

MIKE 11 is developed at the Danish Hydraulic Institute for simulation of flows, sediment transport in rivers, estuaries etc. MIKE 11 is developed especially for application on micro-computers and is based on the earlier version of SYSTEM11. The core of MIKE 11 system consists of the hydrodynamic (HD) module, which is capable of simulating unsteady flows in a network of open channels. The results of a HD simulation consist of time series of water levels and discharges. Associated with the HD module, is the rainfall runoff model NAM, which may be used to generate inflows to the HD module. It allows for two different types of bed resistance descriptions, the Chezy and the Manning equations. Implicit finite difference equations yielded from 6-point Abbot Scheme are solved by double-sweep algorithm.

2.8 HEC-RAS (Version 3.0 January 2001)[32]

This is the latest version developed by US Army Corps of Engineers at Hydrologic Engineering Center. This is Next Generation of hydrologic engineering software which encompasses several aspects of hydrologic engineering including rainfall-runoff analysis; river hydraulics; reservoir system simulation ; flood damage analysis; and real time river forecasting for reservoir operations. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system will ultimately contain three one dimensional hydraulic analysis components (i) Steady flow water surface profile (ii) Unsteady flow simulations (iii) movable boundary sediment transport computations. Apart from this software contains several hydraulic design features. This is capable of importing GIS data or HEC-2 data. However the current version does not yet contain the feature of sediment computation.

2.9 WATER RESOURCES MODELING FROM DHI WATER AND ENVIRONMENT(Manual of DHI)

DHI water and environment of Denmark has come up with software's which, they claim, covers modeling of almost all the aspects of water and environment. Some of them are listed below:

MIKE 21C: predicts

- stream bank erosion
- bend scour, constriction scour, confluence scour and general scour
- channel formation and closure ,including bifurcations
- shoaling, point bar, and alternating bar formations
- armoring ,coarsening of river bed

This model uses two-dimensional St. Venant equations. MIKE BASIN is a versatile management planning tool that is fully integrated with ArcView GIS. It is a comprehensive river network modeling system for water allocation/water rights and environmental studies.

MIKE SHE has features of:

- evapotranspiration Kristensen and Jensen model
- 2-layer water balance for wetlands
- 2D overland flow diffusive wave (finite difference)

MIKE 21-2D models free surface flow, sediment and waves in river.

MIKE FLOOD-carry out 1D and 2D hydrodynamic modeling and storm surge studies.

2.10 SUMMARY

The review of existing models indicates that several models are available with different features. All the models use St. Venant's equations and have different sediment predictors, energy slope relations and distribution of aggradation/degradation equations. A natural river has many complexities due to its size, flow variations, concentration of sediment and its properties, engineering works carried out on the river and other geographical, meteorological, social factors. Due to these reasons, no model can claim to have considered all the factors. Therefore, the models cannot have universal applicability. Hence, for modeling a particular river one should be very careful to choose a model, which is applicable according to the characteristics of that river.

In addition, it could be observed that hardly any significant work has been done so far on modeling the movement of sediment and water on mobile bed boundary in a stream with multi-channel configuration and in this dissertation; it has been envisaged to initiate work on the development of such a model.

CHAPTER - 3

DEVELOPMENT OF NUMERICAL MODEL

3.1 GENERAL

Unsteady flow in a natural river with multi-channel configuration is complicated due to wide differences in hydraulic properties and resistances of flow in the main channel and the subsidiary channels. In this chapter a numerical model for routing water and sediment flow is presented. The technique is based on a modified form of the one dimensional equations of unsteady flow .The one dimensional equations are modified such that the flow in the main channel and the subsidiary channels are identified separately. Thus the differences in geometrical properties and hydraulic resistances of the various flow channels are taken into account in a physically meaningful way. This development differs from the conventional one dimensional treatment of unsteady flow in natural streams wherein the flow is averaged across total cross sectional area. In some of the earlier models the flow in the flood plain is treated as off-channel storage[8, 11, 28, and 31].

In order to treat the flows in different channels separately, it is important that the geometric and other flow characteristics in the governing equations are preserved

3.2 GOVERNING EQUATIONS

Equations of continuity of water flow and momentum are Chow (1959)[11];

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - ql = 0 \qquad (3.1)$$

$$\frac{\partial(\rho Q)}{\partial t} + \frac{\partial(\rho QV)}{\partial x} + gA\,\frac{\partial(\rho y)}{\partial x} = \rho g A\,(S_0 - S_f + D_l) \qquad (3.2)$$

Equation of continuity of sediment flow is

$$\frac{\partial Q_s}{\partial x} + p\,\frac{\partial A_c}{\partial t} + \frac{\partial A_s}{\partial t} - q_s = 0 \qquad (3.3)$$

The above equations have been modified to be used for the present study as given below. (The subscript 'mc' denotes main channel and 'sc' subsidiary channel)

$$\frac{\partial(Q_{mc}+Q_{sc})}{\partial x}+\frac{\partial(A_{mc}+A_{sc})}{\partial t}-q_l=0 \qquad (3.4)$$

$$\frac{\partial[\rho(Q_{mc}+Q_{sc})]}{\partial t}+\frac{\partial[\rho(Q_{mc}+Q_{sc})V]}{\partial x}+g(A_{mc}+A_{sc})\frac{\partial(\rho y)}{\partial x}$$
$$=\rho g(A_{mc}+A_{sc})(S_o-S_f+D_l) \qquad (3.5)$$

Here;

The division of flow among the different channels is to be guided by the conveyance of the channel. The bed slope of the different channels between any two nodes is assumed to be the same.

x = horizontal distance along the channel

t = time

Q = total discharge of sediment laden water

A = total cross sectional area of the channel

Q_{mc} = discharge in main channel

Q_{sc} = discharge in subsidiary channel

A_{mc} = Cross sectional area of main channel

A_{sc} = Cross sectional area of subsidiary channel

A_c = Volume of deposition of sediment per unit length of channel, the value of A_c will be negative when bed erosion occurs

A_s = Volume of sediment suspended in water over the cross section per unit length of channel

Q_s = sediment discharge.

q_l = lateral flow.

ρ = density of sediment laden water which is given by

$\rho_w + c_s(\rho_s - \rho_w)$

c_s = sediment concentration = Q_s/Q

ρ_w = density of water

ρ_s = density of sediment

p = porosity i. e. volume of sediment in unit volume of bed layer

V = mean velocity of flow

y = depth of flow

S_o = bed slope

S_f = energy slope

D_l^1 = dynamic contribution of lateral discharge given by $= \frac{q_l . V_l}{g.A}$

q_s = the sediment discharge per unit length of channel

The governing equations are based on following assumptions;

i) The channel is sufficiently straight and uniform in the reach so that the flow characteristics may be physically represented by a one-dimensional mode.

ii) The velocity is uniform over the cross section.

iii) Hydrostatic pressure prevails at every point in the channel.

iv) The water surface slope is small.

v) The density of sediment laden water is constant over the cross-section.

vi) The unsteady flow resistance coefficients are assumed to be same as steady flow in alluvial channel.

In a short time period, the change in S_o is very small and the value of $\frac{\partial A_c}{\partial t}$ is usually much smaller than that of $\frac{\partial A}{\partial t}$.Hence solution of the above three equations can be obtained by using a simplified uncoupled procedure i. e. first solving the equations (3.4) and (3.5) and then modifying the solution by solving the equation (3.6).To solve the equations (3.4) and (3.5), it can be rewritten as [1]

$$\frac{\partial (Q_{mc} + Q_{sc})}{\partial x} + (T_{mc} + T_{sc}) \frac{\partial y}{\partial t} - q_l = 0 \qquad (3.4a)$$

$$\frac{\partial[\rho(Q_{mc} + Q_{sc})]}{\partial t} + V \frac{\partial[\rho(Q_{mc} + Q_{sc})]}{\partial x} + \rho V \frac{\partial(Q_{mc} + Q_{sc})}{\partial x} - \rho V^2 (T_{mc} + T_{sc}) \frac{\partial y}{\partial x} +$$
$$g(A_{mc} + A_{sc}) \frac{\partial(\rho y)}{\partial x} = \rho g (A_{mc} + A_{sc})[S_o - S_f + D_l] + \rho V^2 A_x^y \qquad (3.5a)$$

Where $T = \frac{\partial A}{\partial y}$, and $A_x^y = (\frac{\partial A}{\partial x})_y$. This is a constant term and represents the departure from a prismatic channel Chen (1973)[8]

3.3 SUPPLEMENTARY EQUATIONS

The model requires mathematical functions for the supplementary equations as described below:

3.3.1 Energy Slope

Energy slope is expressed in the form[10, 11]

$$S_f = \frac{Q^2}{K^2} \tag{3.6}$$

where, K= conveyance = $\frac{AR^{2/3}}{n}$

Here Q, n, and K will be taken for main channel and subsidiary channel separately. The model uses the Manning's roughness coefficients as obtained from field calibration, however any other theoretical method can also be used for calculating the 'n'[9].

As the resistance coefficients are very sensitive in mathematical models , use of a constant value of these coefficients may spoil the results many times. Hence evaluating Manning's 'n', for example , in terms of certain representative grain size is not sufficient. One of the equations, which take depth of flow and representative grain size is Limerinos equation[8,29], which is

$$n = \frac{0.113 y^{1/6}}{1.16 + 2.0(y/d_{84})}$$

The equation used in general form is

$$n = \frac{1}{a \log(y/d_{84}) + b} * \frac{R^{1/6}}{g^{1/2}} \tag{3.6a}$$

When the above equation is used together with Manning's equation it is called Limerinous-Manning's equation, which has been used here.

3.3.2 Sediment Discharge Predictor[1,3,5,8,14,16,18,20]

If measured data on sediment discharge values are not available with respect to time and space, mathematical functions are required to generate these data.

There are two approaches to the problem of total sediment transport in an alluvial river (a) Microscopic methods (b) Macroscopic methods[16, 17, 20].

The microscopic methods includes Einstein's method, Samaga methods etc.

Macroscopic methods to predict total load which are based on single representative bed material are Laursen's method,Garde Albrtson's Equation,Bagnold's Equation,Engelund - Hansen's ,Yang's Equation etc.

Although, there are several sediment discharge relations but none of them can claim sound theoretical basis. However, the methods of Ackers-White, Engelund-Hansen, Yang and Rnga Raju et al. give reasonably good results.[26]

This model uses Engelund Hansen (1966)[14] formulations for calculating the total load assuming a single representative size. This has been done due to its simplicity and some other relations can also be added to the model, for example the relationships given by Yang et al. for large rivers.

Bagnold introduced the concept of stream power for the study of sediment transport. He defined stream power as the product of shear stress along the bed and the average flow velocity. Bagnold's stream power has dimension of power per unit bed area.

3.3.3 Engelund and Hansen Equation

He applied the stream power concept and the similarity principle to obtain a sediment transport equation as given below in M.K.S.:

$f.\varphi_T = 0.4.\tau_*^{5/2}$; Where f is Darcy's friction factor and is given as $f = 8\frac{u_*^2}{u^2}$

u_* is shear velocity and it is given by,

$$u_* = \sqrt{\frac{\tau_o}{\rho_f}}$$

The ϕ_T is the total load function and is given by

$$\varphi_T = \frac{q_T}{\gamma_s}\sqrt{\frac{1}{(\frac{\rho_s}{\rho_f}-1).g.d_{50}^3}} \tag{3.7}$$

where q_T is the total discharge of sediment in N/m-sec. d_{50} is particle's diameter in meter of which 50% is finer. τ_o is ambient shear stress and g is the acceleration due to gravity, u is the mean velocity of flow.

3.3.4 Yang's Total Load Equation

The theory of the Yang's equation is based on the rate of expenditure of potential energy per unit weight of water i.e. the unit stream power. The equation is:

$$\log C_T = 5.435 - 0.286\log\frac{\omega_0 d}{\upsilon} - 0.457\log\frac{u_*}{\omega_0}$$
$$+(1.799 - 0.409\log\frac{\omega_0 d}{\upsilon} - 0.314\log\frac{u_*}{\omega_0})\log\left(\frac{US}{\omega_0} - \frac{U_{cr}S}{\omega_0}\right) \quad (3.7a)$$

here the product of velocity and slope(US) is the unit stream power

C_T= sediment concentration in ppm

ω_0= terminal fall velocity

υ = kinematic viscosity

d = median particle diameter

u_* = shear velocity

The term $\frac{US}{\omega_0}$ is dimensionless unit stream power.

The dimensionless critical velocity $\frac{U_{cr}}{\omega_0}$ is defined as

$$\frac{U_{cr}}{\omega_0} = \frac{2.5}{\log\left(\frac{u_* d}{\upsilon}\right) - 0.06} + 0.66; \qquad \text{for} \qquad 1.2 < \frac{u_* d}{\upsilon} < 70$$

$$\text{and} \frac{U_{cr}}{\omega_0} = 2.05; \qquad \text{for} 70 \le \frac{u_*}{\upsilon}$$

The foregoing equation is valid for d50< 2mm. For d50> 2mm the constants are different.

3.4 BOUNDARY CONDITIONS

In general, two kinds of boundary conditions are needed to be provided (i) Exterior and (ii) Interior boundary conditions

3.4.1 Exterior Boundary:

These are known conditions at the ends of the model. They may vary with the flow characteristics. For example, in a sub critical flow, computation can be proceeded upstream once the downstream condition is known, however in supercritical flow; the influence of downstream boundary is not there and in this case only upstream boundary conditions are given. The commonly used exterior boundary conditions are of five types. They are:

(a) the water discharge hydrograph , $Q = f(t)$

(b) the stage discharge curve , $Q = f(y)$

(c) the stage hydrograph, $y = f(t)$

(d) the sediment hydrograph , $Q_T = f(t)$

(e) the sediment discharge rating curve $Q_T = f(Q)$

Rating curves representing exterior boundary conditions are very sensitive in unsteady flow models. For example, a down stream rating curve provided without sufficient care may completely spoil the simulation results. Chen mentions that significant error may be introduced when the relationships $Q= f(y)$ is imposed at the downstream boundary in sub critical flow. This relation is a single value function corresponding to steady flow. The computed results of unsteady flow in the upstream reach based on this condition are biased within the range of backwater influence. In this case ideally the loop rating curve is to be used.

A special problem with $Q = f(t)$ boundary at downstream end arises when one tries to withdraw water at a rate that exceeds delivery capacity of the channel, when $Q = f(t)$ is imposed at both ends of a channel section, one must be caréful not to withdraw more water than was initially available in the channel, in such case. The rating curve relationship $Q = f(y)$ should not be used as an upstream boundary condition.

This model uses following boundary conditions

At upstream boundary

Q_t=f (Q), and Q = f (t)

At downstream boundary

Q= f(y) here all these relations have been made linear by regression analysis.

3.4.2 Interior Boundary Conditions

As long as flow remains tranquil or sub critical, satisfying internal boundary conditions ensures maintaining flow continuity only, but in case of transitions from sub critical to supercritical or vice versa further complications arises from the standpoint of numerical stability.

For sudden change of cross sections between two neighbouring sections the interior conditions are

(a) Q1 = Q2

(b) $y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g} + h_l$

(c) $Q_{T1} = Q_{T2}$

Confluence of two rivers can be treated as

(a) $Q_c = Q_a + Q_b$

(b) $Q_{tc} = Q_{ta} + Q_{tb}$

(c) $Z_c + y_c + \frac{V_c^2}{2g} + \Delta H(c-a) = Z_a + y_a + \frac{V_a^2}{2g} = z_b + y_b + \frac{V_b^2}{2g}$

In the present model the flow is kept tranquil (sub critical) and the continuity equation has been taken as interior boundary condition.

3.5 CHANGES IN BED LEVEL IN THE STREAM

The changes in stream bed level of an alluvial river are reflected in the changes in the cross sectional area, ΔA_c for any time increment[8, 13, 22, 23]. In an uncoupled solution, the solution of equation (3.3) yields the amount of change in the cross sectional area of channel bed. In the present model the river banks have been considered as rigid. The model considers changes in bed elevation pertaining to aggradation or degradation only.

For each channel cross–section, the change in channel bed deposition area ΔA_c is distributed subsection wise to obtain the new cross-sectional profile. In the model developed in this work an attempt has been made to relate the degradation in the direct proportion to the effective inertial motion which is defined as the difference between the shear velocity and the critical shear velocity for each subsection of the river section. The deposition has been considered to be in the inverse proportion to the conveyance of the subsection. The rationale for this considerations is (a) the sediment particle velocity is proportional to u_* for degradation. And (b) the rate of sediment transport varies in direct proportion to the magnitude of the conveyance.[29]

The formula for calculating the degradation in the different channels is given by

$$d_{sk} = \frac{u_{*k} - u^{c}_{*k}}{\sum_{i=1}^{n}(u_{*i} - u^{c}_{*i})}.\Delta A_c \tag{3.8}$$

where u_{*k} is the shear velocity of the k^{th} subsection u^{c}_{*k} is the shear velocity at critical shear stress, n is total number of subsections, d_{sk} is the degradation area to be assigned to the k^{th} channels. The degradation in the bed level is given by the following relation

$\Delta z_k = \frac{d_{sk}}{B^k}$, where Δz_k is the change in the bed level of the k^{th} channel, and B_k is the width of the kth channel.

Shear velocity is given by $\sqrt{\frac{\tau_o}{\rho_f}}$ and critical shear velocity is $\sqrt{\frac{\tau_c}{\rho_f}}$

The formula to distribute the deposition is, (for n>1)

$$\frac{\Delta A^{d}_{ck}}{\Delta A^{d}_{c}} = \left[1 - \frac{A_k R_k^{2/3}}{\sum_{i=1}^{n} A_i.R_i^{2/3}}\right]\frac{1}{(n-1)} \tag{3.9}$$

Where ΔA^{d}_{ck} is the area of deposition of k^{th} channel and ΔA^{d}_{c} is the total deposition area and $A.R_i^{2/3}$ is the conveyance of the channel.

3.6 DEVELOPMENT OF NUMERICAL MODEL

The analysis of long term unsteady flow problem in long river reaches require fast and accurate method. Keeping this in mind the fully implicit method has been adopted to solve the governing equations.The numerical solution of the governing equations are obtained in an uncoupled manner in which a flow continuity equation (3.4a) and the flow momentum equation (3.5a) are solved first. The solution is then refined by solving the sediment continuity equation (3.3). The partial derivatives in the governing equations are replaced by quotients of finite difference using the implicit scheme. In the present model the linear fully implicit scheme is adopted for solution of the flow continuity and flow momentum equations, which is described below. For stability and accuracy of the numerical solution of the model, iteration procedure has been adopted for computation of the coefficients of downstream boundary condition C13 and C14 till the changes in discharges in successive iterations are within tolerance limit. Similarly, the sediment routing and its subsequent channel adjustment processes are subjected to an iteration procedure in the model till the changes in computed water levels of successive iterations satisfy the accuracy limit.

3.6.1 The Linear Implicit Scheme

With reference to the Fig. 3.1 , it is assumed that all the variables are known at all nodes of network on the time t^j .It is required to compute the values of the variables at all the nodes on the times t^{j+1} .

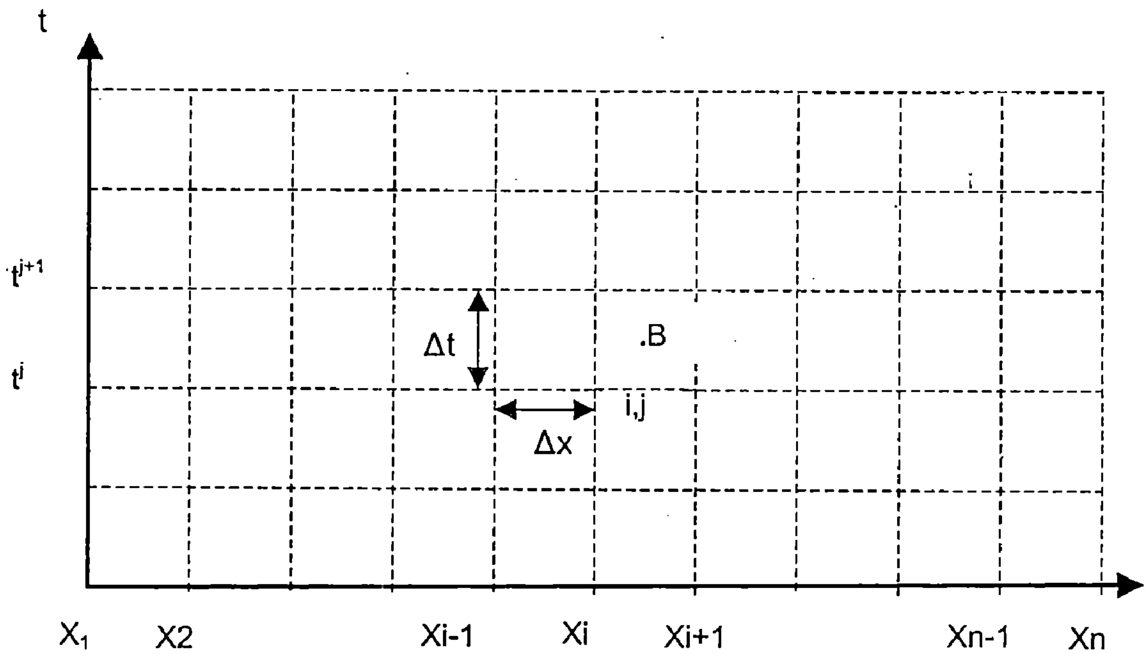


Fig 3.1 Network For Implicit Method

Here the discretisation scheme for linear fully implicit scheme has been taken as:-

$$f^j_{i+\frac{1}{2}} = \frac{1}{2}(f^j_i + f^j_{i+1}) \quad (3.10)$$

$$\frac{\partial f}{\partial x} = \frac{1}{\Delta x}(f_{i+1}^{j+1} - f_i^{j+1}) \quad (3.11)$$

$$\frac{\partial f}{\partial t} = \frac{1}{2\Delta t}\{(f_i^{j+1} - f_i^j) + (f_{i+1}^{j+1} - f_{i+1}^j)\} \quad (3.12)$$

where f may represent Q, y, ρ etc.

