THESIS

EFFECT OF WITHDRAWAL OF UPLAND DISCHARGE ON SALINITY INTRUSION IN GORAI-MADHUMATI-SIBSA-PUSSUR RIVER SYSTEM

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED BY SALEH AHMED WASIMI ENTITLED "EFFECT OF WITHDRAWAL OF UPLAND DISCHARGE ON SALINITY INTRUSION IN GORAI-MADHUMATI-SIBSA-PUSSUR RIVER SYSTEM" BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENGINEERING (WATER RESOURCES)

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ABSTRACT

The purpose of this study has been to assess salinity conditions and its movement in Pussur and Sibsa rivers. Salinity distributation in these rivers in time and space is primarily a function of seawater salinity, tide and upland freshwater discharge. With no remarkable variation in seawater salinity and tide from year to year attention has been focussed mainly on changes is salinity distribution due to variations in upland freshwater discharge.

The methodology included analysis of field data for presentation of an overall picture of salinity conditions and its trend of movement in the delta. However, the major endeavour was in an analytical approach; with fundamental continuity, momentum and salt balance equations; to generate data using a mathematical model in the framework of a computer program. The presented computer program formulated in FORTRAN-IV will compute salinity at all stations in between Nabaganga and Kunga for any given hydrograph of Gorai-Madhumati and hourly water levels at Hiron Point.

Field data on salinity for the study have been collected from Bangladesh Water Development Board and data on channel geometry have been collected from Bangladesh Inland Water Transport Authority.

To explore fully the characteristics of salinity intrusion a well-planned scheme of field data collection as well as an investigation of the effect of other dynamic properties of the estuaries are necessary.

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LIST OF SYMBOLS

Symbol		Definition	Unit
a	=	Amplitude of wave measured from MSL	ft
A	=	Cross-sectional area of channel	ft^2
B	=	Width of channel ...	ft
C	=	Salinity concentration ...	ppm
C_o	=	Salinity of ocean ...	ppm
d	=	Grain diameter ...	mm
D	=	Depth of channel ...	ft
e_x, e_y, e_z	=	Diffusion coefficients along x, y and z directions respectively ...	$ft^{3/2}$
E	=	Longitudinal dispersion coefficient	$ft^{3/2}$
F	=	Froude number or surface area of node	Nil, ft^2
g	=	Gravitational constant = 32.2	ft/sec^2
h	=	Total depth ...	ft
H	=	Water level or stage ...	ft
K	=	Conveyance of channel ...	ft^3/sec
L	=	Length of channel ...	ft
m	=	Number of branches ...	Nil
M	=	Momentum correction factor ...	Nil
n	=	Number of nodes ...	Nil
N	=	Manning roughness coefficient	$sec/ft^{1/3}$
P	=	Pressure ...	lb/ft^2
P_t	=	Tidal prism, volume of seawater entering in flood tide ...	ft^3
q	=	Rate of flow per unit width ...	ft^2/sec

Symbol		Definition	Units
Q	=	Total rate of flow for section	ft^3/sec
R	=	Hydraulic radius ...	ft
t	=	Time or duration ...	sec
T	=	Top width or tidal period ...	ft, hour
U_f	=	Average upland freshwater velocity	ft/sec
V	=	Space-time average velocity of translation in x-direction ...	ft/sec
γ	=	Specific weight ...	lb/ft^3
ρ	=	Density ...	$lb\text{-}sec^2/ft^4$
ρ_m	=	Mean density ...	$lb\text{-}sec^2/ft^4$
ν	=	Kinematic viscosity ...	ft^2/sec

LIST OF NOTATIONS USED IN COMPUTER PROGRAM

Symbol	Description
A1(I),A2(I), A3(I),A4(I)	Specific areas of channel cross-sections of branch I
AB1(J),AB2(J), AB3(J),AB4(J)	Specific areas of Kunga
AMANCO(J)	Roughness coefficient of Kunga
AR(J)	Cross-sectional area of Kunga upto a depth of -18 ft below C.D. at grid point J
BE1(J),BE2(J), BE3(J),BE4(J)	Specific elevations of Kunga
CK(I)	Conveyance of branch I
CL,CM,CN	L(P,Q), M(P,Q), N(P,Q)
DELH	Difference of water level for the time step used in computation in grid model
DELTM	Time interval used in the computation minutes
DELX(I)	Distance interval of channel in miles
DELX	Distance interval between two grid points in Kunga
DIFA(I)	Difference of area at two ends of branch I
DIFH(I)	Difference of water level elevations at ends of branch I
DQ(I)	Change in discharge in branch I for the time step used in computation
EB(I),E1(I), E2(I),E3(I)	Specific elevations of channel cross sections of branch I
EK1,EK2	Coefficients K_1 and K_2

Symbol	Description
ENM(I)	Roughness coefficient of channel
F(I)	Surface area of node I
FGORAI(I)	Daily inflow from Gorai-Madhumati
FMADHU(I)	Daily outflow into Madhumati
FDLUTI(I)	Daily inflow into Sibsa at Deluti
FRPUR(I)	Daily inflow into Sibsa at Raipur
FMONGL(I)	Daily inflow from Mongla-Ghasiakhali canal
G	Acceleration due to gravity
H(I,1),H(I,2)	Water level at node I
H(I1,J),H(I2,J)	Water level at grid point J in Kunga
HI	Water level in a branch
HIRON(I)	Hourly water level at Hiron Point
IPRINT	Time interval in minutes to print out the computed water level, discharge and salinity
IDATE,IHOUR, IMIN	Initial date, hour and minute
JMAX	Number of grid points in Kunga
KDATE,KHOUR, KMIN	Final date, hour and minute
L1(I),L2(I), L3(I),L4(I)	Branch numbers issuing from node I
NB,NN	Number of branches and nodes in Node and Branch Model
NDAY	Number of days for running computation and also reading the input boundary values
NSTD	Number of days for running the steady state initial condition when warming up the model

Symbol	Description
NU(I),ND(I)	Node numbers upstream and downstream of branch I
QGORAI(I), QMADHU(I), QRPUR(I), QDLUTI(I),QMONGL(I)	Initial discharges at the upstream model boundaries
Q(I,1)	Discharge of branch I
Q(I1,J)	Discharge at grid point J in Kunga
QBSI(1)	Inflow at upstream boundary of grid model
R(J)	Hydraulic radius at grid point J of Kunga
RM(I)	Hydraulic radius of channel
S(I)	Constant of continuity equation for node I
SC(I)	Salinity concentration at node I
SM	Salinity concentration of sea
SQ(I)	Constant of momentum equation in branch I
SS(I)	Volumetric change of node I for the time interval used in computation
T(I)	Top width
V(I)	Rate of change of water level in node I
XL	Length of estuary Kinga

CHAPTER - 1

INTRODUCTION

1.1 General Information

Bangladesh is a riverine, deltaic country with the Bay of Bengal bordering its south. Salinity intrusion from the sea is a problem during dry seasons for the southwest region of Bangladesh. With increasing use of natural freshwater supply in rivers for human consumption, agriculture, industries, etc., the problem will attain greater dimensions in years to come.

To prevent inundation of coastal areas by saline water a very extensive set of polder projects known as the Coastal Embankment Project was undertaken. After completion of the project, a gross area of 3.5 million acres has been protected from tidal inundation and reclaimed. To derive full project benefit, supplemental irrigation water along with conservation and control of freshwater supply is necessary for increased agricultural production. The irrigation needs are mostly during the dry season when the freshwater supply is low. The first preference for this supply is freshwater from the rivers. Considering the full irrigation development of Ganges-Kobadak, Faridpur, Barisal, Ganges North Bank and other irrigation projects in southwest region, the water requirement during April will exceed the average flow of the Ganges and Jamuna combined, based on data of Bangladesh Water Development Board. This dwindling of the freshwater supply will have a serious effect in the southwest region as the saline front will be pushed further north during the dry season.

1.2 Background Information on Salinity

In 1961 the International Engineering Company, Inc.(1964) did the first salinity measurements of the coastal areas. In 1966 salinity study was conducted by Leedshill-DeLeuw Engineering Company (1968) by collecting samples from 55 stations at different times of the year. They considered 2000 micromho electrical conductivity to be the acceptable level of salinity for rice irrigation and presented a monthly movement of 2000 micromho salinity front as shown in Fig. 2. The United Nations Hydrological Survey conducted salinity monitoring from October 1966 to September 1968. A multiple correlation study for salinity prediction based on those data were carried out by Chidley (1969). R.K. Bhuiya (1971) prepared a mathematical model for salinity intrusion in the southwest region of Bangladesh based on data obtained from an investigation of tidal phenomenon, hydrology, channel morphology and sediment transport characteristics in the area by NEDECO (1967). The Special Studies Directorate (1977) of Bangladesh Water Development Board made a study by stochastic method on long and short range effects of upstream diversion of freshwater on salinity intrusion.

The short term effect was studied by comparing the base year of 1967-'68 with the diversion years of 1975-'76 and 1976-'77. The deduction from the study is that the salinity pattern in the portion of the delta east of Gorai-Madhumati rivers are largely independent of the flows in the Ganges and Gorai-Madhumati rivers and, on the other hand, the Pussur estuary to Khulna and beyond is completely dependent on freshwater from the Gorai-Madhumati to prevent salinity intrusion. To evaluate the long-term effect of upstream diversion, the effect of 10, 20, 30 and 40 thousand cusecs of upstream diversion on the historic discharge record at Gorai Railway Bridge was computed and four modified flow records, reflecting each of these diversion rates respectively, was synthesized. Regression analysis of the average monthly historic discharge with maximum monthly salinities at selected stations was made. The underlying assumption was that since salinity west of Gorai-Madhumati depends largely on the discharge regime into the Gorai offtake, the prediction of salinity resolves itself into prediction of discharge. This analysis resulted in the correlation coefficient of various stations.

1.3 Importance of the Study

It is now extremely important to investigate fully the seasonal advance and retreat of salinity from the Bay of Bengal with changes in various parameters, identify the areas with year-round acceptable salinity, analyze the magnitude of impact of possible proliferation of the problem and suggest specific and well-planned studies for future. To gain the required confidence in this regard the modern trend has been to start from more elementary concepts and go into details by steps. A hydraulic model can serve this purpose with enough flexibility for subsequent incorporation of morphological and hydrological complexities.

1.4 Scope and Objective of the Study

A single model for the southwest region extending from the Indian border to the Meghna river will be too big to handle. The mathematical model of R.K.Bhuiya for the area between the Baleswar-Haringhata River and the Indian border is also too big to describe the sensitivity of the relatively smaller rivers in the area. Special Studies Directorate (1978) of Bangladesh Water Development Board after analyzing the available tidal and salinity data indicated in their publication division of the area into five distinct compartments which may be considered somewhat independently. These compartments consist of north to south strips about 20 to 25 miles wide and are given following names (Fig. 1):

1. The Meghna-Tentulia Compartment
2. The Arial Khan-Barisal-Buriswar Compartment
3. The Gorai-Madhumati-Baleswar Compartment
4. The Nabaganga-Pussur Compartment
5. The Kobadak Compartment

The present study is confined within the Nabaganga-Pussur compartment. Attempts have been made to make the boundary of the study area correspond to tidal null points. The major rivers in the area are Pussur and Sibsa. In Pussur navigation depths of about 15 to 30 ft are available upto Mongla (which is a seaport) about 50 miles from the bay and about 10 feet on upto Khulna, about 80 miles from the bay. Khulna is the principal industrial and commercial center in the study area.

The primary source of freshwater in the area in dry season is from the Ganges through Gorai-Madhumati. The Mongla-Ghasiakhali canal provides a connection with the east and Sibsa with the west. Sibsa does not contribute appreciable freshwater into the area in dry season because the canals linking Sibsa with Ganges dry up and there is almost no precipitation in the catchment area. The Mongla-Ghasiakhali canal also brings no appreciable freshwater because it has primarily an east-west orientation and that of the cotidal lines in the area too is in the east-west direction which has been found from an study by NEDECO (1967).

CHAPTER - 2

TIDAL DYNAMICS IN ESTUARIES

2.1 Characteristics of Tide in Estuaries

Physical concept of tide is that of an incident wave entering the estuary from the sea. The entire wave motion in the estuary is governed by the characteristics of the ocean tide. The amplitude of the incident wave progressing up the estuary is influenced by the geometry of the estuary in several ways. In a convergent estuary the amplitude tends to increase, whereas wave reflection from side banks and boundary friction has a negative effect on amplitude. In long estuaries with small bottom slope and without physical obstructions, the latter two effects may dominate and the tidal amplitude may gradually diminish. The motion in such estuaries are characterized by shallow water progressive waves. Velocity in estuaries varies with time and space, but may be considered one-dimensional when the width of the estuary is not too large. Velocity is minimum at both low and high water slacks and is maximum in between two slack waters. It is interesting to note that an estuary may simultaneously have more than one slack waters at different points in space. The motion of water is from high water slack to low water slack. Schematic representation of such a situation is shown in Fig. 8 after M.Grant Gross (1972).

2.2 Mathematical Model for Tide

Two dimensional quantitative representation of tide is very complicated owing to complex influences of forces due to sun and moon; reflection, refraction and resonance caused by land and subsurface topography; rotation of the earth; frictional effects; density currents and such others. A one-dimensional model is far more simpler to develop and has been found adequate to simulate tidal motion in estuaries which are not very wide.

The tidal model described here was developed by C.B. Vreugdenhil (1968) of Delft Hydraulics Laboratory. The model can be conveniently applied to a system of channel network. The computation requires a schematization procedure which considers the flow system to be consisted of a number of storage tanks, connected through by a number of channels. The channel joining the storage tanks is assumed to have the average geometrical and hydraulic properties which are only time dependent. The storage tank is called a NODE and the channel joining the storage tanks is called a BRANCH. The function of the node can be visualized to accomodate all storage or mass transfer effects while the branches accomodate the hydraulic frictional and inertial effects which exist between the two nodes.

In the node and branch computation technique, the following assumptions are made:

a) The water surface is horizontal in each node

b) Only a uniform discharge exists along the entire length of a branch at any instant

c) Water level varies linearly from one node to the adjacent nodes

d) The storage in each node is considered equal to the volume of the water in all branches issuing from that node to a distance half way to its adjacent nodes.

Fig. 3 shows the physical interpretation of the river geometry and flow condition assumed in the node and branch schematization. Fig. 4 shows the time variations of the discharges of the branches and the water levels at the nodes along a typical river reach. The limitation of these assumptions is that each branch should be sufficiently small so that variations in cross-sectional area and roughness coefficient in the reach are not large.

The governing equations are the unsteady free surface equations which can describe the main channel and berm flows and can be expressed as follows:

$$\frac{\partial Q}{\partial x} + T\frac{\partial H}{\partial t} - q = 0 \qquad \ldots \qquad \ldots \qquad (2.1)$$

$$2M\frac{Q}{A}\frac{\partial Q}{\partial x} - M\frac{Q^2}{A^2}\frac{\partial A}{\partial x} + \frac{Q^2}{A}\frac{\partial M}{\partial x} + \frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial x} + \frac{gA\,Q|Q|}{\left(\sum_{i=1}^{3} K_i\right)^2} = 0 \quad (2.2)$$

In equations 2.1 and 2.2, Q and H are the discharge and water level, q is the lateral discharge per unit distance which enters the channel perpendicularly, T and A are the total top width and cross sectional flow area, K and M are the conveyance and momentum correction factors, g is the gravitational acceleration, x and t are the space and time co-ordinates. The parameter K and M are defined as

$$K_i = \frac{1.49}{N_i} A_i R_i^{2/3} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2.3)$$

$$M = \frac{\sum_{i=1}^{3} \rho Q_i V_i}{\rho Q V} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2.4)$$

$$Q = \sum_{i=1}^{3} Q_i \text{ and } V = \frac{Q}{\sum_{i=1}^{3} A_i} = \frac{Q}{A} \quad \ldots \quad \ldots \quad (2.5)$$

In equations 2.3, 2.4 and 2.5, the subscript i is the index number of the subsections of the river cross section. The subsection nos. 1, 2 and 3 are the left berm, main channel and right berm. The term ρ, V and N are respectively the water density, the velocity and the Manning roughness coefficient. Evidently when the flow is assumed to be confined within the main channel M is equal to unity and Q_1, Q_3; V_1, V_3; A_1, A_3 are all zeroes.

2.2.1 Reduced Forms of Continuity and Momentum Equations for the Node and Branch Model

Equations 2.1 and 2.2 are the continuity and momentum equations which describe continuous variations of discharges and water levels with respect to time and space co-ordinates. Using the concept of the node and branch schematization, the river cross section and the flow condition are considered as time dependent functions and are uniform within space interval as shown in Figs. 3 and 4. To make Eqs. 2.1 and 2.2 consistent with the node and branch schematization, the partial differentiation with respect to the space co-ordinate, x, is replaced by the linear changes of water levels, discharges or cross sectional areas, etc., with respect to the distance along the branch. The equations are thus reduced to partial differentiation equations with respect to time alone and can be changed to the total differential equations with respect to time.

From Eq. 2.1 the continuity equation for a node can be expressed as

$$\frac{dH}{dt} = \frac{\Sigma Q_{in} - \Sigma Q_{out}}{F} \quad \ldots \quad \ldots \quad \ldots \quad (2.6)$$

where F is the surface area of the node which equals to one half of the sum of the surface areas of the branches issuing from the node to the adjacent nodes, ΣQ_{in} and ΣQ_{out} are the summation of the discharges into and out from the node. The other parameters are previously defined.

Similarly, the momentum equation in Eq. 2.2 can be written as

$$\frac{dQ}{dt} = \frac{MQT}{A}\left[\frac{(\Sigma Q_{in} - \Sigma Q_{out})}{F_1}\text{ node 1} + \frac{(\Sigma Q_{in} - \Sigma Q_{out})}{F_2}\text{ node 2}\right] + \frac{MQ^2}{A^2L}(A_2-A_1) - \frac{Q^2}{AL}(M_2-M_1) - \frac{gA}{L}(H_2-H_1) - \frac{gAQ|Q|}{\left(\sum_{i=1}^{3} K_i\right)^2} \quad \ldots \quad (2.7)$$

where $A = \dfrac{A_1 + A_2}{2}$

$T = \dfrac{T_1 + T_2}{2}$

$M = \dfrac{M_1 + M_2}{2}$

$K_i = \dfrac{(K_i)_1 + (K_i)_2}{2}$

$i = 1,2,3$

The subscripts 1 and 2 designate the upstream and downstream locations of the branch of length L, and i is the subsection number either of the berm or the main channel.

In transforming the continuity and momentum equations in Eqs. 2.6 and 2.7 to the finite difference equations, the following finite difference schemes are used.

$$\frac{\Delta H}{\Delta t} = (1-\theta)\left.\frac{dH}{dt}\right|_t + \theta\left.\frac{dH}{dt}\right|_{t+\Delta t} \quad \ldots \quad \ldots \quad \ldots \quad (2.8)$$

$$\frac{\Delta Q}{\Delta t} = (1-\theta)\left.\frac{dQ}{dt}\right|_{t} + \theta\left.\frac{dQ}{dt}\right|_{t+\Delta t} \quad \ldots \quad \ldots \quad \ldots \quad (2.9)$$

In Eqs. 2.8 and 2.9, ΔH and ΔQ are the incremental changes in the discharge and water level within the time interval Δt, θ is the weighting factor, the subscripts t and $t + \Delta t$ are the times at the beginning and at the end of the period Δt. For explicit computation, θ is equal to zero. When θ is taken as unity, the computation is fully implicit. In general, Vreugdenhil (1968) suggested that θ should be taken as 0.55 for numerical stability and accuracy in the implicit computation.

After substituting Eq. 2.8 and 2.9 into the continuity and momentum equations as expressed in Eqs. 2.6 and 2.7 and the equations obtained are linearized assuming the products of water level and discharge increments, e.g. $(\Delta H)^2, (\Delta Q)^2$ and $(\Delta H . \Delta Q)$ are negligible. This is true only when the values of ΔQ's and ΔH's are small within the time Δt. The process of linearization is required to enable the non-linear finite difference continuity and momentum equations to be transformed to the set of linear equations which can be solved further simultaneously using matrix inversion or other iteration techniques. A set of finite difference continuity and momentum equation for the nodes and branches in the schematized river system can be expressed as

Continuity Equations for n nodes

$$\theta C_{1,1}\Delta H_1 + \ldots \theta C_{1,n}\Delta H_n + \theta C_{1,n+1}\Delta Q_1 \ldots \theta C_{1,n+m}\Delta Q_m = D_1$$
$$\vdots$$
$$\theta C_{n,1}\Delta H_1 + \ldots \theta C_{n,n}\Delta H_n + \theta C_{n,n+1}\Delta Q_1 \ldots \theta C_{n,n+m}\Delta Q_m = D_n$$

Momentum Equations for m branches

$$\theta C_{n+1,1}\Delta H_1 + \ldots \theta C_{n+1,n}\Delta H_m + \theta C_{n+1,n+1}\Delta Q_1 \ldots \theta C_{n+1,n+m}\Delta Q_m = D_{n+1}$$
$$\vdots$$
$$\theta C_{n+m,1}\Delta H_1 + \ldots \theta C_{n+m,n}\Delta H_n + \theta C_{n+m,n+1}\Delta Q_1 \ldots \theta C_{n+m,n+m}\Delta Q_m = D_{n+m}$$

$$\ldots \qquad \ldots \qquad \ldots \qquad (2.10)$$

where n and m are respectively the numbers of nodes and branches in the schematized river system. The coefficients $C_{i,j}$ in the above equations are the function of water levels, discharges, river geometry and roughness coefficients which are known from the initial conditions or from the previous step of computation.

To solve equation 2.10 explicitly, θ has to be taken as zero. In that case, the increments of water levels and discharges are solved using the known flow conditions at time t i.e., from the previous step of computation or from the initial condition, for the nodes and branches far from the boundaries. For the nodes and branches located next to the boundaries, the computation includes the boundary conditions given at the boundary points at time $t+\Delta t$.

For an implicit computation i.e., θ is taken equal to 0.55, the water level and discharge increments in Eq. 2.10 can be solved using matrix inversion. The matrix representation of Eq. 2.10 can be written as

$$[C][X] = [D]$$
$$\text{or } [X] = [C]^{-1}[D]$$

where $[C]$ is the coefficient matrix, $[X]$ is the unknown matrix consisting of all ΔH's and ΔQ's, $[D]$ is the unknown matrix on the right hand side of Eq. 2.10.

2.2.1.1 Method of Solution

The numerical solutions are obtained through the iteration process developed in the present study similar to the Gauss Seidel Method. The iteration process is developed through the combination of the explicit and implicit schemes. The method has improved the model stability as regard to the time step which imposes serious restriction on the explicit scheme. On the simplicity of the computational procedure the iteration process has shown its advantage over the implicit scheme in solving the unsteady free surface flow equations describing river flows in complicated river networks. The procedure of solving the river flow using the developed method in this study can be given as follows:-

Rewriting Eq. 2.10

Continuity Eqs. for n nodes:

$$C_{1,1}\Delta H_1 + \ldots \theta C_{1,n}\Delta H_n + \theta C_{1,n+1}\Delta Q_1 + \ldots \theta C_{1,n+m}\Delta Q_m = D_1$$
$$\vdots$$
$$\theta C_{n,1}\Delta H_1 + \ldots C_{n,n}\Delta H_n + \theta C_{n,n+1}\Delta Q_1 + \ldots \theta C_{n,n+m}\Delta Q_m = D_n$$

Momentum Eqs. for m branches:

$$\theta C_{n+1,1}\Delta H_1 + \ldots \theta C_{n+1,n}\Delta H_n + C_{n+1,n+1}\Delta Q_1 + \ldots \theta C_{n+1,n+m}\Delta Q_m = D_{n+1}$$
$$\vdots$$
$$\theta C_{n+m,1}\Delta H_1 + \ldots \theta C_{n+m,n}\Delta H_n + \theta C_{n+m,n+1}\Delta Q_1 + \ldots C_{n+m,n+m}\Delta Q_m = D_{n+m} \quad \ldots \ldots \ldots \ldots (2.11)$$

Eq. 2.11 consists of n unknowns in the continuity equations and m unknowns in the momentum equations. The method of solving the equations are as follows:

Step 1 Putting $\theta = 0$ (explicit), Eq. 2.11 can be written in the form

$$
\begin{array}{llll}
C_{1,1}\Delta H_1 & & & = D_1 \\
\ddots\; C_{2,2}\Delta H_2 & & & = D_2 \\
\quad\ddots\; C_{n,n}\Delta H_n & & & = D_n \\
\hline
& C_{n+1,n+1}\Delta Q_1 & & = D_{n+1} \\
& \ddots\; C_{n+2,n+2}\Delta Q_2 & & = D_{n+2} \\
& \quad\ddots\; C_{n+m,n+m}\Delta Q_m & & = D_{n+m}
\end{array}
\qquad \ldots (2.12)
$$

In Eq. 2.12, ΔH and ΔQ can be solved explicitly of all nodes and branches.

Step 2 Putting $\theta = 0.55$

a) ΔH_i is computed from the continuity equation of node i by substituting $\Delta H_1, \ldots \Delta H_{i-1}, \Delta H_{i+1} \ldots \Delta H_n$ and $\Delta Q_1, \ldots \Delta Q_m$ determined from explicit computation in step 1 into the continuity equation in Eq. 2.11.

The same procedure is also used in determining ΔH's for all nodes.

b) ΔQ_j is computed from the momentum equation of branch j by substituting $\Delta H_1, \ldots \Delta H_n$ and $\Delta Q_1, \ldots \Delta Q_{j-1}, \Delta Q_{j+1}, \ldots \Delta Q_m$ determined from explicit computation in step 1 into the momentum equation in Eq. 2.11.

The same procedure is also used in determining ΔQ's for all branches.

<u>Step 3</u> Putting $\theta = 0.55$

a) ΔH_i is recomputed from the continuity equation of node i by substituting $\Delta H_1, \ldots \Delta H_{i-1}, \Delta H_{i+1}, \ldots \Delta H_n$ and $Q_1, \ldots Q_m$ determined from step 2 into the corresponding continuity equation in Eq. 2.11.

The same procedure is also used in determining ΔH's for all nodes.

b) ΔQ_j is computed from the momentum equation of branch j by substituting $\Delta H_1, \ldots \Delta H_n$ and $\Delta Q_1, \ldots \Delta Q_{j-1}, \Delta Q_{j+1}, \ldots \Delta Q_m$ determined from step 2 into the corresponding momentum equation in Eq. 2.11.

The same procedure is also used in determining ΔQ's for all branches.

<u>Step 4</u> Difference between ΔH's and ΔQ's obtained from step 2 and step 3 for each node each branch is checked to see whether they exceed the allowable limits or not. If the limits are exceeded, step 3 and step 4 are repeated until the differences are within the allowable limits. In cases that instability occurs, the value of Δt has to be reduced.

2.2.2 Grid Model

To describe flow condition in Kunga estuary a grid model has been developed considering the estuary to be a single channel reach from Jefford Point to the confluence of Hansraj, Kunga and Pussur rivers. The governing equations which are used in describing the river flow are written as:-

$$\frac{\partial Q}{\partial x} + T\frac{\partial H}{\partial t} - q = 0 \quad \cdots \quad \cdots \quad \cdots \quad \cdots \qquad (2.13)$$

$$\frac{\partial Q}{\partial t} + \frac{2Q}{A}\frac{\partial Q}{\partial x} - \frac{Q^2}{A^2}\frac{\partial A}{\partial x} + gA\frac{\partial H}{\partial x} + g\frac{N^2 Q|Q|}{AR^{4/3}} = 0 \quad \cdots \qquad (2.14)$$

Since there are no overbank spillages or return flows in the reach described by the Grid Model, the lateral discharge q is dropped out from Eq. 2.13. In solving the governing equations, the following finite difference approximations of implicit scheme, as referred to Fig. 5 are used

$$\frac{\partial f}{\partial t} = \frac{1}{\Delta t}\left[\frac{f(P')+f(Q')}{2} - \frac{f(P)+f(Q)}{2}\right] \cdots \qquad (2.15)$$

$$\frac{\partial f}{\partial x} = \frac{1}{\Delta x}\left[f(Q') - f(P')\right] \quad \cdots \quad \cdots \qquad (2.16)$$

$$f = \frac{1}{2}\left[f(P') + f(Q')\right] \quad \cdots \quad \cdots \qquad (2.17)$$

In the above equations, f is the dependent variable which can be either discharge or water level, Δx and Δt are the space and time increments used in the numerical computation.

Refering to Fig. 5 for a small increment of time Δt, the linear relationship may be approximated in the following way,

$$f(P') = f(P) + \Delta f(P) \quad \ldots \quad \ldots \quad (2.18)$$

$$f(Q') = f(Q) + \Delta f(Q) \quad \ldots \quad \ldots \quad (2.19)$$

In Eqs. 2.18 and 2.19, $\Delta f(P)$ and $\Delta f(Q)$ are small increments of f at the grid points P and Q respectively. They are so small that the square and the higher powers of their values can be neglected. Using the above linearization Eqs. 2.15, 2.16 and 2.17 respectively become

$$\frac{\partial f}{\partial t} = \frac{1}{2\Delta t}\left[\Delta f(P) + \Delta f(Q)\right] \quad \ldots \quad \ldots \quad \ldots \quad (2.20)$$

$$\frac{\partial f}{\partial x} = \frac{1}{\Delta x}\left[\left\{f(Q) - f(P)\right\} + \left\{\Delta f(Q) - \Delta f(P)\right\}\right] \quad \ldots \quad (2.21)$$

$$f = \frac{1}{2}\left[\left\{f(P) + f(Q)\right\} + \left\{\Delta f(P) + \Delta f(Q)\right\}\right] \quad \ldots \quad (2.22)$$

Using Eqs. 2.20, 2.21, and 2.22, the continuity and momentum equations can be transferred into two linear difference equations. The following are the linearized continuity and momentum equations for the grid PQQ'P' as shown in Fig. 5.

Substituting Eqs. 2.20, 2.21 and 2.22 into Eq. 2.13 and simplifying we get the following finite difference continuity equations

$$C(P,Q)\Delta H(P)+D(P,Q)\Delta H(Q)+E(P,Q)\Delta Q(P)+F(P,Q)\Delta Q(Q)+K(P,Q) = 0 \quad \ldots (2.23)$$

In Eq. 2.23

$$C(P,Q) = D(P,Q) = \left[\frac{T(P)+T(Q)}{2}\right]\Delta x$$

$$E(P,Q) = -F(P,Q) = -2\Delta t$$

$$K(P,Q) = 2\Delta t\,[Q(Q) - Q(P)]$$

Similarly, substituting Eqs. 2.20, 2.21 and 2.22 into Eq. 2.14 and simplifying we get the finite difference momentum equation

$$C'(P,Q)\Delta H(P)+D'(P,Q)\Delta H(Q)+E'(P,Q)\Delta Q(P)+F'(P,Q)\Delta Q(Q)+K'(P,Q) = 0 \qquad \ldots \quad \ldots \quad (2.24)$$

$$C'(P,Q) = -g\Delta t\{A(P)+A(Q)\}$$

$$D'(P,Q) = g\Delta t\{A(P)+A(Q)\}$$

$$E'(P,Q) = \Delta x - \frac{8\Delta t Q(P)}{A(P)+A(Q)} + \frac{2^{7/3} g\Delta x\Delta t N^2\{Q(P)+Q(Q)\}}{\{A(P)+A(Q)\}\{R(P)+R(Q)\}^{4/3}} \cdot \frac{|Q(P)+Q(Q)|}{Q(P)+Q(Q)} - \frac{4\Delta t\{A(Q)-A(P)\}\{Q(P)+Q(Q)\}}{\{A(P)+A(Q)\}^2}$$

$$F'(P,Q) = \Delta x + \frac{8\Delta t Q(Q)}{A(P)+AQ)} + \frac{2^{7/3} g\Delta x\Delta t N^2\{Q(P)+Q(Q)\}}{\{A(P)+A(Q)\}\{R(P)+R(Q)\}^{4/3}} \cdot \frac{|Q(P)+Q(Q)|}{Q(P)+Q(Q)} - \frac{4\Delta t\{A(Q)-A(P)\}\{Q(P)+Q(Q)\}}{\{A(P)+A(Q)\}^2}$$

$$K'(P,Q) = \frac{4\Delta t\left[\{Q(Q)\}^2 - \{Q(P)\}^2\right]}{A(P)+A(Q)} + g\Delta t\{A(P)+A(Q)\}. \{H(Q)-H(P)\} + \frac{2^{4/3} g\Delta x\Delta t N^2\{Q(P)+Q(Q)\}^2}{\{A(P)+A(Q)\}\{R(P)+R(Q)\}^{4/3}} \frac{|Q(P)+Q(Q)|}{Q(P)+Q(Q)} - \frac{2\Delta t\{A(Q)-A(P)\}\{Q(P)+Q(Q)\}^2}{\{A(P)+A(Q)\}^2}$$

In the above derivations, the symbols in the brackets are referred to the co-ordinates in Fig.5.

The values of the coefficients C(P,Q)..K(P,Q) and C'(P,Q).. K'(P,Q) of Eqs. 2.23 and 2.24 respectively are the functions of known quantities such as Δx, Δt, N ,g, as well as the discharges, water levels and the geometry of the cross sections at the current time t. These coefficients are either obtained from the initial conditions or from the previous step of computation.

2.2.2.1 Method of Solution

In solving for the numerical solutions of the governing equations, the finite difference equations like Eqs. 2.23 and 2.24 are written for every grid from upstream to downstream. The total number of equations are equal to the number of grids i.e., NG while the number of unknowns exceeds the number of equations by two i.e., NG+2. Therefore two unknowns must be given beforehand e.g., at each boundary of the model the discharge or water level hydrographs must be given. The number of unknowns is then reduced equal to the number of equations. The unknowns are thus solved simultaneously through the uses of the technique called "Double Sweep Method".

Referring to Fig. 6 the boundary condition is given at G, thus, the known parameters are $\Delta H(G)$, at any time $n\Delta t$, so as $\Delta H(X)$.

Writing Eq. 2.23 for Grid GPP'G',

$$C(G,P)\Delta H(G)+D(G,P)\Delta H(P)+E(G,P)\Delta Q(G)+F(G,P)\Delta Q(P)+K(G,P) = 0 \quad \ldots \quad \ldots \quad \ldots \quad (2.25)$$

Substituting the value of $\Delta H(G)$ into Eq. 2.25 and let

$J(G,P) = K(G,P) + C(G,P)\Delta H(G)$

We shall have,

$$D(G,P)\Delta H(P)+E(G,P)\Delta Q(G)+F(G,P)\Delta Q(P)+J(G,P) = 0 \quad \ldots \quad (2.26)$$

Similarly, from Eq. 2.24 for the same grid, we have,

$$C'(G,P)\Delta H(G) +D'(G,P)\Delta H(P)+E'(G,P)\Delta Q(G)+F'(G,P)\Delta Q(P)+ K'(G,P) = 0 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2.27)$$

Subsituting the value of $\Delta H(G)$, and letting

$J'(G,P) = K'(G,P) + C'(G,P)\Delta H(G)$

we get,

$$D'(G,P)\Delta H(P)+E'(G,P)\Delta Q(G)+F'(G,P)\Delta Q(P)+J'(G,P) = 0 \quad \ldots (2.28)$$

Eliminating $\Delta Q(G)$ in Eqs. 2.26 and 2.28 by multiplying Eq. 2.26 by $E'(G,P)$ and Eq. 2.28 by $- E(G,P)$, adding the two equations results to

$$\Delta Q(P) = \gamma(G,P)\, H(P) + \beta(G,P) \quad \ldots \quad \ldots \quad \ldots \quad (2.29)$$

where, $\gamma(G,P) = \left. \dfrac{D'E - DE'}{FE' - F'E} \right|_{(G,P)}$

$$\beta(G,P) = \left. \frac{J'E - JE'}{FE' - F'E} \right|_{(G,P)}$$

Writing Eqs. 2.23 and 2.24 for the next Grid PQQ'P',

$$C(P,Q)\Delta H(P)+D(P,Q)\Delta H(Q)+E(P,Q)\Delta Q(P)+F(P,Q)\Delta Q(Q)+K(P,Q) = 0 \quad \ldots \quad \ldots \quad \ldots \quad (2.30)$$

$$C'(P,Q)\Delta H(P)+D'(P,Q)\Delta H(Q)+E'(P,Q)\Delta Q(P)+F'(P,Q)\Delta Q(Q)+K'(P,Q) = 0 \quad \ldots \quad (2.31)$$

Substituting $\Delta Q(P)$ from Eq.2.29 into Eqs.2.30 & 2.31, eliminating $\Delta H(P)$, and solving $\Delta Q(Q)$ in terms of $\Delta H(Q)$,

$$\Delta Q(Q) = \theta(P,Q)\Delta H(Q) + \omega(P,Q) \quad \ldots \quad \ldots \quad \ldots \quad (2.32)$$

where,

$$\theta(P,Q) = \frac{D'(C+E\gamma) - D(C'+E'\gamma)}{F(C'+E'\gamma) - F'(C+E\gamma)}$$

$D' = D'(P,Q)$ $\qquad$ $D = D(P,Q)$

$C' = C'(P,Q)$ $\qquad$ $C = C(P,Q)$

$E' = E'(P,Q)$ $\qquad$ $E = E(P,Q)$

$F' = F'(P,Q)$ $\qquad$ $F = F(P,Q)$

$\gamma = \gamma(G,P)$

$$\omega(P,Q) = \frac{(K'+E'\beta)(C+E) - (K+E\beta)(C'+E'\beta)}{F(C'+E'\gamma) - F'(C+E\gamma)} \quad \ldots \quad \ldots \quad \ldots$$

$\beta = \beta(G,P)$

$K = K(P,Q)$ $\qquad$ $K' = K'(P,Q)$

Similarly for Grid QRR'Q', we have the relationship,

$$\Delta Q(R) = \theta(Q,R)\Delta H(R)+\omega(Q,R) \quad \ldots \quad \ldots \quad \ldots \quad (2.33)$$

where

$$\theta(Q,R) = \frac{D'[C+E\theta(P,Q)] - D[C'+E'\theta(P,Q)]}{F[C'+E'\theta(P,Q)] - F'[C+E\theta(P,Q)]}$$

$$\omega(Q,R) = \frac{[K'+E'\omega(P,Q)][C+E\theta(P,Q)] - [K+E\omega(P,Q)][C'+E'\theta(P,Q)]}{F[C'+E'\theta(P,Q)] - F'[C+E\theta(P,Q)]}$$

Similar equations can be written successively for every grid from grid GPP'G' to grid WXX'W'.

Therefore, for the last Grid WXX'W', at the model boundary we shall have

$$\Delta Q(X) = \theta\ (W,X)\Delta H(X) + \omega(W,X) \quad \ldots \quad \ldots \quad \ldots \quad (2.34)$$

In Eq. 2.34, $\Delta H(X)$ is known from the given boundary condition. The values of $\theta(W,X)$ and $\omega(W,X)$ can be computed using the values of $\theta(U,W)$ and $\omega(U,W)$ from the previous grid UWW'U'. Having these known parameters, the value of $\Delta Q(X)$ can be solved directly from Eq. 2.34.

Referring again to Eqs. 2.30 and 2.31, we eliminate $\Delta Q(P)$ by multiplying Eq. 2.30 by $E'(P,Q)$ and Eq. 2.31 by $-E(P,Q)$, solving for $\Delta H(P)$ we can get,

$$\Delta H(P) = L(P,Q)\Delta H(Q) + M(P,Q)\Delta Q(Q) + N(P,Q) \quad \ldots \quad \ldots \quad (2.35)$$

where, $L(P,Q) = \left.\dfrac{D'E - DE'}{CE' - C'E}\right|_{(P,Q)}$

$$M(P,Q) = \left.\frac{F'E - FE'}{CE' - C'E}\right|_{(P,Q)}$$

$$N(P,Q) = \left.\frac{K'E - KE'}{CE' - C'E}\right|_{(P,Q)}$$

From Eq. 2.35, $\Delta H(P)$ can be determined provided that the values of $\Delta H(Q)$ and $\Delta Q(Q)$ are known.

The computation can be processed upto the grid GPP'G' in which $\Delta Q(G)$ is the only unknown. Since the values of $\theta(JM1)$ and $\omega(JM1)$ are known making possible for the determination of $\Delta Q(G)$, at grid GPP'G' from Eqs. 2.25 and 2.26.

2.2.2.1.1 Procedure

a) From the initial condition and physical data of the river, we can compute the values of C,D,E,F,K and C',D',E',F',K' the coefficients of the equations like Eqs. 2.25 and 2.26 for every grid.

b) We can obtain the values of $\Delta H(G)$ for an increment of time Δt, from the given boundary condition.

c) We can compute the values of γ and β, the coefficients of Eq. 2.29; θ's and ω's the coefficients of the equations like Eqs. 2.32, 2.33 for every grid.

d) We can compute the values of L, M and N, the coefficients of the equations like Eq. 2.35 for every grid.

e) From the given boundary condition at X', $\Delta H(X)$ can be obtained and $\Delta Q(X)$ can be computed from Eq. 2.34.

f) We can compute $\Delta H(W)$ from the equation like Eq. 2.35 and $\Delta Q(W)$ from the equation like Eq. 2.34.

g) Steps (e) and (f) are repeated from grid to grid until the grid GPP'G' is reached. In this grid the value of $\Delta Q(G)$ is computed from Eqs. 2.25 & 2,26 with unknown values of $\Delta H(P)$, $\Delta Q(P)$ & $\Delta H(G)$, i.e.,

$$\Delta Q(G) = \alpha H(P) + \beta Q(P) + \nu$$

where,

$$\alpha = \frac{CD' - C'D}{CE' - C'E}$$

$$\beta = \frac{CF' - F'C}{CE' - C'E}$$

$$\nu = \frac{CK' - C'K}{CE' - C'E}$$

Similar procedure is used when the given boundary condition at G is the discharge.

h) The values of Q and H at time $t+\Delta t$ are computed by adding ΔQ and ΔH at each grid point to their values of Q and H at time t respectively. The values of Q and H at the locations between any two grid points can be obtained by interpolating the values at these grid points.

i) The values of H and Q are used at every grid point in (h) as the initial condition and steps (a) to (h) are repeated as far as desired.

2.2.3 Connection of Node and Branch Model and Grid Model

The node and branch model is connected with the grid model at the confluence of Hansraj, Kunga and Passur rivers using the following approach.

Writing the equation for Q(JMAX), using Eq. 2.34 for the grid model, we get $\Delta Q(JMAX) = \theta(JM1)\Delta H(JMAX) + \omega(JM1)$ ... (2.36)

Where JMAX is the number of grid between the grid points JMAX and (JMAX-1).

For the Node and Branch model, writing the continuity equation for the node number 1 at the abovementioned confluence referring to Eq. 2.10 and Fig. 7.

$$\frac{\Delta H_i}{\Delta t} = \frac{(Q_1+Q_2+Q_3-Q_{JMAX}) + \lambda\Delta Q_1+\lambda\Delta Q_2+\lambda\Delta Q_3 - \Delta Q_{JMAX}}{F_1} \quad \ldots \quad (2.37)$$

where Q_1, Q_2 and Q_3 are flows in the branches which meet at node 1, F_1 is the surface area of node 1, and λ is the weighting factor equal to 0.55.

Letting $H_1 = H(JMAX)$ or $\Delta H_1 = \Delta H(JMAX) = \Delta H$

$A = Q_1+\lambda\Delta Q_1+Q_2+\lambda\Delta Q_2+Q_3+\lambda\Delta Q_3-Q(JMAX)$ and $B = \dfrac{F_1}{\Delta t}$

Eqs. 2.36 and 2.37 can be rewritten as

$$\lambda\Delta Q + B\,\Delta H = A$$

$$\Delta Q + \theta(JMAX)\Delta H = -\omega(JM1)$$

Solving ΔQ and ΔH simultaneously we get

$$\Delta H = \frac{A + \omega(JM1)\lambda}{B - \theta(JM1)\lambda} \quad \ldots \quad \ldots \quad \ldots \quad (2.38)$$

$$\Delta Q = \frac{A\theta(JM1)+\omega(JM1)B}{\theta(JM1)\lambda - B} \quad \ldots \quad \ldots \quad \ldots \quad (2.39)$$

Eqs. 2.38 and 2.39 make up the equations for connecting the Node and Branch model and Grid model. The paramters A and B are computed from the Node and Branch model while the parameters θ and ω are computed from the Grid model.

CHAPTER - 3

SALINITY INTRUSION IN ESTUARIES

3.1 Internal Flow Processes

Two extreme cases arise for salinity intrusions in estuaries as a result of either minimal tidal action or intensive mixing produced by tidal currents. The first type is termed 'stratified estuary' and the second type 'mixed estuary'. Schematic representation of both types are shown in Fig. 9 as given by A.T. Ippen (1966). In stratified estuary river water being less dense than seawater flows as upper layer. Due to frictional drag it entrains seawater from below. Mixed water being less dense than seawater, the process is irreversible, and subsurface layer moves inland to replace sea-ward-flowing saltwater entrained in the upper layer. The flow profile is divided into two distinct portions. In the lower layer salinity is practically the same as in the ocean and is referred to as salinity wedge. The action of this wedge may be compared hydraulically to a long weir, over which the freshwater discharges to the sea. There is no net flow within the wedge in a stationary position; the salt water Q_s moving upstream near the bottom is balanced by the flow Q_s moving seaward. Q_s is decreasing in the upstream direction as if in a converging conduit with a porous upper boundary.

This system of flow is dynamically dependent on the hydrostatic pressures, which are also indicated in Fig. 9 for the ends of the intrusion. It is seen that at station (1_i) the pressure corresponding to depth h is augmented by a constant amount $\gamma\Delta h$ due to the rise in water level needed to overcome the excess pressure$(\gamma_s - \gamma)h_{so}$ $= \Delta\gamma h_{so}$ due to salinity in the wedge at station l_o. These forces must always give rise to a moment which is related to the circulation and to the rate of change of momentum of the fluid masses involved in the horizontal direction. Since the longitudinal pressure gradients vary over the depth, the shape of the velocity distribution is readily apparent.

Estuarine conditions with stratified flow may prevail in the absence of or with only weak tidal action, giving a stable salinity wedge with a well-defined interface. The large density difference between fresh and seawater is capable of suppressing largely turbulent mixing and interfacial waves at the interface.

Some estuaries may display the completely stratified character only at certain favourable times, while at other times unusually high tides, turbulence by wave action, low fresh-water flows, and wind induced currents produce a more mixed condition. Certain differences between this type of salinity intrusion and that of the saline wedge are clearly evident. The intrusion cannot be identified by a clearly defined boundary such as the interface, but is only artificially expressed by a line indicating the local mean values of the salinity C_x over the intrusion length averaged over a tidal period and over the depth. It is important to note that the density currents still generated due to longitudinal and vertical salinity gradients are now inextricably coupled to the mixing process produced by tidal shear flows. Tidal velocities greatly exceed the density currents in magnitude, but even weak currents due to salinity gradients greatly enhance the internal diffusion process. In an extreme case of mixing the interface becomes vertical. Langeweg and Van Weerden (1976) introduced estuary number as a measure of the degree of mixing. Estuary number = $\frac{P_t F_o^2}{Q_s T}$, $F_o = \frac{U_{max}}{\sqrt{gD}}$. If estuary number $>$ 0.15, it indicates well-mixed estuary.

3.2 Mathematical Model for Salinity Intrusion

Mathematical representation of saline wedge characteristics can be done fairly accurately in stratified flow. Length of the saline wedge at ebb tide is given by A.T. Ippen (1966) as

$$L_s = 6D_o \left[\frac{V_\Delta D_o}{\nu}\right]^{\frac{1}{4}} \left[\frac{2 U_f}{V_\Delta}\right]^{-5/2} \quad \ldots \quad \ldots \quad (3.1)$$

where

$$V_\Delta = \sqrt{\frac{\rho_2 - \rho_1}{\rho_m} g D_o}$$

The relationship of affineness of wedge is obtained by expressing the height of salt wedge h_s in terms of the height of the wedge at the river mouth h_{so} and the distance L in terms of wedge length L_s. Table 1 gives affine shape of arrested saline wedge, which is independent of salinity of seawater, freshwater discharge, depth, width and kinematic viscosity. The location of saline wedge at any other time is given by the excursion of tide.

In mixed and inter-connected estuaries such simple relationships cannot be developed. In general terms, salinity distribution is an unsteady, three dimensional problem. That is $C = f(x,y,z,t)$. Holley and Harleman (1965) gave the following general equation to describe the process of mass transfer and mass conservation of a substance in a turbulent flow field.

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial x}\left(e_x\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(e_y\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(e_z\frac{\partial C}{\partial z}\right) + r_a - r_r \quad \ldots \quad (3.2)$$

where r_a and r_r are non-advective rates of addition of salinity and withdrawal of salinity respectively.

The first term in equation 3.2 is the unsteady part. The other terms on the left represent the mass transfer by the advective motion of the fluid. The first three terms on the right hand side of equation 3.2 represent the non-advective turbulent diffusion. The forced diffusion induced by the pressure gradient due to density difference in the fluid media and the thermal diffusion due to temperature gradient has not been considered.

It is generally agreed that no analytical methods have yet been developed to handle the three dimensional problem, and transverse variations (at right angles to longitudinal axis) are ignored. The mathematical formulation of the unsteady, two-dimensional problem requires four partial differential equations:

1. Equation of motion in longitudinal direction
2. Equation of motion in vertical direction
3. Continuity equation and
4. Conservation of mass equation for salt.

Various investigators have worked on this problem using a wide variety of simplifying assumptions. However, it must be concluded that these attempts have so far not yielded an analytical framework or a formulation of the boundary conditions which are capable of predicting the effect of changes in one or more of the many independent parameters which affect the salinity distribution. Further consideration will therefore be restricted to the unsteady, one dimensional problem and since the predominant flow in an estuary is in the longitudinal direction, a one-dimensional treatment in most estuaries have been found adequate.

By integrating equation 3.2 over the cross-sectional area Holley and Harleman (1965) derived for one-dimensional case

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = \frac{1}{A}\frac{\partial}{\partial x}\left(EA\frac{\partial c}{\partial x}\right) \quad \ldots \quad \ldots \quad \ldots \quad (3.3)$$

Equation 3.3 is parabolic partial differential equation of the second order which requires the known initial and boundary conditions for its solution. For rectangular channels with simple sinusoidal tide A.T. Ippen (1966) derived the following equations analytically to describe sanility with distance and time.

$$\frac{C(x,t)}{C_o} = \exp\left[- \frac{U_f}{2\, E'_o B} \left\{ N - (N-x)\, e^{\frac{a_o}{h}(1-\cos\sigma t)} + B \right\} \right]^2 \quad \ldots (3.4)$$

with $N = \dfrac{h\, uo}{a_o \sigma}$, $\sigma = \dfrac{2\pi}{T}$

$$B = \frac{h_o\, U_{omax}}{a_o \sigma} \left(e^{\frac{a_o}{h_o}(1 - \cos\sigma t)} - 1 \right)$$

$$E_o = 4.5\, R_o\, U_{omax} \cdot \frac{N_o \sqrt{8g}}{1.486\, R_o^{1/6}}$$

For estuaries with variable cross-sectional areas and non-linear tidal propagation solution of the mass conservation equation is possible only by the numerical method. The solution of mass conservation equation has been of increasing interest. Lee (1970) developed a model for water quality using the six-point stone and Brian operator in explicit scheme. Bella and Dobbin (1967) proposed a model of mass transfer and mass conservation processes in estuaries and rivers by a mass balance approach directly in finite difference terms. Orlob (1967) developed a water quality model for San Francisco Bay and Delta which is being used in the present problem of salinity intrusion.

According to the numerical scheme of Orlob the channels were discretized into a number of reaches and therefore equation (3.3) can be integrated with respect to x to give the mass conservation in each channel reach as

$$\frac{\partial M}{\partial t} = Qc - AE \frac{\partial C}{\partial x} \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad (3.5)$$

where M = mass of salinity in a given reach.
The solution of equation 3.5 can be best approached by the numerical methods. The mass continuity in the model can be maintained at the node while the mass advection and diffusion occur through the channel. Since the tidal propagation is the cause of mass conservation and mass transfer process in an estuary the numerical solution of both hydraulic and salinity propagation should follow simultaneously. Equation 3.5 in finite difference form.

$$\frac{\Delta M_n}{\Delta t} = \bar{C}\, Q_i - A_i E_i \frac{\Delta C_i}{\Delta x_i} \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad (3.6)$$

C_i may be taken as difference of concentration between the nodes at two ends of the channels i, and x_i is the length of the channel. The $\bar{C}$, is the representative concentration at which the rate of advection is taking place. Orlob et al in their study of Suisan Bay found that the estimation of $\bar{C}$ by the quarter point method such as $\bar{C} = \frac{3C_n + C_k}{4}$ ... ... (3.7)

best produces the mass advection in a first order equation. In equation(3.7) C_n is the mass concentration at the node under consideration and C_k is the mass concentration at the other node of the channel under consideration.

The longitudinal dispersion co-efficient E_i is the parameter to be calibrated in the salinity model. However, the dispersion co-efficient for a river varies with location as well as time. Thatcher and Harleman (1972) suggested the following expression for E,

$$E(x,t) = K_1 Nu\, R^{5/6} + K_2 \left| \frac{\partial c}{\partial x} \right| \quad \ldots \quad \ldots \quad \ldots \quad (3.8)$$

where K_1 [Nil] and K_2 [(ft^2/sec)/(ppm/ft)] are co-efficients to be calibrated. The term $K_1 Nu\ R^{5/6}$ represents the dispersion contributed by the tidal current while the term $K_2 \left|\frac{\partial c}{\partial x}\right|$ accounts for the effects of density gradient. It has been found that the co-efficient K_1 generally has a value between 100 and 600 for natural rivers; K_2 varies widely from river to river.

CHAPTER - 4

HYDRAULIC AND SALINITY CHARACTERISTICS OF GORAI-MADHUMATI-SIBSA-PUSSUR RIVER SYSTEM

4.1 Hydraulic Characteristics

The study area is largely affected by tidal fluctuation. The tidal limit extends as far upstream as Bheramara during low water months. During the monsoon period the tidal fluctuation cannot propagate so far inland due to large amount of freshwater flow. In general the factors affecting the tidal propagation in the estuaries are tides in shoaling bay, the geometry of the channel through which the tides are propagated, roughness characteristics of the channel, upland discharge, transport properties of the channel bed material, meteorological effects and bars characterising the coastal processes at entrance of the channel.