Putting the above expressions in the equation (3.4a) (3.5a) then simplifying, we get, Chen (1973),

$$(C_1)_i = \frac{1}{4}\left((T_{mc} + T_{sc})_i^j + (T_{mc} + T_{sc})_{j+1}^j\right) \tag{3.13}$$

$$(C_2)_i = C_1\left(y_i^j + y_{i+1}^j\right) + \frac{\Delta t}{2}\left[(q_l)_{i+½}^j + (q_l)_{i+(½)}^{j+1}\right] \tag{3.14}$$

$$(C_3)_i = \rho_i^j[1 - CS1 + g\Delta t(\frac{S_f}{V})_i^j] - CS2 + g\Delta t(CK3) \tag{3.15}$$

$$(C_4)_i = \rho_{i+1}^j[1 + CS1 + g\Delta t(\frac{S_f}{V})_{i+1}^j] + CS2 + g\Delta t(CK4) \tag{3.16}$$

$$(C_5)_i = CS3 - \rho_i^j(CS4) - g\Delta t(CK1) \tag{3.17}$$

$$(C_6)_i = CS3 - \rho_{i+1}^j(CS4) - g\Delta t(CK2) \tag{3.18}$$

$$\begin{aligned}(C_7)_i = \; & (\rho(Q_{mc} + Q_{sc}))_i^j + (\rho(Q_{mc} + Q_{sc}))_{i+1}^j - (CS1)[(\rho(Q_{mc} + Q_{sc}))_{i+1}^j - (\rho(Q_{mc} + Q_{sc})_i^j] \\ & -(CS2)((Q_{mc} + Q_{sc})_{i+1}^j - (Q_{mc} + Q_{sc})_i^j + (CS3(y_{i+1}^j - y_i^j) - (CS4) \\ & [(\rho y)_{i+1}^j - (\rho y)_i^j] + g\theta[(\rho(A_{mc} + A_{sc})_{i+1}^j](z_i^j - z_{i+1}^j) \\ & -\Delta t\{g[(CK1)y_i^j + (CK2)y_{i+1}^j - (CK3)(Q_{mc} + Q_{sc})_i^j - (CK4)(Q_{mc} + Q_{sc})_{i+1}^j] \\ & [(\rho V^2)_i^j + (\rho V^2)_{i+1}^j](A_x^y)_{i+(½)}^j - \frac{1}{2}(\rho_i^j + \rho_{i+1}^j) \\ & [(q_l V_l)_{i+(½)}^j + (q_l V_l)_{i+(½)}^{j+1}]\}\end{aligned} \tag{3.19}$$

where,

$$\theta = \frac{\Delta t}{\Delta x}$$

$$CS1 = \theta(V_i^j + V_{i+1}^j)$$

$$CS2 = \theta((\rho V)_i^j + (\rho V)_{i+1}^j)$$

$$CS3 = \theta[(\rho V^2(T_{mc} + T_{sc}))_i^j + (\rho V^2(T_{mc} + T_{sc}))_{i+1}^j]$$

$$CS4 = \theta g[(A_{mc} + A_{sc})_i^j + (A_{mc} + A_{sc})_{i+1}^j]$$

$$CK1 = [\rho s_f(\frac{5(T_{mc} + T_{sc})}{3} - \frac{2R}{3}\frac{dp}{dy} - \frac{A}{n}\frac{\partial n}{\partial y})]_i^j$$

$$CK2 = [\rho s_f(\frac{5(T_{mc} + T_{sc})}{3} - \frac{2R}{3}\frac{dp}{dy} - \frac{A}{n}\frac{\partial n}{\partial y})]_{i+1}^j$$

$$CK3 = [\rho s_f (\frac{A}{n}\frac{\partial n}{\partial Q})]_i^j$$

$$CK4 = [\rho s_f (\frac{A}{n}\frac{\partial n}{\partial Q})]_{i+1}^j$$

With these coefficients it can be shown that at any point of time step t^j the relation between unknown Q and depth of flow y is given by:

$$-\theta Q_i + (C_1)_i y_i + \theta Q_{i+1} + (C_1)_i y_{i+1} = (C_2)_i \qquad (3.20)$$

$$(C_3)_i Q_i + (C_5)_i y_i + (C_4)_i Q_{i+1} + (C_6)_i y_{i+1} = (C_7)_i \qquad (3.21)$$

Thus for N nodes we get 2(N-1) equations

The two boundary conditions are also expressed in the linear form and is given by

Up stream Boundary Condition

$$C_9 Q_1 + C_{10} y_1 = C_{11} \qquad (3.22)$$

Down stream Boundary Condition

$$C_{12} Q_N + C_{13} y_N = C_{14} \qquad (3.23)$$

The above is a system of linear equations of 2N X 2N order which gives the values of unknown Q and y at all the nodes of the grid. at any time step.

3.6.2 Sediment Routing[4, 8,16,20,21]

A procedure for routing sediment in natural channel is presented as follows, the equation (3.3) can be written as

$$\frac{\partial Q_s}{\partial x} + p\frac{\partial A_c}{\partial t} + \frac{\partial A_s}{\partial t} - q_s = 0$$

Where $A_s = A.c_s$, and $c_s = Q_s/Q$

For the interior points:

$$\Delta A_{c_{i-(1/2)}} = \frac{1}{p}\{\frac{\Delta t}{2}[q^j_{s i-(1/2)} + q^{j+1}_{s_i-(1/2)}] - \frac{1}{2}[(Ac_s)^{j+1}_{i-1} - (Ac_s)^j_{i-1} + (Ac_s)^{j+1}_i - (Ac_s)^j_i]$$
$$-\frac{\theta}{2}[(Q^j_{si} - Q^j_{si-1}) + (Q^{j+1}_{si} - Q^{j+1}_{si-1})]\} \qquad (3.24)$$

At the upstream boundary:

$$\Delta A_{c_1} = \frac{1}{2p}\{\Delta t[q_{s1+(\frac{1}{2})}^{j} + q_{s1+(\frac{1}{2})}^{j+1}] - [(Ac_s)_1^{j+1} - (Ac_s)_1^{j} + (Ac_s)_2^{j+1} - (Ac_s)_2^{j}]$$
$$-\frac{\theta}{2}[(Q_{s2}^{j} - Q_{s0}^{j}) + (Q_{s2}^{j+1} - Q_{s0}^{j+1})]\} \tag{3.25}$$

At the down stream boundary:

$$\Delta A_{cN} = \frac{1}{2p}\{\Delta t[q_{sN-(\frac{1}{2})}^{j} + q_{sN-(\frac{1}{2})}^{j+1}] - [(Ac_s)_{N-1}^{j+1} - (Ac_s)_{N-1}^{j} + (Ac_s)_N^{j+1} - (Ac_s)_N^{j}]$$
$$-\theta(Q_{sN}^{j} - Q_{sN-1}^{j} + Q_{sN}^{j+1} - Q_{sN-1}^{j+1})\} \tag{3.26}$$

3.6.3 The Distribution Of Degradation Or Deposition Of Sediment Over the Cross Section

In the case of **Degradation**

$$d_{sk\,i} = \frac{(u_{*k} - u_{*k}^{c})_i}{(\sum_{i=1}^{n}(u_{*i} - u_{*i}^{c}))_i}.\Delta A_{c_i} \tag{3.27}$$

In the case of **aggradation**

$$\frac{(\Delta A_{ck}^{d})_i}{\Delta A_{c_i}} = \left[1 - \frac{(A_k y_k^{2/3})_i}{(\sum_{i=1}^{n} A_i.y_i^{2/3})_i}\right]\frac{1}{(n-1)} \tag{3.28}$$

The rationale behind using these relations are discussed in earlier section.

The set of equations (3.13), (3.14), (3.15), (3.16), (3.17), (3.18), (3.19), (3.20), (3.21), (3.22), (3.23), (3.24), (3.25), (3.26), (3.27),and (3.28) constitute the required **model to simulate the gradually varied flow of water and sediment in an alluvial river of multi-channel configuration**. A solution algorithm to get the solutions of these equations is explored in the next chapter.

CHAPTER - 4

SOLUTION ALGORITHM

4.1 GENERAL

The analysis of long-term unsteady flow in river reaches requires fast and accurate method. The solution scheme can be formulated in one of the two methods; (i) Explicit and (ii) Implicit[28]. The term explicit refers to those difference methods where finite difference quotients evaluated on time line tj, on which all variables are known (fig.3.1), while in implicit finite difference the unknown values on the time line t^{j+1} occur implicitly in the difference equation. Again the linear implicit scheme can be either linear fully implicit or linear centre implicit. According to Chen (1973)[5,6,7,8], the fully linear implicit method is unconditionally stable, accurate and efficient. It is convenient because all the results at the point of interest can be directly computed. In addition, it is efficient, because the size of the time increment can be large without loss of stability, and the finite difference formulations can be solved directly without iterations. Keeping this in mind the model adopts linear fully implicit method.

4.2 MODEL COMPUTATIONAL SEQUENCE

The computational sequences to get the solution of the model conceptualized in the earlier chapter are as below:

4.2.1 Input Data

For the operation of the model, following data are required

i) Lengths of the river reach to be simulated, total number of cross-sections in the reach where bed profile is known.

ii) Distance between different sections.

iii) No. of subsections in each cross- section.

iv) The distances of the river bed points from the leftmost reference line.

v) The bed level (elevations) of the points in the river bed.

vi) Initial discharges at all the cross-sections.

vii) Initial water level at all the sections.

viii) Total time base of the inflow hydrograph and number of time intervals.

ix) Value of Manning's n at each cross section and sub-channels.

x) Upstream discharge hydrograph at the beginning of the river reach which also serves as upstream boundary condition.

xi) Downstream stage Vs discharge hydrograph at the end of the river reach.

xii) The value of sediment size d_{50} at every section.

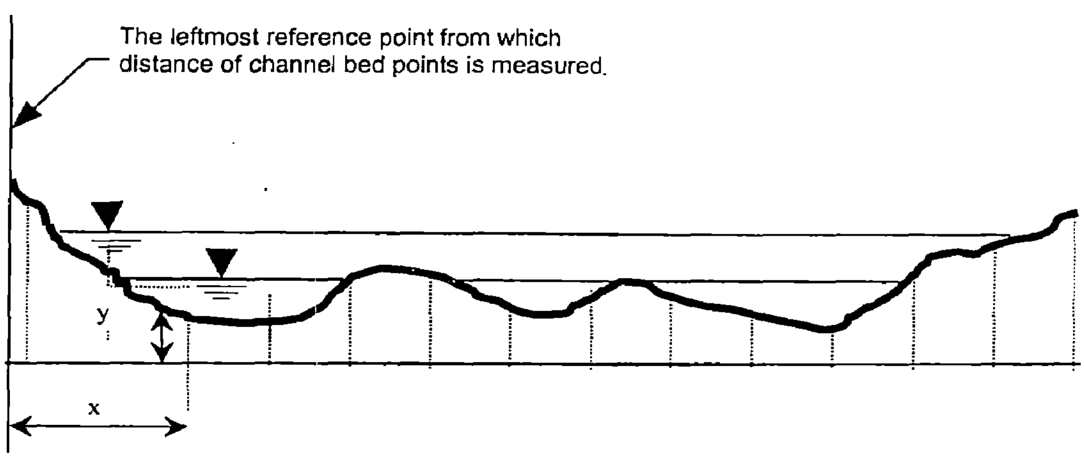
xiii) Lateral discharge per unit length and longitudinal component of the velocity of lateral flow.

4.2.2 Geometric and Hydraulic Properties

As per the initial stage of flow and the bed profile given in the input data, the following parameters are calculated at each section of main and subsidiary channels:

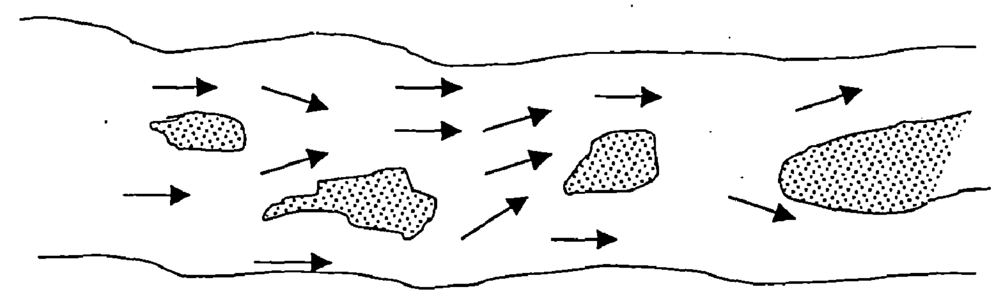
i) The time step is set to be zero.

ii) Area of flow, Top width, Hydraulic radius, number of subsidiary channels at each section, depth of flow, velocity of flow, bed slope of each section, conveyances of all the sections and the energy gradients at all the sections corresponding to initial water level.



A Typical Cross Section of an Alluvial Stream Of Multi-Channel Configuration

This Figure 4.1 shows the change in the number of channels with the change in the water level. The model has been geared to take this into account while computing the various geometrical properties of the stream



A Typical Plan of a an alluvial stream with multi-channel Configuration

Fig. 4.2

4.2.3 Computation Of Sediment Flow

The flow of sediment is calculated at each section with the help of sediment predictor. In this model, Engelund and Hansen relation has been used for sediment discharge predictor.

4.2.4 Energy Gradient Equation

The Manning's Equation can be written as

$$s_f = \frac{Q^2 n^2 P^{4/3}}{A^{10/3}}$$

Differentiating w.r.t. Q and simplifying we get

$$\frac{\partial s_f}{\partial Q} = 2s_f[\frac{1}{Q} + \frac{1}{n}\frac{\partial n}{\partial Q}]$$

Differentiating w.r.t. y and simplifying we get

$$\frac{\partial s_f}{\partial y} = -2s_f\left[\frac{1}{A}\left(\frac{2}{3}T - \frac{2}{3}R\frac{\partial P}{\partial y}\right) - \frac{1}{n}\frac{\partial n}{\partial y}\right]$$

In the above equation the derivatives $\partial n/\partial Q$ and $\partial n/\partial y$ need to be further evaluated. As discussed in the previous chapter, the Limerinous Equation has been adopted which gives:

$$n = \frac{0.113y^{1/6}}{1.16 + 2.0[y/d_{84}]}$$

Differentiating w.r.t y and Q separately and simplifying this equation we get

$$\frac{\partial n}{\partial y} = \left[-\frac{a}{y\left(a\log(\frac{y}{d_{84}})+b\right)} + \frac{T}{6R} - \frac{1}{6P}\frac{\partial P}{\partial y} \right]$$

where a= 1.16 and b=2.0

Also $$\frac{\partial n}{\partial Q} = n\left[-\frac{aA}{yQT\left(a\log(\frac{y}{d_{84}})+b\right)} + \frac{1}{6QT}\left(T - R\frac{\partial P}{\partial y}\right) \right]$$

4.2.5 Computation Of Finite Difference Coefficients

When geometric and hydraulic properties are known the finite difference coefficients C1, C2, C3, C4, C5, C6, and C7 are calculated for each section from equations (3.13), (3.14), (3.15), (3.16), (3.17), (3.18), (3.19) respectively . If there are N sections then all the seven coefficients are calculated at (N-1) points. C9, C10, C11, C12, C13, and C14 are read from the input data of the upstream and downstream boundary conditions respectively.

4.2.6 Construction Of Linear Algebraic Equations

When all the coefficients are obtained, a system of 2N linear algebraic equations with 2N unknowns are constituted from the equations (3.20), (3.21), (3.22) and (3.23) as given below:

$$C_9 Q_1 + C_{10} y_1 = C_{11}$$

$$-\theta Q_1 + (C_1)_1 y_1 + \theta Q_2 + (C_1)_1 y_2 = (C_2)_1$$

$$(C_3)_1 Q_1 + (C_5)_1 y_1 + (C_4)_1 Q_2 + (C_6)_1 y_2 = (C_7)_1$$

$$-\theta Q_i + (C_1)_i y_i + \theta Q_{i+1} + (C_1)_i y_{i+1} = (C_2)_i$$

$$(C_3)_i Q_i + (C_5)_i y_i + (C_4)_i Q_{i+1} + (C_6)_i y_{i+1} = (C_7)_i$$

$$-\theta Q_{N-1} + (C_1)_{N-1} y_{N-1} + \theta Q_N + (C_1)_{N-1} y_N = (C_2)_{N-1}$$

$$(C_3)_{N-1} Q_{N-1} + (C_5)_{N-1} y_{N-1} + (C_4)_{N-1} Q_N + (C_6)_{N-1} y_N = (C_7)_{N-1}$$

$$C_{12} Q_N + C_{13} y_N = C_{14}$$

The above system of linear equations can be solved by any standard method. In this model Gauss - Jordon method has been adopted. The solution gives discharges and depths of flow at each section at any time step say t^{j+1}.

4.2.7 Sediment Routing[6,8,9,13,28]

Using the new flow conditions, we compute the value of changes in cross sectional area by solving the sediment continuity equations (3.24), (3.25), and (3.26) depending upon whether the cross-section is at interior or at upstream /downstream point. Then the changes in cross sectional area is appropriately distributed along the channel width by the equations (3.27) and (3.28) in case of bed degradation and aggradation respectively. If the ΔA_c is positive then it is a case of aggradation and the area is distributed in the inverse proportion to the conveyance of the section. Negative ΔA_c indicates degradation, which is distributed in direct proportion to effective inertial motion given by the equation (3.27).

4.2.8 Modifying the solution

After duly accounting for channel changes sub-section wise, the new profile of the channel cross-section is obtained. We compute the revised water level after iterating sediment routing until tolerance limit is satisfied.

The above operations are repeated till the required time period is covered.

4.3 STABILITY AND ACCURACY

The greatest hindrance in the use of unsteady flow models is perhaps due to instability of solution if proper care is not taken Samuels(1990) et al.[27]. A solution is considered to be stable when small numerical errors of truncation and round off inevitably introduced at time step zero are not amplified during successive applications of the procedure have not grown so large as to obscure the valid part of the solution. Unlike in explicit schemes, where stability criterion is strictly limited by the Courant condition, there is no limiting condition of time and space intervals in implicit scheme. The Courant condition is given as

$$\Delta t \leq \frac{\Delta x}{c}$$

Where c is the celerity of small gravity wave given by

$$c = \sqrt{gy} + V$$

V being the mean velocity and Δt and Δx are time and distance steps respectively. However, even in implicit schemes, one cannot take any arbitrary steps size. There could be a possibility of downstream dry condition, a condition in which zero or negative or excessively less discharge appears if time step is too large compared to distance step. The other criterion may be the accuracy needed in modeling. Accuracy refers to the degree of difference between observed real life data such as measured hydrographs and computed results. Unfortunately, as there may be errors in the measurement of actual values, there is equal possibility of errors due to the simplifications and approximations in the basic equations. Therefore, it is difficult to judge errors on any part.

Price[27] used an approach of checking numerical simulation results with those of analytical methods for simplified problems. Using this technique for different numerical schemes, he found that Preissmann type implicit scheme is the most efficient method for flood routing problems, and the optimum accuracy is obtained when the finite difference time step is chosen approximately equal to the space step divided by the kinematic wave speed.

$$\Delta t = \frac{\Delta x}{c_k}$$

Where kinematic wave speed c_k is given by $c_k = 1.5V$.

Since c_k is much smaller than c, hence time step in implicit scheme can be taken much larger than in explicit scheme for the same degree of accuracy.

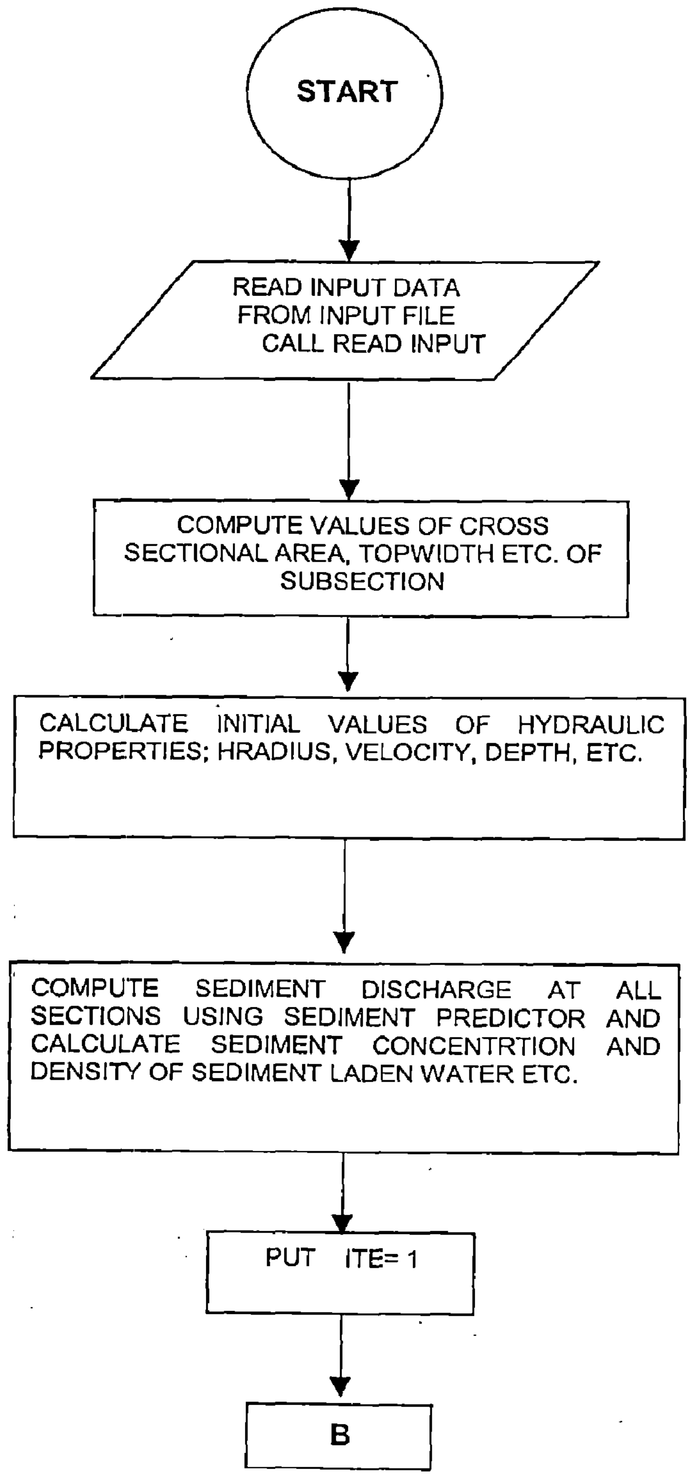
The problem of instability becomes further complicated , when bed evolution is to be simulated with the flow routing. Lyn and Godwin[22] concluded that the conventional Preissmann implicit scheme may give rise to oscillations of solution for bed elevation because of small bed courant number compared to that of kinematic flood wave, because movable bed problem, in general has singularly perturbed nature. In order to avoid such numerically induced oscillations, the bed Courant number should be greater than unity.

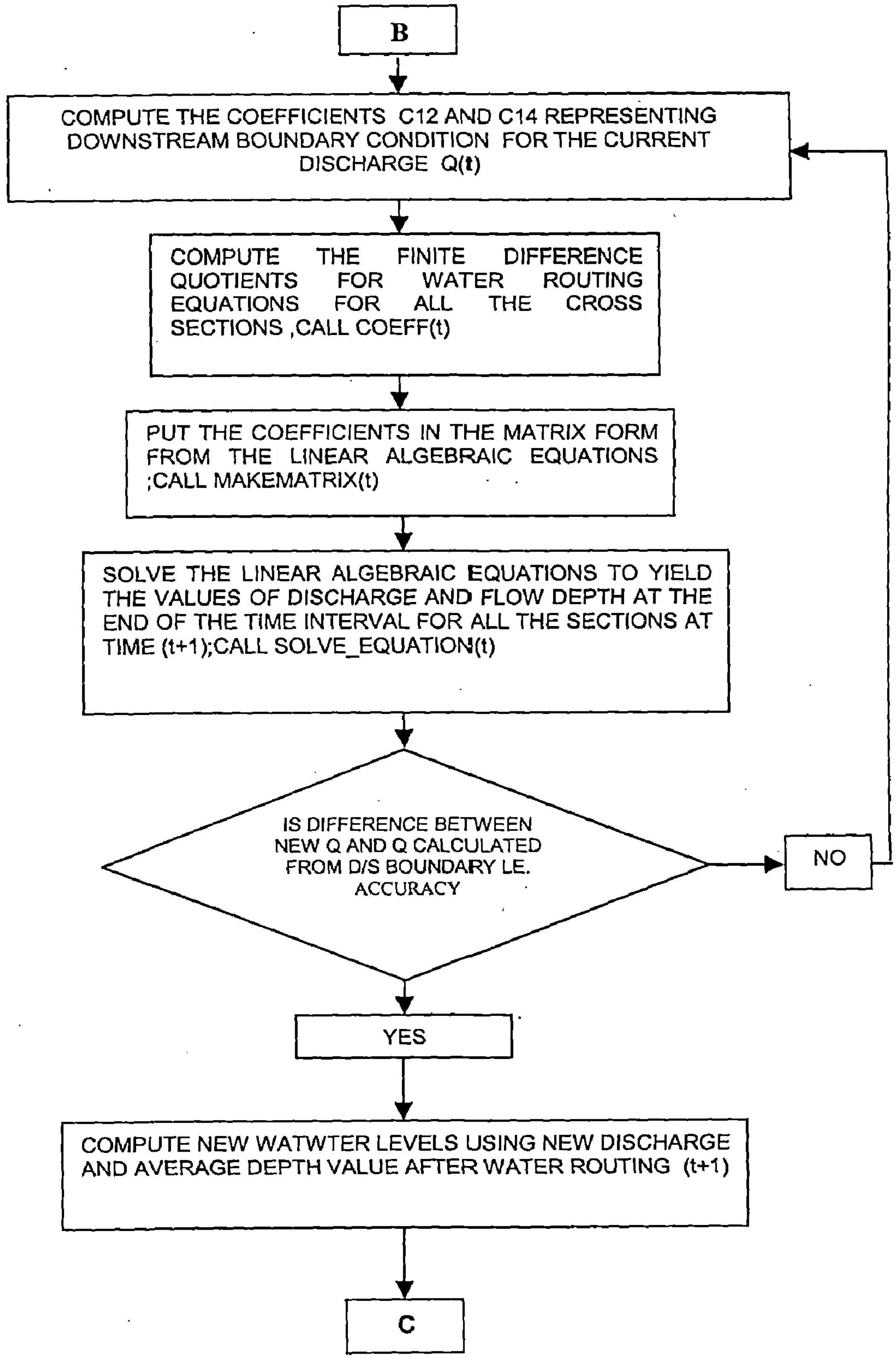
4.4 SCHEMATIC DIAGRAM OF THE MODEL OPERATION

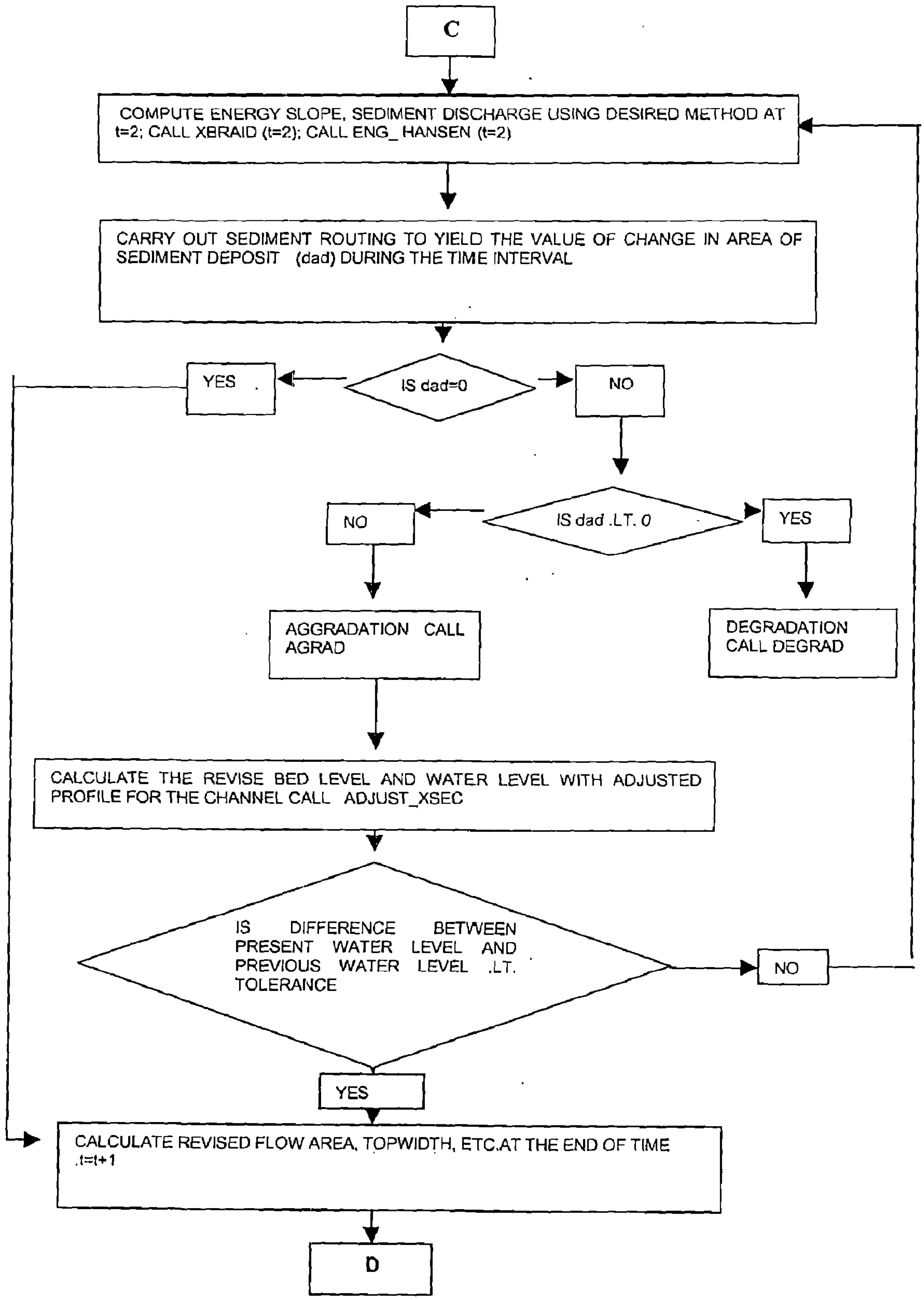
A schematic diagram is presented in the subsequent pages to show computational sequence of the model. Development of computer software named **MODBRAID** based on these sequences is discussed in the next Chapter.

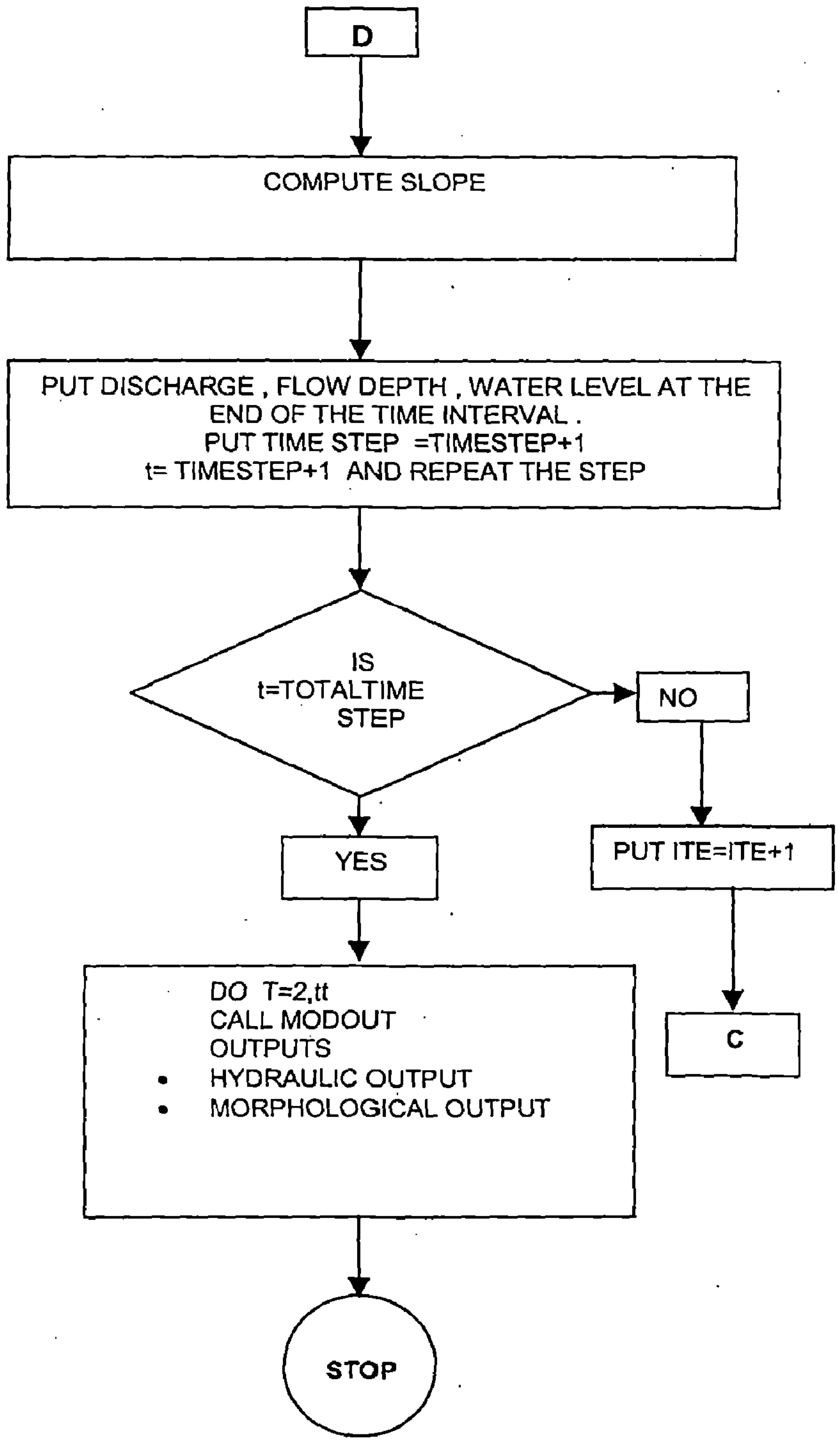
Fig. 4.3

4.4.1 SCHEMATIC DIAGRAM




B
COMPUTE THE COEFFICIENTS C12 AND C14 REPRESENTING DOWNSTREAM BOUNDARY CONDITION FOR THE CURRENT DISCHARGE Q(t)
COMPUTE THE FINITE DIFFERENCE QUOTIENTS FOR WATER ROUTING EQUATIONS FOR ALL THE CROSS SECTIONS ,CALL COEFF(t)
PUT THE COEFFICIENTS IN THE MATRIX FORM FROM THE LINEAR ALGEBRAIC EQUATIONS ;CALL MAKEMATRIX(t)
SOLVE THE LINEAR ALGEBRAIC EQUATIONS TO YIELD THE VALUES OF DISCHARGE AND FLOW DEPTH AT THE END OF THE TIME INTERVAL FOR ALL THE SECTIONS AT TIME (t+1);CALL SOLVE_EQUATION(t)
IS DIFFERENCE BETWEEN NEW Q AND Q CALCULATED FROM D/S BOUNDARY LE. ACCURACY
NO
YES
COMPUTE NEW WATWTER LEVELS USING NEW DISCHARGE AND AVERAGE DEPTH VALUE AFTER WATER ROUTING (t+1)
C


C
COMPUTE ENERGY SLOPE, SEDIMENT DISCHARGE USING DESIRED METHOD AT t=2; CALL XBRAID (t=2); CALL ENG_ HANSEN (t=2)
CARRY OUT SEDIMENT ROUTING TO YIELD THE VALUE OF CHANGE IN AREA OF SEDIMENT DEPOSIT (dad) DURING THE TIME INTERVAL
IS dad=0
YES
NO
IS dad .LT. 0
NO
YES
AGGRADATION CALL AGRAD
DEGRADATION CALL DEGRAD
CALCULATE THE REVISE BED LEVEL AND WATER LEVEL WITH ADJUSTED PROFILE FOR THE CHANNEL CALL ADJUST_XSEC
IS DIFFERENCE BETWEEN PRESENT WATER LEVEL AND PREVIOUS WATER LEVEL .LT. TOLERANCE
NO
YES
CALCULATE REVISED FLOW AREA, TOPWIDTH, ETC.AT THE END OF TIME .t=t+1
D


D
COMPUTE SLOPE
PUT DISCHARGE , FLOW DEPTH , WATER LEVEL AT THE END OF THE TIME INTERVAL .
PUT TIME STEP =TIMESTEP+1
t= TIMESTEP+1 AND REPEAT THE STEP
IS t=TOTALTIME STEP
NO
PUT ITE=ITE+1
C
YES
DO T=2,tt
CALL MODOUT
OUTPUTS
• HYDRAULIC OUTPUT
• MORPHOLOGICAL OUTPUT
STOP

4.5 DEVELOPMENT OF COMPUTER SOFTWARE FOR MODEL IMPLEMETATION

4.5.1 General

For implementing the theoretical concept in the preceding chapters and computing the results, a simulation model called **MODBRAID** for **Alluvial Streams with multi-channel configuration** has been developed in the present dissertation. The program is written in the MS- FORTRAN 90, Rajaraman (2001)[25] code and has 1 main program, 12 subroutines and 1 module. In the following sections, the basic structure of the program, the input specifications and its limitations are discussed.

4.5.2 Main Program

The main program acts as a hub of the overall program and it invokes various subroutines as necessary. It keeps track of the program for reading of the data, initialization of the system, computations of the necessary intermediate terms, solution of the problem and printing out the results for every time step if required.

4.5.3 MODULE

This is a new feature available in FORTRAN 90. The whole program is dependent on the module where all the global variables are declared. These variables can be accessed by the main program as well as by the various subroutines.

4.5.4 SUBROUTINES

The names and the functions of the various subroutines are as follow:

4.5.5 Subroutine INPUT.FOR

This subroutine is invoked in the beginning of program execution to read the data file input.dat. There is only one data file to supply all the necessary input to the model. The input specifications are an important part of the model; hence, it is discussed in detail in the end.

4.5.6 Xsec.FOR

These subroutines calculate area of a sub channel and it is called by the subroutine xsec_braid.FOR.

4.5.7 Xsec_braid.FOR

This is the most vital subroutine for the streams of multi-channel configuration as it calculates number of subsections at all the cross-sections at various stages of flow. It also calculates the other geometric and hydraulic properties at each section viz. hydraulic radius, area of flow, depth of flow, riverbed slope, energy gradient, velocity, top width, etc. This also gives the number of subsidiary channels at each cross-section at various stages of flow.

4.5.8 Coefficient. FOR

After obtaining various geometric and hydraulic characteristics of a flow at the various sections, the finite difference quotients are computed by calling this subroutine.

4.5.9 ds_boundary.FOR

This subroutine reads the downstream boundary conditions. If the results obtained are not within the tolerance limit then this subroutine can be called upon iteratively to improve the solution.

4.5.10 eng_hansen.FOR

This subroutine calculates the sediment flow at the various sections at different conditions of flow.

4.5.11 solve_eqn.FOR

This is called to solve the linear equation by Gauss-Jordan method.

4.5.12 sed_rout.FOR

This subroutine is called when routing of sediment is needed. This returns the value of the change in area i.e. ΔA_c.

4.5.13 Output

There are two subroutines which give output of the model namely modout.FOR and modout1.FOR. The subroutine modout.FOR is called to give output at various time steps while the other one is called once at the beginning.

The above set of codes along with the input and output files constitute the **MODBRAID.**

4.6 INPUT SPECIFICATIONS

To use this model the following inputs are given in the format as specified below:

i) The reach length of the stream is to be given in meters.

ii) Number of cross sections is given, it is an integer.

iii) If distances between two cross-sections are equal then input is 'y' otherwise type n and give the distances of all the consecutive sections in meter.

iv) Enter the number of subsections in each section. It is an integer and should not be more than 100.

v) Enter the initial discharges at all the sections in cumecs from the u/s end.

vi) Enter the initial water level (stage) in meter from u/s end.

vii) Enter the distances of every points of subsection row wise in meter.

viii) Enter the elevations of every point in the subsection row wise in meter (bed profile).

ix) Enter the initial sediment concentration in ppm or option to use predictor.

x) Enter the value of Manning's coefficients at every section.

xi) Enter the value of d_{50} in millimeter.

xii) Enter the lateral inflow in cumecs per meter.

xiii) Enter the total time base in hours.

xiv) Enter the total time steps. It should be less than 50.

xv) Enter the u/s boundary condition that is the flood hydrograph.

xvi) Enter the d/s boundary condition that is stage discharge curve of the d/s end of the reach.

CHAPTER - 5

TESTING OF THE MODEL

5.1 GENERAL

The numerical model developed in this dissertation has been tested with data of Brahmaputra River. The data has been obtained from Flood control department Govt. of Assam and Brahmaputra Board , Master Plan of Brahmaputra Basin,1986 [2]. The Brahmaputra is one of the largest alluvial rivers with multi-channel configuration, in terms of its both size and discharge. These attributes make the Brahmaputra River an ideal example for testing the model.

5.2 THE REACH OF THE RIVER UNDER STUDY

The reach of the river for the model application lies between Pandu (Guwahati) and Jogighopa covering a distance of 102 Km. along the length of the river. At Pandu and at Jogighopa gauge and discharge measurements are made daily by the flood control department of Assam. There is no tributary in this reach hence lateral flow in this reach is less than 0.5 percent of the flow. The minimum width of river in this reach is 3.5 Km. Mostly the river flows in multi-channel configuration between alluvial banks. During floods, the river becomes one sheet of water from bank to bank and occupies a maximum width of about 19.5 Km. The average bed gradient of the river is about 1 in 8875.

5.3 DATA AVAILABLE FOR THE STUDY REACH

The following data are available for conducting simulation runs with the model formulated herein:

5.3.1 Hydrographic Survey Data

14 numbers of cross-sectional profiles of the river from Pandu to Jogighopa in 102 Km. reach length pertaining to year 1977 has been obtained from the records of Floods Control Department of Assam Table (5.1). The cross-sectional profiles and the longitudinal section of the river have been plotted and attached in the appendices Fig. (5.1a) to Fig. (5.1n). The cross

section no. 1 is located in the upstream end of the study reach at the Pandu near Guwahati, while the cross- section no. 14 is situated at the downstream end of the study reach i. e. Jogighopa. C/s 1 and c/s 14 have relatively rigid constricted bank lines due to presence of rock outcrops at both the sites. The remaining 12 nos. of intermediate cross sections of the reach depict character of the alluvial river with multi-channel configuration.

5.3.2 Hydrological Data

Daily discharge and stage records at Jogighopa and daily discharge at Pandu were obtained from 1st of April to 10th of June, 1977.The discharge variation at Pandu for the hydrograph consideration in the study ranges from 8887 cumecs to 28993 cumecs. Refer flood hydrograph Fig. (5.3).

At Jogighopa the observed stage vs. discharge has been plotted in Fig.(5.4). In the absence of observed records, the intermediate water levels and discharges at the intermediate 12 nos. of cross-sections at the beginning of the hydrograph i.e. on 1.4.1977 were interpolated adopting the water surface gradient between Pandu and Jogighopa. Since the required sediment load data are not available, these are generated by the sediment discharge predictor.

5.4 MODEL CALIBERATION

Model calibration is the process of adjusting the dimensions of simplified geometrical elements and the values of empirical hydraulic coefficients so that the flow events simulated on the model reproduce as closely as possible the actual observed values at some reference point. In the present case, the calibration has been done by adjusting model features in such a way that the observed and computed time dependent hydrographs of water levels at Jogighopa matches as closely as possible.

A brief description of the calibration procedure adopted in this study is given below:

i) The space increment of the model Δx is kept same as per the actual available cross-sectional data. As such this has been taken uniform as 7.846 Km. in this study.

ii) The size of time increment Δt is kept as 120 hours.

iii) Lateral flow

In the absence of available data, the lateral flow q_l is estimated to be less than 0.5 % of the flow hence; it has not been taken into account.

iv) Upstream boundary condition: The inflow Flood hydrograph observed at Pandu is taken as upstream boundary condition Fig. (5.3).

v) Downstream boundary condition: Available stage–discharge records for the period 1977 at downstream section (Jogighopa) were used for the purpose of developing the relationship for downstream boundary condition Fig (5.4). To represent the downstream boundary, the following power function is fitted to the observed data by regression analysis[10,30].

$$Q = \alpha(G-z)^{\beta}$$

The values of α and β were found to be 3808.6 and 1.28 respectively and that of z which is level at zero discharge 28.2.

The boundary condition is represented in linear form as stated in section 3.23 with the following equations:

$$C_{12}Q + C_{12}y = C_{14}$$

.For $C_{12} = 1$, the equation becomes

$$C_{14} = Q + C_{13}(h - z)$$

Where h is stage and z is bed elevation.

The values of C13 and C14 have been found from the regression analysis.

C_{13}= -10000 C_{14}= -296140

vi) Manning's roughness coefficient 'n'

The roughness coefficient 'n' in the present case is calibrated by varying its value till the cumulative error between the computed and observed water levels at Jogighopa comes to a minimum cumulative error was obtained from n=0.03 to 0.039 at different cross sections.

vii) Initial Flow Conditions

In the absence of observed data, the initial stage and discharge at each section (other than the first and the last section) are estimated by linear interpolation between upstream and downstream discharge at t=0.

viii) Sediment flow Discharge

In the absence of measured sediment discharge data at the 14 nos. of cross-sectional points, the same were generated by using sediment transport relationship Engelund Hansen. This function has been used because it is simple and requires less number of sediment data. However, in this model the other formulations like Toffaleti or Swamee and Ojha can also be used .Sediment size d_{50} has been taken ranging from 0.1 mm to .2mm.

5.5 SIMULATION STUDIES

With the available data of the Brahmaputra river, simulation studies were conducted for the purpose of studying the model behaviour on a large alluvial river with multi-channel configuration. The study was planned with a view to:

- **Verify the model prediction with help of measured stage data at Jogighopa site on Brahmaputra.**
- **Verify the model prediction with help of measured discharge data at Jogighopa.**
- **Predict the discharge at the end of the simulation times at the interior points.**
- **To obtain the bed profiles predicted by the model. Also to compare the profile obtained by the model with one obtained by uniformly distributing the bed scour/deposition at some sections in a multi-channel configuration.**

5.6 DIFFICULTIES ENCOUNTERED IN RUNNING THE MODEL

(i) Brahmaputra is a large river and its width varies from 3.5 Km. at Pandu section1 to 12 km. At section 7. This poses a lot of difficulty in computing the initial water surface profile and discharge at all the interior points of the reach. At some places the initial velocity becomes too large to be true. Hence a lot of trials are needed to arrive at reasonable values of initial data.The wrong assumption may completely spoil the simulation results. Here the best way is to apply Newton-Rapson approximation method to get the initial values.