Tides in Bangladesh are semi-diurnal, i.e., consisting of two high water and two low water in a day. There is a variation of the amplitudes of two tides in a day and such tides are called mixed tides. Amplitude of tide is highest during a new moon or a full moon and the tide is called spring tide. Amplitude of tide is least during the first quarter or third quarter of the moon and the tide is called neap tide. Fig. 10 gives the tidal water levels observed in 1978 at Hiron Point. The tide originates at the Indian Ocean and travels very fast through the Bay of Bengal. Sea level variation affects the tide. Apart from the seasonal variation of the freshwater discharge, the sea level variation is mainly due to the southwesterly monsoon. The friction force exerted by the monsoon on the surface of the water causes it to rise in the northeasterly direction of the Bay of Bengal. This variation of sea level is about one foot at the mouth of Kunga.

The channel morphology, roughness and transport properties of the river bed in the area are mainly those of alluvial rivers. The channels are both straight and meandering types with bifurcations and connective links which make the crisscrossed channel pattern. The slope is less than six inches per mile. From the study of NEDECO (1967) it has been found that the channel beds are mostly composed of fine silt with an average d_{50} values of 0.1 mm. The main rivers have the d_{90} values higher than those of the small streams. Again the d_{90} values are higher near the coast than inland. The "apparent roughness" which is the total effect of the roughness due to grain size and bed form is higher in inland than coastal areas. The resistance parameter as defined by the Manning's roughness coefficient has a value of 0.05 at the inland channels decreasing to 0.02 for the channels near the bay.

The prototype area under consideration is in the general influence of the Ganges River. The Gorai-Madhumati is the primary distributary carrying the spill water of the Ganges into the area. There is practically no rainfall during the dry months of December through February. The ground water data of the area under study is not available.

4.2 Salinity Characteristics

The Bay of Bengal is the source of saline water in the coastal areas of Bangladesh. Heavy monsoon flooding prevents the saline water from intruding too far inland. But during the dry season the tidal flow carries the saline water inland against the relatively small freshwater discharge. The variation of the hydrologic conditions of the area in space and time causes the salinity to be dynamic in space and time. The salinity starts penetrating inland from November and moves farthest inland during April and May. Then with the start of high flow, the salinity starts retreating. In 1968 the lowest flow in April did not show the farthest penetration of sanility. Instead, May was the worst month of salinity. This was because the sea level is higher during May than April. Figure 11 to 16 presents salinity condition of the south-west delta at various times. With respect to highwater and lowwater there is generally a variation of salinity at a section. This can be seen in Figures 17 and 18, but this periodic fluctuation of salinity may not be found in case of low salinity as shown in Figure 19 or very high salinity near the estuary mouth as shown in Figure 20. The salinity variation with depth have been found negligible. The tidal currents in the area are strong enough to mix the saltwater with freshwater and there is no clearly defined saltwater-freshwater interface. Fig. 21 shows the result of salinity sampling along the vertical collected by the Hydrology Directorate of Bangladesh Water Development Board. For all practical purposes the bottom salinity may be taken as the average salinity for the section.

By far the most important factor that determines salinity at a reach is the upland freshwater discharge. This can be easily seen from the superimposed salinity profiles in Figures 22-26. Figure 27 presents the plot of salinity as recorded in Khulna in 1968, 1976 and 1977. From this plot it is seen that the sanility is minimum in 1968 when the dry season upland freshwater discharge was maximum (average Ganges flow for February, March and April, 1968 was 78,700 cusecs) and salinity is maximum in 1976 when the dry season flow was minimum (average Ganges flow for February, March and April, 1976 was 35,700 cusecs). Velocity in channels play a very important role in pushing salinity downstream. Due to the channel arrangement at Khulna, the freshwater flow is confined to a single channel at Khulna and has a higher velocity than 5 or 6 miles downstream or upstream where the flow is divided between two channels and later divided again. This higher average velocity at Khulna is more effective in holding back the saline bay waters. Thus, in 1968 with 3,800micromhos registered only four miles downstream, the maximum salinity registered at Khulna was about 1000 micromhos But when the Gorai flows dropped almost to zero in 1976, the high salinities moved past Khulna and on upto Bardia. The maximum salinity measured at Khulna in 1976 was about 13,600 micromhos.

CHAPTER - 5

DISCUSSION ON CUMPUTER PROGRAM AND RESULTS

5.1 Computer Program

The mathematical model developed to have an impression of the magnitudes of saline water penetration in Gorai-Madhumati-Sibsa-Pussur river system for different quantities of upland freshwater discharge comprises a main program and 7 subroutines written in FORTRAN-IV. Flow charts of these computer programs are presented in Appendix - C. Computer programs are given in Appendix - D. Figure 32 shows schematic representation of computational procedure. For the purpose of computation the prototype delta has been discretized into 59 nodes and 75 branches as shown in Figure 7. The main program reads in the data necessary for computation in the node and branch Model. It computes the water levels and discharges in each node and branch by the explicit method using Eq. 2.12. The subroutine REP stabilizes and adjusts the computed solution by Gauss-Seidel iteration technique using Eq. 2.11. The subroutine GEOM reads in the data necessary for grid model and also the tidal water levels at Hiron Point. The subroutine AREA computes the cross-sectional areas, hydraulic radii and top widths at any given water levels in node and branch model. The subroutine TIDE2 computes the cross-sectional areas, hydraulic radii and top widths at grid points in grid model. It also interpolates the observed hourly water levels at Hiron Point at the time interval Δt to be used as the downstream boundary condition in the grid model. This subroutine calls the subroutine COMHQ to compute water levels and discharges at the grid points. The subroutine COMHQ computes the values of θ and ω for all grids in Eqs. 2.32 and 2.33. The computed θ and ω are then transferred to the main program and then to subroutine REP for further computation of the incremental changes of the water levels and discharges at the connection point of node and branch model and grid model using Eqs. 2.38 and 2.39. The subroutine COMS computes salinity at all nodes using Eqs. 3.6, 3.7 and 3.8. The subroutine TIDE3 recomputes the water levels and discharges in the grid model at grid points with the value of water level in node 1 computed in subroutine REP and the values of θ and ω computed from the subroutine COMHQ using Eqs. 2.34 and 2.35.

As regards schematization of river geometry five different elevations including elevation of channel bottom were taken. The portion of area between channel bottom and immediately higher specific elevation were taken to be of triangular section and that between any two other specific elevations were assumed trapezoidal. Table 2 presents the bottom elevation and four other specific elevations, measured with respect to Chart Datum (Chart Datum is that level for a particular river which has been recorded as the lowest water level for that river), and corresponding specific areas. Lengths of the channels are given in table 3. The division of a river section into a multiple number of rectilineal figures have been necessary because of irregularities of the river section.

Figure 28 to 30 presents some of the channel sections in the study area. Obviously in the river geometry schematization heights of banks have not been considered, because dry season flows are too lean to cause overtopping of banks.

The parameters which required calibration in the model are Manning roughness coefficient (ENM) and calibration constants K_1(EK1) and K_2 (EK2). Table 4 gives calibrated values of roughness coefficients of all the channels. These coefficients have been obtained by assuming different values of the roughness coefficient and then computing water levels and discharges. The set of assumptions which gave computed water levels and discharges wellnigh equal to those observed and recorded has been chosen. In order to have an idea about sensitivity of the model towards channel roughness Figure 31 compares computed water levels at Mongla for two values of roughness coefficients, 0.015 and 0.02, in channel no. 1, with actual observed water levels. The values of K_1 and K_2 have been found to be 20 [Nil] and 0.3 {$(ft^2/sec)/(ppm/ft)$}. It is to be noted that different channels are likely to have different values of parameters K_1 and K_2. If hourly records of salinity data at sufficient number of stations are available, K_1 and K_2 of individual channels may be calibrated precisely.

The only source of salinity in the study area is the seawater. Seawater salinity is most variable in coastal areas because of mixing of river water. In the present model an average constant value of salinity, 33000 micromho has been used due to non-availability of salinity data of the seawater in the vicinity of Pussur river mouth.

5.2 Results of the Study

To investigate the effect of withdrawal of upland discharge freshwater discharge entering through Madhumati river into the study area has been varied from 2000 to 10,000 cusecs. The extent of saline water penetration for each particular value of upland discharge has been computed. Table 5 to 7 and Fig. 33 presents computed salinity levels at Mongla, Chalna, Nalianala, Khulna and Bardia for three values of upland discharges, 2,000, 5,000 and 10,000 cusecs. The tables also give lengths along Pussur river which experiences 2,000 micromho or more salinity for each case. It is to be noted that salinity intrusion in the prototype delta occurs for several months, but in the present model the computation has been carried for a few days and iterated several times due to limitations in fund and also in memory spaces available in the computer used (IBM 360N-FO-479 3-6, total memory = 64K). The results therefore should not be taken as absolute, rather it should be looked upon as the sensitivity of salinity to variations in upland freshwater discharge.

A look at tables 5,6 and 7 shows that with increasing values of upland freshwater discharge there is a decrease in salinity concentration. The reduction of high water salinity concentration is more sharp than that of low water salinity concentration. It is interesting to note that although no freshwater discharge into Sibsa have been considered there has been a decrease in salinity concentration at Nalianala with reduction of salinity in Pussur. This establishes the fact that the river systems are interconnected in their salinity distribution characteristics.

CHAPTER - 6

CONCLUSION AND RECOMMENDATIONS

The conclusion that can be inferred from the study is that upland discharge plays a very important role to prevent salinity intrusion. Not withstanding the fact that there are other dynamic characteristics; such as changes in river regime, tide, ground water contribution, etc.; which have major influence on salinity movement, the upland discharge data can provide an extremely useful insight as to the degree of deterioration of salinity problems. Again the salinity characteristics of a single channel in the delta cannot be considered independently since there is interchange and transport of salinity between channels in the complicated criss-crossed channel pattern of the delta. In the light of this study the followings are recommended :-

1. To predict salinity intrusion in Southwest region of Bangladesh a hydrodynamic model may be developed for the whole prototype delta with scope for detailing part of the area if such need arises. The model may comprise a multiple number of models of small areas, such as the one developed, connected and superposed or a single model when adequate memory spaces are available in the computer to include all channels in the delta.

2. To make such a model reliable, care that should be taken in collecting field data cannot be overmphasized. The data required for such a model are neither too voluminous nor too costly a venture. They should be recent. Previous data beyond a few years are not necessary. The data required are hydrographic charts of channels, hourly water levels, hourly salinity concentrations and hydrographs of flows at upstream model boundary.

3. Tidal water level recorders should be located at important estuary mouths. Inland installation of tidal gages should be uniformly distributed in space. A total of 100 tidal gages for the whole prototype delta should be adequate. Salinity observations should be hourly and static. Some salinity monitoring stations should be located offshore. Inland installations should be uniformly distributed in space. A total of 100 salinity recording stations should be sufficient for the delta and both salinity and tidal gages may be installed together.

4. The present practice of collecting static and dynamic salinity data from field samples by Bangladesh Water Development Board may be improved by installing automatic salinity gages which will record daily salinity concentrations. It is relatively simple to design an automatic

salinometer which will transfer reading on a current meter to a pen that will record on a moving paper.

5. The depth of water at which salinity readings are to be taken can be arbitrary since vertical variation of salinity is negligible, but to avoid interference due to water level fluctuation it should be near the channel bottom.

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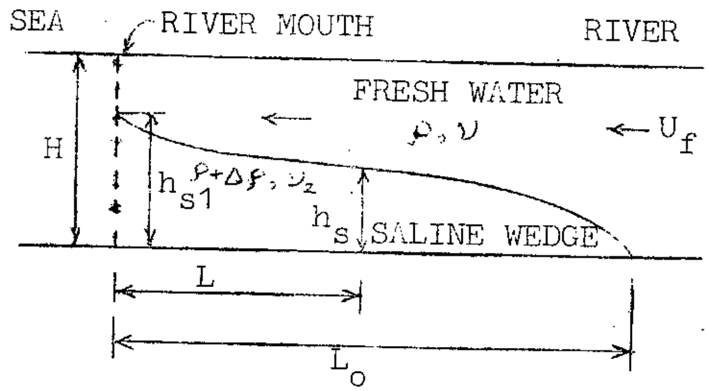
APPENDIX - A

TABLES



Definition of notations in arrested saline wedge

TABLE - 1

Affine Shape of Arrested Saline Wedges

L/L_o	h_s/h_{s1}	L/L_o	h_s/h_{s1}	L/L_o	h_s/h_{s1}
0.00	1.000	0.35	0.570	0.70	0.345
.05	.885	.40	.538	.75	.318
.10	.812	.45	.500	.80	.280
.15	.748	.50	.468	.85	.240
.20	.685	.55	.440	.90	.189
.25	.647	.60	.410	.95	.138
.30	.608	.65	.380	1.00	.000

TABLE 2

SPECIFIC ELEVATIONS AND CORRESPONDING AREAS OF CHANNELS

** NODE AND BRANCH MODEL **

Branch No.	Bottom Elevation EB	E1	A1	E2	A2	E3	A3	E4	A4
(1)	-65.0	-40.0	63000.0	-20.0	183000.0	0.0	360000.0	10.0	46000.0
(2)	-20.0	- 5.0	20000.0	0.0	35000.0	10.0	75000.0	20.0	115000.0
(3)	-35.0	-20.0	3500.0	-10.0	16000.0	0.0	40000.0	10.0	65000.0
(4)	-35.0	0.0	10800.0	10.0	16800.0	20.0	22800.0	30.0	29000.0
(5)	-12.0	0.0	1200.0	10.0	3200.0	20.0	5200.0	30.0	7500.0
(6)	-10.0	0.0	1000.0	10.0	3000.0	20.0	5000.0	30.0	7000.0
(7)	-30.0	0.0	8000.0	10.0	13000.0	20.0	18000.0	30.0	23000.0
(8)	-15.0	0.0	4000.0	10.0	9000.0	20.0	14000.0	30.0	19000.0
(9)	-30.0	-10.0	3000.0	0.0	7000.0	10.0	11000.0	20.0	15000.0
(10)	-40.0	-20.0	7000.0	0.0	27000.0	10.0	38000.0	20.0	50000.0
(11)	-20.0	-10.0	4500.0	0.0	18000.0	10.0	36000.0	20.0	54000.0
(12)	-20.0	-10.0	5000.0	0.0	17000.0	10.0	31000.0	20.0	45000.0
(13)	-23.0	-20.0	1200.0	-10.0	16000.0	0.0	40000.0	10.0	66000.0
(14)	-30.0	-18.0	15000.0	0.0	73000.0	10.0	115000.0	20.0	160000.0
(15)	-50.0	-40.0	6000.0	-18.0	41000.0	0.0	95000.0	10.0	137000.0
(16)	-40.0	-35.0	700.0	-18.0	26000.0	-5.0	68000.0	10.0	150000.0
(17)	-40.0	-35.0	2500.0	-18.0	40000.0	0.0	120000.0	10.0	175000.0
(18)	-35.0	-25.0	5000.0	-18.0	25000.0	0.0	130000.0	10.0	200000.0
(19)	-75.0	-50.0	20000.0	-30.0	110000.0	0.0	440000.0	10.0	595000.0
(20)	-22.0	-10.0	10000.0	0.0	35000.0	10.0	65000.0	20.0	95000.0

* Elevations are expressed in feet above Chart Datum and areas in square feet.

TABLE 2 (Continued)

Branch No.	Bottom Elevation EB	E1	A1	E2	A2	E3	A3	E4	A4
(21)	-50.0	-30.0	10000.0	-20.0	22000.0	0.0	50000.0	10.0	70000.0
(22)	-40.0	-30.0	5000.0	-20.0	20000.0	0.0	70000.0	10.0	105000.0
(23)	-50.0	-30.0	20000.0	-20.0	50000.0	0.0	135000.0	10.0	180000.0
(24)	-75.0	-45.0	37500.0	-20.0	112500.0	0.0	192500.0	10.0	237000.0
(25)	-70.0	-50.0	15000.0	-30.0	60000.0	0.0	157000.0	10.0	192000.0
(26)	-75.0	-60.0	11000.0	-30.0	100000.0	0.0	235000.0	10.0	285000.0
(27)	-55.0	-40.0	22000.0	-20.0	102000.0	0.0	222000.0	10.0	300000.0
(28)	-76.0	-60.0	9000.0	-10.0	159000.0	0.0	205000.0	10.0	250000.0
(29)	-100.0	-60.0	40000.0	-30.0	110000.0	0.0	230000.0	10.0	280000.0
(30)	-120.0	-40.0	120000.0	-10.0	270000.0	0.0	345000.0	10.0	430000.0
(31)	-15.0	0.0	7500.0	10.0	17500.0	20.0	27500.0	30.0	37500.0
(32)	-15.0	0.0	7500.0	10.0	17500.0	20.0	27500.0	30.0	37500.0
(33)	-20.0	-10.0	5000.0	0.0	16000.0	10.0	28000.0	20.0	40000.0
(34)	-50.0	-30.0	9000.0	-10.0	30000.0	0.0	42000.0	10.0	55000.0
(35)	-20.0	0.0	10000.0	-10.0	20000.0	20.0	30000.0	30.0	40000.0
(36)	-20.0	0.0	5000.0	10.0	10000.0	20.0	15000.0	30.0	20000.0
(37)	-20.0	0.0	4000.0	10.0	11000.0	20.0	19000.0	30.0	27000.0
(38)	-35.0	-10.0	3750.0	0.0	7500.0	10.0	11500.0	20.0	15500.0
(39)	-50.0	-30.0	5000.0	-10.0	20000.0	0.0	30000.0	10.0	40000.0
(40)	-30.0	-20.0	2500.0	-10.0	10500.0	0.0	21000.0	10.0	40000.0

* Elevations are expressed in feet above Chart Datum and areas in square feet.

TABLE 2 (Continued)

Branch No.	Bottom Elevation EB	E1	A1	E2	A2	E3	A3	E4	A4
(41)	-35.0	0.0	12000.0	10.0	18000.0	20.0	24000.0	30.0	30000.0
(42)	-40.0	-20.0	2000.0	-10.0	6000.0	0.0	11000.0	10.0	16000.0
(43)	-30.0	0.0	6000.0	10.0	10000.0	20.0	14000.0	30.0	18000.0
(44)	-18.0	0.0	1800.0	10.0	3800.0	20.0	5800.0	30.0	7800.0
(45)	-16.0	0.0	1600.0	10.0	3600.0	20.0	5600.0	30.0	7600.0
(46)	-16.0	0.0	1600.0	10.0	3600.0	20.0	5600.0	30.0	7600.0
(47)	-24.0	0.0	2400.0	10.0	4400.0	20.0	6400.0	30.0	8500.0
(48)	-45.0	0.0	9200.0	10.0	13200.0	20.0	17200.0	30.0	21500.0
(49)	-30.0	0.0	4500.0	10.0	7500.0	20.0	10500.0	30.0	14000.0
(50)	-36.0	0.0	10800.0	10.0	16800.0	20.0	23000.0	30.0	30000.0
(51)	-34.0	0.0	5100.0	10.0	8100.0	20.0	11100.0	30.0	14500.0
(52)	-70.0	0.0	35000.0	10.0	45000.0	20.0	55000.0	30.0	65000.0
(53)	-50.0	0.0	25000.0	10.0	35000.0	20.0	45000.0	30.0	55000.0
(54)	-20.0	0.0	4000.0	10.0	11000.0	20.0	19000.0	30.0	27000.0
(55)	-40.0	0.0	20000.0	10.0	30000.0	20.0	40000.0	30.0	50000.0
(56)	-30.0	0.0	9000.0	10.0	15000.0	20.0	21000.0	30.0	27000.0
(57)	-50.0	-30.0	5000.0	0.0	29000.0	10.0	40000.0	20.0	52000.0
(58)	-30.0	0.0	12000.0	10.0	20000.0	20.0	28000.0	30.0	36000.0
(59)	-50.0	0.0	12500.0	10.0	17500.0	20.0	22500.0	30.0	28000.0
(60)	-20.0	-10.0	5000.0	0.0	10000.0	10.0	15000.0	20.0	20000.0

*Elevations are expressed in feet above Chart Datum and areas in square feet.

TABLE 2 (Continued)

Branch No.	Bottom Elevation EB	E1	A1	E2	A2	E3	A3	E4	A4
(61)	-40.0	-10.0	3800.0	0.0	7800.0	10.0	12800.0	20.0	18000.0
(62)	-10.0	0.0	5000.0	10.0	16000.0	20.0	28000.0	30.0	40000.0
(63)	-30.0	0.0	9000.0	10.0	15000.0	20.0	21000.0	30.0	27000.0
(64)	-13.0	0.0	3500.0	10.0	13500.0	20.0	27000.0	30.0	40000.0
(65)	-30.0	0.0	15000.0	10.0	25000.0	20.0	35000.0	30.0	45000.0
(66)	-60.0	-30.0	15000.0	0.0	60000.0	10.0	80000.0	20.0	105000.0
(67)	-30.0	-20.0	5000.0	-10.0	20000.0	0.0	42000.0	10.0	65000.0
(68)	-25.0	-10.0	7000.0	0.0	17000.0	10.0	27000.0	20.0	37000.0
(69)	-20.0	-10.0	5000.0	0.0	18000.0	10.0	43000.0	20.0	68000.0
(70)	-15.0	-10.0	2500.0	0.0	18000.0	10.0	38000.0	20.0	58000.0
(71)	-25.0	-10.0	7500.0	0.0	20000.0	10.0	33000.0	20.0	47000.0
(72)	-30.0	-10.0	5000.0	0.0	11000.0	10.0	17000.0	20.0	23000.0
(73)	-15.0	- 5.0	10000.0	0.0	25000.0	10.0	65000.0	20.0	110000.0
(74)	-30.0	-20.0	5000.0	-10.0	16000.0	0.0	28000.0	10.0	40000.0
(75)	-25.0	-10.0	3000.0	0.0	8000.0	10.0	15000.0	20.0	23000.0

*Elevations are expressed in feet above Chart Datum and areas in square feet.

TABLE 2 (Continued)

SPECIFIC ELEVATIONS AND CORRESPONDING AREAS OF CHANNELS

** GRID MODEL **

Segment Length from Sea in miles	Elevation B	AREA AR	BE1	AB1	BE2	AB2	BE3	AB3	BE4	AB4
0.0	-18	195000.	-12.0	325000.	-6.0	480000.	0.0	654000.	10.0	955000.
1.5	-18	240000.	- 6.0	480000.	0.0	645000.	10.0	950000.	20.0	11300000.
3.0	-18	215000.	-6.0	490000.	0.0	634000.	10.0	875000.	20.0	1115000.
4.5	-18	245000.	-6.0	485000.	0.0	620000.	10.0	860000.	20.0	1115000.
6.1	-18	170000.	-12.0	254000.	-6.0	380000.	0.0	550000.	10.0	870000.
7.6	-18	172000.	-12.0	247000.	-6.0	397000.	0.0	353000.	10.0	910000.
9.1	-18	253000.	-12.0	355000.	-6.0	500000.	0.0	675000.	10.0	975000.

* Elevations are expressed in feet above Chart Datum and areas in square feet.

TABLE 3

LENGTHS OF CHANNELS
** NODE AND BRANCH MODEL **

Branch No.	Length DELX(I) in mile	Branch No.	Length DELX(I) in mile	Branch No.	Length DELX(I) in mile
1	5.50	26	4.00	51	20.00
2	4.50	27	7.00	52	5.00
3	11.50	28	5.75	53	4.50
4	9.00	29	6.00	54	4.00
5	12.00	30	3.00	55	9.50
6	17.00	31	11.50	56	8.50
7	16.00	32	1.00	57	1.70
8	4.00	33	2.00	58	15.00
9	11.00	34	4.00	59	12.50
10	8.30	35	4.00	60	4.00
11	7.54	36	3.75	61	4.00
12	1.50	37	1.75	62	4.00
13	10.30	38	4.00	63	4.00
14	8.50	39	2.60	64	2.00
15	3.50	40	8.50	65	4.00
16	6.00	41	1.50	66	7.25
17	9.00	42	6.00	67	3.25
18	10.00	43	20.70	68	11.50
19	2.25	44	12.00	69	6.00
20	3.00	45	4.00	70	6.00
21	1.00	46	5.00	71	3.25
22	5.00	47	10.00	72	2.50
23	8.50	48	3.00	73	2.20
24	3.00	49	10.00	74	4.50
25	4.50	50	7.00	75	7.00

** GRID MODEL **

LENGTH OF ESTUARY KUNGA = 48000.0 FEET

TABLE 4

MANNING ROUGHNESS COEFFICIENT OF CHANNELS

** NODE AND BRANCH MODEL **

Branch No.	Manning's n ENM(I)	Branch No.	Manning's n ENM(I)	Branch No.	Manning's n ENM(I)
1	0.020	26	0.030	51	0.040
2	0.020	27	0.025	52	0.030
3	0.020	28	0.020	53	0.030
4	0.040	29	0.020	54	0.045
5	0.020	30	0.020	55	0.050
6	0.040	31	0.030	56	0.030
7	0.030	32	0.035	57	0.030
8	0.040	33	0.035	58	0.030
9	0.040	34	0.030	59	0.040
10	0.040	35	0.035	60	0.040
11	0.030	36	0.030	61	0.040
12	0.030	37	0.030	62	0.040
13	0.030	38	0.040	63	0.040
14	0.030	39	0.040	64	0.030
15	0.030	40	0.040	65	0.030
16	0.030	41	0.040	66	0.030
17	0.025	42	0.040	67	0.030
18	0.020	43	0.040	68	0.040
19	0.020	44	0.050	69	0.025
20	0.020	45	0.050	70	0.020
21	0.030	46	0.040	71	0.025
22	0.030	47	0.040	72	0.020
23	0.030	48	0.040	73	0.020
24	0.030	49	0.040	74	0.030
25	0.030	50	0.040	75	0.040

TABLE - 5

COMPUTED SALINITY CONCENTRATIONS FOR AN UPLAND FRESHWATER DISCHARGE OF 2000 CUSECS FROM GORAI-MADHUMATI INTO PUSSUR RIVER SYSTEM

Stations	Node No.	Salinity in micromhos
Bardia	7	600 (High water) 270 (Low water)
Chalna	13	17800 (High water) 11700 (Low water)
Khulna	39	4500 (High water) 4000 (Low water)
Mongla	14	22600 (High water) 16700 (Low water)
Nalianala	24	17000 (High water) 13000 (Low water)

Distance of 2000 micromhos salinity front from the sea along Pussur River = 100 miles.

TABLE - 6

COMPUTED SALINITY CONCENTRATIONS FOR AN UPLAND FRESHWATER DISCHARGE OF 5000 CUSECS FROM GORAI-MADHUMATI INTO PUSSUR RIVER SYSTEM.

Station	Node No.	Salinity in micromhos
Bardia	7	240 (High water) 50 (Low water)
Chalna	13	15900 (High water) 11900 (Low water)
Khulna	39	4200 (High water) 3640 (Low water)
Mongla	14	21400 (High water) 16600 (Low water)
Nalianala	24	16300 (High water) 13000 (Low water)

Distance of 2000 micromhos salinity front from the sea along Pussur River = 94 miles.