(ii) Since the cross-sections are very large up to 14 Km. a large number of points are needed to correctly represent the bed profiles. The computer program to process it and get the geometric and hydraulic properties become complex while in traditional modeling approach the representative sectional approach the things become easier.

(iii) The unique thing in this reach is that at cross section 5 to 6 the bed slope is negative and in sediment discharge predictor the square root of slope is used. In this an absolute value is taken.

(iv) The changes in the bed profile are to be done only in those channels where flow is taking place. This has been done in excel due to the complexities in writing the source code.

(v) The model is very sensitive to the down stream boundary condition. The down stream boundary condition in this case is stage discharge curve at Jogighopa which is in linear form. Since no linear relation can represent stage discharge at all the stages of flow within the reasonable limits of accuracy the water levels obtained at each time step has certain error which get multiply in successive iterations which may spoil the result completely. Hence at every step the reasonable correction is required in the water level.

(vi) The suitable sediment discharge predictor is needed to precisely predict the change in bed profile. In this model only Engelund- Hansen predictor is used to quickly get the result. The sediment flows predicted by this appear to be on higher side and the simulations with various predictors need to be done to improve the accuracy of the result.

(vii) The computation of the model requires a lot of programming skills to get the solution.

5.7 MODEL VERIFICATION

Since the sectional geometries were available only for the beginning of the simulation period, model calibration and verification was done with the help of measured water stages at the Jogighopa for the simulation period. Fig (5.5) and (5.6) shows the computed and observed stages and discharges at Jogighopa respectively.

5.8 SIMULATION RESULTS AND DISCUSSION

From the figure (5.5) it can be seen that simulated stages are in fair agreement with the measured values at Jogighopa this indicates that the behaviour of the Model is normal and encouraging.

However, there are variations in the observed and computed values of discharges at Jogighopa fig (5.6). The variations can be attributed to the following factors:

- The measurement of discharge is not made directly but is obtained from indirect method by measuring cross sectional area and velocities at different points in the river section. Therefore, even slight error in these measurements can cause large error in estimation of discharge especially during high floods. Thus, the observed discharge data may not be very precise.
- The model assumes values of d_{50}, n, initial water surface and discharge at interior points which can influence the accuracy of results.
- The computed values are very sensitive to the boundary conditions and the linearization of stage discharge curve can introduce appreciable errors.
- The accuracy of the computed values is also lost during the iterations. If suitable rectification is not made at every iteration then end results are spoilt completely. In the present model rectifications at each step has been made manually which is not very precise.
- Also the sediment flow predictor adopted here is not suitable for a large river with multi-channel configuration and better results could be obtained if sediment data were available and other sediment predictor could be used.

5.8.1 Bed Profile predictions

One of the very important aspects of the modeling of alluvial river with multi-channel configuration is to device a correct methodology in predicting the changes of bed profiles with the changes in flow conditions. Hence, an endeavour has been made to introduce the more scientific criteria to distribute the change in area (ΔAc) per unit length of the river over the cross-section.

The results of the bed profiles at the end of simulation period have been obtained for sections 3, 7, ~~and 13.~~

These results could not be compared due to non-availability of bed profiles at any of the section.

However, a sample profiles in the course of aggradation and degradation has been obtained at section 7 Fig.(5.8) and (5.9) with conveyance/shear velocity approach respectively used in this model and the same has been compared with the traditional approach of distributing the sediment over the cross-section. Findings and discussions are presented herewith:

Case of bed Degradation

Figure (5.8) shows the bed profiles in case of general bed scour obtained with the two different approaches. Here following observations are made:

The differences in change of bed levels in two cases are significant.

With shear velocity approach, the erosion in the bed level in the main channel is less but it is more in subsidiary channels when compared to the uniform distribution simplification.

Case of bed deposition

Fig (5.9) shows the bed profiles in case of general aggradation of the bed in two approaches namely inverse of conveyance approach and uniform distribution approach. Here also the following observations can be made:

The differences in the bed levels are significant in the two cases.

Here also the approach adopted in the model predicts less deposition in the main channel and more deposition in the subsidiary channels compared to the later approach.

Similarly after close examination of the bed profile at various sections one inference can be drawn that larger the channel lesser is the change in the bed profile with the variations in flow condition in a large alluvial stream with multi-channel configuration. This observation necessitates the modification in the models which simplify the solution assuming uniform changes over the cross section specifically when dealing with a stream with multi-channel configuration.

This needs to be further examined with the experimental and observed data in the field.

5.9 LIMITATIONS OF THE MODEL

The major limitation of the model is that the bank of the river has been considered as rigid.

The model adopts Engelund –Hansen sediment transport equations. Though the results obtained with the present predictor is also within the reasonable tolerance, the suitability of other sediment predictor equations need to be further explored for the river like Brahmaputra.

Also, this model is one dimensional. A two dimensional approach could be a better model when dealing in complex morphological changes in a large alluvial stream with multi-channel configuration.

CHAPTER - 6

SUMMARY AND CONCLUSIONS

In the present work a model named **MODBRAID** has been developed to simulate water and sediment flow. It also gives a rational relation for the computation of aggradation and degradation phenomena in a river of multi-channel configuration on the basis of some modifications in the existing technique.

The model is based on unsteady flow equations of water and sediment along with other supplementary equations. Rivers with multi-channel configuration are interspersed with formation of braided bars on a highly random pattern with flow channels of variable conveyances. In case of large rivers with high discharge and heavy sediment load, the bars often assume sizes which may run into kilometers on both longitudinal and transverse directions. This kind of channel morphology poses difficulties at the time of modeling for flow simulation, especially for hydraulic representation of the complex channel geometry. This makes the solution algorithm very cumbersome. The main thrust in this modeling is for **alluvial streams with multi-channel configuration.**

The model herein adopts an uncoupled solution procedure with fully linear implicit method. Here the bed deposition has been considered to be in inverse proportion to the conveyances of the subsections and bed degradation is conceptualized to be in direct proportion of the net inertial motion i.e. the difference between the shear velocity of flow and critical shear velocity.

The model has been tested with the help of the actual fluvial data of 102 km. long reach of the Brahmaputra River in Assam which is a large alluvial river with multi-channel configuration.

The model was verified with the help of observed water stages as available at the outflow section of Jogighopa.

The results obtained from the model are found to be in good agreement with the observed data. On the basis of the results obtained from the study, the major conclusions are summarized below:

CONCLUSIONS

(i) The results of the present study have shown that the uncoupled numerical model developed in this work on the basis of the modified form of the three basic partial differential equations can simulate gradually varied unsteady flow fairly well in a natural alluvial stream with multi-channel configuration.

(ii) The study has indicated that conceptualising the main channel flow and subsidiary channel flow as separate entities in numerical simulation for alluvial stream with multi-channel configuration has the advantage over conventional model in the respect that the hydraulic properties remain intact at various stages of flow simulation and can gainfully be used in prediction of bed profile in a more realistic manner.

(iii) Simulation results show that there is significant divergence in the results of the bed profiles predicted by this model compared to conventional approach in a stream with varying sizes of multiple channels. The present model has displayed marked improvement over the conventional treatment of unsteady flow in natural stream wherein the flow is averaged across the total cross-sectional area.

(iv) The linear fully implicit scheme is found to be capable of keeping at bay the usual numerical oscillations associated with the multi-channel stream modeling.

(v) From the present study it could be discernible that temporal and spatial size increments for discretization of flow variables in this numerical scheme profoundly influence the simulation results.

(vi) The present simulation runs in subcritical flow condition have highlighted that the accuracy of results in the numerical model is highly sensitive to downstream boundary condition and Manning's rugosity coefficient. Hence these data need very careful treatment.

SUGGESTIONS OF FUTURE WORK

- The model can be run using various sediment discharge predictors and the result can be compared with actual field observation so that a suitable sediment predictor can be adopted for a river like Brahmaputra.

- It is known that secondary circulation affects aggradation, degradation and bank erosion processes in an alluvial stream with multi-channel configuration. There is a need to study the effect of secondary flow in this context.

- For a better topological and hydraulic representation of the braided channel, extension work to two-dimensional flow incorporating momentum transfer at the interface of flow divisions needs to be carried out for model development of alluvial stream with multi-channel configuration.

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APPENDIX-1

Table 5.1 Bed Profile of Brhmaputra (Study reach) ,Distance(first coulmn) Elevation (second column)1/4/1977

C/S No.9Jogighopa		C/S No. 10		C/S No. 11		C/S No. 12		C/S No. 13	
0	36.78	0	34.10	0	41.65	0	38.91	0	40.70
55	38.09	16	12.38	50	41.51	840	34.06	290	39.61
115	29.08	256	27.18	100	41.38	970	31.85	580	40.85
138	27.88	391	29.70	150	41.24	1100	29.64	940	36.23
280	27.28	811	33.69	175	41.17	1220	29.89	1180	40.48
362	26.08	931	32.74	200	41.10	1340	30.14	1375	40.68
379	25.83	1111	30.10	300	38.06	1460	34.40	1605	41.21
395	25.58	1205	29.60	400	35.02	1580	38.66	1905	40.98
442	25.32	1400	25.00	500	31.98	1780	38.19	2208	40.76
488	25.06	1525	28.20	600	28.94	1980	37.73	2393	39.84
515	24.45	1605	29.30	800	32.36	2050	38.52	2610	40.96
542	23.85	1985	24.20	1000	35.77	2120	39.31	2870	40.88
641	23.06	1991	35.35	1500	35.90	2230	39.29	3090	39.00
740	22.28	2111	33.28	2000	36.04	2340	39.27	3340	39.82
791	22.43	2291	33.51	2500	35.87	2580	38.44	3540	41.30
841	22.58	2351	35.87	3000	35.71	2820	37.60	3785	40.99
929	22.43	2381	35.64	3150	33.59	3020	36.91	4010	38.61
1017	22.28	2411	35.40	3300	31.47	3220	36.21	4210	39.51
1062	23.48	2531	34.16	3400	34.72	3310	37.44	4405	40.90
1106	24.68	2651	32.93	3500	37.98	3400	38.68	4540	32.16
1137	25.38	2691	34.71	3850	37.90	3478	37.19	4787	31.86
1167	26.08	2731	36.49	4200	37.82	3556	35.70	4960	36.33
1197	26.18	2801	36.49	4550	37.11	3878	35.81	5240	39.00
1227	26.28	2871	36.49	4900	36.40	4200	35.92	5400	39.09
1304	26.58	2916	33.99	5100	35.20	4440	37.12	5600	39.19
1381	26.88	2961	31.49	5300	34.01	4680	38.32	5800	39.75
1454	26.88	3001	30.75	5400	22.64	4790	36.87	6000	41.02
1527	26.88	3041	30.01	5500	11.27	4900	35.43	6200	40.71
1550	27.08	3081	30.10	5850	19.22	5150	36.02	6400	40.90
1573	27.28	3121	30.18	6200	27.17	5400	36.61	6600	40.86
1622	27.43	3201	30.58	6400	30.80	5855	36.01	6800	40.70
1670	27.58	3281	30.98	6600	34.43	6309	35.41	7000	40.75
1712	27.73	3321	35.14	6950	35.90	6540	35.88	7200	40.72
1753	27.88	3361	39.29	7300	37.36	6770	36.36	7400	40.78
1801	27.68	3401	35.05	7550	36.87	7104	37.28	7600	40.60
1848	27.48	3441	30.80	7800	36.39	7438	38.19	7800	40.83
1903	24.28	3521	30.39	7950	35.20	7589	37.91	8051	41.05
1958	21.08	3601	29.98	8100	34.01	7740	37.63	8200	40.02
2005	20.41	3616	33.24	8300	33.72	7997	37.42	8400	36.94
2051	19.75	3631	36.49	8500	33.42	8254	37.22	8600	39.08
2092	18.91	3696	36.49	8750	31.81	8357	35.24	8800	39.75
2133	18.08	3761	36.49	9000	30.21	8460	33.26	9000	40.75
2154	19.08	3798	36.00	9150	30.04	8790	34.13	9200	40.92
2175	20.08	3835	35.51	9300	29.88	9119	35.00	9400	40.73
2208	21.08	3950	35.73	9400	29.87	9376	34.51	9600	37.66
2241	22.08	4065	35.96	9500	29.85	9632	34.03	9843	31.46
2258	24.78	4135	35.95	9775	29.29	9826	30.39	10193	29.01
2275	27.48	4205	35.94	9913	29.01	10020	26.76	10383	23.71
2303	27.68	4285	35.92	9981	28.87	10160	30.55	10683	21.31
2331	27.88	4365	35.91	10050	28.74	10300	34.34	10873	21.21
2356	28.48	4425	35.67	10175	33.49	10551	30.70	11035	20.91
2380	29.08	4485	35.44	10238	35.86	10801	27.06	11193	19.11
2390	32.07	4590	35.35	10269	37.05	10821	27.96	11433	28.31
2400	35.06	4695	35.25	10300	38.24	10840	28.86	11809	32.13
2452	35.40	4728	35.60	10400	40.15	10941	25.86	12019	38.81
2504	35.75	4760	35.94	10450	41.10	11041	22.86	12219	39.43
2556	36.27	4885	36.02	10475	41.57	11091	28.46	12429	39.18
2608	36.79	5009	36.09	10500	42.05	11141	34.06	12831	40.21

Table 5.1 Continued

C/S No. 14		C/S No. 15		C/S No. 16		C/S No. 17		C/S No. 18	
0	40.50	0	39.78	0	41.95	0	46.31	0	45.32
323	32.81	37	41.83	200	41.05	500	42.46	500	45.20
750	32.21	120	39.92	300	40.60	650	41.30	1000	44.00
1210	40.64	402	40.20	400	40.15	800	48.90	1250	40.20
1603	40.43	500	44.13	650	40.93	900	43.40	1500	40.60
2000	40.21	600	39.84	900	41.70	1000	44.10	1700	42.60
2300	39.93	800	40.16	1050	39.30	1400	43.10	2000	44.30
2560	39.47	1100	40.51	1200	36.90	1500	43.00	2300	44.75
3000	40.71	1300	40.29	1475	36.85	1700	43.80	2550	45.60
3520	37.78	1600	41.44	1750	36.80	1800	48.50	2750	43.80
3660	38.12	2000	41.95	1875	38.55	2000	41.00	3000	43.20
3800	38.45	2400	42.02	2000	40.30	2550	43.00	3250	41.40
4000	38.79	2600	41.85	2250	40.75	3000	41.90	3500	40.00
4200	39.12	2700	42.19	2500	41.20	3500	39.20	3700	41.20
4300	38.43	2800	40.52	2650	37.45	3800	40.35	4000	42.30
4400	37.73	3100	41.51	2800	33.70	4000	39.00	4250	46.00
4530	36.09	3210	40.85	2900	35.70	4250	36.80	4600	47.60
4660	34.44	3400	41.33	3000	37.70	4550	30.30	4900	37.95
4780	36.01	3600	40.67	3300	38.18	4750	35.50	5200	42.10
4900	37.58	3900	40.95	3600	38.65	4950	39.50	5400	43.10
5070	38.19	4001	39.86	3800	39.23	5500	36.80	5700	43.40
5240	38.80	4100	40.32	4000	39.80	5700	35.80	6000	43.53
5559	37.41	4500	38.96	4240	39.66	6000	38.30	6300	44.20
5878	36.01	4600	39.67	4480	39.52	6550	42.90	6500	44.00
6069	38.05	4700	35.32	4640	39.80	6750	43.20	6700	43.70
6260	40.09	4800	39.99	4800	40.07	7000	42.00	7100	43.80
6526	38.03	5180	33.55	5025	38.75	7500	43.00	7500	43.80
6791	35.97	5300	40.00	5250	37.43	7700	45.41	7750	42.80
6826	35.97	5410	24.39	5425	38.04	8000	44.47	8000	40.80
6860	35.96	5810	27.79	5600	38.65	8400	39.30	8400	43.50
7031	34.48	6130	28.04	5750	38.18	8500	42.10	8750	44.10
7201	33.00	6450	31.87	5900	37.70	8600	45.00	9250	43.85
7372	34.92	6610	38.38	6050	35.70	8800	44.10	9500	44.30
7543	36.84	6850	30.79	6200	33.70	9000	45.08	10000	43.00
7692	30.75	6930	33.19	6500	36.30	9500	46.01	10300	43.70
7840	24.65	7510	22.99	6800	38.90	10000	44.96	10500	44.20
8048	26.68	7890	25.29	7025	40.12	10250	43.07	11500	41.60
8255	28.70	8170	20.39	7250	41.33	10500	46.65	11950	38.76
8465	29.12	8330	20.59	7375	39.64	11000	47.00	12300	44.00
8675	29.53	9200	38.19	7500	37.95	11500	46.80	12500	43.40
8875	33.00	9780	31.56	7750	36.33	12000	46.84	13000	41.30
9075	36.47	10180	28.86	8000	34.70	12500	48.20	13500	40.00
9253	37.12	10600	37.10	8225	33.45	12750	49.93	14100	37.70
9430	37.77	10900	32.82	8450	32.20	13000	47.79	14500	39.75
9520	38.09	11300	39.28	8725	36.77	13600	44.20	15000	37.40
9610	38.41	11355	30.48	9000	41.33	14000	41.60	15250	35.40
9840	35.30	11595	40.40	9250	41.64	14150	39.31	15500	33.45
10070	32.19	11966	26.41	9500	41.95	14500	38.00	15800	29.90
10255	35.56	12304	39.81	9750	41.88	14850	39.79	16000	31.10
10439	38.92	12414	39.15	10000	41.80	14900	40.51	16300	40.71
10593	39.78	12530	39.66	10250	41.96	14950	42.41	16500	43.75
10746	40.64	12730	39.24	10500	42.12	15000	44.30	17000	43.70
10909	40.95	12926	39.67	10600	40.19	15125	41.15	17250	41.40
11072	41.25	13034	31.00	10700	38.26	15250	38.00	17550	33.10
11343	40.41	13060	40.11	10975	40.02	15375	42.10	17800	43.00
11613	39.56	13218	33.96	11250	41.77	15500	46.20	18100	44.00
11683	41.69	13436	41.53	11525	41.45	15520	46.46	19000	42.00
11752	43.81	13465	39.92	11800	41.13	15540	46.71	19500	41.45

Table 5.1 Continued

C/S No. 19		C/S No. 20		C/S No. 21		C/S No. 22 Pandu	
0	45.73	0	53.28	0	49.25	0	50.32
300	39.15	10	43.10	200	47.73	150	50.00
600	45.45	250	47.20	350	48.62	152	49.99
1000	46.20	350	46.90	500	49.50	153	49.98
1350	45.95	500	46.45	550	46.53	155	49.97
1600	44.40	650	45.95	600	43.55	156	49.97
1750	42.15	750	45.90	700	46.49	159	49.95
2000	44.00	850	45.80	800	49.43	163	49.93
2550	37.30	920	47.25	1025	49.32	169	49.90
2800	36.30	1000	48.66	1250	49.20	175	49.86
3200	42.06	1050	39.90	1335	50.04	188	49.80
3400	43.20	1100	37.60	1420	50.87	200	49.73
3800	33.57	1150	36.40	1535	46.36	225	49.59
4200	35.70	1200	33.00	1650	41.84	250	49.46
4350	36.55	1250	30.30	1725	41.22	300	49.18
4500	37.40	1300	28.00	1800	40.60	350	48.91
4650	35.95	1400	25.00	2025	43.00	475	48.26
4800	34.50	1450	28.00	2250	45.40	600	47.60
4950	31.20	1500	30.00	2375	45.60	675	47.10
5100	27.90	1550	32.40	2500	45.80	750	46.60
5200	26.40	1600	32.85	2625	47.14	875	47.30
5300	24.90	1700	33.40	2750	48.48	1000	48.00
5400	32.76	1800	33.90	2875	47.04	1100	48.60
5500	40.62	1900	34.40	3000	45.60	1200	49.19
5675	43.69	2000	35.52	3075	43.77	1265	49.60
5850	46.75	2100	36.70	3150	41.93	1330	50.00
5925	46.45	2200	37.90	3275	42.79	1460	49.78
6000	46.15	2300	38.70	3400	43.65	1590	49.55
6150	46.18	2450	39.90	3500	43.20	1605	47.28
6300	46.20	2550	40.95	3600	42.75	1620	45.00
6500	46.13	2650	41.80	3800	42.58	1660	42.35
6700	46.05	2750	42.80	4000	42.40	1700	39.70
6950	45.80	2900	43.85	4100	42.20	1750	37.35
7200	45.55	3000	44.60	4200	42.00	1800	35.00
7350	45.23	3160	44.75	4400	39.50	1850	33.43
7500	44.90	3250	44.80	4600	37.00	1900	31.85
7600	45.03	3400	44.50	4700	36.25	1950	31.44
7700	45.15	3500	44.80	4800	35.50	2000	31.02
7850	45.38	3650	44.70	4900	35.15	2075	31.66
8000	45.60	3750	44.76	5000	34.80	2150	32.30
8175	46.03	3805	44.85	5200	34.08	2225	33.40
8350	46.45	4000	44.40	5400	33.35	2300	34.50
8575	46.15	4150	42.90	5600	38.68	2350	34.75
8800	45.85	4250	41.80	5800	44.00	2400	35.00
9100	44.93	4350	41.25	5900	45.70	2525	36.50
9400	44.00	4450	40.65	6000	47.40	2650	38.00
9700	43.55	4500	39.60	6175	47.95	2700	38.45
10000	43.10	4550	38.65	6350	48.50	2750	38.90
10250	43.20	4650	40.65	6550	47.93	2810	39.40
10500	43.30	4750	42.58	6750	47.35	2870	39.90
10750	43.51	4850	40.60	6825	47.68	2935	40.45
11000	43.72	4900	45.72	6900	48.00	3000	41.00
11250	44.36	4950	46.46	7325	47.30	3015	43.00
11500	45.00	5000	47.20	7750	46.60	3030	45.00
11600	45.80	5050	47.75	7875	46.76	3090	47.33
11700	46.60	5100	48.30	8000	46.91	3150	49.65
11800	47.41	5125	48.90	8265	47.06	3220	49.73
11900	48.22	5150	49.50	8530	47.20	3290	49.8

Source : Brahmaputra Board Master Plan of Brahmaputra Basin.1986

Table 5.2 Geometric Properties of Brahmaputra (Study reach) 1/4/1977

Section . No	No. of Channels	Channel Area			Channel Top Width			Channel Perimeter			H-Radius	Velocity	Slope
		(I,1,1) m^2	(I,2,1) m^2	(I,3,1) m^2	(I,1,1) m	(I,2,1) m	(I,3,1) m	(I,1,1) m	(I,2,1) m	(I,3,1) m	m	m/s	
1	1	9178	0	0	9178	0	0	1358	0	0	7	0.97	0.000127
2	1	21138	0	0	21138	0	0	3484	0	0	6	0.41	0.000428
3	1	4274	0	0	4274	0	0	963	0	0	4	1.96	0.000032
4	1	12330	0	0	12330	0	0	2551	0	0	5	0.66	-0.000961
5	2	146	10809	0	146	10809	0	326	3159	0	3	0.40	0.000207
6	2	6194	453	0	6194	453	0	2189	629	0	2	1.42	0.000282
7	3	376	801	2267	376	801	2267	260	552	1007	2	1.08	0.000788
8	1	46580	0	0	46580	0	0	7450	0	0	6	0.19	-0.000386
9	2	367	7367	0	367	7367	0	387	1394	0	4	0.67	-0.000031
10	3	887	387	7376	887	387	7376	477	429	1437	4	0.43	0.000311
11	3	1207	1747	3286	1207	1747	3286	519	565	741	3	0.94	-0.000008
12	2	2808	3368	0	2808	3368	0	1047	1519	0	2	0.89	0.000113
13	2	395	2311	0	395	2311	0	296	862	0	2	1.25	0.000570
14	1	10666	0	0	10666	0	0	2270	0	0	5	0.52	

Table No. 5.3 Up Stream Boundary Condition (Flow Hydrograph at Pandu)

S.No.	Observation Date(Year 1977) (Time)	Discharge Cumecs
1	1-Apr	8887
2	6-Apr	13701
3	11-Apr	17974
4	16-Apr	15140
5	21-Apr	12450
6	26-Apr	11696
7	1-May	17135
8	6-May	24684
9	11-May	20177
10	16-May	16713
11	21-May	25279
12	26-May	18179
13	31-May	21653
14	5-Jun	29547
15	10-Jun	28993

Table 5.4 Observed Stage and Discharge at Jogighopa

S.No.	Date of observation	Observed Dischrges cum.	Stages Observed m
1	1-Apr-77	5500 ✓	29.552
2	6-Apr-77	6800	30.067
3	11-Apr-77	10900	31.172
4	16-Apr-77	9900	30.952
5	21-Apr-77	7700	30.372
6	26-Apr-77	7600	30.016
7	1-May-77	15300	32.057
8	6-May-77	21902	33.287
9	11-May-77	15558	32.383
10	16-May-77	10512	31.817
11	21-May-77	18400	32.572
12	26-May-77	17501	32.075
13	31-May-77	20798	32.521
14	5-Jun-77	29900	34.057
15	10-Jun-77	33300	34.120

Table 5.5 Simulation Results at Jogighopa

S.No.	Date of Observations	Stages Observed m	Predicted Stage m	Percentage Variation	Observed Discharge cumec	Predicted Discharge cumec	Variation Percentage %
1	1-Apr-77	29.552	29.55	-0.01	5500	5500.0	0.00
2	6-Apr-77	30.067	31.00	3.10	6800	9608.0	41.29
3	11-Apr-77	31.172	31.30	0.41	10900	15745.4	44.45
4	16-Apr-77	30.952	31.50	1.77	9900	16953.7	71.25
5	21-Apr-77	30.372	32.10	5.69	7700	14670.3	90.52
6	26-Apr-77	30.016	32.90	9.61	7600	13609.8	79.08
7	1-May-77	32.057	34.50	7.62	15300	18347.2	19.92
8	6-May-77	33.287	32.50	-2.36	21902	25583.5	16.81
9	11-May-77	32.383	32.50	0.36	15558	22272.8	43.16
10	16-May-77	31.817	33.20	4.35	10512	18848.0	79.30
11	21-May-77	32.572	33.20	1.93	18400	26446.3	43.73
12	26-May-77	32.075	32.90	2.57	17501	20312.6	16.07
13	31-May-77	32.521	34.20	5.16	20798	20312.6	-2.33
14	5-Jun-77	34.057	34.50	1.30	29900	20312.6	-32.06
15	10-Jun-77	34.120	34.60	1.41	33300	29816.5	-10.46

Table 5.6 Sample Calculation of Aggraded Bed Profile

<table>
<tr><th>No. of channels cn(7,2)</th><th>Discharge</th><th>Area (7,cn,2)</th><th>Perimeter</th><th>H-Radius</th><th>Slope</th><th>Channel top width</th></tr>
<tr><td>No.</td><td>cumec</td><td>m2</td><td>m</td><td>m</td><td></td><td>m</td></tr>
<tr><td rowspan="5">5</td><td rowspan="5">27180.13</td><td>84.85</td><td>315.29</td><td>0.269</td><td rowspan="5">1.22E-03</td><td>315.29</td></tr>
<tr><td>3163.63</td><td>1254.43</td><td>2.522</td><td>1254.43</td></tr>
<tr><td>11977.43</td><td>4624.27</td><td>2.590</td><td>4624.27</td></tr>
<tr><td>7940.62</td><td>1673.36</td><td>4.745</td><td>1673.36</td></tr>
<tr><td>630.6</td><td>514.45</td><td>1.226</td><td>514.45</td></tr>
</table>

<table>
<tr><th>Total topwidth</th><th>Aggradation area obtained from model</th><th>Ak R2/3</th><th>$1-((A_kR^{2/3}) / \Sigma A_iR^{2/3})$</th><th>Aggradation area</th><th>Aggradation depth</th><th>Uniform distn.of Agggrdn.</th></tr>
<tr><td>m</td><td>m3 per m</td><td>m8/3</td><td></td><td>m3 per m</td><td>m</td><td>m</td></tr>
<tr><td rowspan="5">8381.41</td><td rowspan="5">5048.88</td><td>35.37</td><td>1.00</td><td>1261.355</td><td>0.500</td><td rowspan="5">0.60</td></tr>
<tr><td>5861.54</td><td>0.89</td><td>1118.926</td><td>0.892</td></tr>
<tr><td>22589.71</td><td>0.56</td><td>709.982</td><td>0.154</td></tr>
<tr><td>22423.21</td><td>0.57</td><td>714.053</td><td>0.427</td></tr>
<tr><td>722.26</td><td>0.99</td><td>1244.563</td><td>2.419</td></tr>
</table>

Note: cn indicates channel number.

The numbers in parentheses indicates section, channel and time step respectively.

Table 5.7 Sample Calculation of Degraded Bed Profile at Section 7after Time Step 2

No. of channels cn(7,2) No	Discharge Cumec	area (7,cn,2) m2	perimeter m	H-radius m	slope	Channel top width meter	Total Top width meter
3	13976.2	376.24	259.54	1.450	0.00132	259.54	1818.75
		800.57	552.15	1.450		552.15	
		2266.56	1007.21	2.250		1007.21	
	TOTAL	3443.37	1818.90	1.893		1818.90	

Deggradation area obtained from model m3 per m	u*channel m per sec	$\tau\chi$ N per m2	u*c channel m per sec	u*-u*c m per sec.	dsk m2	depth m	Uniform distn.of degradation m
-1910.56	0.137	0.23	0.015	0.122	-583.09	-2.25	-1.05
	0.137	0.23	0.015	0.122	-583.15	-1.06	
	0.171	0.23	0.015	0.156	-744.33	-0.74	
TOTAL				0.399			

Note: cn indicates channel number.
The numbers in parentheses indicate section, channel and time step respectively.

Table 5.8 Geometrical Properties of Brahmaputra River at the Sections Under Study on 10/6/1977

Sec. tion No.	No.of Cha- nnels.	Disch- arge	Channel area					Channel Top width					Channel Perimeter					H- Ra- dius	Slope
			(I,1,15)	(I,2,15)	(I,3,15)	(I,4,15)	(I,5,15)	(I,1,15)	(I,2,15)	(I,3,15)	(I,4,15)	(I,5,15)	(I,1,15)	(I,2,15)	(I,3,15)	(I,4,15)	(I,5,15)		
		cumec	m2	m2	m2	m2	m2	m	m	m	m	m	m	m	m	m	m	m	
1	1	28993	13542	0	0	0	0	1437	0	0	0	0	1438	0	0	0	0	9.4	0.00013
2	1	28472	34968	0	0	0	0	4267	0	0	0	0	4268	0	0	0	0	8.2	0.00022
3	2	28129	12706	1153	0	0	0	1731	619	0	0	0	1732	619	0	0	0	5.9	0.00017
4	2	27964	25369	2979	0	0	0	3499	1749	0	0	0	3500	1749	0	0	0	5.4	0.00074
5	2	26513	2923	3598	0	0	0	1591	1518	0	0	0	1591	1518	0	0	0	2.1	0.00025
6	1	22247	36799	0	0	0	0	8259	0	0	0	0	8259	0	0	0	0	4.5	0.00021
7	2	20401	31770	1248	0	0	0	9271	720	0	0	0	9272	720	0	0	0	3.3	0.0012
8	1	22059	44128	0	0	0	0	7409	0	0	0	0	7409	0	0	0	0	6.0	0.00074
9	3	21751	463	13132	1127	0	0	453	2704	665	0	0	453	2704	665	0	0	3.9	0.00017
10	5	21663	1814	209	1657	9949	721	614	493	1218	1590	677.3	614	493	1218	1590	677	3.1	0.00011
11	1	22095	2795	0	0	0	0	875	0	0	0	0	876	0	0	0	0	3.2	0.000015
12	4	22956	1627	614	7736	10572	0	618	735	1927	2404	0	618	735	1927	2405	0	3.6	0.00061
13	5	23926	0	494	1969	1061	28	0	354	444	234	175.53	0	355	444	235	176	2.4	0.00042
14	1	23985	22255	0	0	0	0	2320	0	0	0	0	2322	0	0	0	0	9.6	

Note: The arguments in the parantheses indicate section,channel and time step respectively.

Table 5.9 Calculation of Aggraded Bed Profile section 5 on10/6/1977

No. of channels cn(7,2)	Discharge	Area (7,cn,2)	Perimeter	H-Radius	Slope	Channel top width
No.	cumec	m2	m	m		m
2	26513.32	2922.7	315.3	9.270	2.50E-04	1590.83
		3597.5	1254.4	2.868		1517.52

Total topwidth	Aggradation area obtained from model	Ak R2/3	1-($(A_kR^{2/3})$ / $\sum A_iR^{2/3}$))	Aggradation area	Aggradation depth	Uniform distn.of Agggrdn.
m	m3 per m	m8/3		m3 per m	m	m
8381.41	8952.27	12896.976	0.36	3224.882	2.0	2.9
		7261.814	0.64	5727.388	3.8	

APPENDIX-2

Cross-Sectional Profiles of Brahmaputra River From Pandu To Jogighopa on (1-4-77)

The First Section is at Pandu
All other sections are at equal distances of 7.84 km.