TABLE - 7

COMPUTED SALINITY CONCENTRATION FOR AN UPLAND FRESHWATER DISCHARGE OF 10,000 CUSECS FROM GORAI-MADHUMATI INTO PUSSUR RIVER SYSTEM.

Stations	Nodes No.	Salinity in micromhos.
Bardia	7	90 (High water) 0 (Low water)
Chalna	13	14400 (High water) 3900 (Low water)
Khulna	39	3800 (High water) 3200 (Low water)
Mongla	14	21500 (High water) 15000 (Low water)
Nalianala	24	16600 (High water) 12000 (Low water)

Distance of 2000 micromhos salinity front from the sea along Pussur River = 85 miles.

APPENDIX - B

FIGURES

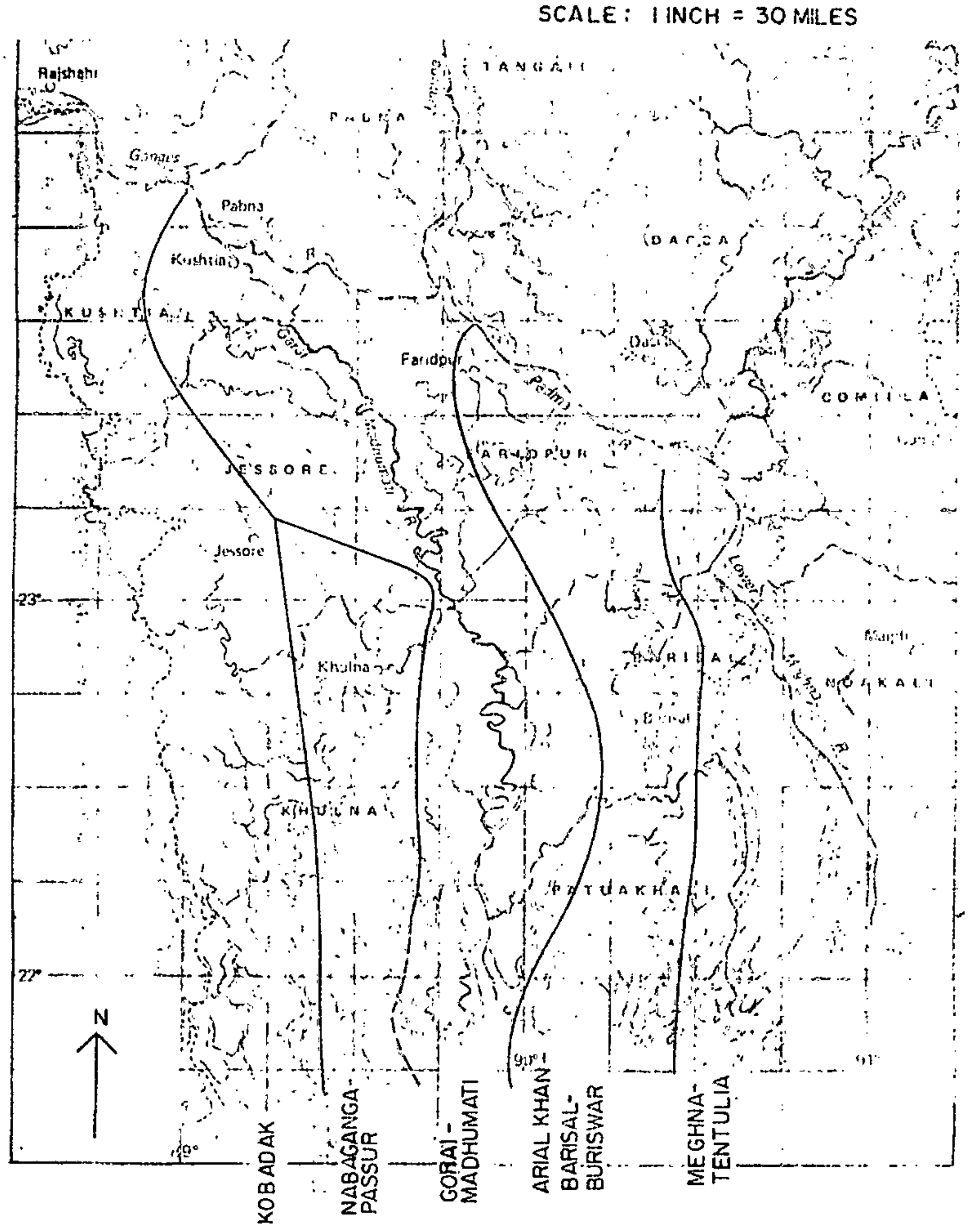


FIG. I FIVE SALINITY COMPARTMENTS OF SOUTHWEST DELTA OF BANGLADESH
(Source: Special Studies, BWDB, 1977)

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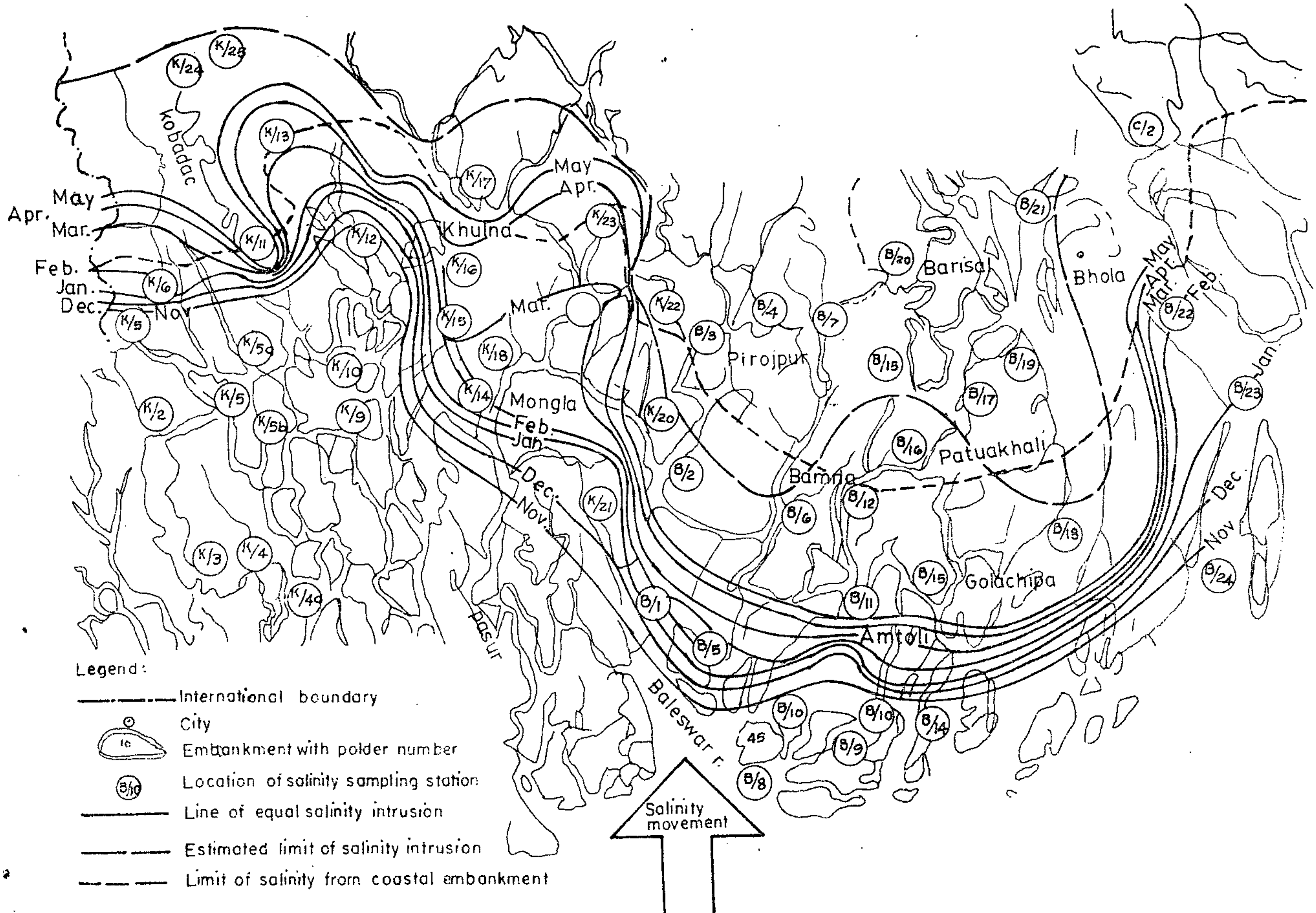

FIG.2 LINES OF EQUAL SALINITY FOR THE KHULNA BAKERGANJ AREA NOVEMBER-MAY

(Source: Leedshill - DeLeuw, 1968)

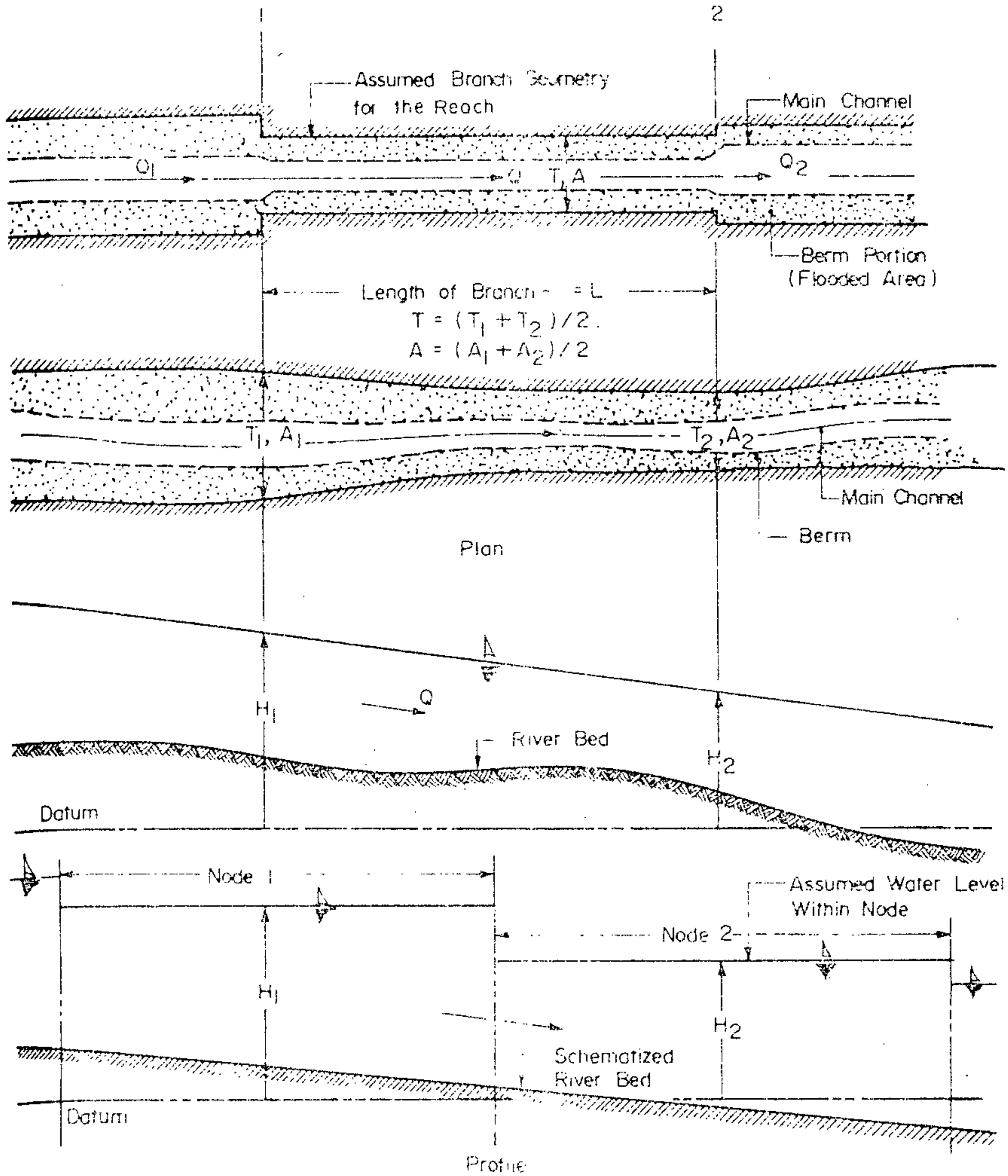

Fig. 3 Schematized Flow System for Node and Branch Computation

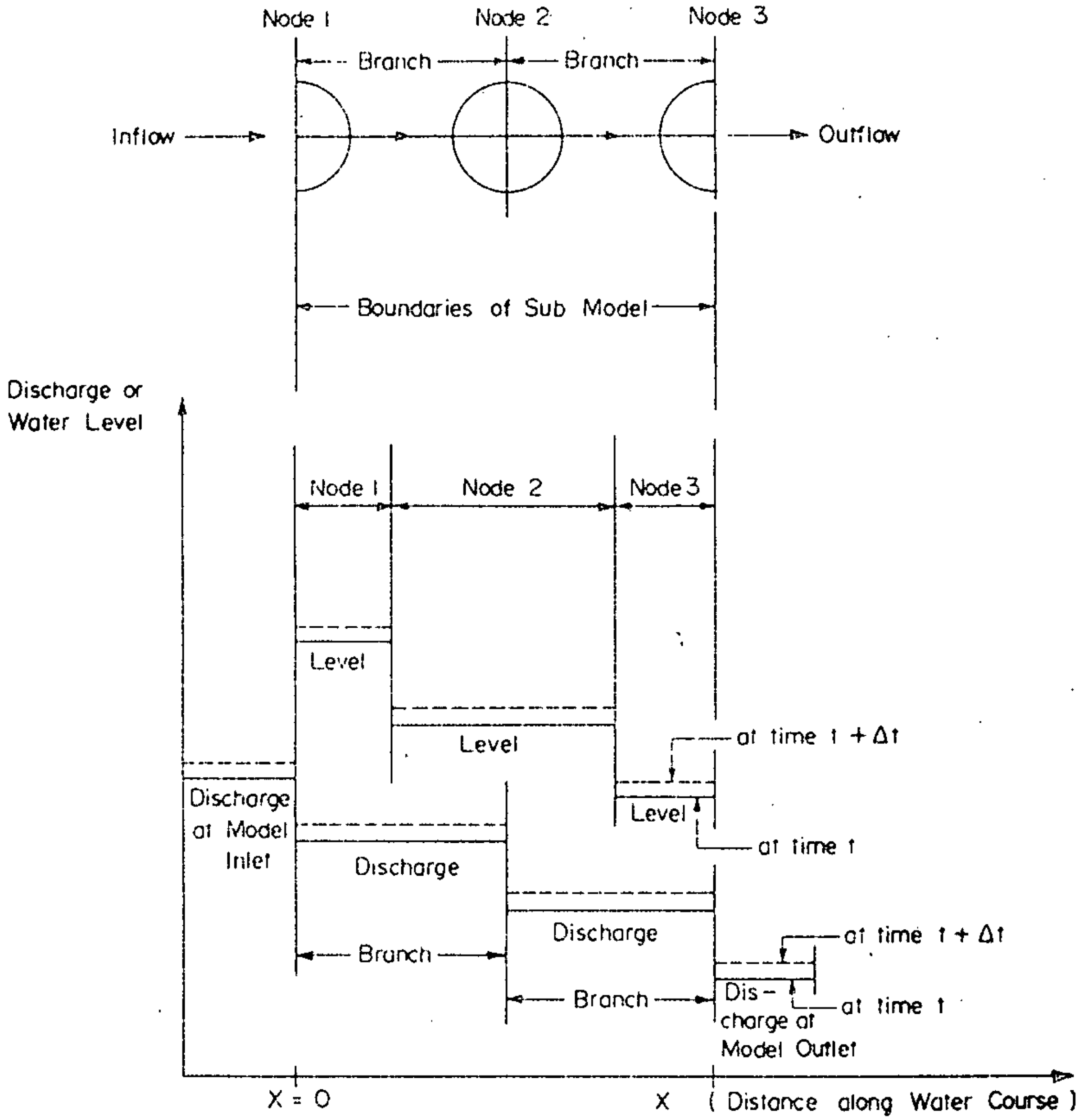

Fig. 4 Graphical Representation of Assumptions Regarding Discharges in Branches and Water Levels in Nodes.

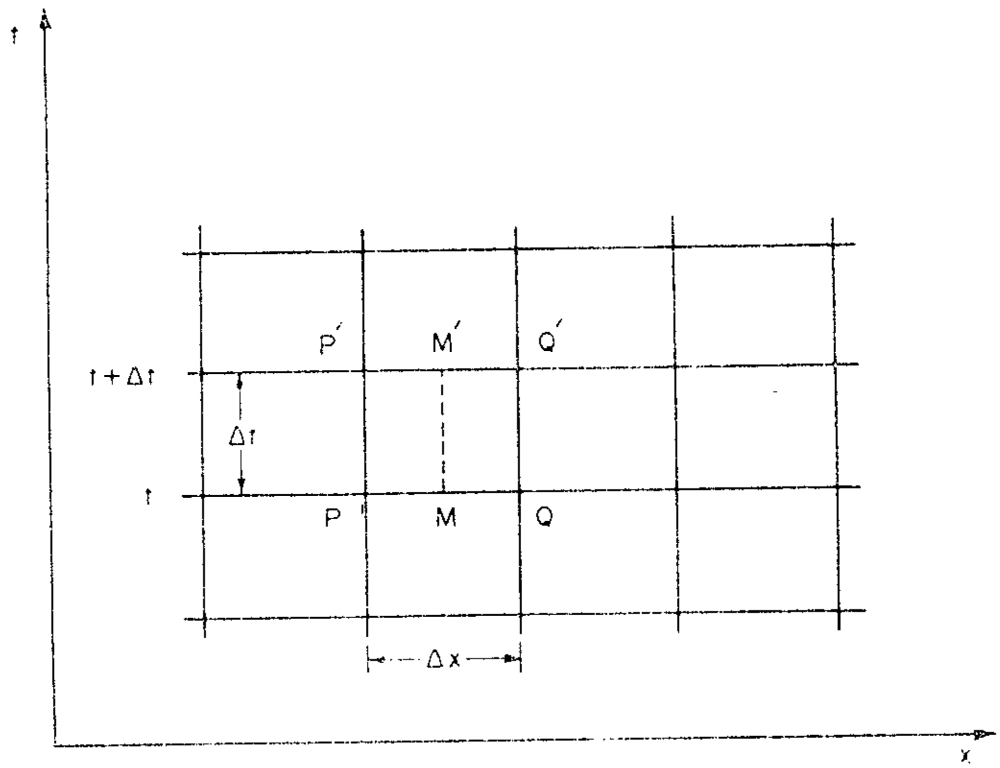

FIG. 5 Rectangular Grid Showing Approximation to Derivatives.

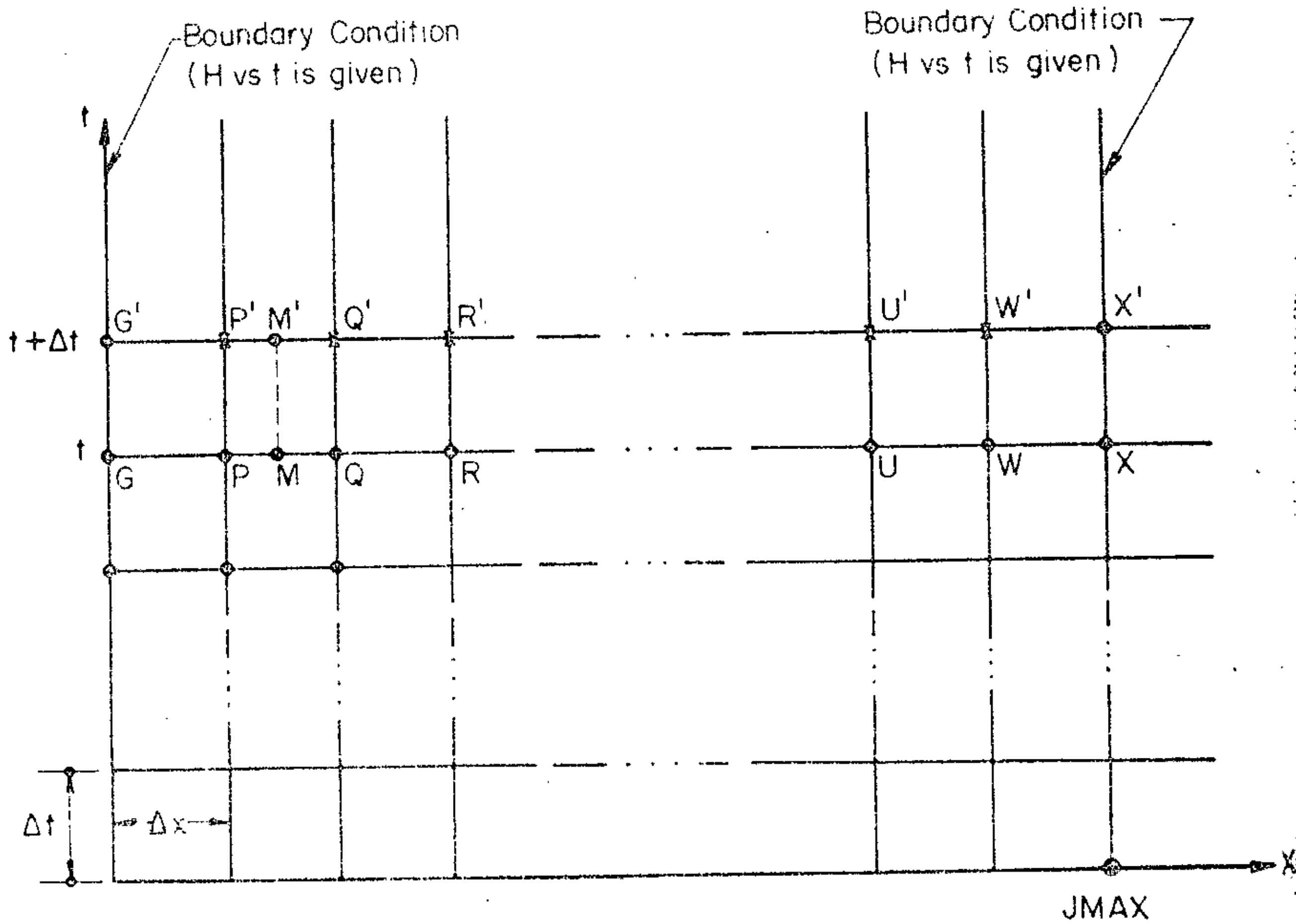

FIG. 6 Rectangular Grid Applied to a Single River Reach.

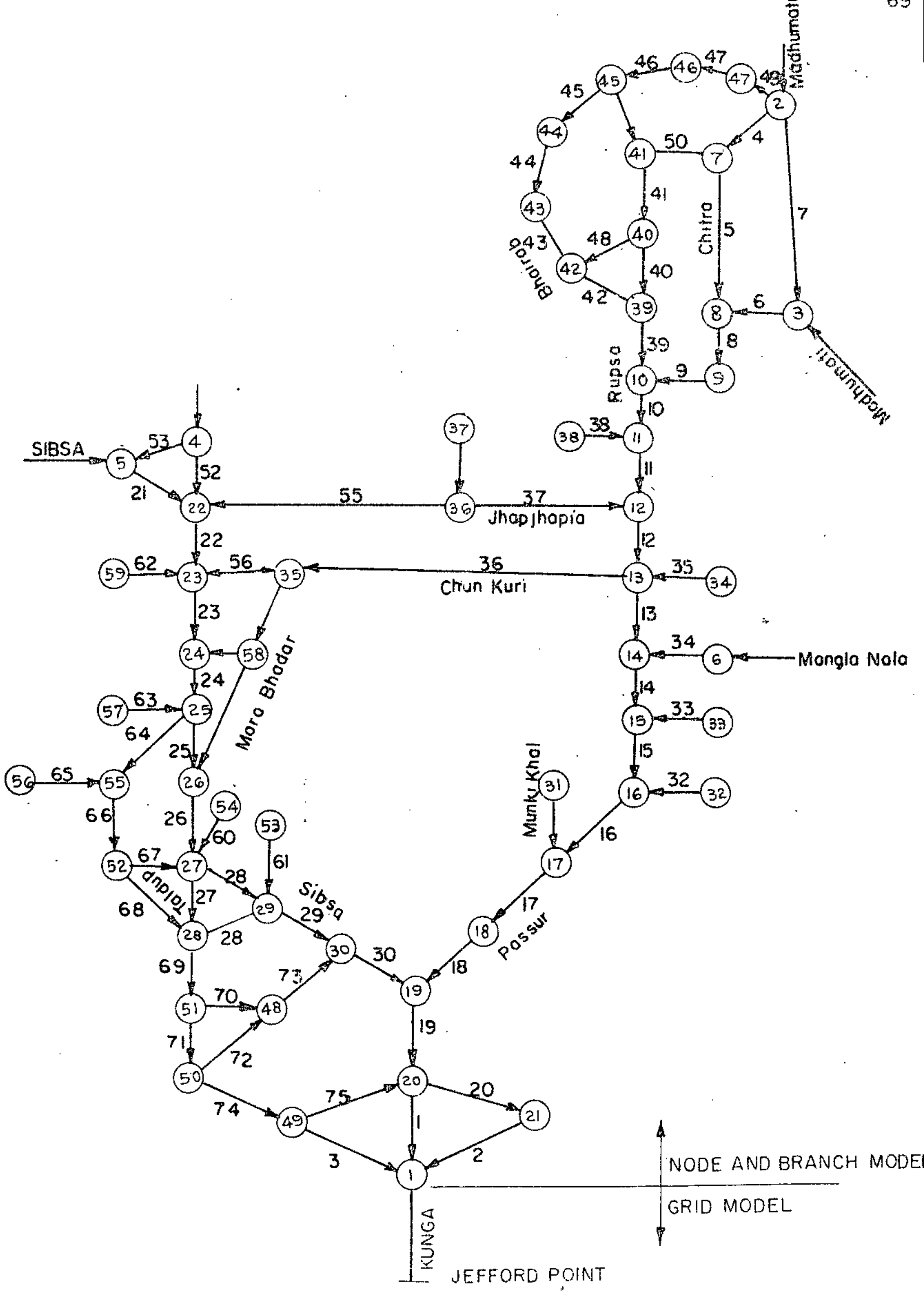

Fig. 7 NODES AND BRANCHES DIAGRAM WITH GRID MODEL FOR GORAI MADHUMATI SIBSA PASSUR RIVER SYSTEM

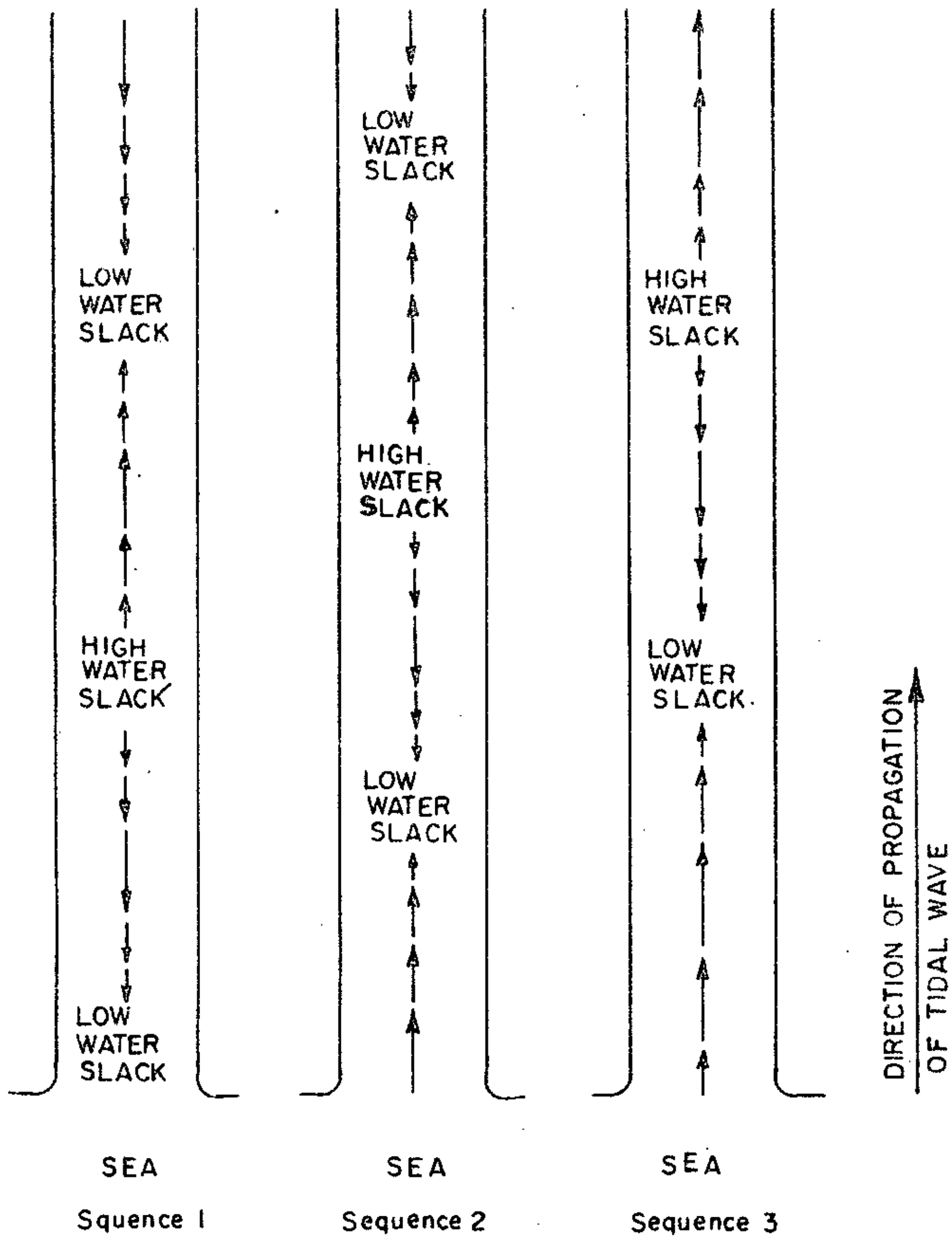

FIG. 8 SCHEMATIC REPRESENTATION OF VELOCITY DISTRIBUTION IN AN ESTUARY AND PROPAGATION OF SLACK WATERS

(Source: M. Grant Gross, 1972)