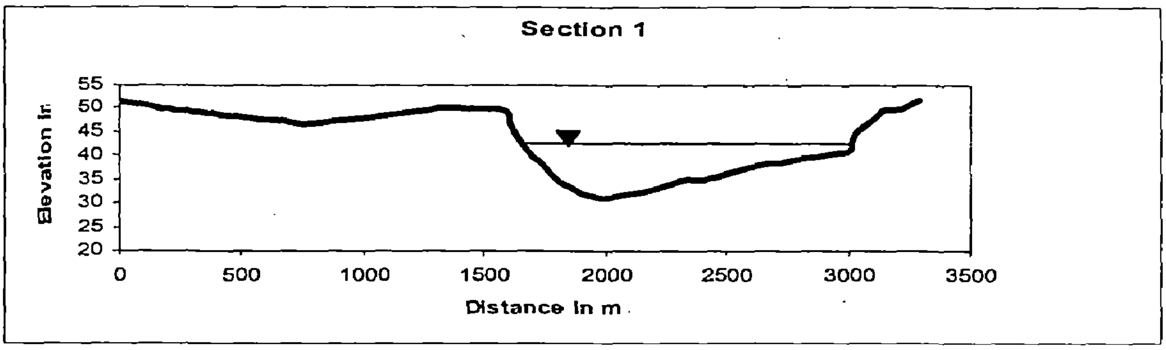


Fig.5.1a

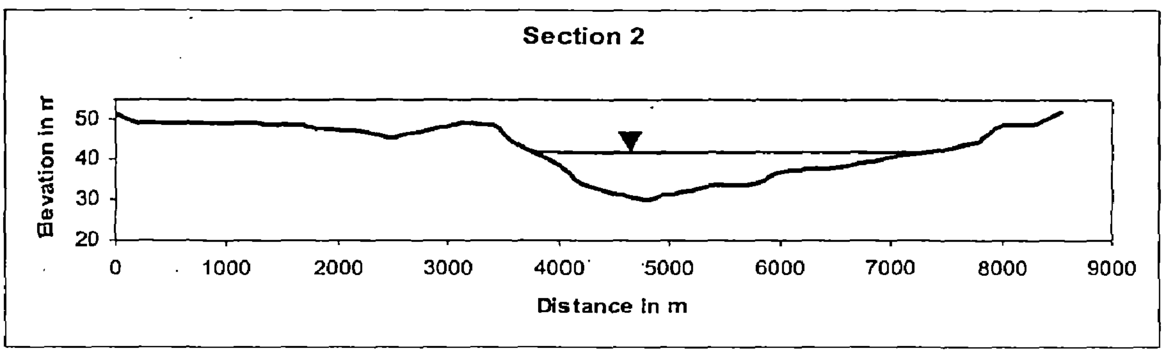


Fig.5.1b

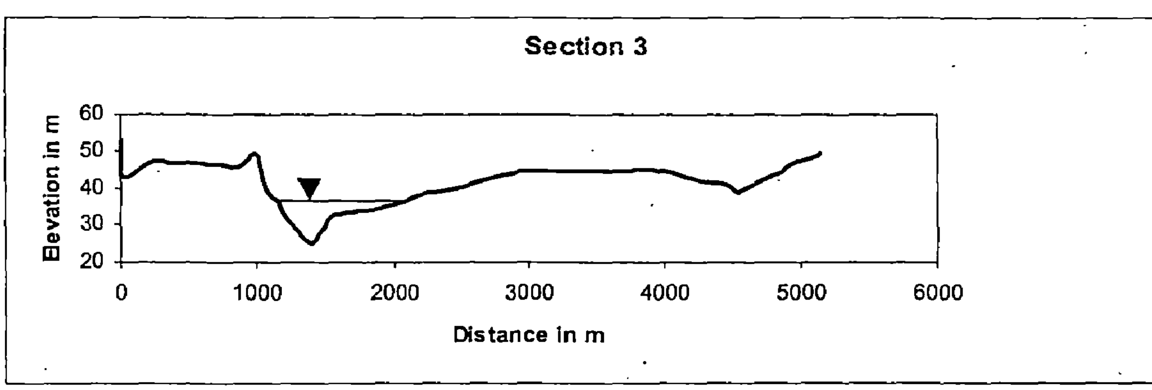


Fig.5.1c

continued

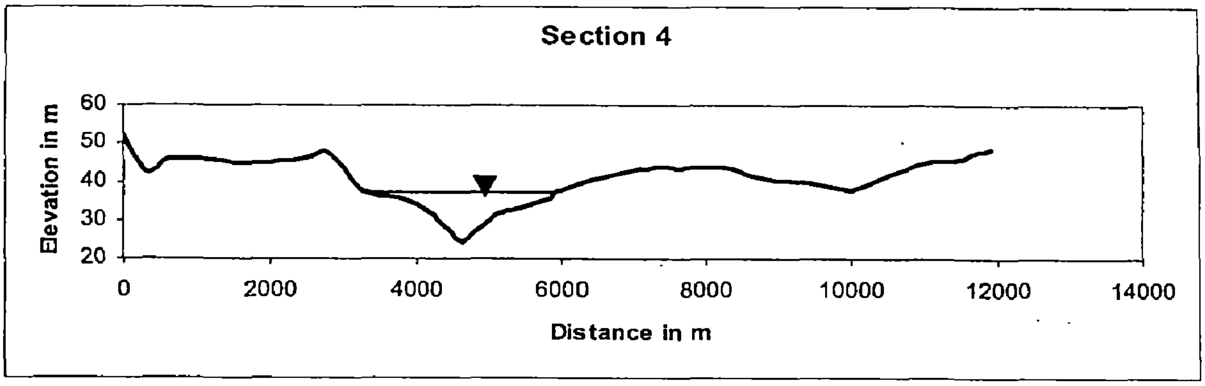


Fig.5.1d

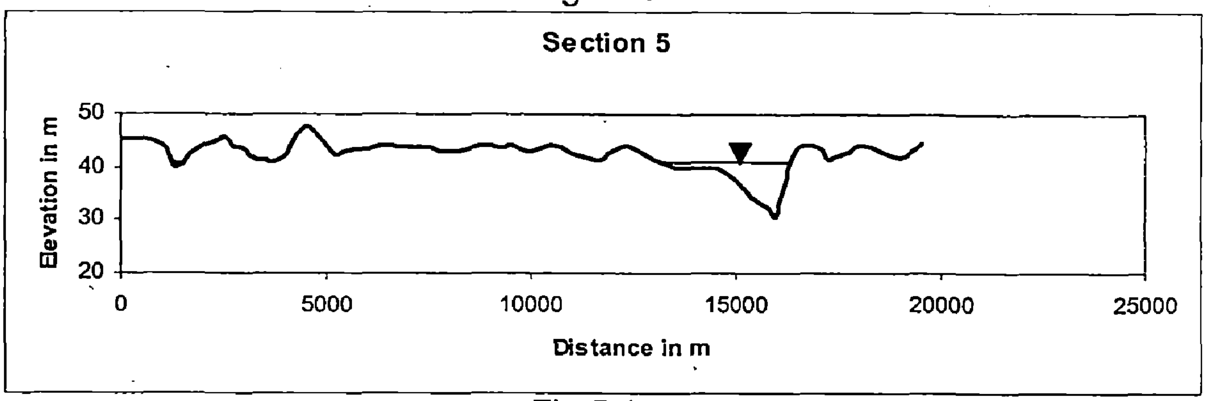


Fig.5.1e

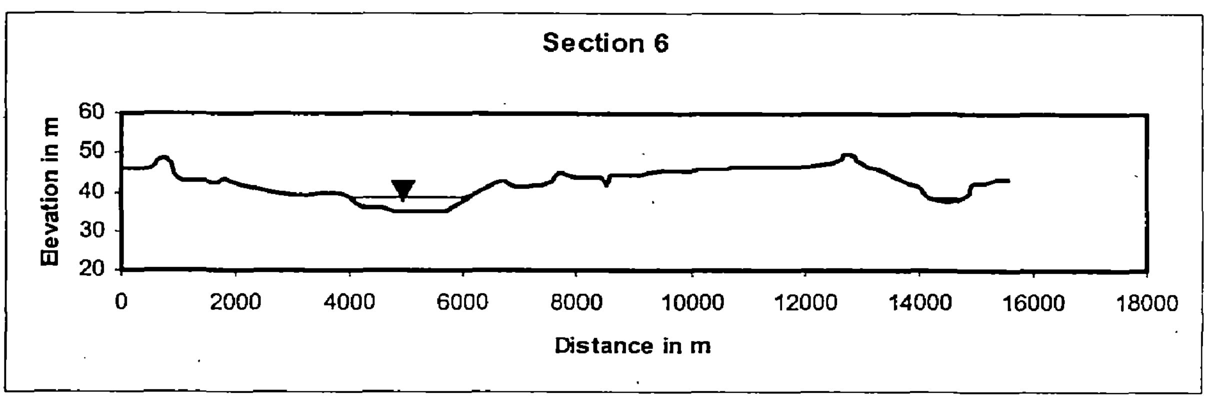


Fig.5.1f

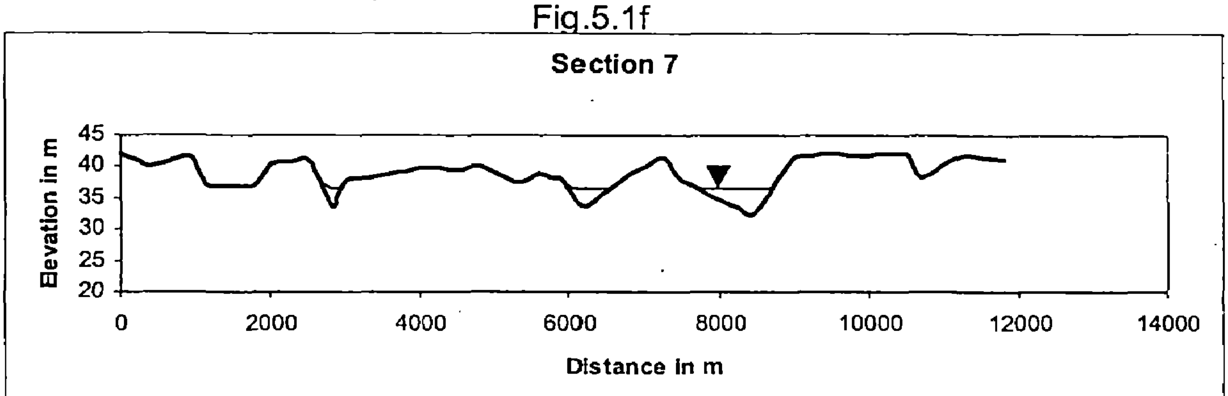


Fig.5.1g

continued

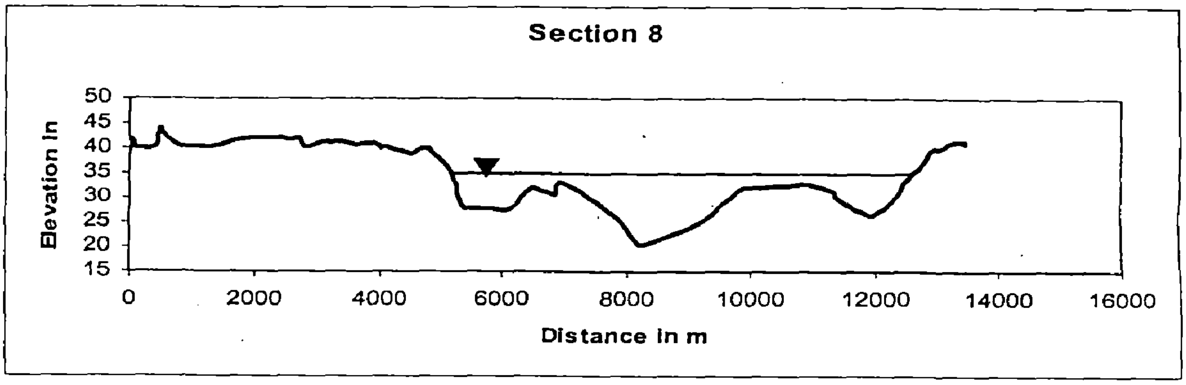


Fig.5.1h

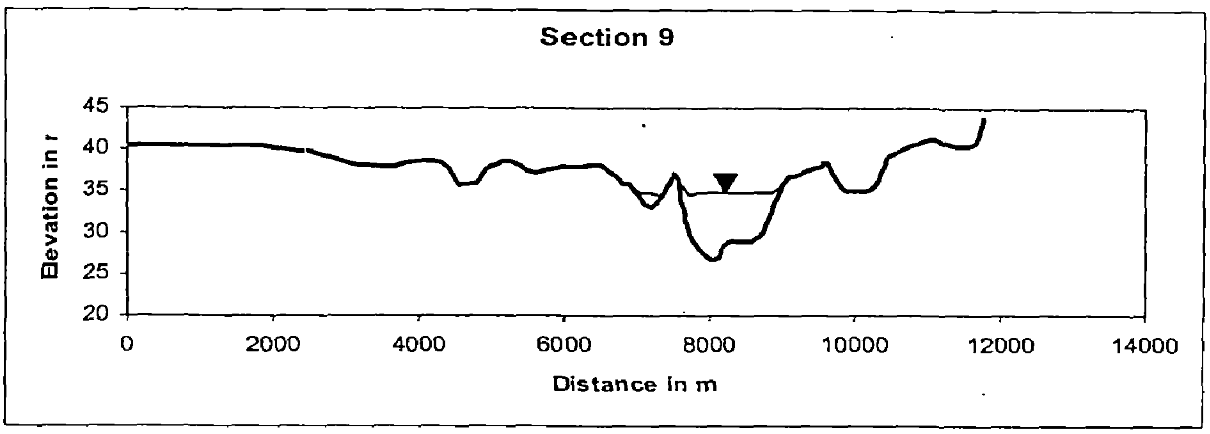


Fig.5.1i

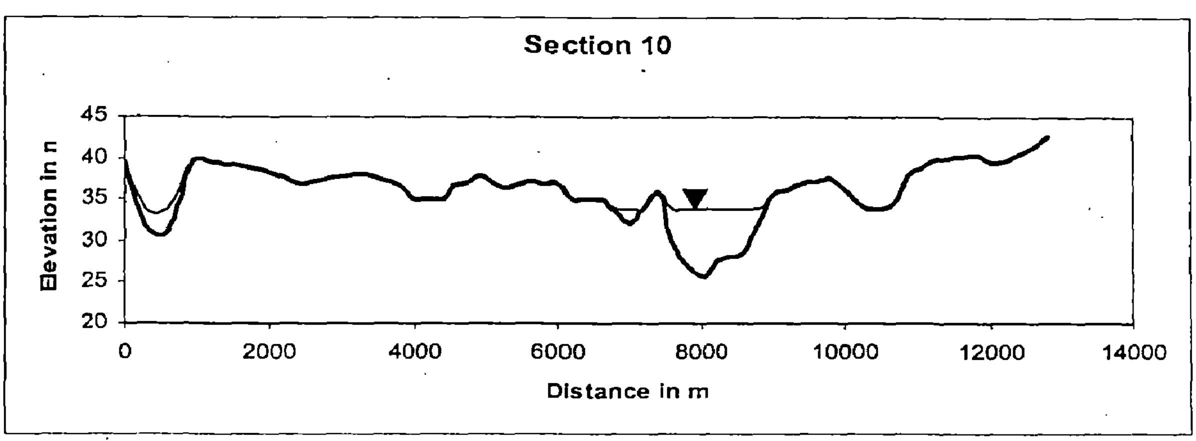


Fig.5.1j

continued

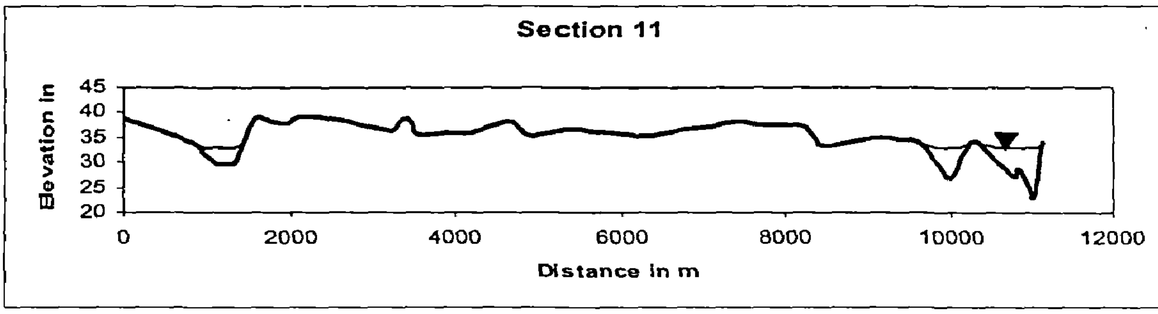


Fig.5.1k

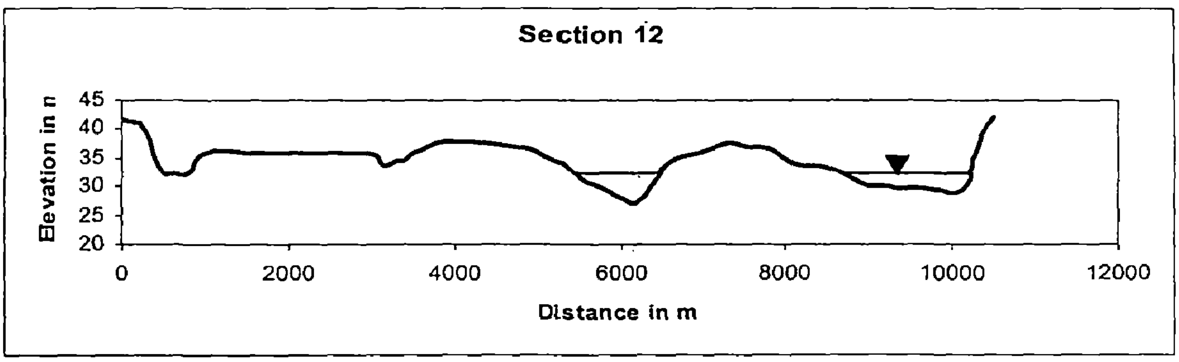


Fig.5.1l

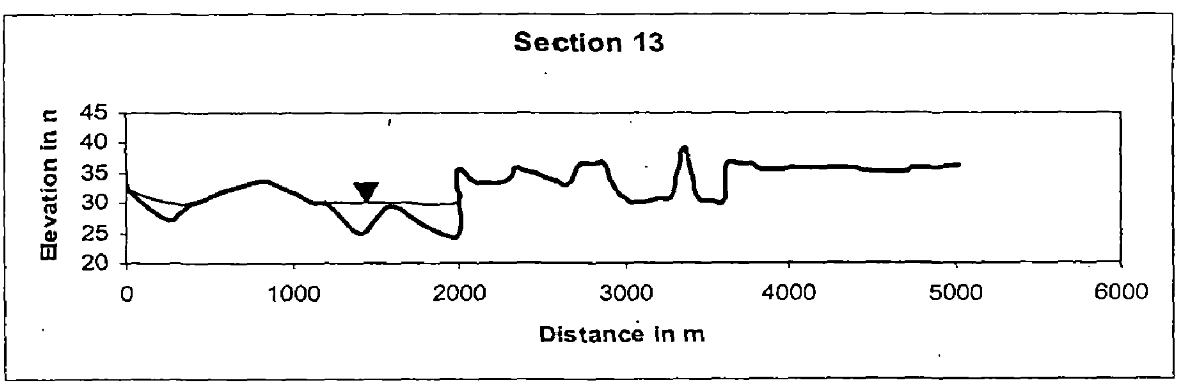


Fig.5.1m

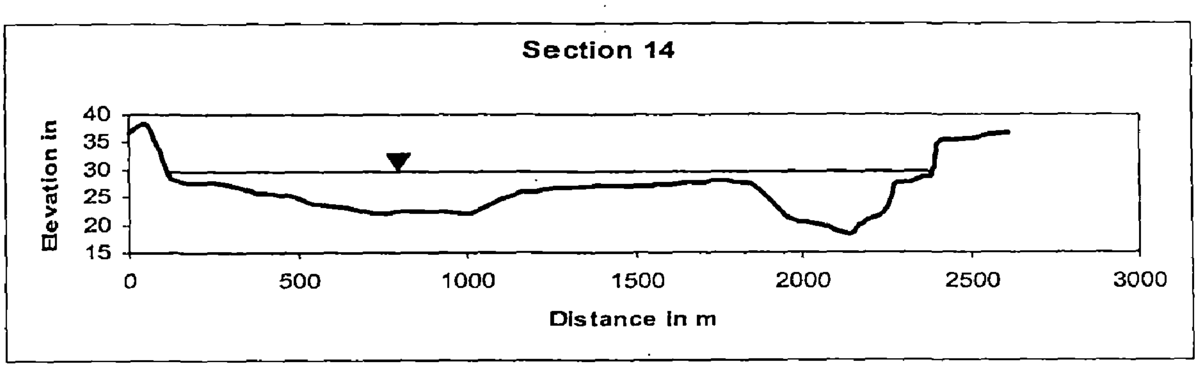


Fig.5.1n

The Last Section is at Jogighopa

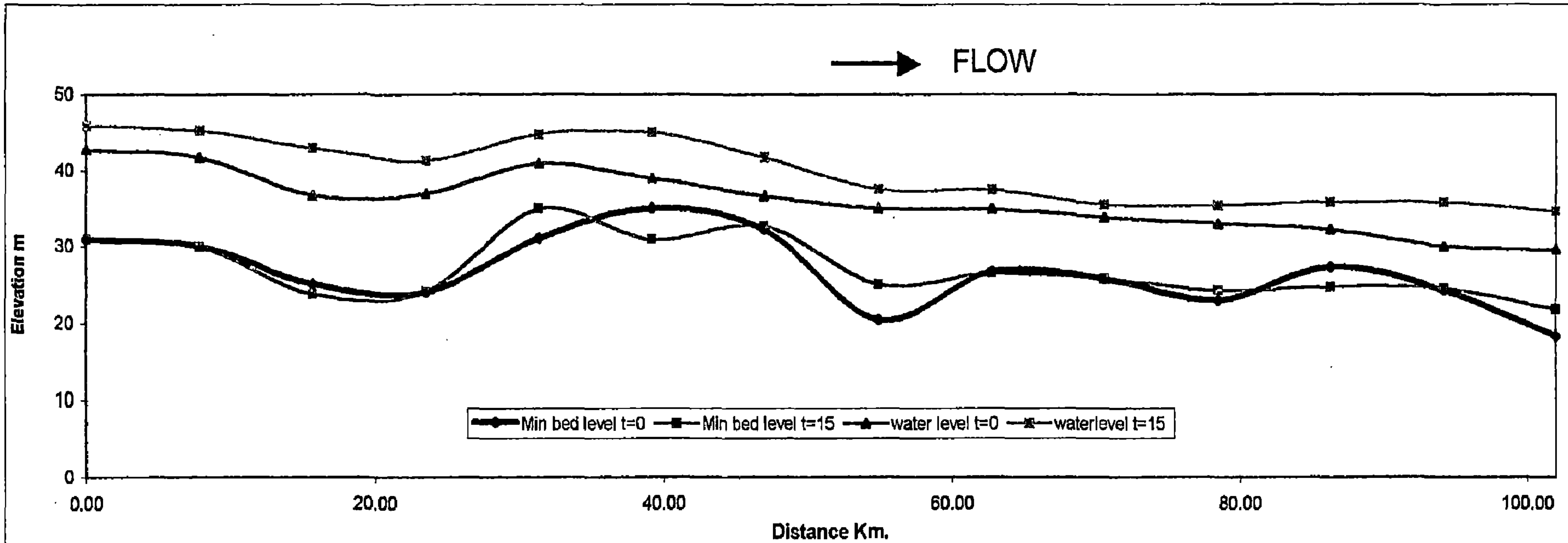


Fig.5.2 Longitudinal Section of River with Water Surface and Bed Levels

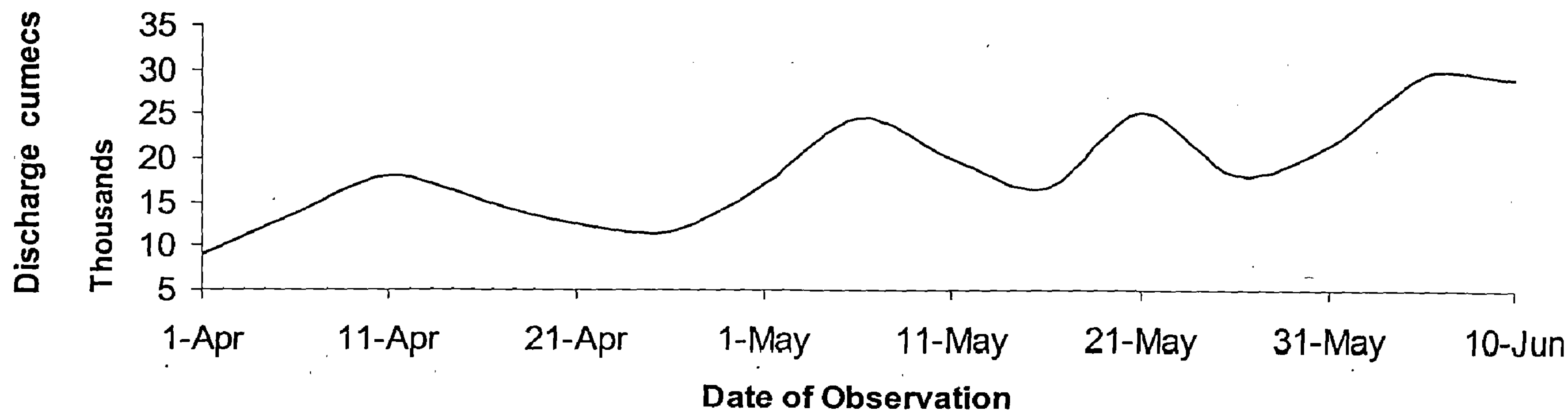


Fig 5.3 Observed Discharge at Pandu in 1977 from 1st April to 10th June Upstream boundary condition

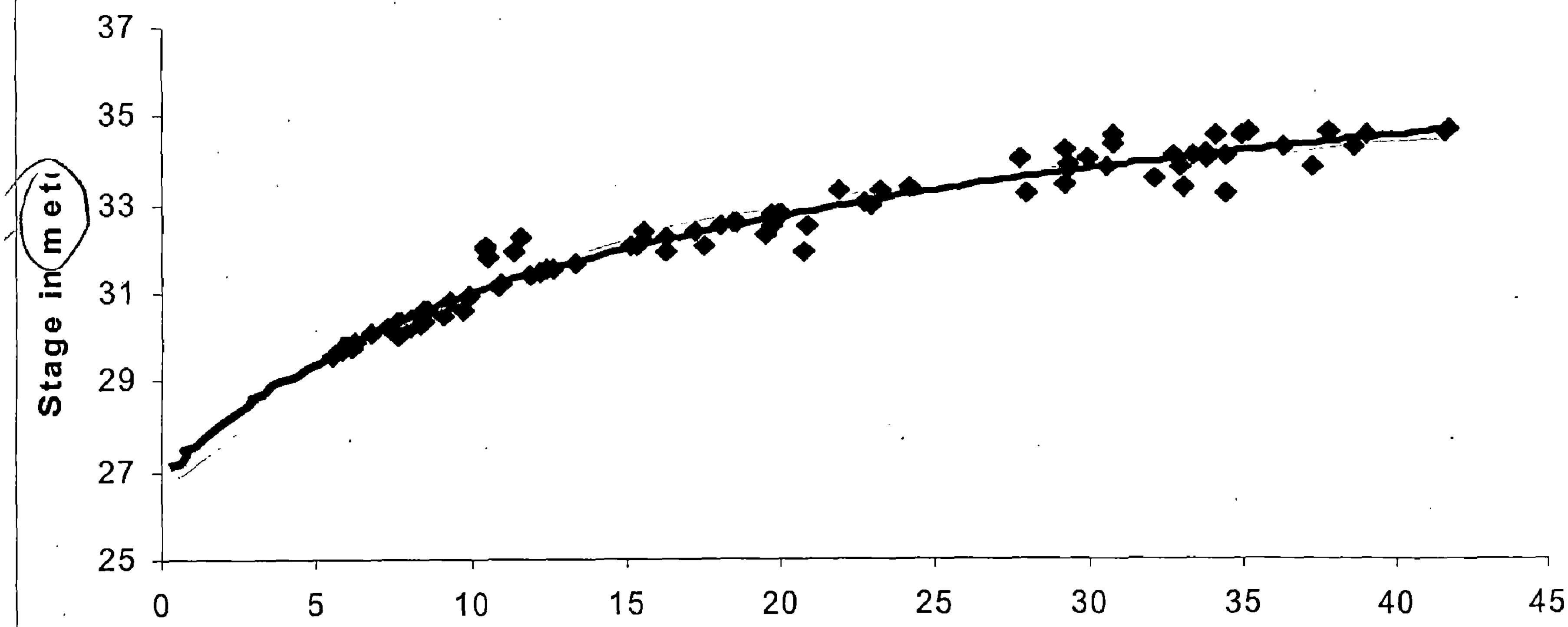


Fig 5.4 Discharge in Thousand Cumecs

Fig.5.4 Stage-Discharge Curve at Jogighopa d/s boundary condition

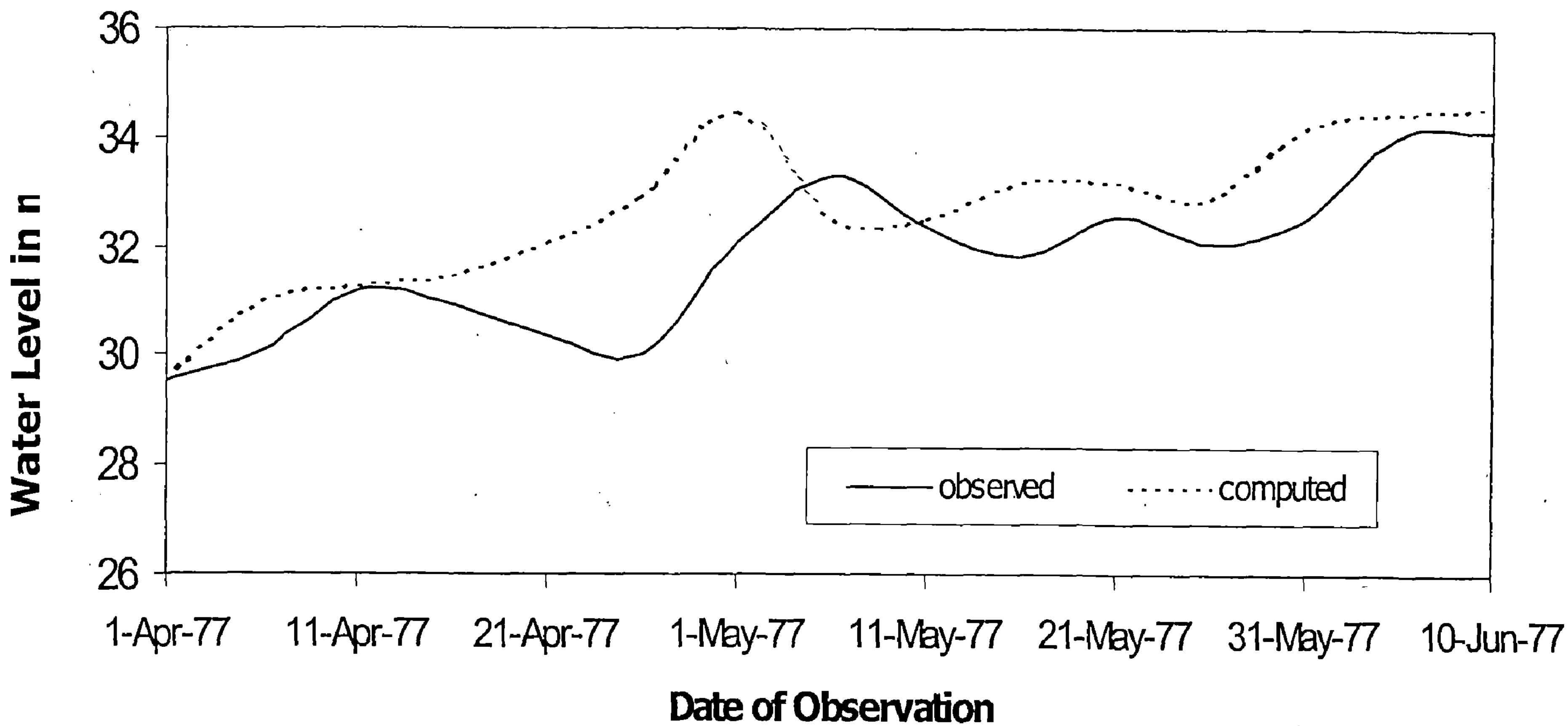


Fig. 5.5 Computed and Oserved stage at Jogighopa

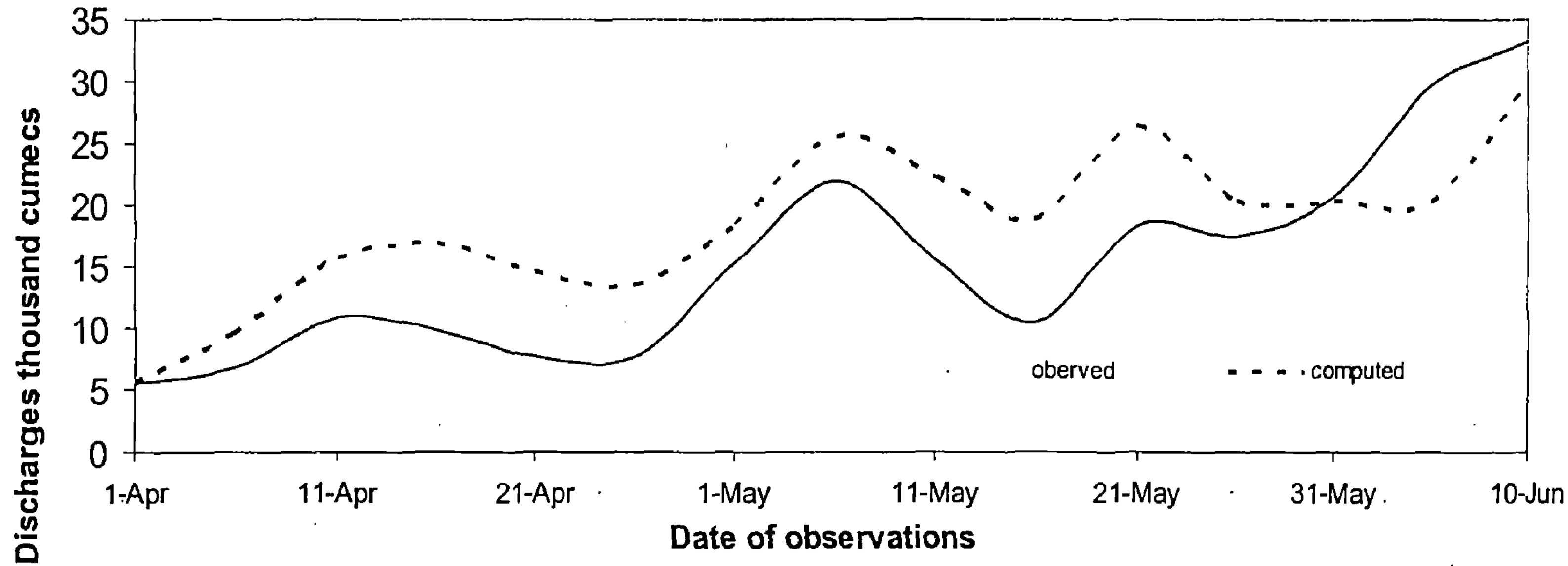


Fig 5.6 Observed and Computed Discharges at Jogighopa

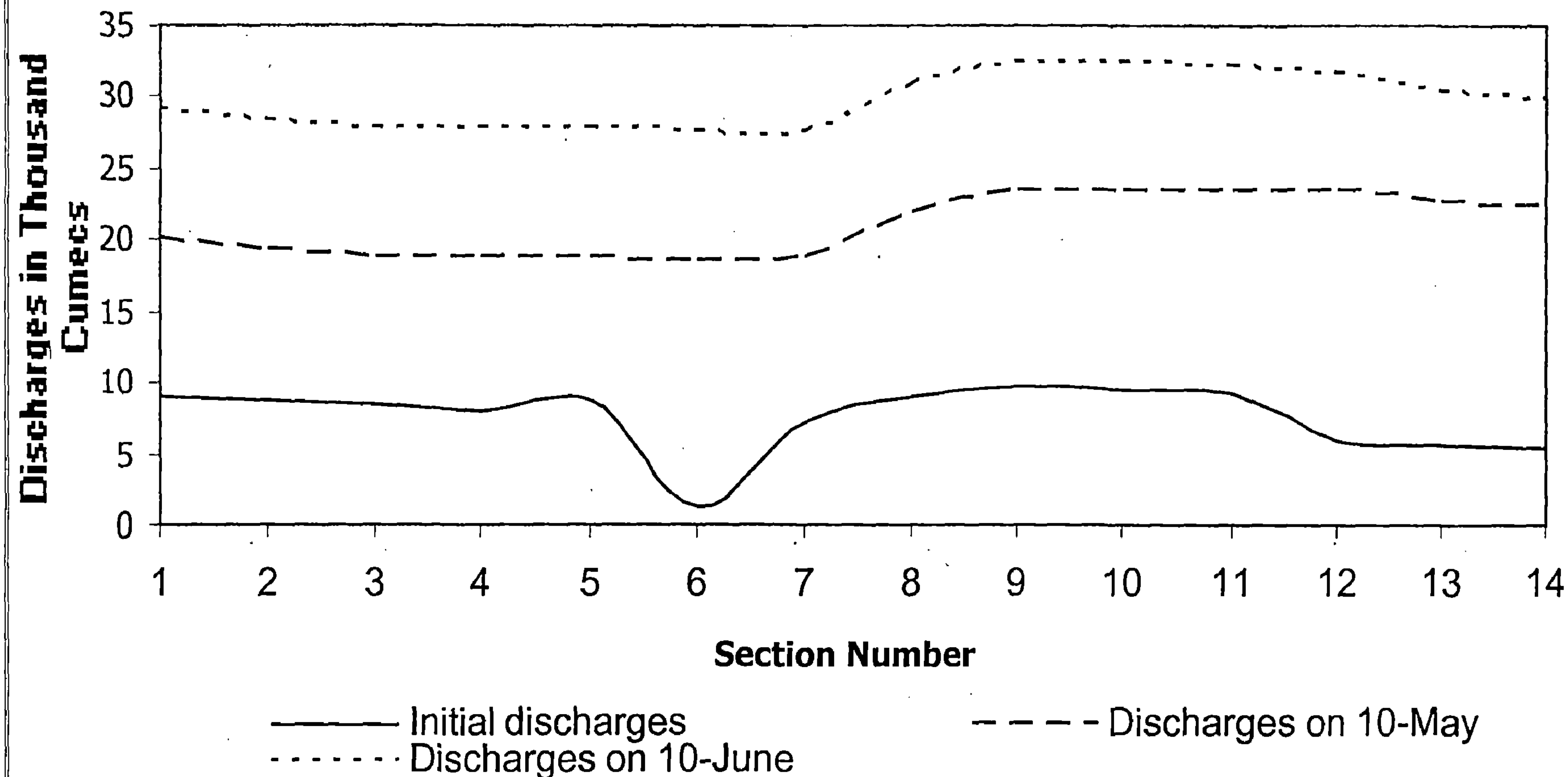


Fig 5.7 Simulated Discharges at all the sections from Pandu to Jogighopa on 10th May and 10 th June

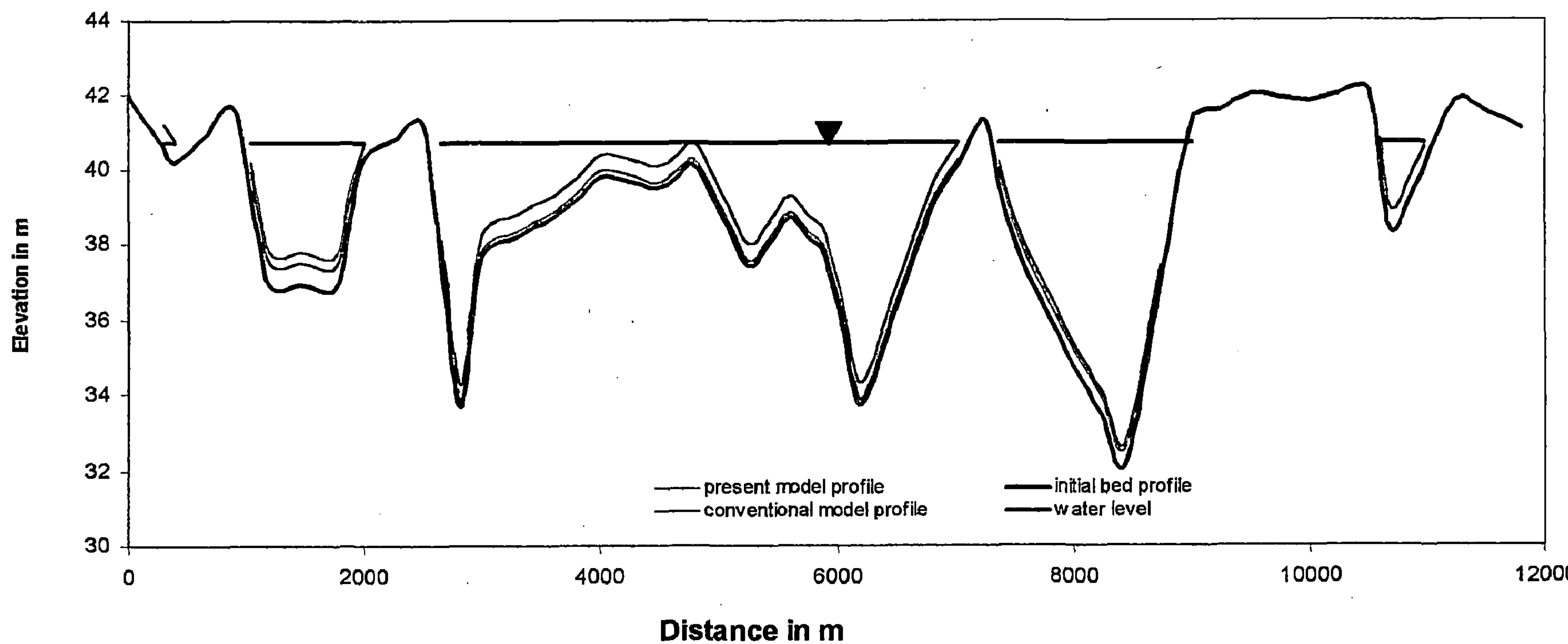
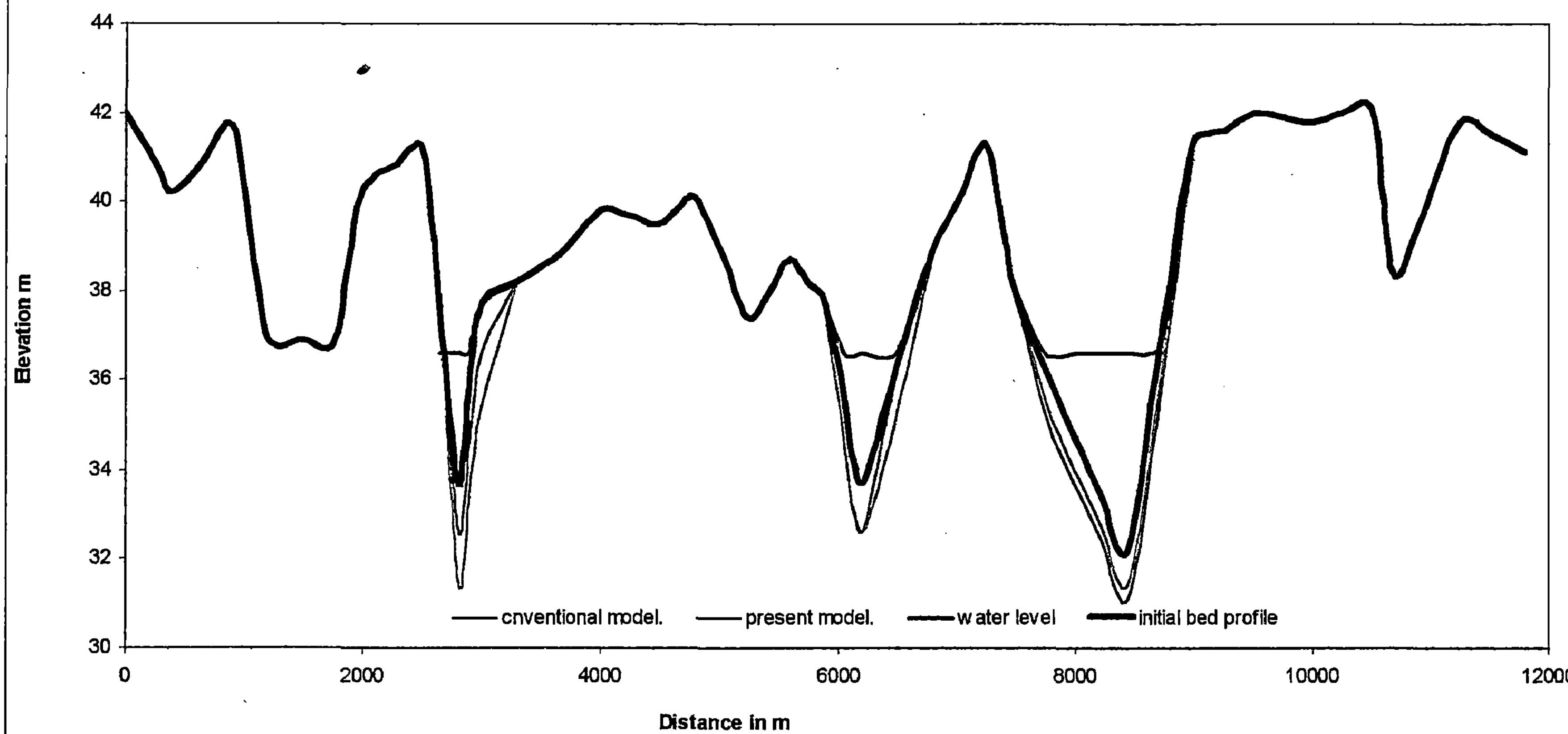


Fig 5.8 Aggraded Bed Profiles, Section 7, t=4



Fg 5.9 Comparison of Bed Degradation at Section 7,t=2

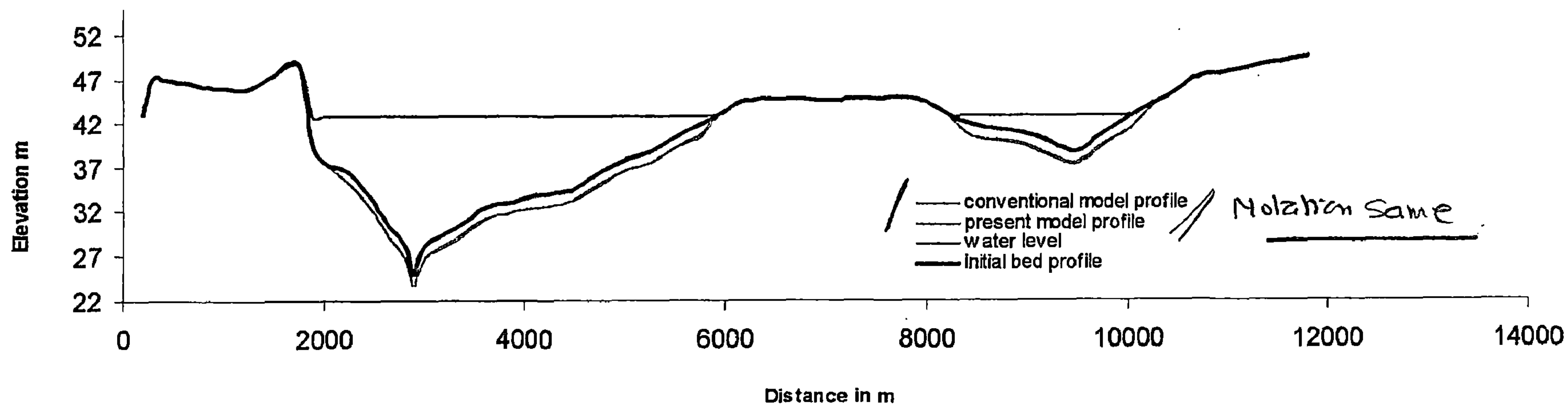


Fig.5.10 Degraded Bed Profile at section3, t=15

APPENDIX-3 SAMPLE OUTPUT OF THE SOFTWARE

****

MODBRAID-2002_ WRDTC_I.I.T. ROORKEE

For unsteady flow in stream of multi-channel configuration;

Model developed by B.K.Sinha,under the guidence of Dr.Nayan Sharma ,Professor,WRDTC,IIT Roorkee.

****

The length of the reach in meter = 102000.00

The total number of sections in the reach are

14

Distances between two consecutive sections from u/s in meter are

7846.15 7846.15 7846.15 7846.15 7846.15 7846.15
7846.15 7846.15 7846.15 7846.15 7846.15 7846.15
7846.15

The initial discharges at each sections in cumecs from u/s end

8887.00 8626.00 8366.00 8105.00 8685.00 1284.00
7324.00 9063.00 9803.00 9542.00 9282.00 6021.00
5761.00 5500.00

Discharge and stage at Jogighopa 1April-10June is

Discharge	Stage
5500.00	29.55
15331.71	31.00
15252.81	31.30
16870.87	31.50
14674.42	32.10
14606.33	32.90
20209.06	34.50
26805.43	32.50
20270.83	32.50
18340.37	33.20
27281.87	33.20
18363.65	32.90

18363.65	34.20
18363.65	34.00
23985.19	34.60

Discharge and stage on 10June at all points are

Discharge	Stage
28993.00	45.84
28472.22	45.20
28128.66	42.90
27963.68	41.26
26513.32	44.73
22247.30	44.96
20400.66	41.73
22058.72	37.67
21750.89	37.35
21663.03	35.50
22095.35	35.40
22956.25	35.80
23926.49	35.80
23985.19	34.60