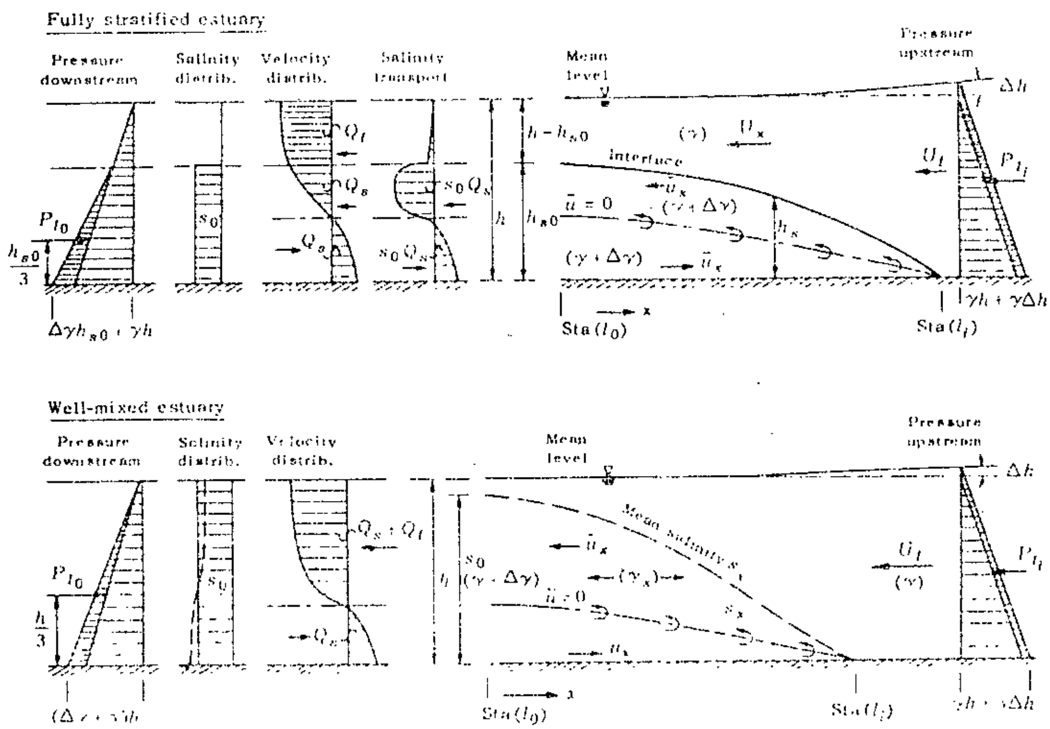

FIG. 9 SCHEMATIC REPRESENTATION OF SALINITY INTRUSIONS IN ESTUARIES
(Source: A.T. Ippen, 1966)

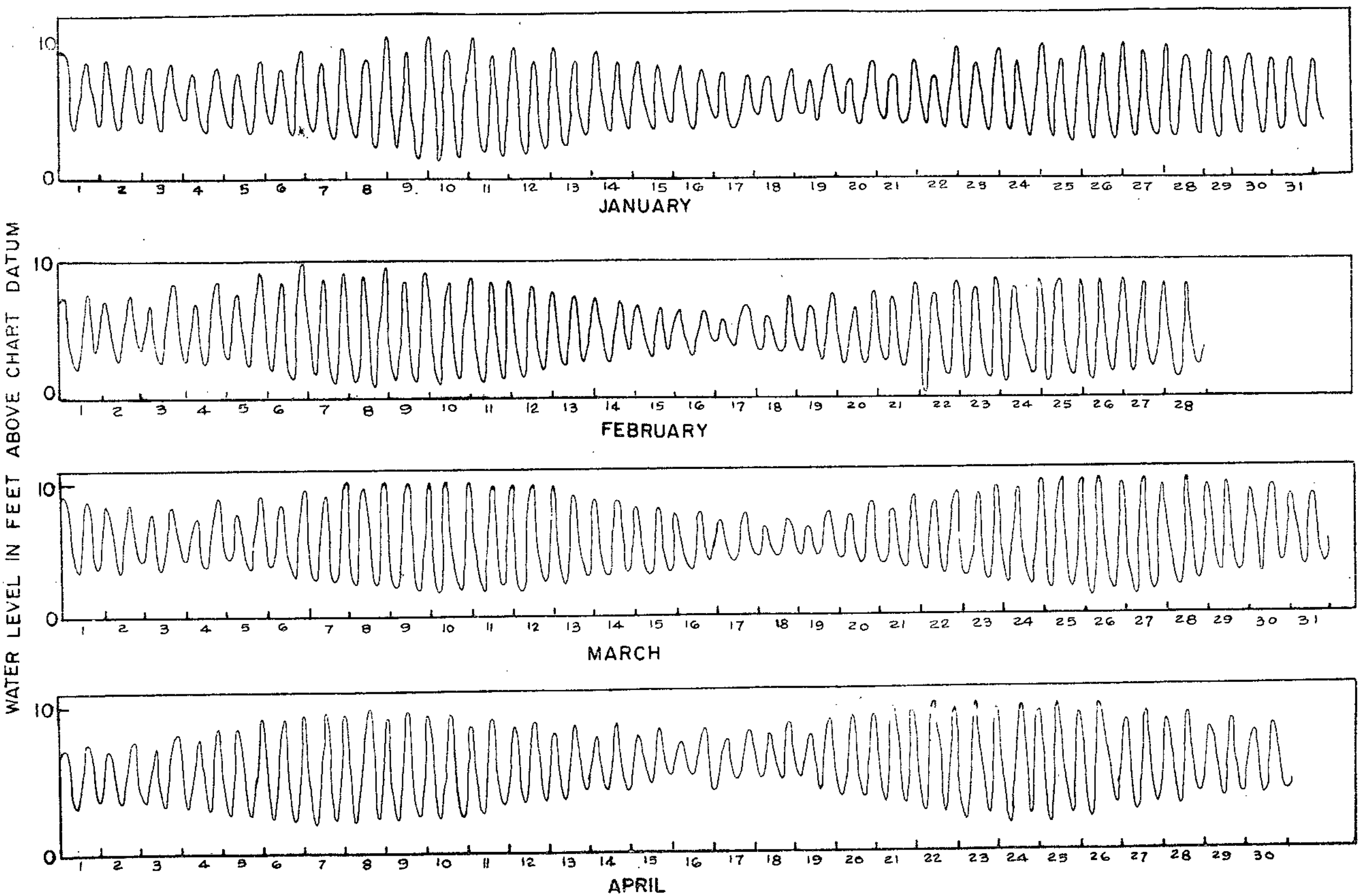

FIG.10 TIDE AT HIRON POINT (1978)