APPENDIX-4 COMPUTER PROGRAM OF THE SOFTWARE

```
*********************************************************

c     Main program to call all the subroutines and do the
iterations

*********************************************************
       use mod_dec
       implicit none
      integer::i,t,j
      open(1,file='input3.dat',status='old')
      open(2,file='output')
      call read_input
c      Calculating the geometric properties at timestep
zero
      timestep =  0
       t = timestep+1
        call xsec_braid(t)

c       Sediment load function
       do i=1,nx-1
      call eng_hansen(i,t)
      enddo
      call coeff(t)
      wltemp(nx,t)=wl(nx,t)
      qintemp(nx,t)=qin(nx,t)
      call ds_boundary(t)
       call make_matrix(t)
      call solve_equation(t)
      do i=1,nx
      qin(i,t+1)=q(i,t+1)
       wl1(i,t+1)=zmin(i,t)+y(i,t+1)
      enddo
      do j=2,18
      do i=1,nx
      zmin(i,j)=zmin(i,1)
      enddo
      enddo
      t=2

      call xsec_braid(t)

      do i=1,nx-1
      call eng_hansen(i,t)
      enddo

      call sed_rout(t)
      call coeff(t)
      wltemp(nx,t)=wl(nx,t)
```

```
qintemp(nx,t)=qin(nx,t)
     call ds_boundary(t)
     call make_matrix(t)
     call solve_equation(t)
do i=1,nx
qin(i,t+1)=q(i,t+1)
wl(i,t+1)=zmin(i,t)+y(i,t+1)
enddo
 t=3
call xsec_braid(t)
do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call make_matrix(t)
 call solve_equation(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
  enddo
 t=4
call xsec_braid(t)
do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call make_matrix(t)
 call solve_equation(t)
 call sed_rout(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
  enddo

 t=5
 call xsec_braid(t)
 do i=1,nx-1
 call eng_hansen(i,t)
 enddo
  call coeff(t)
  wltemp(nx,t)=wl(nx,t)
  qintemp(nx,t)=qin(nx,t)
  call ds_boundary(t)
  call make_matrix(t)
  call solve_equation(t)
```

```
call sed_rout(t)
do i=1,nx
qin(i,t+1)=q(i,t+1)
wl1(i,t+1)=zmin(i,t)+y(i,t+1)
 enddo
t=6
call xsec_braid(t)
do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call make_matrix(t)
 call solve_equation(t)
 call sed_rout(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
  enddo
 t=7
call xsec_braid(t)
do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call make_matrix(t)
 call solve_equation(t)
 call sed_rout(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
  enddo
 t=8
call xsec_braid(t)
do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call make_matrix(t)
 call solve_equation(t)
 call sed_rout(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
```

```
   enddo
  t=9
 call xsec_braid(t)
 do i=1,nx-1
 call eng_hansen(i,t)
 enddo
  call coeff(t)
  qintemp(nx,t)=qin(nx,t)
  call ds_boundary(t)
  call make_matrix(t)
  call solve_equation(t)
  call sed_rout(t)
  do i=1,nx
  qin(i,t+1)=q(i,t+1)
  wl1(i,t+1)=zmin(i,t)+y(i,t+1)
   enddo
  t=10
 call xsec_braid(t)
 do i=1,nx-1
 call eng_hansen(i,t)
 enddo
  call coeff(t)
  wltemp(nx,t)=wl(nx,t)
  qintemp(nx,t)=qin(nx,t)
  call ds_boundary(t)
  call make_matrix(t)
  call solve_equation(t)
  call sed_rout(t)
  do i=1,nx
  qin(i,t+1)=q(i,t+1)
  wl1(i,t+1)=zmin(i,t)+y(i,t+1)
   enddo
  t=11
 call xsec_braid(t)
 do i=1,nx-1
 call eng_hansen(i,t)
 enddo
  call coeff(t)
  wltemp(nx,t)=wl(nx,t)
  qintemp(nx,t)=qin(nx,t)
  call ds_boundary(t)
  call make_matrix(t)
  call solve_equation(t)
  call sed_rout(t)
  do i=1,nx
  qin(i,t+1)=q(i,t+1)
  wl1(i,t+1)=zmin(i,t)+y(i,t+1)
   enddo
  t=12
 call xsec_braid(t)
 do i=1,nx-1
```

```
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call solve_equation(t)
 call sed_rout(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
  enddo
 t=13
call xsec_braid(t)
do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call solve_equation(t)
 call sed_rout(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
  enddo
 t=14
call xsec_braid(t)
do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
 qintemp(nx,t)=qin(nx,t)
 call ds_boundary(t)
 call make_matrix(t)
 call solve_equation(t)
 call sed_rout(t)
 do i=1,nx
 qin(i,t+1)=q(i,t+1)
 wl1(i,t+1)=zmin(i,t)+y(i,t+1)
  enddo
 t=15
call xsec_braid(t)

do i=1,nx-1
call eng_hansen(i,t)
enddo
 call coeff(t)
 wltemp(nx,t)=wl(nx,t)
```

```
       qintemp(nx,t)=qin(nx,t)
       call ds_boundary(t)
       call make_matrix(t)
       call solve_equation(t)
       call sed_rout(t)
       do i=1,nx
       qin(i,t+1)=q(i,t+1)
       wl1(i,t+1)=zmin(i,t)+y(i,t+1)
        enddo
       call modout1
        write(2,*)'Discharge and stage at Jogighopa
1April-10June is'
       write(2,*)
      write(2,*)'  Discharge    Stage'
        do i=1,15
       write(2,1000)qin(14,i),wl(14,i)
       enddo
 1000       format(1x,2f10.2)
      write(2,*)'Discharge and stage on 10June at all
points are'
      write(2,*)
      write(2,*)'  Discharge    Stage'
       do i=1,nx
       write(2,2000)qin(i,15),wl(i,15)
      enddo
 2000       format(1x,2f10.2)
      end

*********************************************************
c     SUBROUTINE FOR CALCULATING COEFFICIENTS
*********************************************************
       subroutine coeff(t)
      use mod_dec
      implicit none
      integer::t,i
      real,dimension(20,35)::cs1,cs2,cs3,cs4,ck1,ck2
      do i=1,nx-1

sf(i,t)=((.5*(qin(i,t)+qin(i+1,t)))**2)/(.5*(conv(i,t)+
      1conv(i+1,t))**2)
      c1(i,t)=0.25*(topwidth(i,t)+topwidth(i+1,t))
      c2(i,t)=c1(i,t)*(y(i,t)+y(i+1,t))+.5*dt*(ql(i)+ql(i+
1))
      cs1(i,t)=theta(i)*(v(i,t)+v(i,t))
      cs2(i,t)=theta(i)*(ro(i,t)*v(i,t)+ro(i+1,t)*v(i+1,t)
     cs3(i,t)=theta(i)*(ro(i,t)*(v(i,t)**2)*topwidth(i,t)+
      1ro(i+1,t)*(v(i+1,t)**2)*topwidth(i+1,t))
       cs4(i,t)=theta(i)*g*(area(i,t)+area(i+1,t))
      ck1=ro(i,t)*sf(i,t)*(5/3*topwidth(i,t)-
2/3*hradius(i,t)*dpy
      1 -area(i,t)/n(i)*dny(i,t))
```

```
7       ck2=ro(i+1,t)*sf(i+1,t)*(5/3*topwidth(i+1,t)-
2/3*hradius(i,t)*
      1 dpy-area(i+1,t)/n(i)*dny(i,t))
      c3(i,t)=ro(i,t)*(1-cs1(i,t)+g*dt*sf(i,t)/v(i,t))-
cs2(i,t)
  8
c4(i,t)=ro(i+1,t)*(1+cs1(i,t)+g*dt*sf(i+1,t)/v(i+1;t))+cs
2(i,t)
      c5(i,t)=cs3(i,t)-ro(i,t)*cs4(i,t)-g*dt*ck1(i,t)
      c6(i,t)=-cs3(i,t)+ro(i+1,t)*cs4(i,t)-g*dt*ck2(i,t)
      c7(i,t)=ro(i,t)*qin(i,t)+ro(i+1,t)*qin(i+1,t)
      1-cs1(i,t)*(ro(i+1,t)*qin(i+1,t)-ro(i,t)*qin(i,t))
      2    -cs2(i,t)*(qin(i+1,t)-qin(i,t))
      3 -cs3(i,t)*(y(i+1,t)-y(i,t))
      4 -cs4(i,t)*(ro(i+1,t)*y(i+1,t)-ro(i,t)*y(i,t))
      5
+g*theta(i)*(ro(i,t)*area(i,t)+ro(i+1,t)*area(i+1,t))
      6 *(zmin(i,t)-zmin(i+1,t))
      7-dt*(g*(ck1(i,t)*y(i,t)+ck2(i,t)*y(i+1,t))
      8-(ro(i,t)*v(i,t)**2+ro(i+1,t)*v(i+1,t)**2)*
      9(area(i+1,t)-area(i,t))/dx(i)
      1 -
.5*(ro(i,t)+ro(i+1,t))*(ql(i)*vl(i)+ql(i+1)*vl(i+1)))
      enddo
      return
      end

**********************************************************
c      Subroutine Engelund and Hansen    approach for
sediment discharge calculation
**********************************************************
       subroutine eng_hansen(i,t)
      use mod_dec
      implicit none

       integer::i,t
      real,dimension(30,35)::shear,f,phi_t,u,qt
      shear(i,t)=ro_w*g*.5*((hradius(i,t)+hradius(i+1,t))*
abs(slope(i,t)
      1))
      u(i,t)=sqrt(abs(shear(i,t)/ro_w))
      f(i,t)=8*(u(i,t)/v(i,t))**2
      phi_t(i,t)=0.4*(shear(i,t)/((spg-
1)*9810*.5*(d50(i)+d50(i+1))/1000
      1))**2.5/f(i,t)
c      qt is total load in N/m-sec
      qt(i,t)=phi_t(i,t)*spg*g*ro_w*sqrt(1.65*g*(d50(i)/10
00)**3)
```

```
c     qs is total load in cubic meter,1.49 is taken as
density of sediment in MKS
      qs(i,t) = qt(i,t)*topwidth(i,t)/(1.49*g*ro_w)
c     ro(i,t)=ro_w
c     ro(i,t)=ro_w*(1-qs(i,t))+qs(i,t)*1490
      ro(nx,t)= ro(nx-1,t)
      cs(i,t)=qs(i,t)/qin(i,t)
      cs(nx,t)=cs(nx-1,t)
      ro(i,t)=1000+cs(i,t)*(2650-1000)
      return
      end

*********************************************************
c     Subroutine to read or calculate downstream boundary
condition
*********************************************************
      subroutine ds_boundary(t)
c       assuming Q=alpha*y**beta  relation
C      c12Qn+c13Yn=C14
      use mod_dec
      implicit none
      integer::t
      c12(t)=1.0
c     c13(t)=-c12(t)*(wltemp(nx,t)-
zmin(nx,t))/(beta*qintemp(nx,t))
c     c14(t)=qintemp(nx,t)+c13(t)*(wltemp(nx,t)-
zmin(nx,t))
      c13(t)= -10000
      c14(t)=-296140
      return
      end

*******************************************************
c     Subroutine to construct matrix of coefficients
*******************************************************
       subroutine make_matrix(t)
      use mod_dec
      implicit none
      integer::t,i,j,m,k
      do i=1,nn
      do j=1,nn
      A(i,j)=0.0
      enddo
      enddo
      A(1,1)=c9(t)
      A(1,2)=c10(t)
      A(nn,nn-1)=c12(t)
      A(nn,nn)=c13(t)
      do i=1,nx-1
       m=2*i
       A(m,m-1)=-theta(t)
```

```
       A(m,m)  =c1(i,t)
       A(m,m+1)= theta(t)
       A(m,m+2)=c1(i,t)
        k=2*i+1
        A(k,k-2)=c3(i,t)
        A(k,k-1)=c5(i,t)
        A(k,k)  =c4(i,t)
        A(k,k+1)=c6(i,t)
        enddo
C       Construction of row  vector  R
      R(1,1)=c11(t)
      R(nn,1)=c14(t)
      do i=1,nx-1
       m=2*i
      R(m,1)=c2(i,t)
      R(m+1,1)=c7(i,t)
      enddo
        return
        end
**************************************************
C          M  O  D  U  L  E

**************************************************
      module mod_dec
      implicit none
      save
      integer::nc,nx,timestep,nn,ITE
      integer,parameter::maxrow=19,maxcol=19
      real,dimension(maxrow)::theta,dx,n,ql,vl,d84,qw,qls,
d84mm
      1,d50,c9,c10,c11,c12,c13,c14
      real::spg,dt,totalt,ro_w,g,reachlen,dpy,alpha,beta
      real,dimension(maxrow,maxcol)::wl,area,perimeter,top
width,totalwid
      1th,hradius,qin,sdmt,sf,ro,v,conv,zmin,c1,c2,c3,eqd,
eqwidth,zmean,
      2c4,c5,c6,c7,dsq,q,d,wltemp,qintemp,y,
      3dsy,dny,dry,cn,qs,cs,dad,slope,wl1
            real,dimension(2*maxrow,2*maxcol)::A
      real,dimension(2*maxrow,1)::R,X
      real,dimension(19,58)::xx, zz

real,dimension(19,19,19)::cy,czmean,carea,cperimeter,ctop
width

       end module mod_dec
```

```
*************************************************************
c                       Subprogram for output of MODBRAID
*************************************************************
subroutine modout(t)
     use mod_dec
     implicit none
     integer::i,t
     write(2,'(///1x,a,i3,a)')'The followings are the
detailed output at t
     1imestep= [',timestep,']  from the begining of flood
hydrogaph'
      write(2,1)
   1  format(//1x,'The water level in meter at various
setions are')
       write(2,2)(wl(i,t),i=1,nx)
   2  format(//1x,50f10.2)
     write(2,3)
   3   format(//1x,'The discharges in cumecs at the cross
sections in t
     1he order from u/s to d/s are')
      write(2,4)(qin(i,t),i=1,nx)
   4  format(//1x,50f10.2)
          write(2,5)
   5 format(//1x,'The average depth of flow in meters at
various sectio
     1 ns in the above order are')
       write(2,6)(y(i,t),i=1,nx)
   6  format(//1x,50f8.2)
     write(2,7)
   7  format(1x,'The average slope between two sections
are')
     write(2,8)(slope(i,t),i=1,nx-1)
   8   format(//1x,50E15.4)
     write(2,9)
   9 format(//1x,'The average depth of flow in meters at
various sectio
     1ns in the above order are')
       write(2,10)(y(i,t),i=1,nx)
   10       format(//1x,50f8.2)
c      write(2,11)
c   11      format(//1x,'The discharge in cubic meters per
sec at various sect
c      1ions in the above order are')
c        write(2,12)(q(i,t),i=1,nx)
c   12       format(//1x,50f8.2)
     return
      end
*************************************************************
C     Subroutine to give output at the initial stage
(first time only)
*************************************************************
```

```
      subroutine modout1
      use mod_dec
      implicit none
       integer::i
           write(2,3)
  3
format(1x,'**********************************************
*******
     1****************')
      write(2,31)
 31   format(//1x,'MODBRAID-2002_ WRDTC_I.I.T. ROORKEE ')
           write(2,32)
 32   format(/1x,'For unsteady flow in stream of multi-
channel configur
     1ation;')
      write(2,34)
 34  format(/1x,'Model developed by B.K.Sinha,under the
guidence of Dr.
     1Nayan Sharma ,Professor,WRDTC,IIT Roorkee.')

       write(2,33)
 33
format(//1x,'******************************************
*********
     1*****************')
          write(2,1)reachlen

  1    format(//1x,'The length of the reach in meter
=',f10.2)
c    write(2,2)
c  2  format(1x,f10.2)
     write(2,13)
  13  format(/1x,'The total number of sections in the
reach are')
     write(2,4)nx
  4   format(/1x,i3)
     write(2,5)
  5  format(/1x,'Distances between two consecutive
sections from u/s in
     1 meter are')
     write(2,6)(dx(i),i=1,nx-1)
  6   format(/1x,50F10.2)
     write(2,9)
  9   format(/1x,'The initial discharges at each sections
in cumecs fro
     1m u/s end')
     write(2,10)(qin(i,1),i=1,nx)
  10  format(//1x,50f10.2)
     write(2,*)
     write(2,*)
     return
```

```
      end


*********************************************************
c     Subroutine to read the input data of the stream
*********************************************************
      subroutine read_input
      use mod_dec
      implicit none
c      character:: yn*1
       integer::i,j,tt
       dpy=2.0
c      Enter lenth of stream reach 'reachlen' in meter.
    1       read(1,*) reachlen
c      Enter number of cross sections 'nx' including start
and end point.
    2       read(1,*) nx
        nn=2*nx
c      Enter distances between two cross sections'nx' in
meter
c      write(*,'(1x,a\)')'Are distances between all cross
sections equal
c     1?(y/n)........'

c      read(*,'(a1)') yn
c      if (yn.eq.'y')then
      do i=1,nx
      dx(i)=reachlen/real(nx-1)
      enddo
c     else
c     read(1,*)(dx(i),i=1,nx-1)
c     endif
c      Enter total number of subsections for each cross
section.
    3       read(1,*) nc
      if(nx.ge.50) stop 'Number of sections should not be
more than 49'
      if(nc.ge.100) stop 'Number of subsections should not
be more than
      1 99 '
c      Enter the initial discharge at all cross sections.
    4       read(1,*)(qin(i,1),i=1,nx)
c      Enter the initial water level'stage' at each cross
section
    5       read(1,*)(wl(i,1),i=1,nx)
c      Enter the distances of subsections at every section
row wise.
    6       read(1,*)((xx(i,j),j=1,nc),i=1,nx)
c      Enter the bed level in the order of distance.
    7  read(1,*)((zz(i,j),j=1,nc),i=1,nx)
```

```
c      Enter the initial sediment concentration in ppm.
c        read(1,*)(sdmt(i,1),i=1,nx)
c      Enter the value of Mannings coefficients at all
section
    8   read(1,*)(n(i),i=1,nx)
c      Enter d50 in mm
    9      read(1,*)(d50(i),i=1,nx)
c      Enter d84 in milimeter
c      write(*,*) 'Is Mannings n to be taken
constant?(y/n).....'
c     read(*,*)yn
c      if(yn.eq.'y') then
c*    do i=1,nx
c*     do j=1,50
c*    dny(i,j)=0.0
c*      enddo
c*    enddo
c     else
c    10      read(1,*)(d84mm(i),i=1,nx)
c      do i=1,nx
c      d84(i)=d84mm(i)/1000
c      enddo
c     endif
c       Enter the lateral water inflow in cubic meter per
meter
c       write(*,*)'Is lateral inflow of water
zero?(y/n)....'
c      read(*,*)yn
c      if(yn.eq.'y') then
       do i=1,nx-1
       ql(i)=0.0
       vl(i)=0.0
       enddo
c      else
c    11      read(1,*)(qw(i),i=1,nx-1)
c    12      read(1,*)(vl(i),i=1,nx-1)
c
c      write(*,*)'Is lateral inflow of sediment
zero?(y/n)....'
c      read(*,*) yn
c      if(yn.eq.'y') then
       do i=1,nx
       qls(i)=0.0
       enddo
cc     else
c      read(1,*)(qls(i),i=1,nx-1)
c      endif
c      do i=1,nx
c      ql(i)=qw(i)+qls(i)
```

```
c     enddo
c     endif
c     Enter total time totalt in hours
   13       read(1,*) totalt
c      Enter the total timesteps(should be an iteger less
than 25)
   14        read(1,*) tt
     dt= totalt*3600/tt

c    Enter the upstream boundry
condition(C9q1+C10y1=C11)or discharge hydrograph type
   15       read(1,*)(c11(i),i=1,tt+1)
      do i=1,tt+1
     c10(i)=0.0
     c9(i)=1.0
     enddo
c     Enter the d/s boundry condition stage discharge
curve
c       C12qn+C13yn=c14
   16       read(1,*) alpha
   17       read(1,*) beta

     ro_w=1000
     g=9.81
     spg=2.65
     do i=1,nx
     theta(i)=dt/dx(i)
     enddo
     return
     end

********************************************************
**
c     Subroutine for routing sediment by explicit method
********************************************************
**
      subroutine sed_rout(t)
     use mod_dec
     implicit none
     integer::i,t
     real,dimension(20,35)::part1,part2,part3
     real::porosity
     porosity=0.6
c     For u/s boundry point
     if (i.eq.1)then
     dad(i,t)=.5*(dt*.5*(qls(i)+qls(i+1)+qls(i)+qls(i+1))
-
     1(area(1,t+1)*cs(1,t+1)-
area(1,t)*cs(1,t)+area(2,t)*cs(2,t))-
     2theta(1)*(qs(2,t)-qs(1,t)+qs(2,t+1)-
qs(1,t+1)))/porosity
```

```
      endif

c      For interior points
      doi=2,nx-1
      part1(i,t)=.5*(qls(i-1)+2*qls(i)+qls(i-1)+2*qls(i)+
      1qls(i)+qls(i+1))
      part2(i,t)=2*area(i,t+1)*cs(i,t+1)-
2*area(i,t)*cs(i,t)+
      1area(i-1,t+1)*cs(i-1,t+1)-area(i-1,t)*cs(i-
1,t)+area(i+1,t+1)*
      2cs(i+1,t+1)-area(i+1,t)*cs(i+1,t)
      part3(i,t)=qs(i+1,t)-qs(i-1,t)+qs(i+1,t+1)-qs(i-
1,t+1)
       dad(i,t)=.25*(dt*part1(i,t)-part2(i,t)-
theta(i)*part3(i,t))/
      1porosity
      enddo
c      At the d/s boundry
        if(i.eq.nx)then
      dad(i,t)=.5*(dt*.5*(qls(nx-1)+qls(nx)+qls(nx-1)+
      1qls(nx))-area(nx-1,t+1)*cs(nx-1,t+1)+area(nx-1,t)*
      2cs(nx-1,t)+area(nx,t+1)*cs(nx,t+1)-
area(nx,t)*cs(nx,t))
      3-theta(nx)*(qs(nx,t)-qs(nx-1,t)+qs(nx,t+1)-qs(nx-
1,t+1))/
      4porosity
      endif
      return
      end


*********************************************************
c      Subroutine for routing sediment by explicit method
*********************************************************
       subroutine sed_rout(t)
      use mod_dec
      implicit none
      integer::i,t
      real,dimension(20,35)::part1,part2,part3
      real::porosity
      porosity=0.6
c      For u/s boundry point
      if (i.eq.1)then
      dad(i,t)=.5*(dt*.5*(qls(i)+qls(i+1)+qls(i)+qls(i+1))
-
      1(area(1,t+1)*cs(1,t+1)-
area(1,t)*cs(1,t)+area(2,t)*cs(2,t))-
      2theta(1)*(qs(2,t)-qs(1,t)+qs(2,t+1)-
qs(1,t+1)))/porosity
      endif
```

```
c      For interior points
      doi=2,nx-1
      part1(i,t)=.5*(qls(i-1)+2*qls(i)+qls(i-1)+2*qls(i)+
      1qls(i)+qls(i+1))
      part2(i,t)=2*area(i,t+1)*cs(i,t+1)-
2*area(i,t)*cs(i,t)+
      1area(i-1,t+1)*cs(i-1,t+1)-area(i-1,t)*cs(i-
1,t)+area(i+1,t+1)*
      2cs(i+1,t+1)-area(i+1,t)*cs(i+1,t)
      part3(i,t)=qs(i+1,t)-qs(i-1,t)+qs(i+1,t+1)-qs(i-
1,t+1)
       dad(i,t)=.25*(dt*part1(i,t)-part2(i,t)-
theta(i)*part3(i,t))/
      1porosity
      enddo
c      At the d/s boundry
        if(i.eq.nx)then
      dad(i,t)=.5*(dt*.5*(qls(nx-1)+qls(nx)+qls(nx-1)+
      1qls(nx))-area(nx-1,t+1)*cs(nx-1,t+1)+area(nx-1,t)*
      2cs(nx-1,t)+area(nx,t+1)*cs(nx,t+1)-
area(nx,t)*cs(nx,t))
      3-theta(nx)*(qs(nx,t)-qs(nx-1,t)+qs(nx,t+1)-qs(nx-
1,t+1))/
      4porosity
      endif
      return
      end

*********************************************************
c      Subroutine to solve equqtions Gauss-Jordon method
*********************************************************
      subroutine solve_equation(t)
      use mod_dec
      implicit none
      integer::t,k,i,j
      real::aa(nn,nn+1),temp


      do i=1,nn
      do j=1,nn
      aa(i,j)=A(i,j)
      enddo
      aa(i,nn+1)=R(i,1)
      enddo
      do k=1,nn
       temp = aa(k,k)
      if(temp.eq.0) stop 'Pivot element becomes zero'
      do j=k,nn+1
      aa(k,j)=aa(k,j)/temp
      enddo
      do i=1,nn
```

```
      if(i.ne.k) then
       temp=aa(i,k)
      do j=k,nn+1
      aa(i,j)=aa(i,j)-temp*aa(k,j)
      enddo
      endif
      enddo
      enddo
      do i=1,nn
      q(i,t+1)= aa(2*i-1,nn+1)
      y(i,t+1)= aa(2*i,nn+1)
      enddo
      return
      end

**********************************************************
c        Subroutine xsec calculation
**********************************************************
      subroutine xsec(i,bn,kitemp,ktemp,dav,t)
       use mod_dec
       implicit none
      integer::i,k,bn,kitemp,ktemp,t,m

      real:: ztemp, z1,z2,x1,x2,wl1(50),suma,sump,sumt,
      1 da,daa,dpp
      real::dav(50,50),depthtotal(50,50),czmin(50,50)
           suma=0
        sump=0
        sumt=0
       czmean(i,bn,t)=0
      depthtotal(i,bn)=0
       do 10 k=kitemp+1,ktemp
        ztemp = zz(i,k-1)
       if(ztemp.gt.zz(i,k)) then
       ztemp=zz(i,k)
       else
      czmin(i,bn)=ztemp
      endif
      cy(i,bn,t)=wl(i,t)-czmin(i,bn)
      depthtotal(i,bn)=depthtotal(i,bn)+(wl(i,t)-zz(i,k))
      dav(i,bn)=depthtotal(i,bn)/(ktemp-kitemp-2)

c      calculation of geometrical properties
      z1=zz(i,k-1)
      x1=xx(i,k-1)
      z2=zz(i,k)
      x2=xx(i,k)
      wl1(t)=wl(i,t)
      if(z2.gt.wl1(t).and.z1.gt.wl1(t)) then
      goto 10
      endif
```

```
      if(z2.lt.wll(t).and.z1.gt.wll(t)) then
      x1=x1+(x2-x1)/(z2-z1)*(wll(t)-z1)
       z1=wll(t)
      endif
      if(z2.gt.wll(t).and.z1.lt.wll(t)) then
      x2=x1+(x2-x1)/(z2-z1)*(wll(t)-z1)
      z2=wll(t)
      endif
      da=abs(2*wll(t)-z2-z1)/2
      daa=da*(x2-x1)
c      calculating perimeter, hradius,etc.
      dpp = sqrt((x2-x1)**2+(z2-z1)**2)
      sumt=sumt+(x2-x1)
      suma=suma+daa
      sump=sump+dpp
10      continue
      carea(i,bn,t)=suma
      cperimeter(i,bn,t)=sump
      ctopwidth(i,bn,t)=sumt
c      calculation of czmean
      do m=kitemp,ktemp
      czmean(i,bn,t)=czmean(i,bn,t)+zz(i,m)/(ktemp-
kitemp+1)
      enddo
      return
      end
*********************************************************
c      subroutine to  calculate cross sectional properties
of braided river
*********************************************************
      subroutine xsec_braid(t)
      use mod_dec
      implicit none
      integer::t,i,bn,kitemp,ktemp,j,k,m,u
      real::xmin,xmax,z1,z2,x1,x2,wll(50)
      real::dav(50,50)
c      Initialisation of channel braid number matrix

c      Calculation of xsectional properties
      do u=1,nx
      zmin(u,t)=zz(u,1)
      do j=2,nc
      if (zz(u,j).le.zmin(u,t)) then
      zmin(u,t)=zz(u,j)

      endif
      enddo
       enddo
      do i=1,nx
      y(i,t)=wl(i,t)-zmin(i,t)
      enddo
```

```
      do i=1,nx
       cn(i,t)=0

c       calculation of braid number
      do 10 j=2,nc
      z1=zz(i,j-1)
      z2=zz(i,j)
      x1=xx(i,j-1)
      x2=xx(i,j)

      wl1(t)=wl(i,t)
      if(z2.gt.wl1(t).and.z1.gt.wl1(t))then
      goto 10
      endif
      if(z2.lt.wl1(t).and.z1.ge.wl1(t)) then
      kitemp=j-1
      endif
      if(z2.ge.wl1(t).and.z1.lt.wl1(t)) then
      cn(i,t)=cn(i,t)+1
      bn=cn(i,t)
      ktemp=j
      if(bn.eq.1) then
      xmin=xx(i,kitemp)
      endif
      xmax=xx(i,j-1)
      if(xmax.lt.xx(i,j)) then
      xmax=xx(i,j)
      endif
      call xsec(i,bn,kitemp,ktemp,dav,t)
      endif
   10  continue
      totalwidth(i,t)=xmax-xmin
c     eqd(i,t)=0
c     eqwidth(i,t)=0
       area(i,t)=0
      perimeter(i,t)=0
      topwidth(i,t)=0
      zmean(i,t)=0
      do k=1,bn
c      eqd(i,t)=
eqd(i,t)+(carea(i,bn)*dav(i,bn)**(5/3))/(carea(i,bn)*
c     1dav(i,bn)**(2/3))
c
eqwidth(i,t)=eqwidth(i,t)+(carea(i,bn)*dav(i,bn)**(2/3))/
c     1(eqd(i,t)**(5/3))
c      Calculation of sectional properties of braided
river
       area(i,t)=area(i,t)+carea(i,bn,t)
      perimeter(i,t)=perimeter(i,t)+cperimeter(i,k,t)
      topwidth(i,t)=topwidth(i,t)+ctopwidth(i,k,t)
      zmean(i,t)=zmean(i,t)+czmean(i,k,t)/bn
```

```
      enddo
c      calculation of mean slope
        do m =1,nx-1
      slope(m,t)=(zmean(m,t)-zmean(m+1,t))/dx(m)
      enddo

      hradius(i,t)=area(i,t)/perimeter(i,t)
      conv(i,t)= area(i,t)*hradius(i,t)**(2/3)/n(i)

dry(i,t)=topwidth(i,t)**2/(topwidth(i,t)+2*y(i,t))**2
c     dny(i,t)=n(i)*1/hradius(i,t)*dry(i,t)*(1/6-
1/(1.335+2.3026*
c     1 LOG10((hradius(i,t)/d84(i)))))
      dny(i,t)=3.0E-04
       v(i,t)=qin(i,t)/area(i,t)
       enddo
      return
  end
```

****