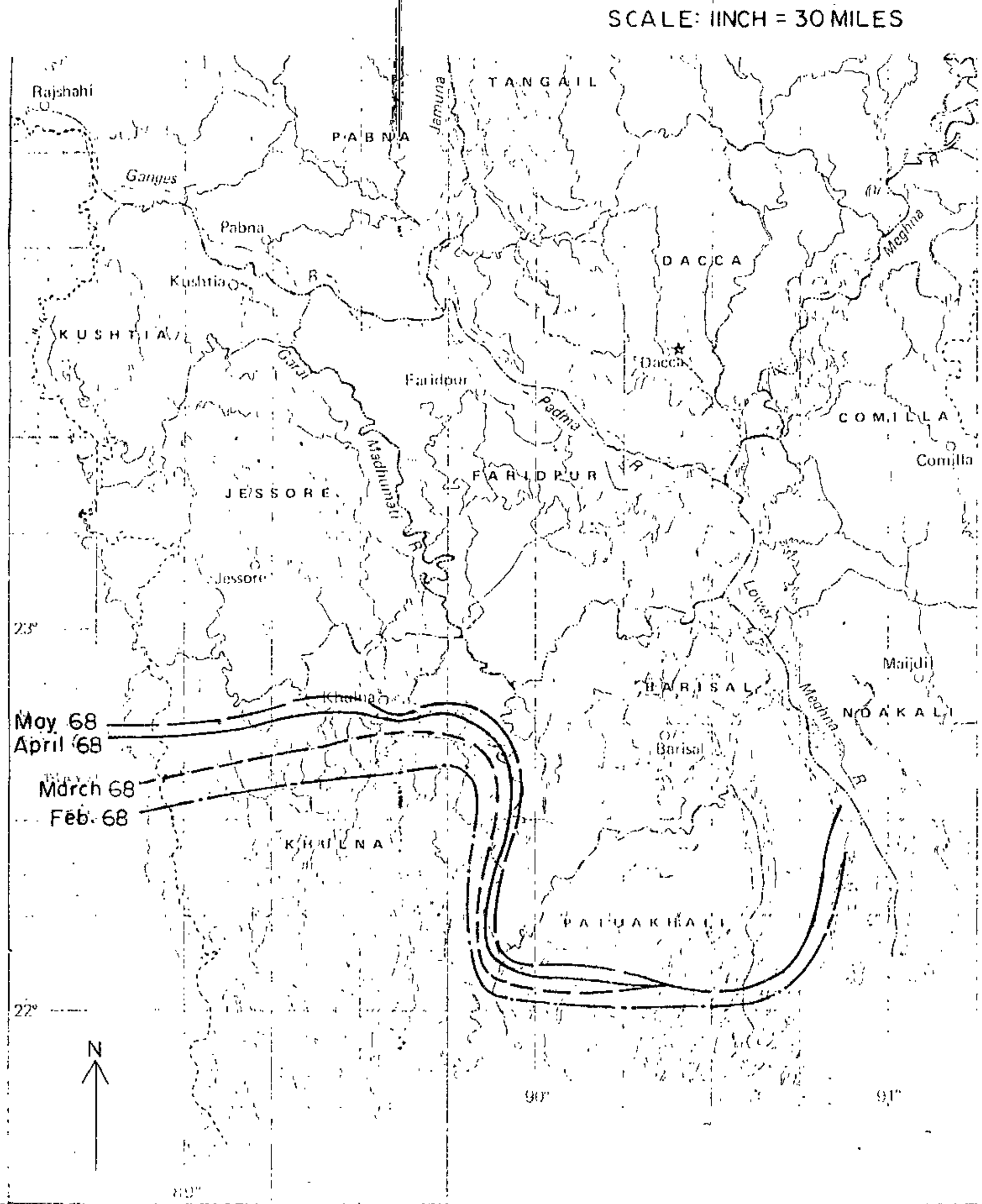

FIG. II 2000 MICROMHO SALINITY LINES IN 1968

SCALE: 1INCH = 30 MILES

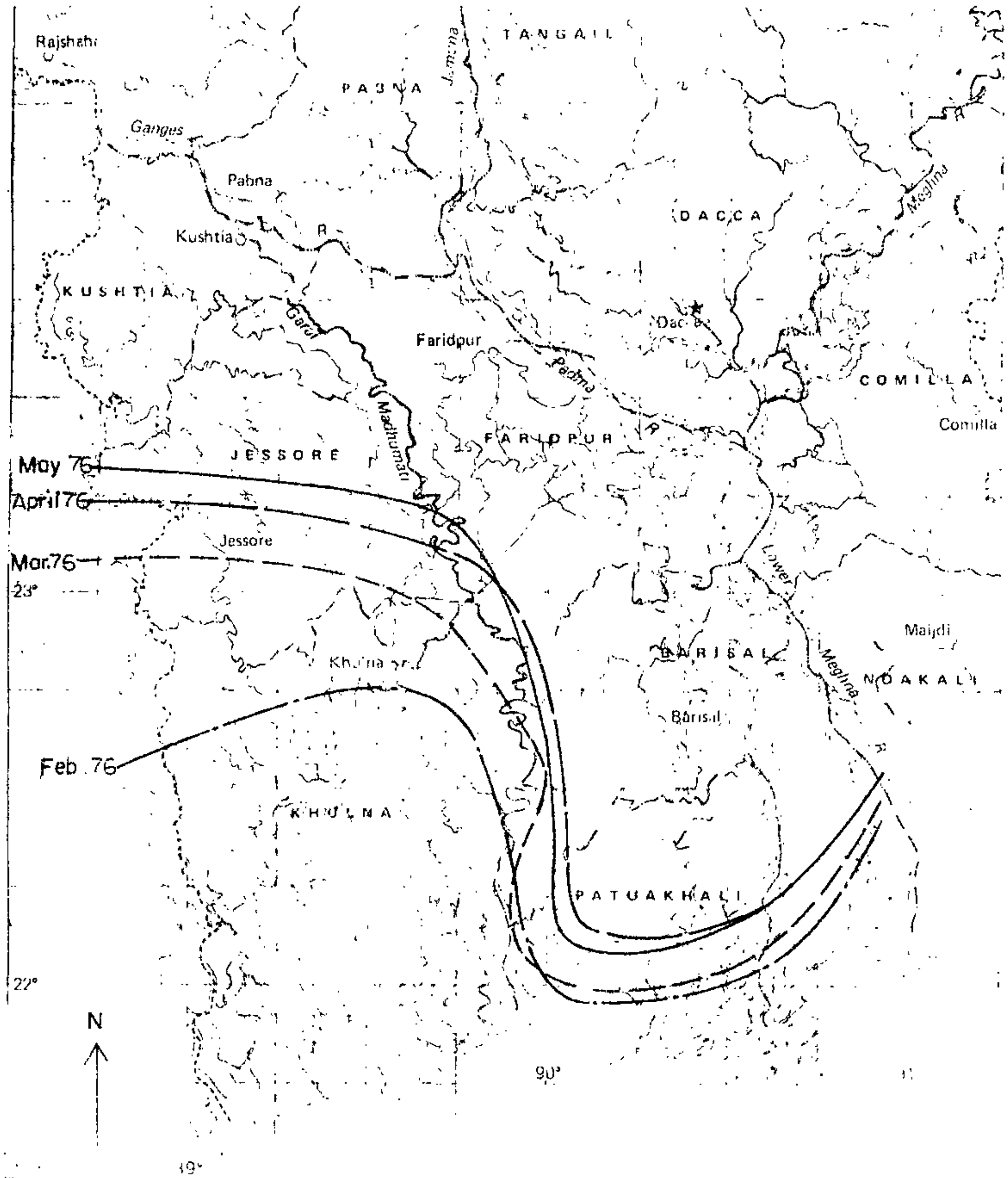

FIG.12 2000 MICROMHO SALINITY LINES IN 1976

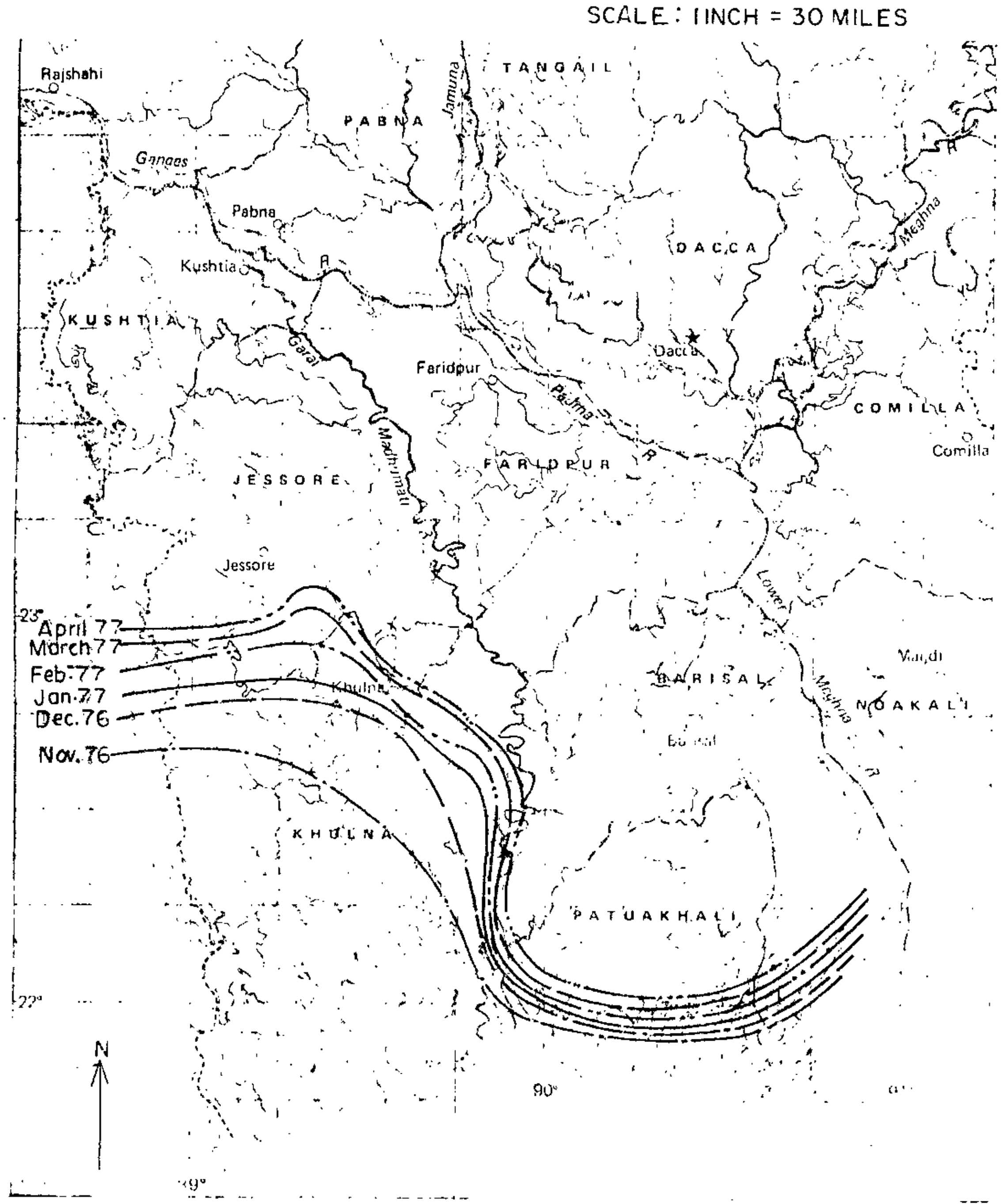

FIG. 13 2000 MICROMHO SALINITY LINES IN 1977

SCALE: 1" = 30 MILES

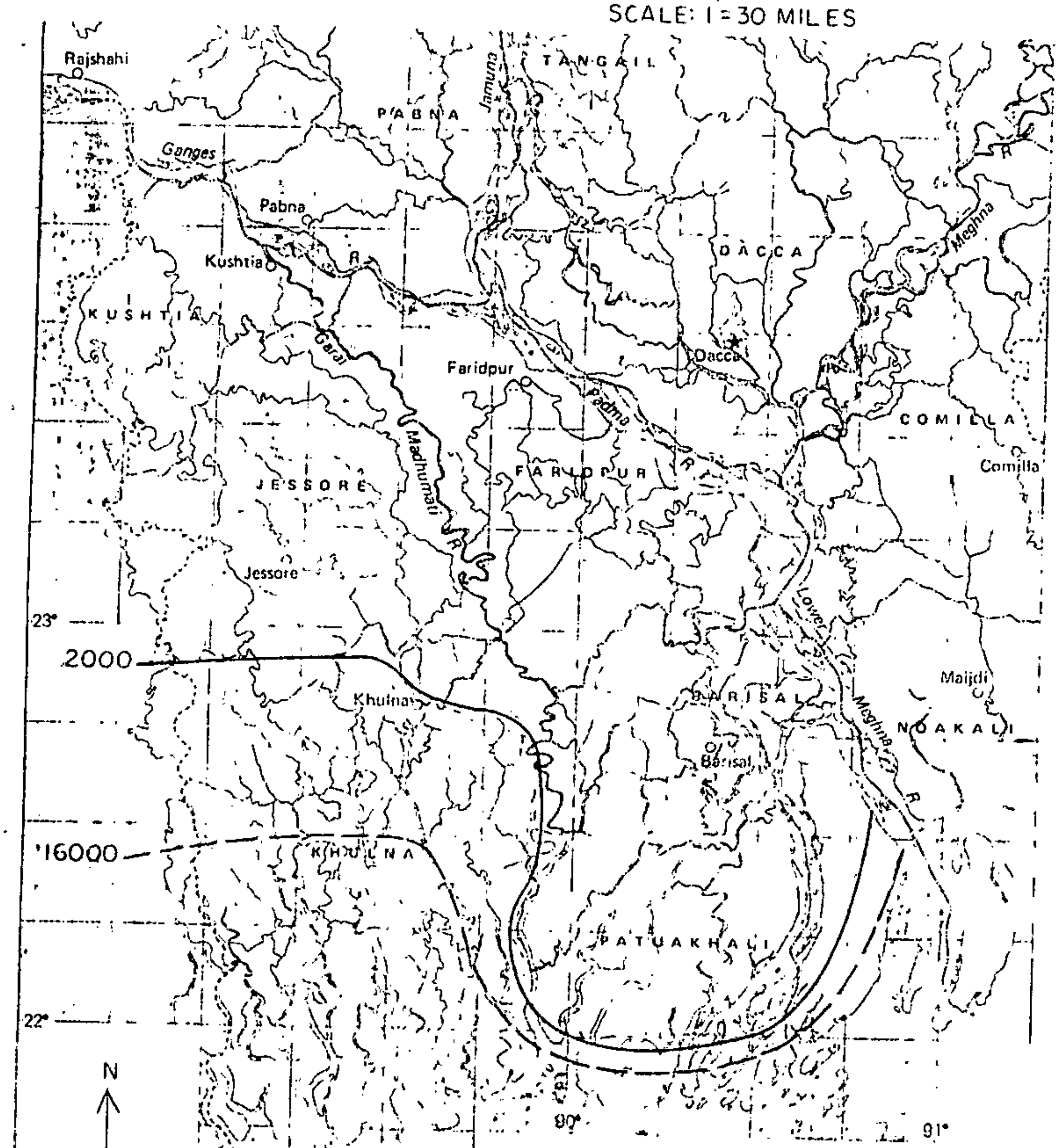

FIG. 14 LINES OF EQUAL SALINITY IN APRIL, 1968

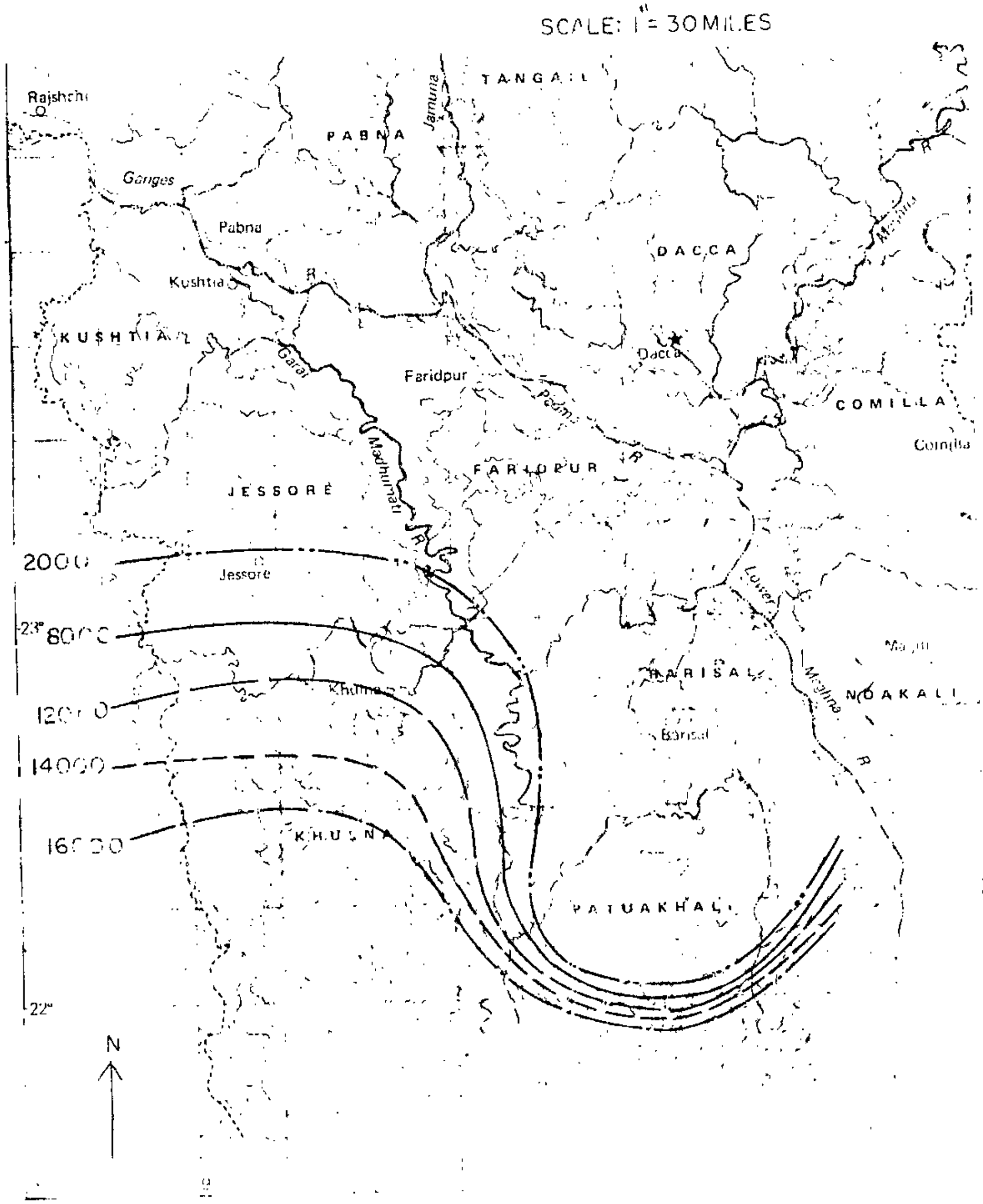

FIG. 15 LINES OF EQUAL SALINITY IN APRIL, 1976

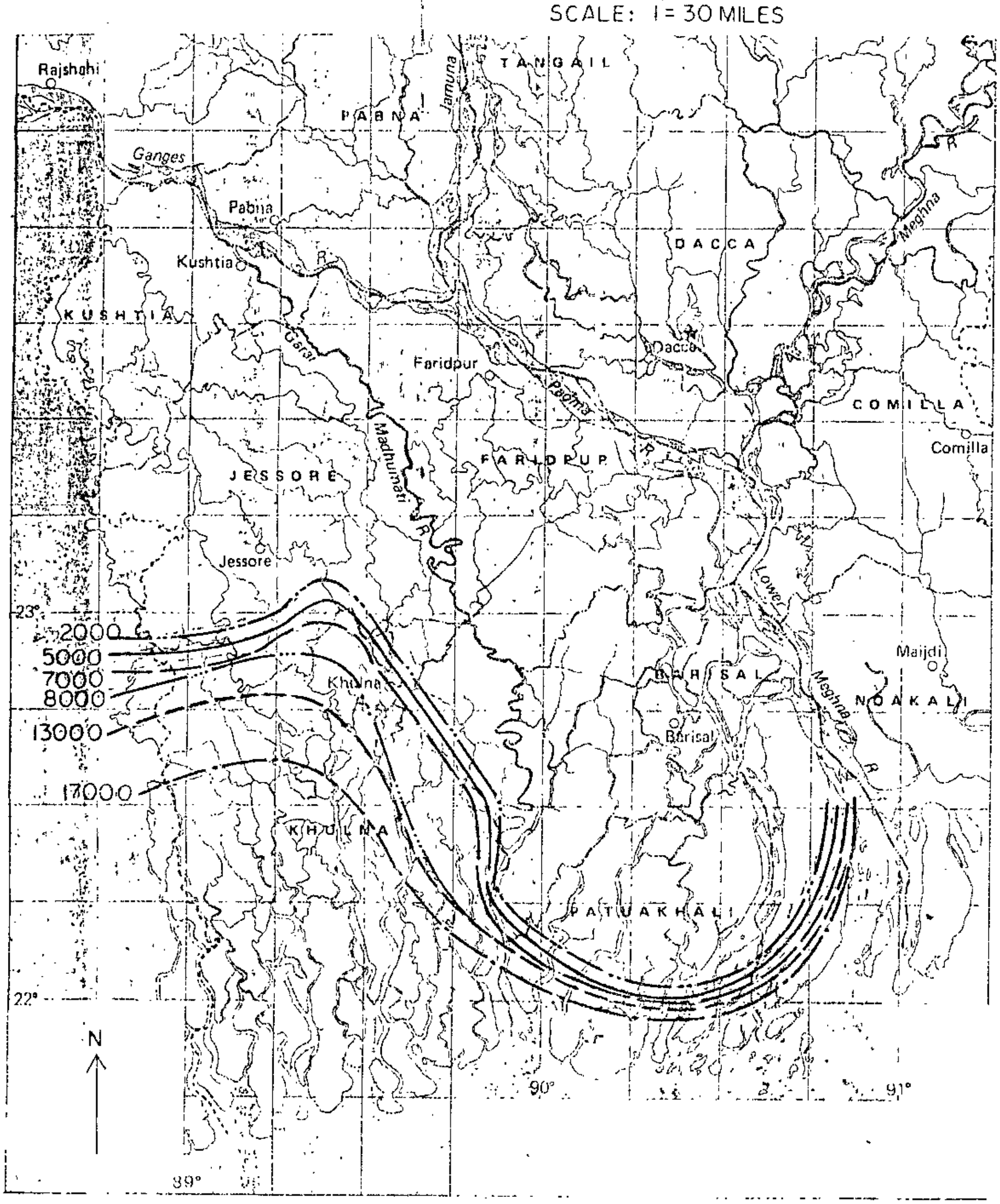

FIG. 16 LINES OF EQUAL SALINITY IN APRIL, 1977

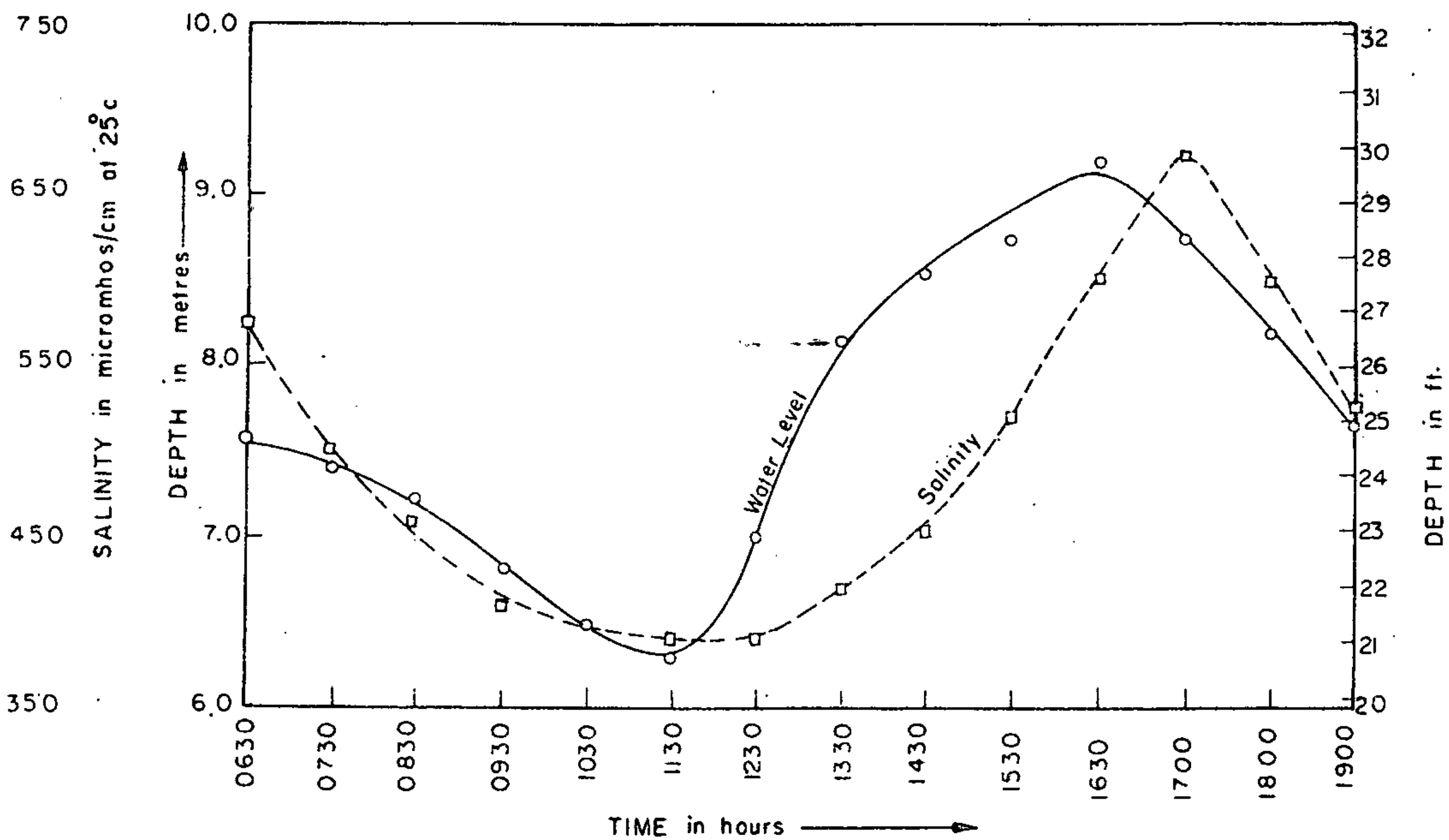

FIG. 17 SALINITY AND TIDAL FLUCTUATION OF RUPSA AT KHULNA ON MARCH 10, 1978
(AVERAGE WATER TEMPERATURE 25°c)

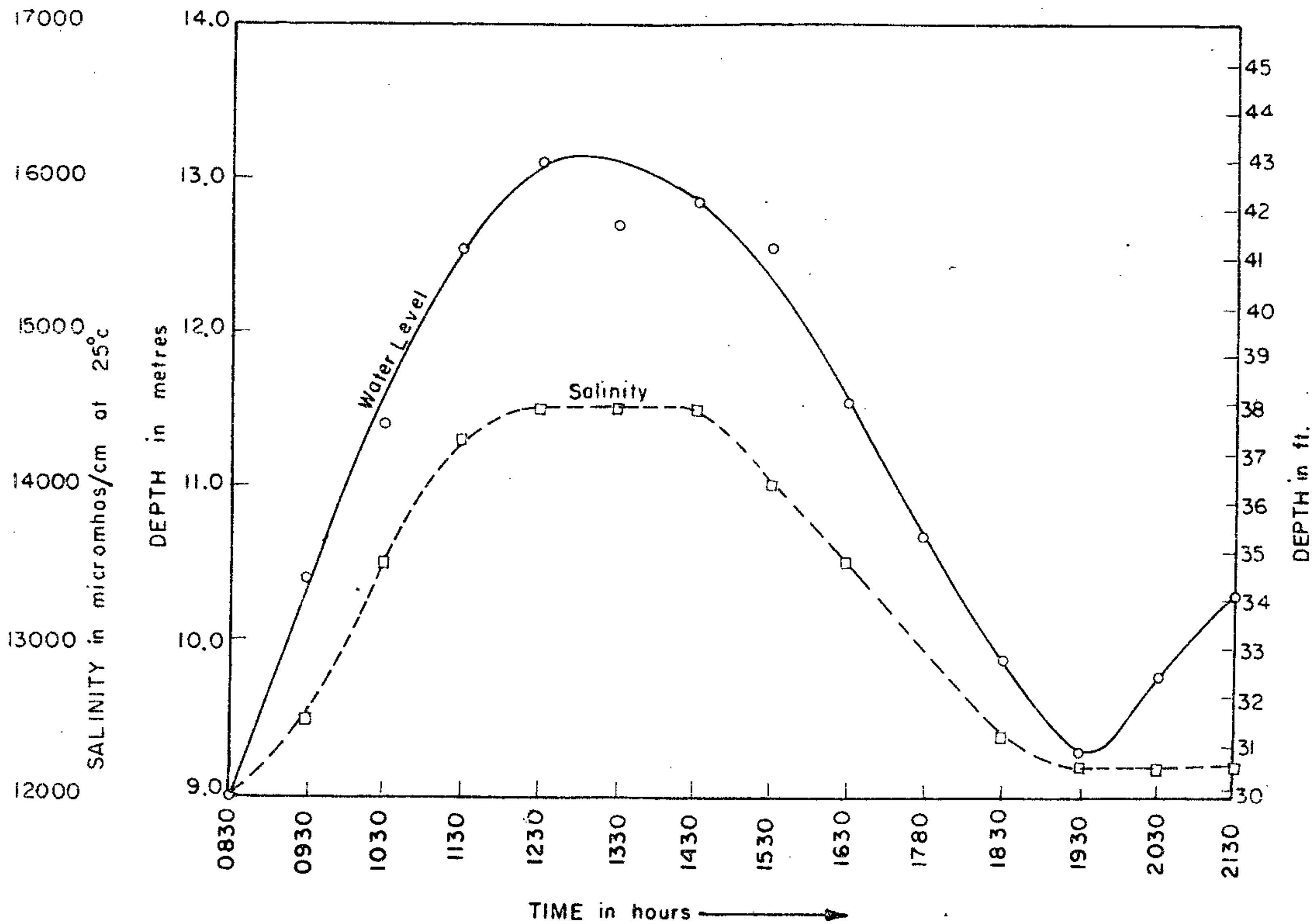

FIG.18 SALINITY AND TIDAL FLUCTUATION OF SIBSA AT NALIANALA ON MARCH 25, 1978
(AVERAGE WATER TEMPERATURE 28°c)

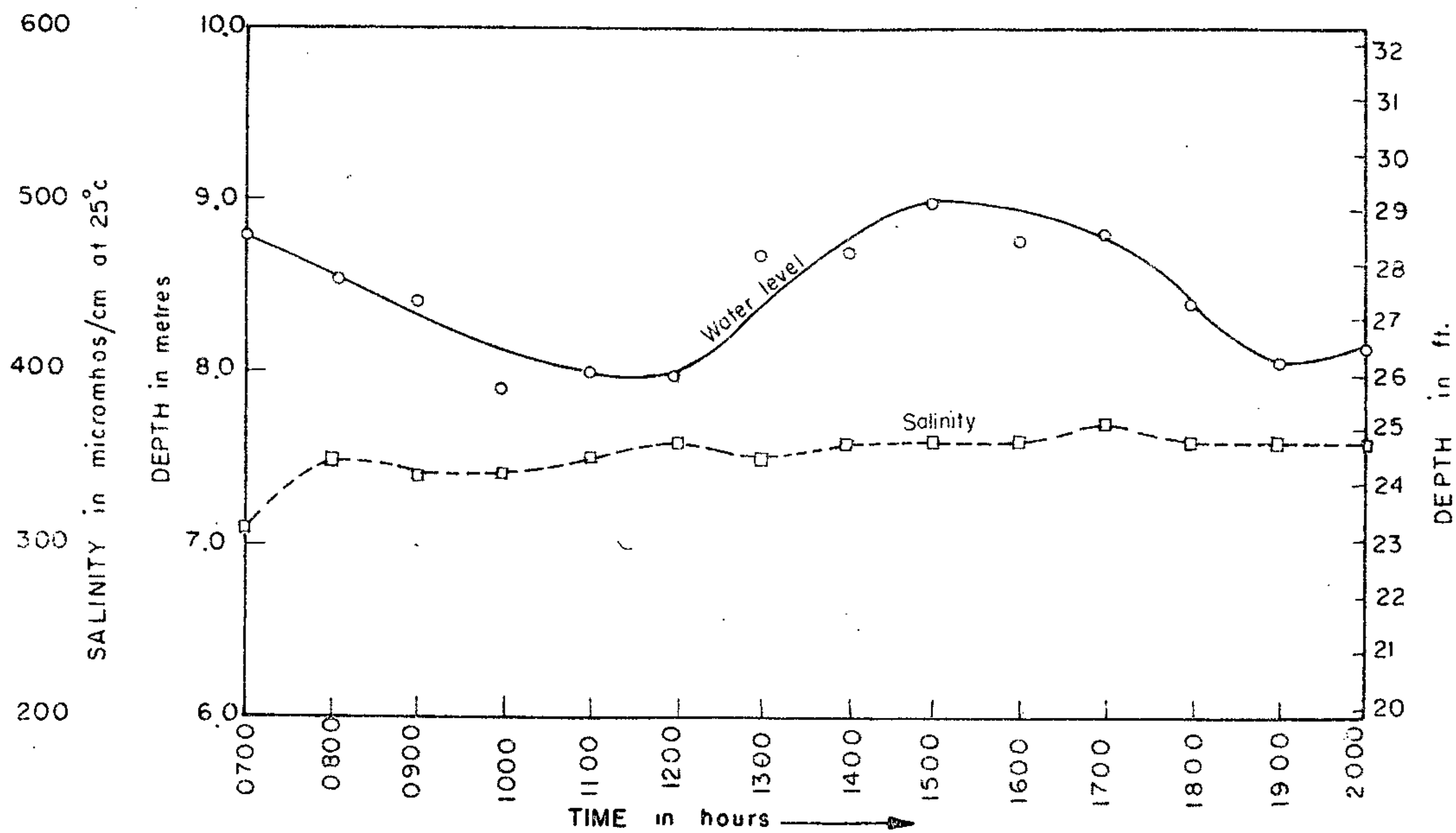

FIG. 19 SALINITY AND TIDAL FLUCTUATION OF MADHUMATI AT BARDIA ON MARCH 7, 1978 (AVERAGE WATER TEMPERATURE 25°c)

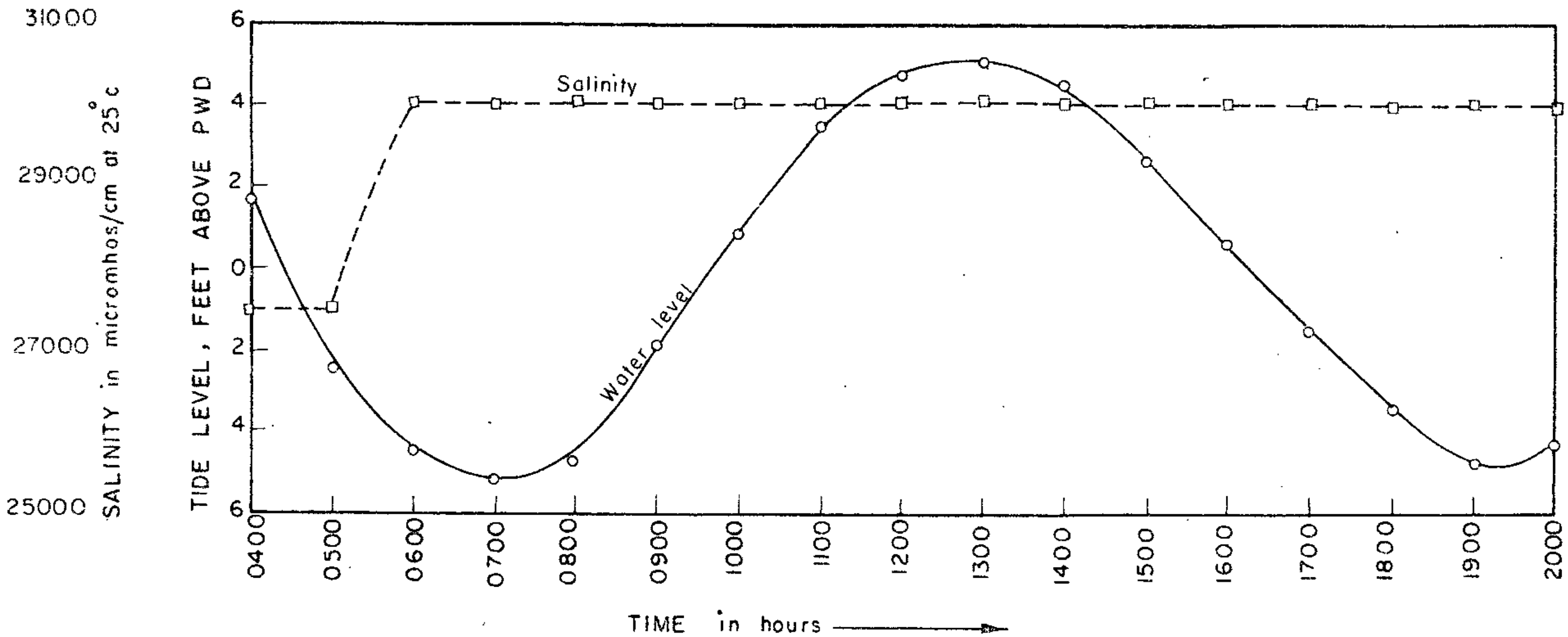

FIG.20 SALINITY AND TIDAL FLUCTUATION OF ARPANGACHA RIVER AT KOBADAK FOREST OFFICE ON APRIL 11, 1967 (Source: R. K. Bhuiya, 1971)

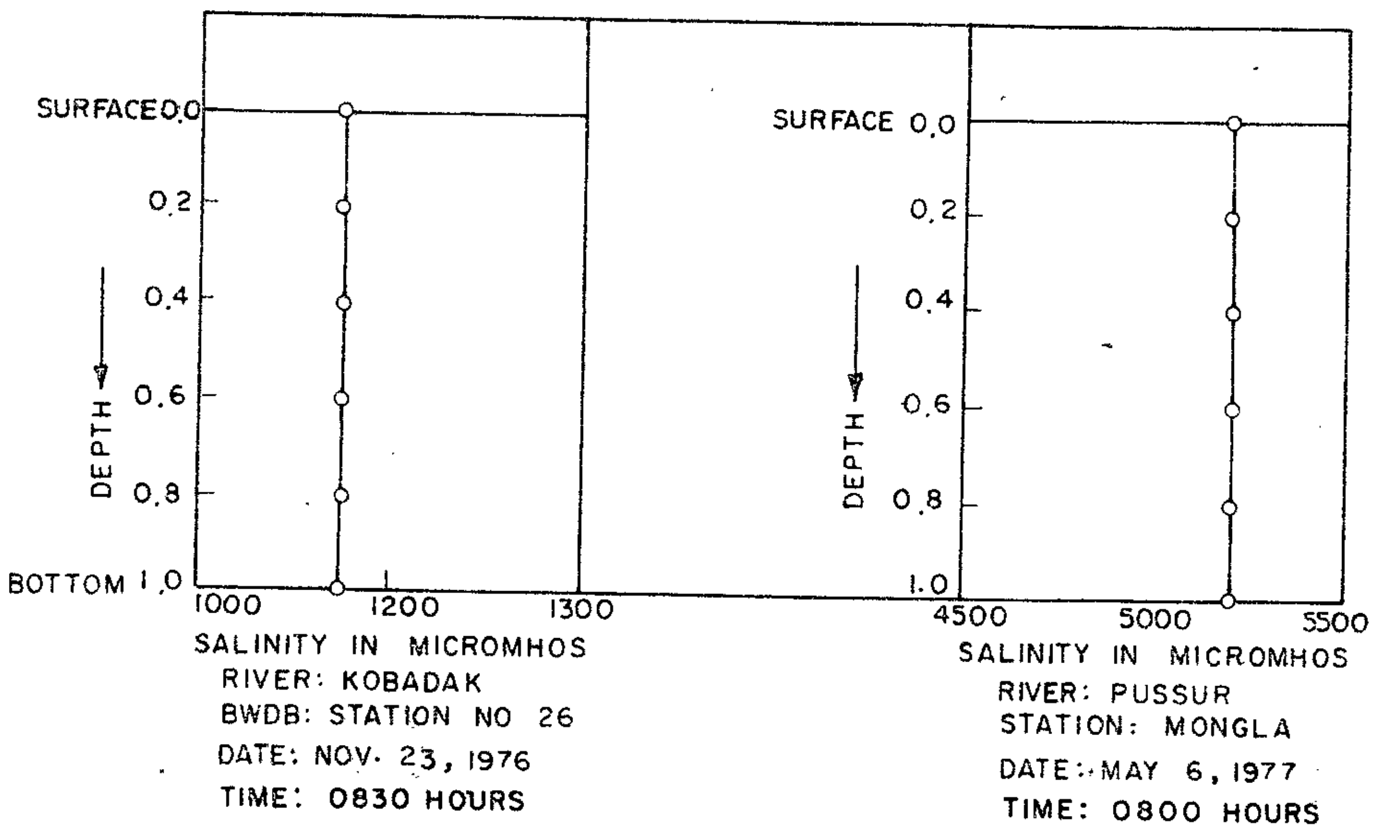

FIG. 21 SALINITY PROFILE ALONG VERTICAL

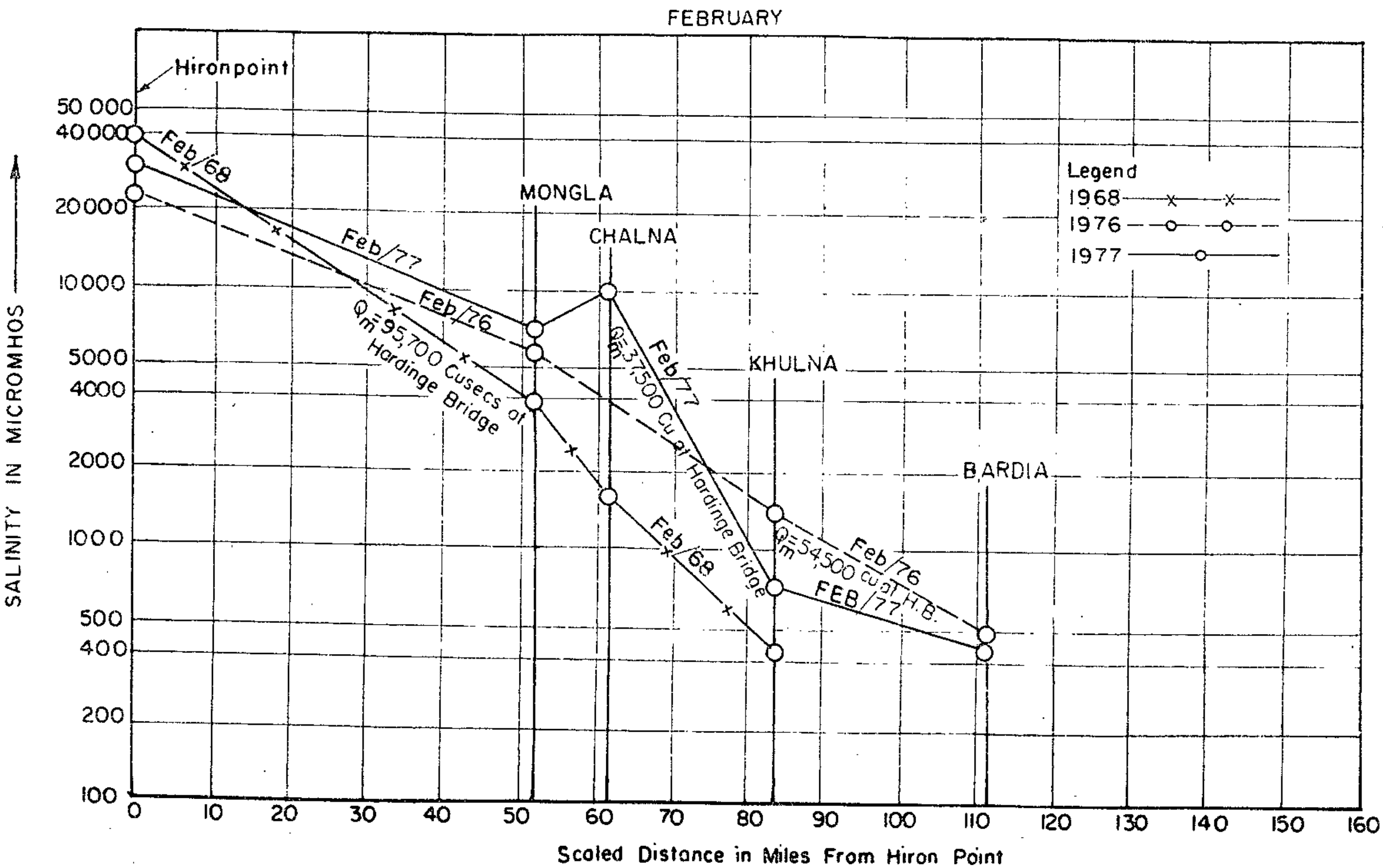

FIG. 22 SUPERIMPOSED SALINITY PROFILES, LOWER NABAGANGA RUPSA
(Source: Special Studies, BWDB, 1977)

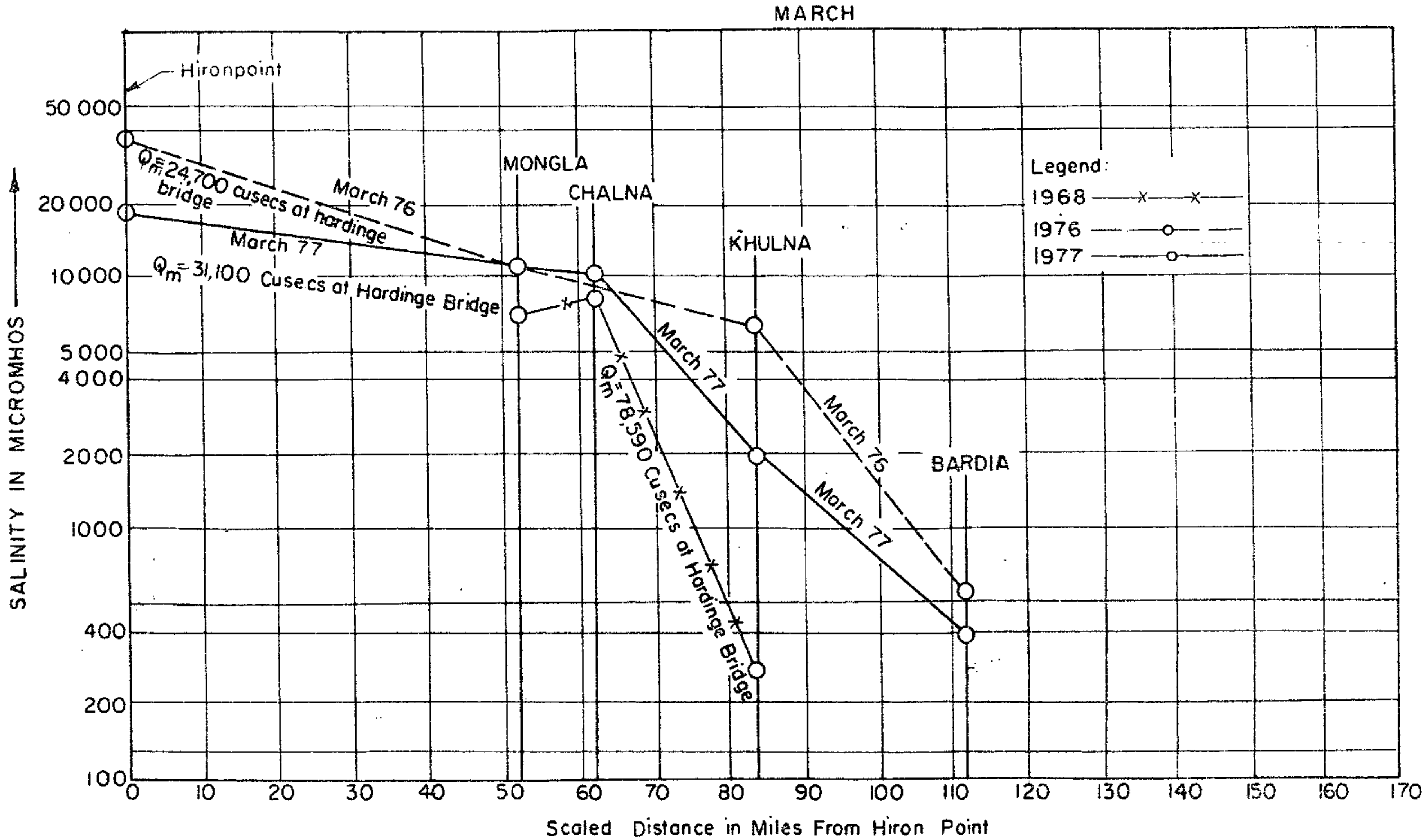

FIG. 23 SUPERIMPOSED SALINITY PROFILES, LOWER NABAGANGA RUPSA
(Source: Special Studies, BWDB, 1977)

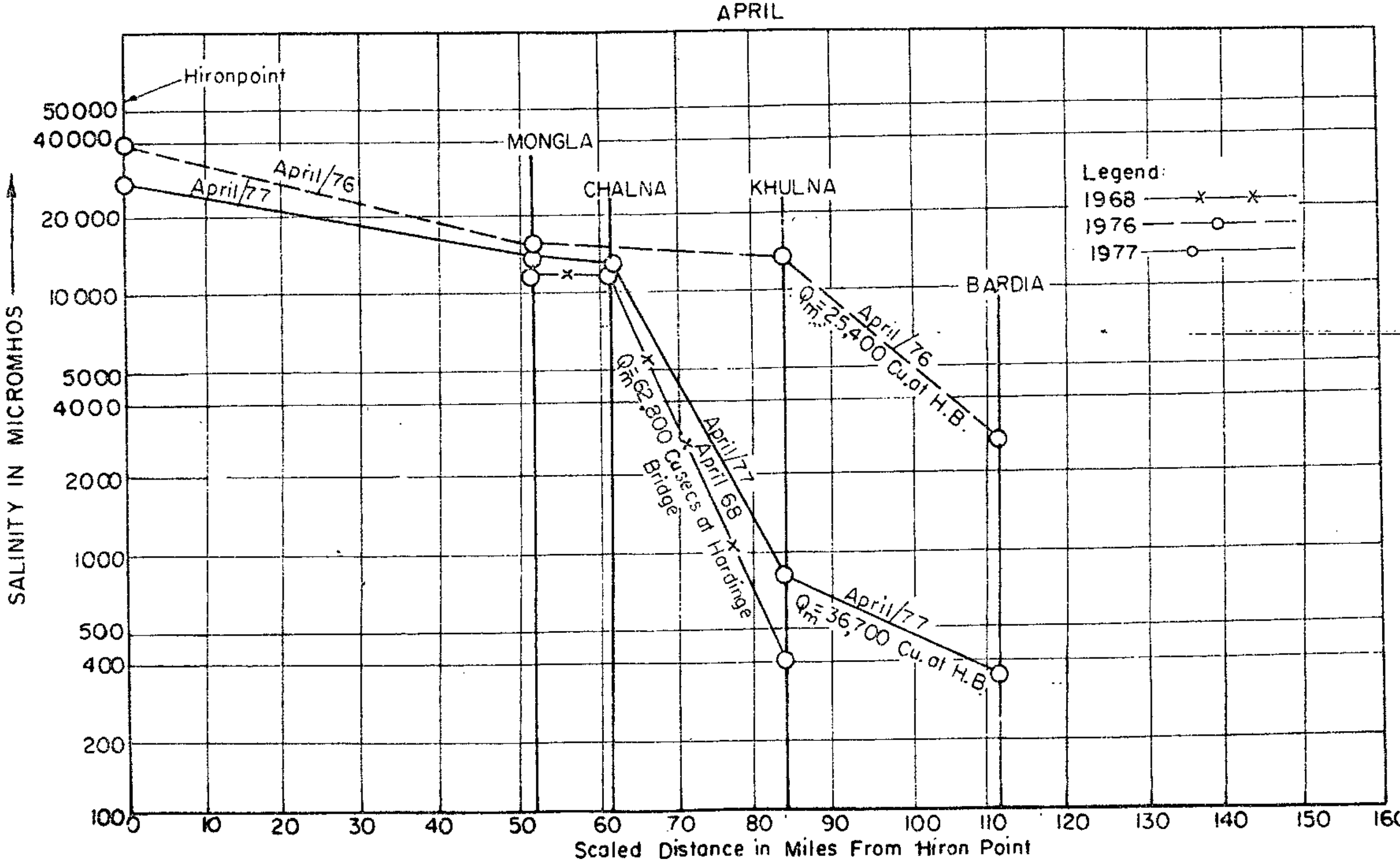

FIG. 24 SUPERIMPOSED SALINITY PROFILES, LOWER NABAGANGA RUPSA
(Source: Special Studies, BWDB, 1977)

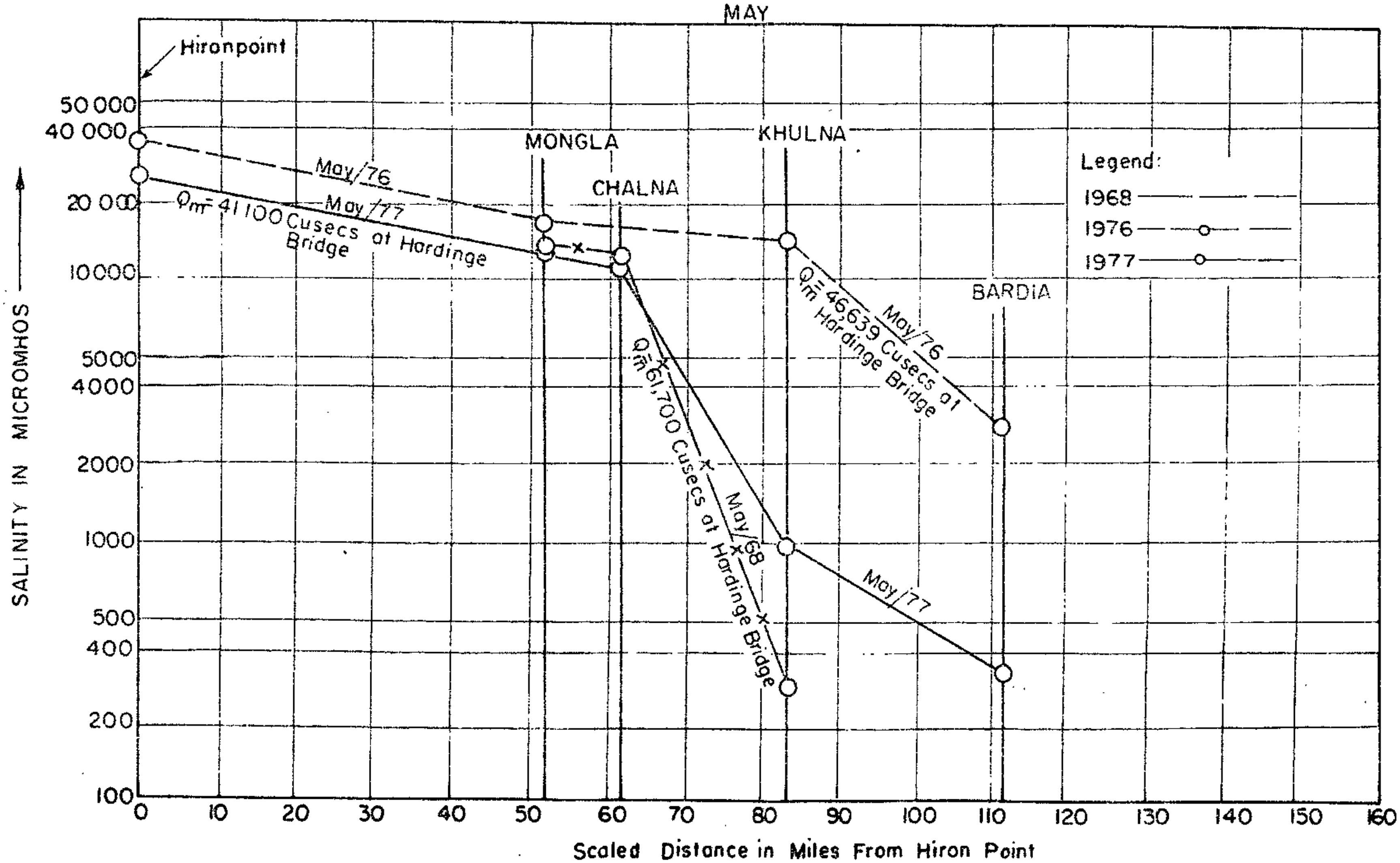

FIG.25 SUPERIMPOSED SALINITY PROFILES, LOWER NABAGANGA RUPSA
(Source: Special Studies, BWDB,1977)

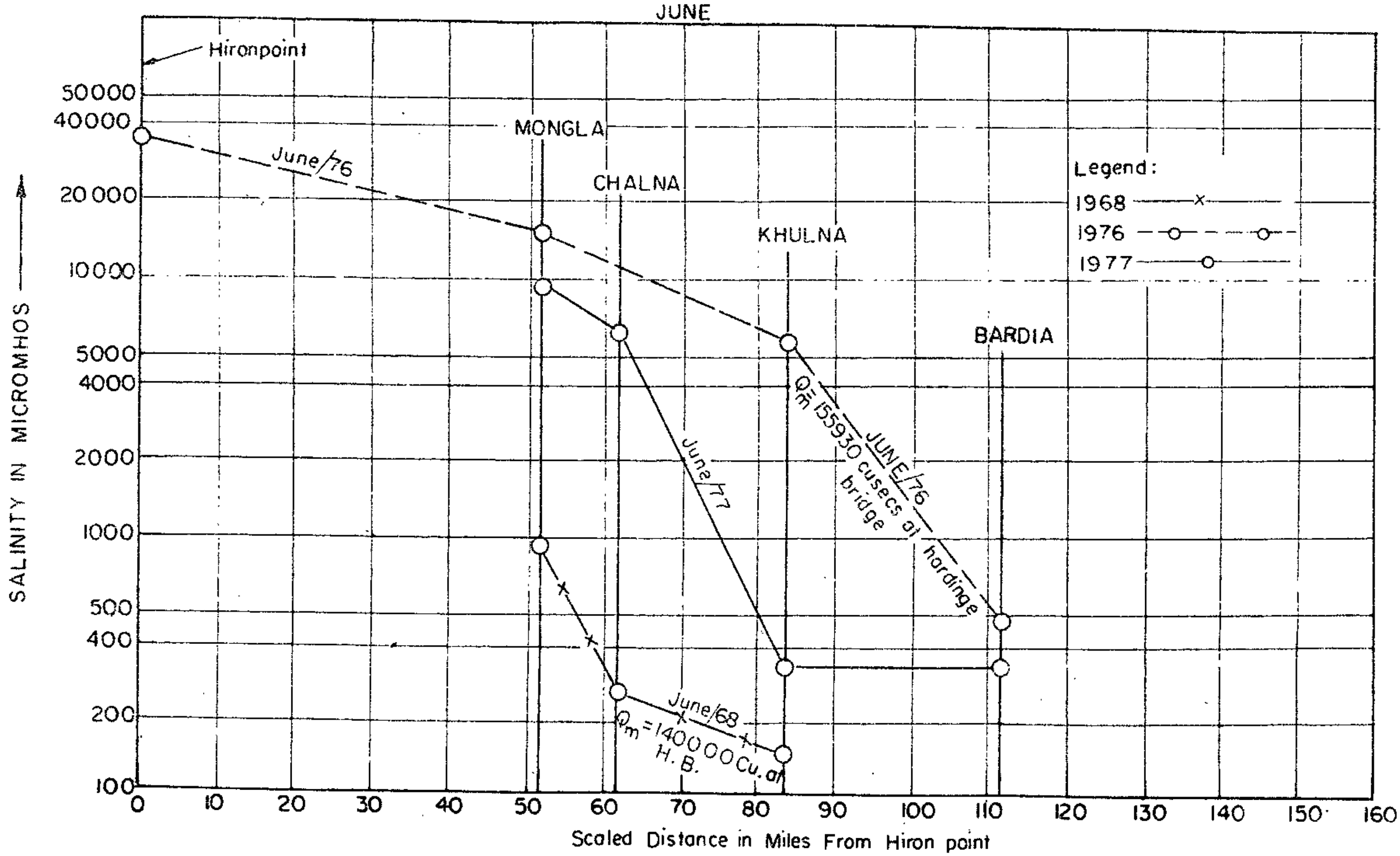

FIG. 26 SUPERIMPOSED SALINITY PROFILES, LOWER NABAGANGA RUPSA
(Source: Special Studies, BWDB, 1977)

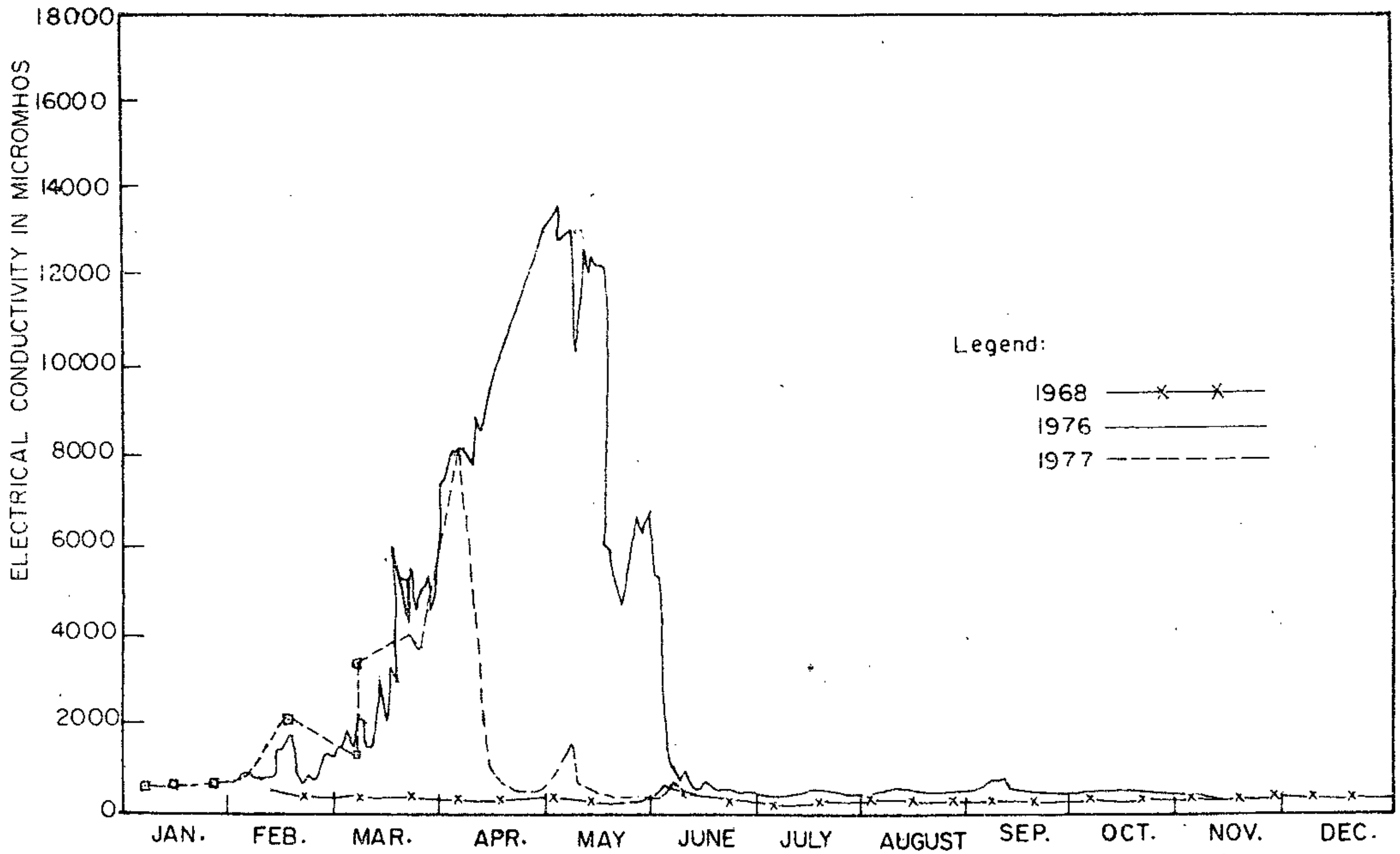

FIG. 27 SALINITY IN RUPSA AT KHULNA
(Source: Special Studies, BWDB, 1977)

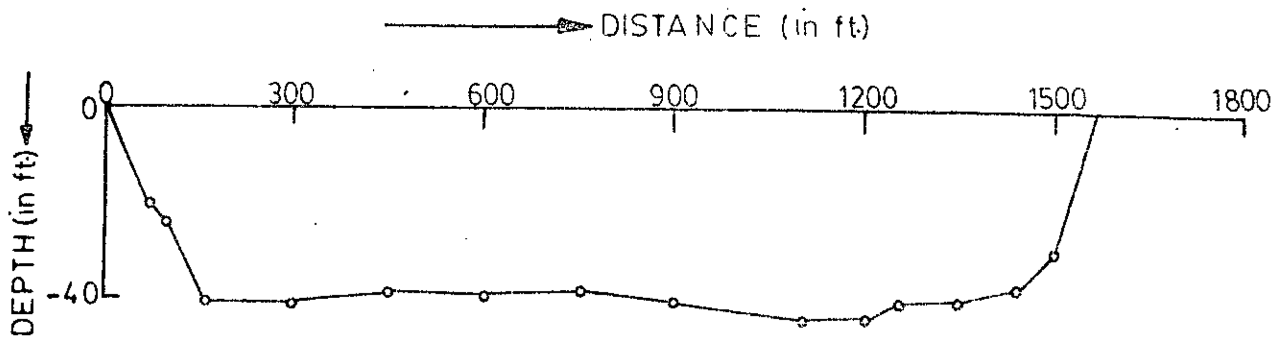

FIG. 28 CROSS SECTION OF MONGLA KHAL AT MONGLA (1977)

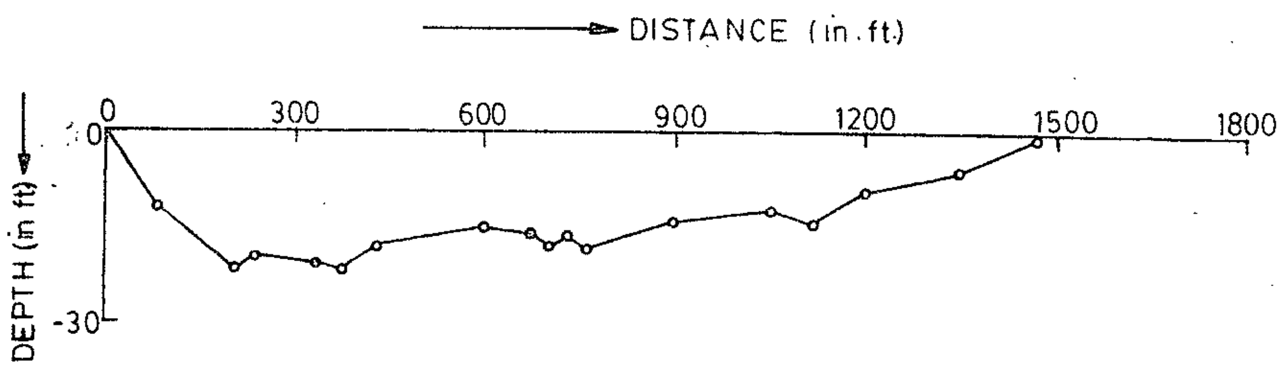

FIG. 29 CROSS SECTION OF NABAGANGA AT BARDIA (1976)

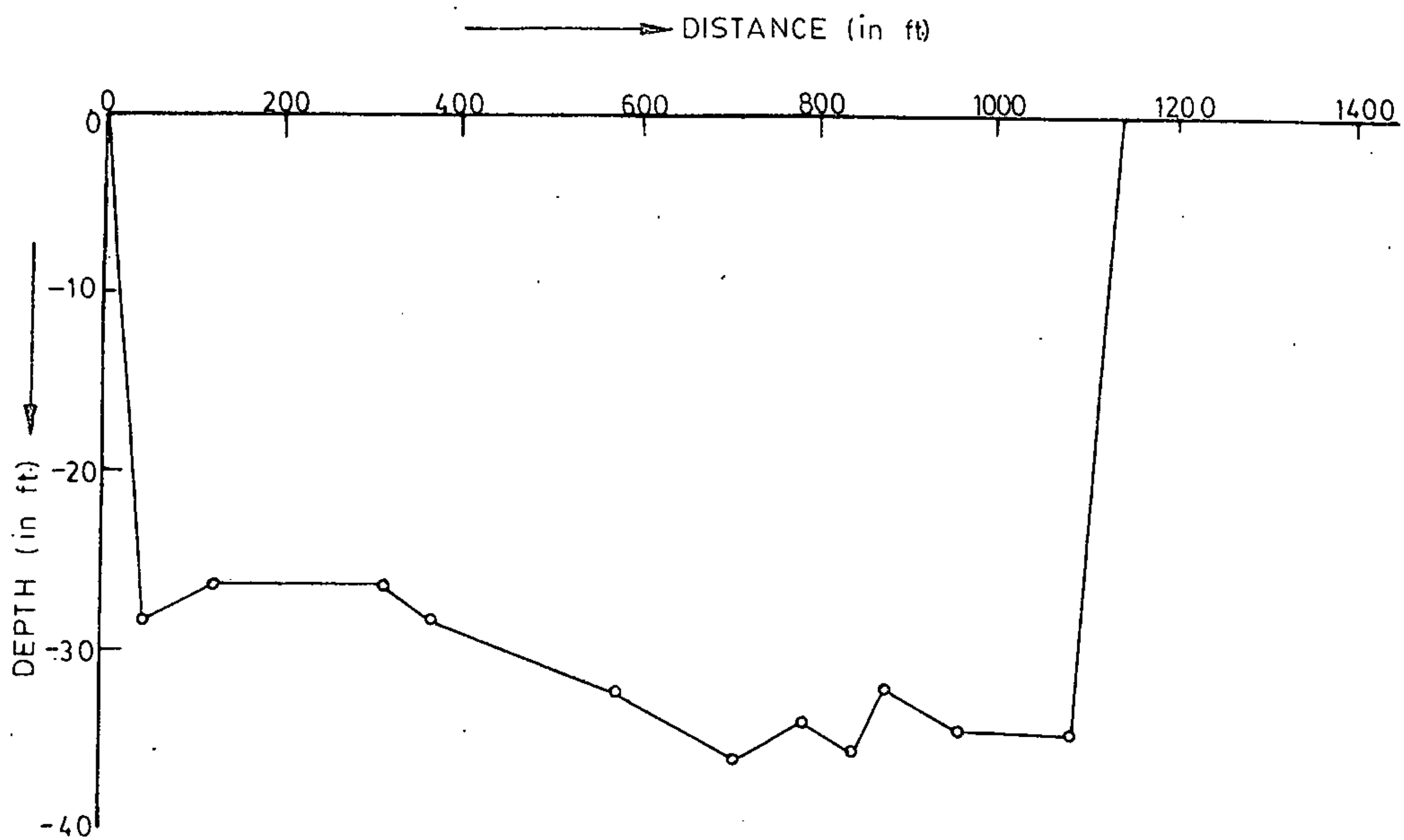

FIG. 30 CROSS SECTION OF RUPSA AT KHULNA (1977)

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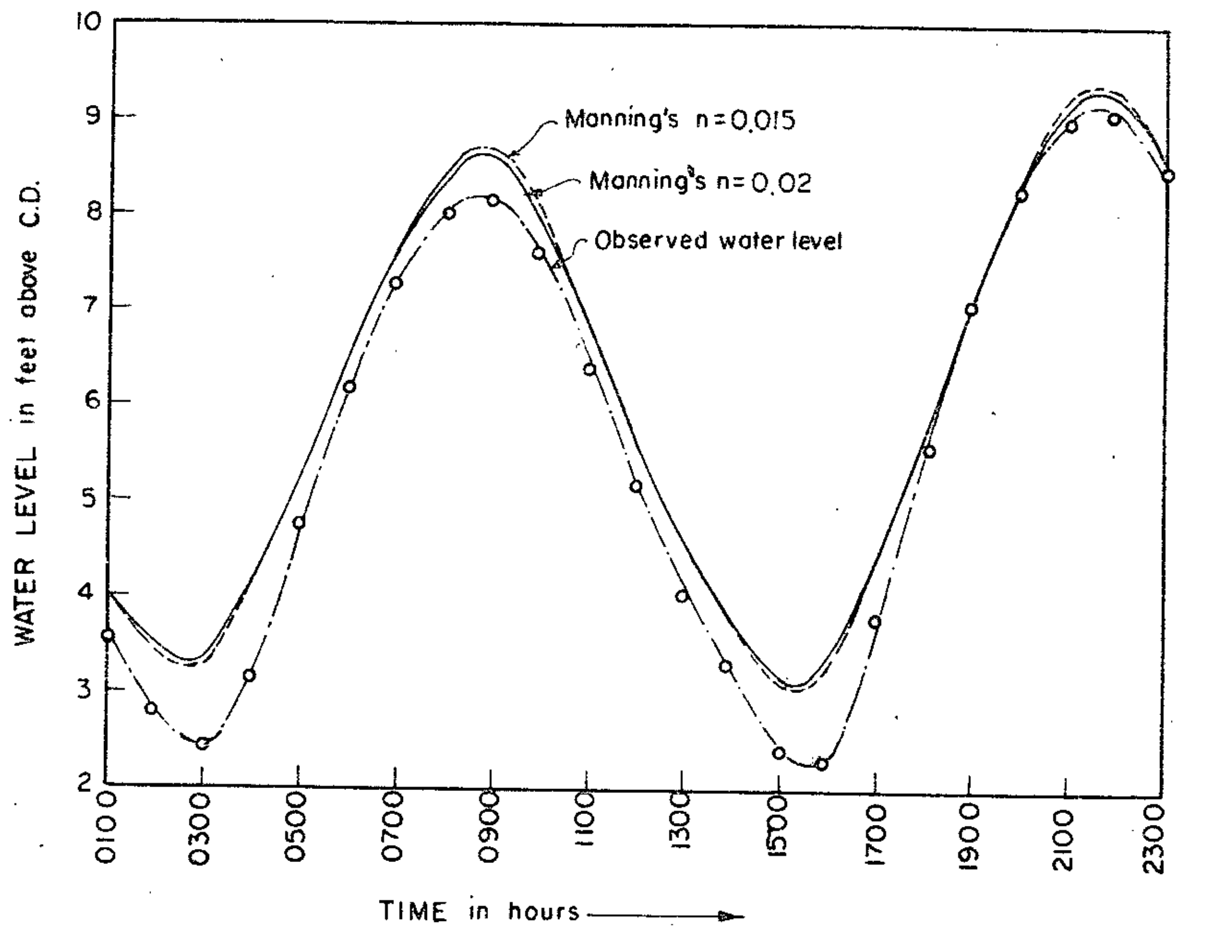
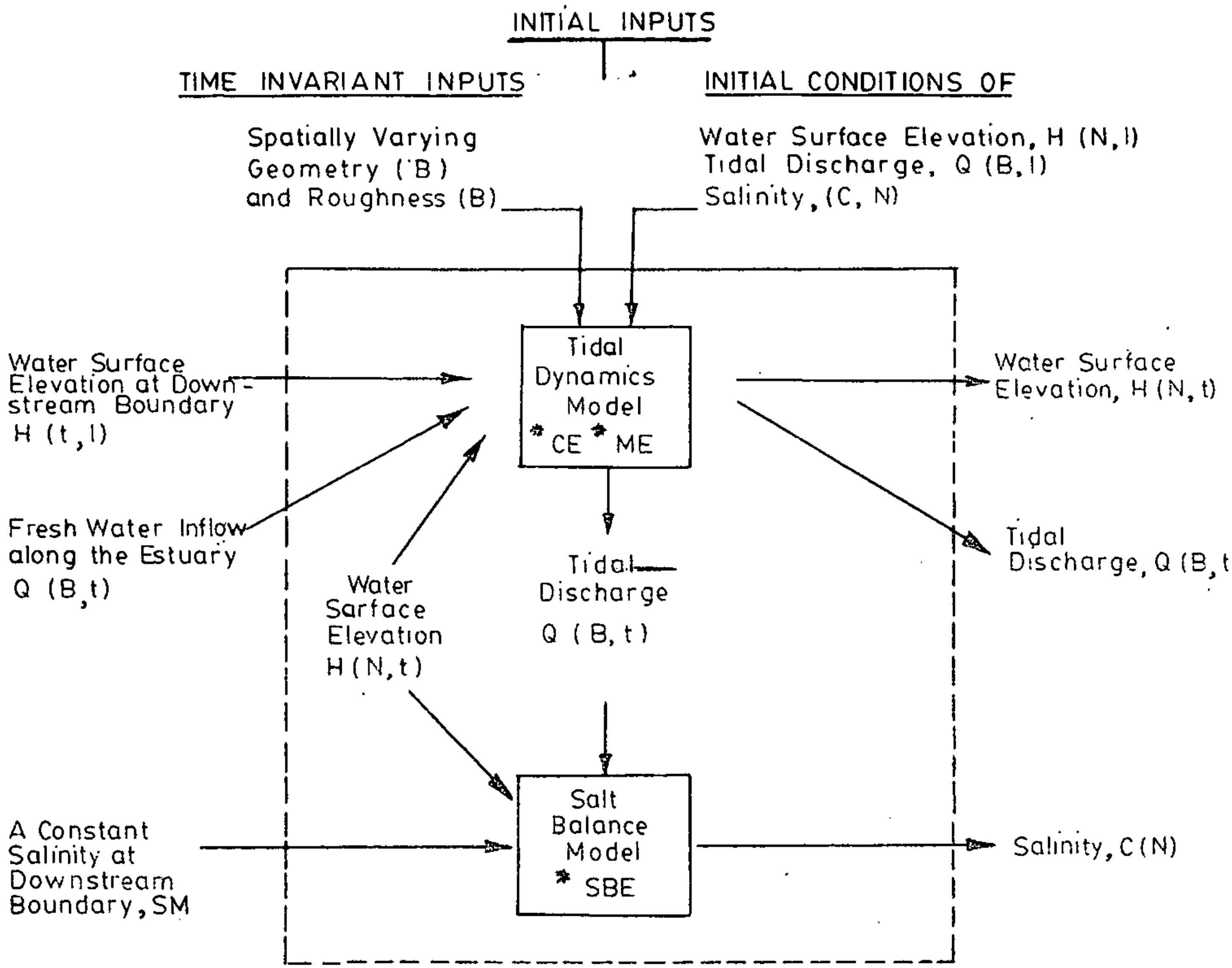


FIG. 31 COMPARISON OF COMPUTED WATER LEVELS OF PUSSUR AT MONGLA FOR TWO ROUGHNESS COEFFICIENTS WITH OBSERVED WATER LEVEL ON APRIL 2, 1978 (A CONSTANT LAG BETWEEN OBSERVED AND COMPUTED VALUES IS DUE TO ASSUMED UPLAND DISCHARGE OF 500 CUSECS)



Remarks (1) N = Node Number, B = Branch Number and t = time

(2) CE = Continuity Equation, ME = Momentum Equation, SBE = Salt Balance Equation

FIG.32 GENERAL FORMULATION OF MATHEMATICAL MODEL OF TRANSIENT SALINITY INTRUSION

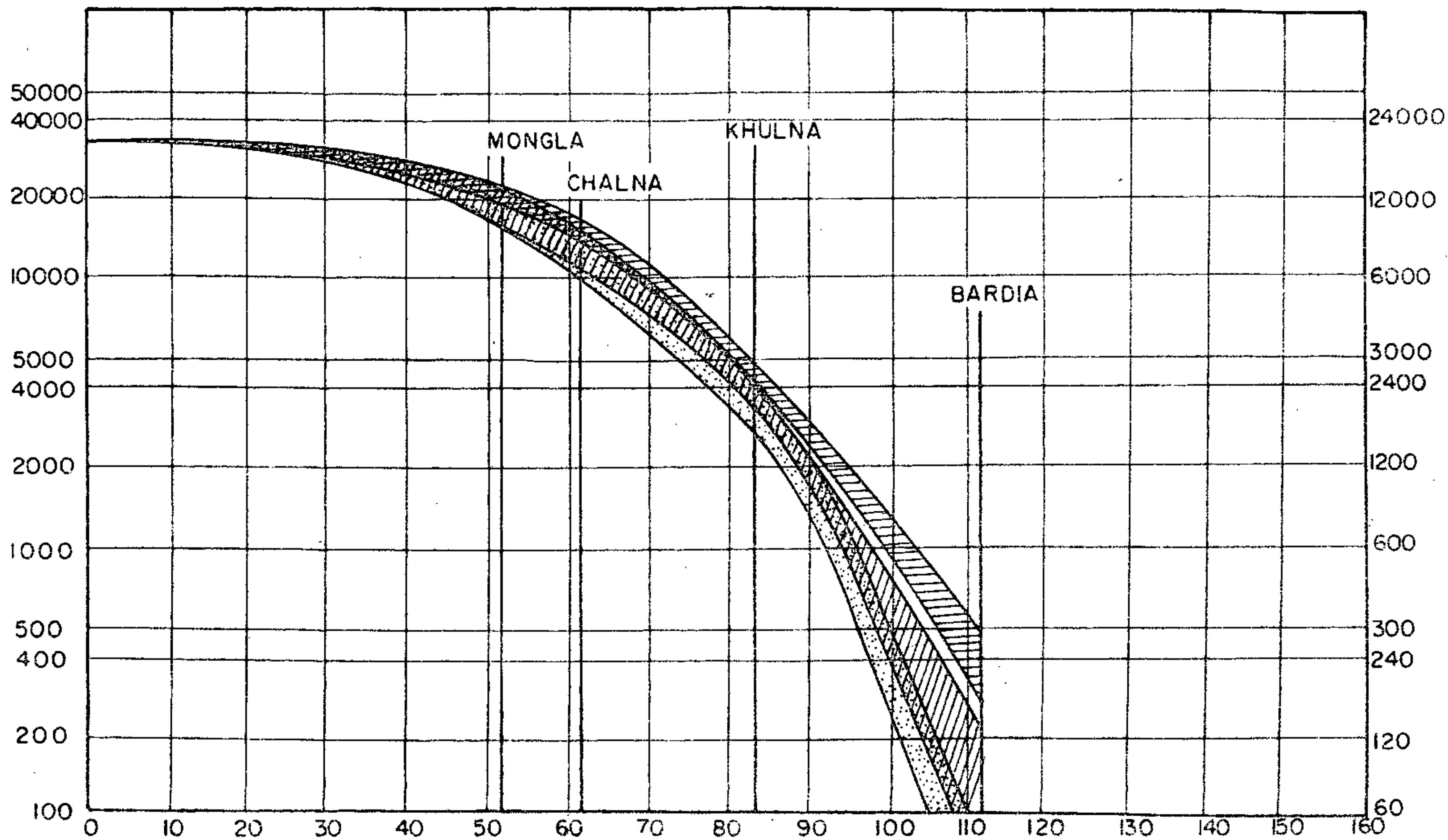
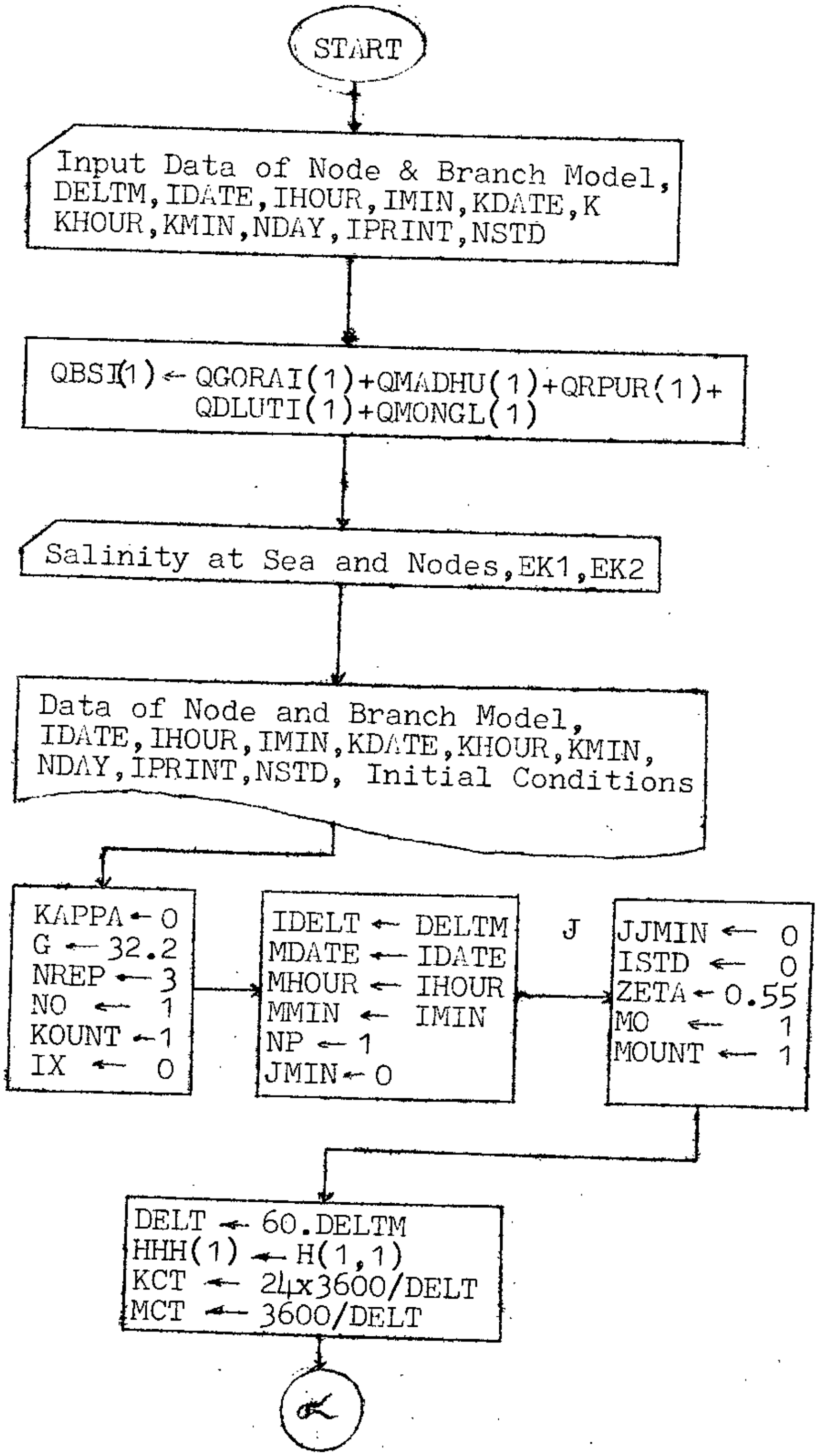


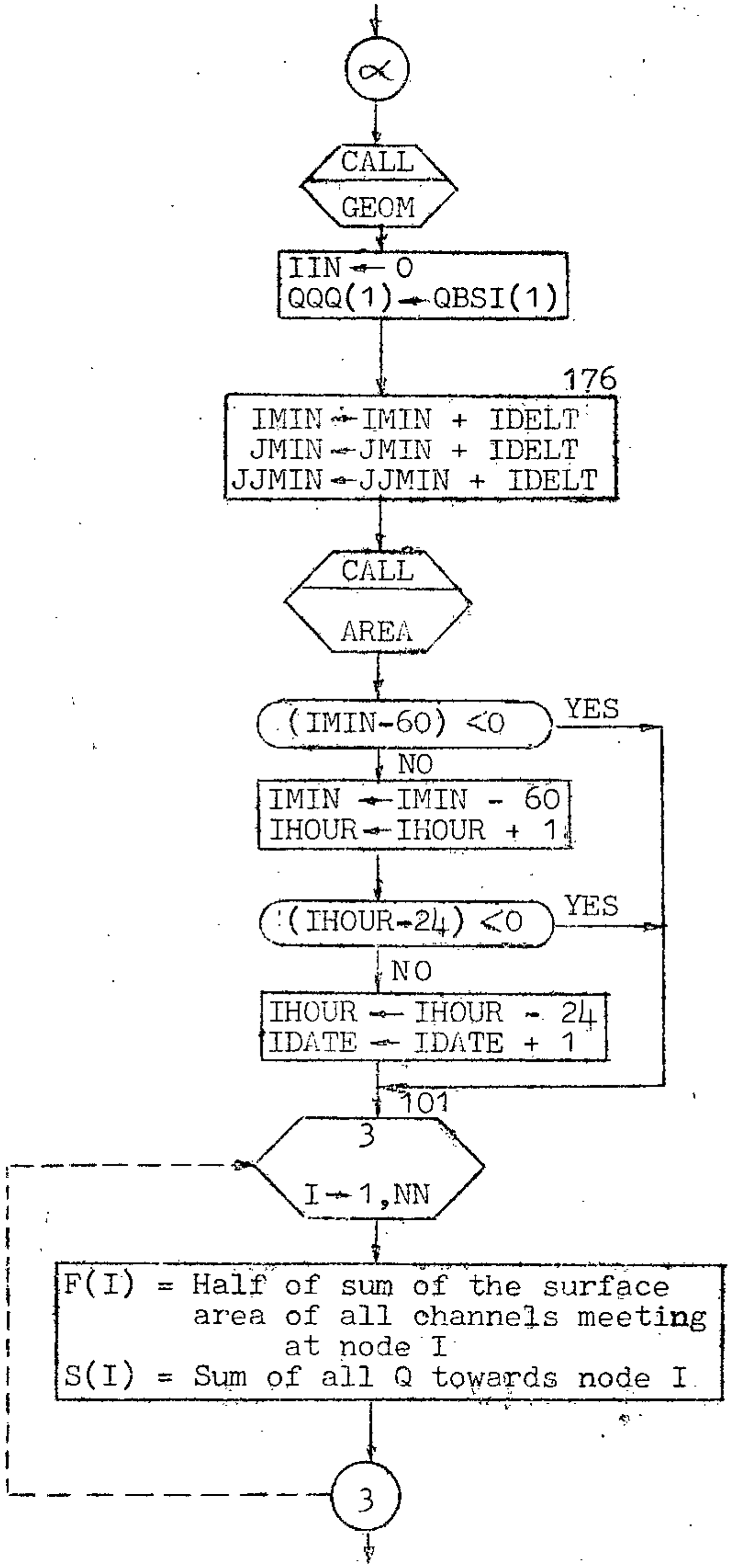
FIG.33 COMPUTED SALINITY CONCENTRATIONS FOR FRESHWATER DISCHARGE OF 2000 CUSECS, 5000 CUSECS AND 10000 CUSECS

APPENDIX - C

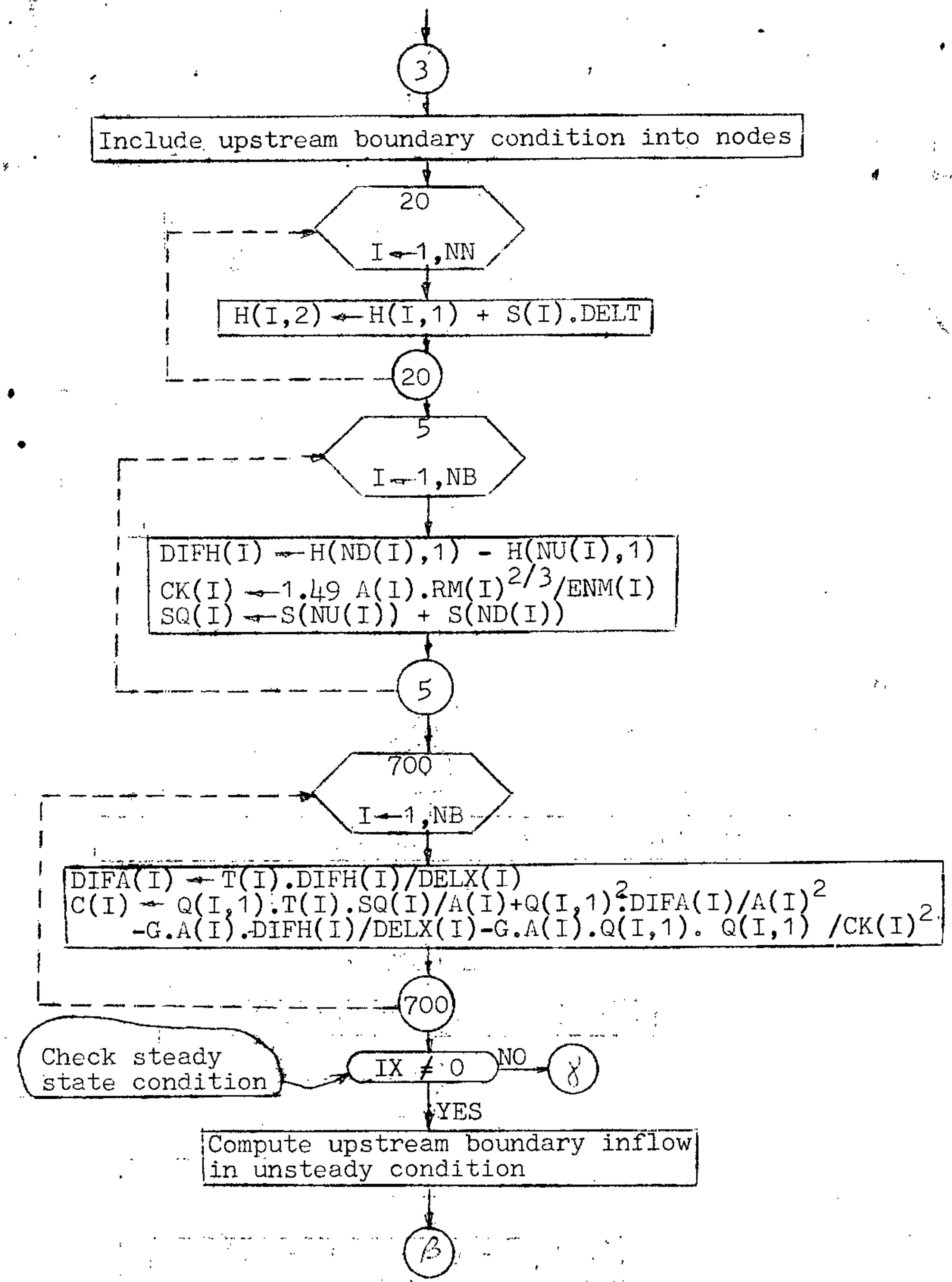
FLOW CHARTS



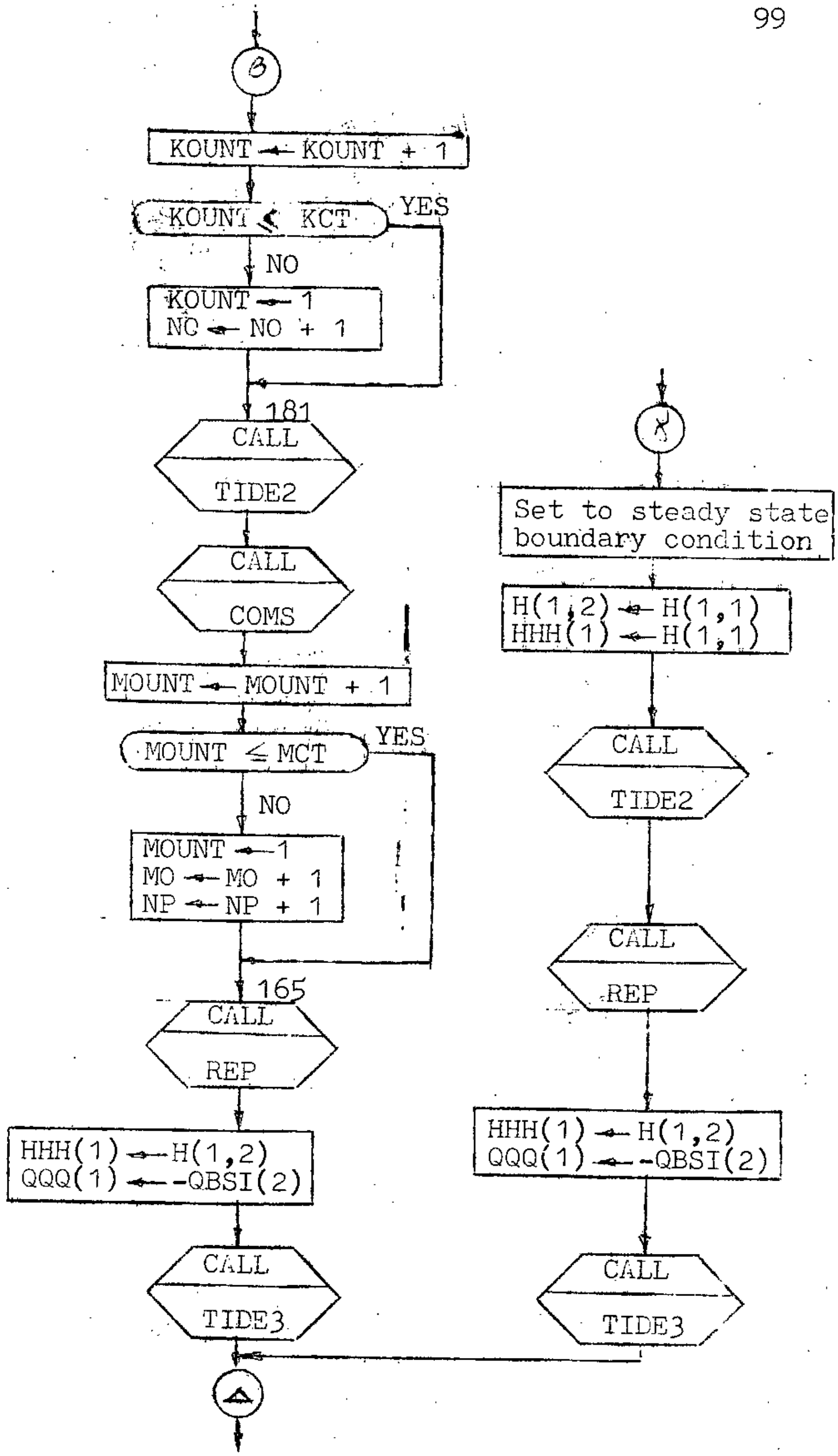
FLOW DIAGRAM OF MAIN PROGRAM



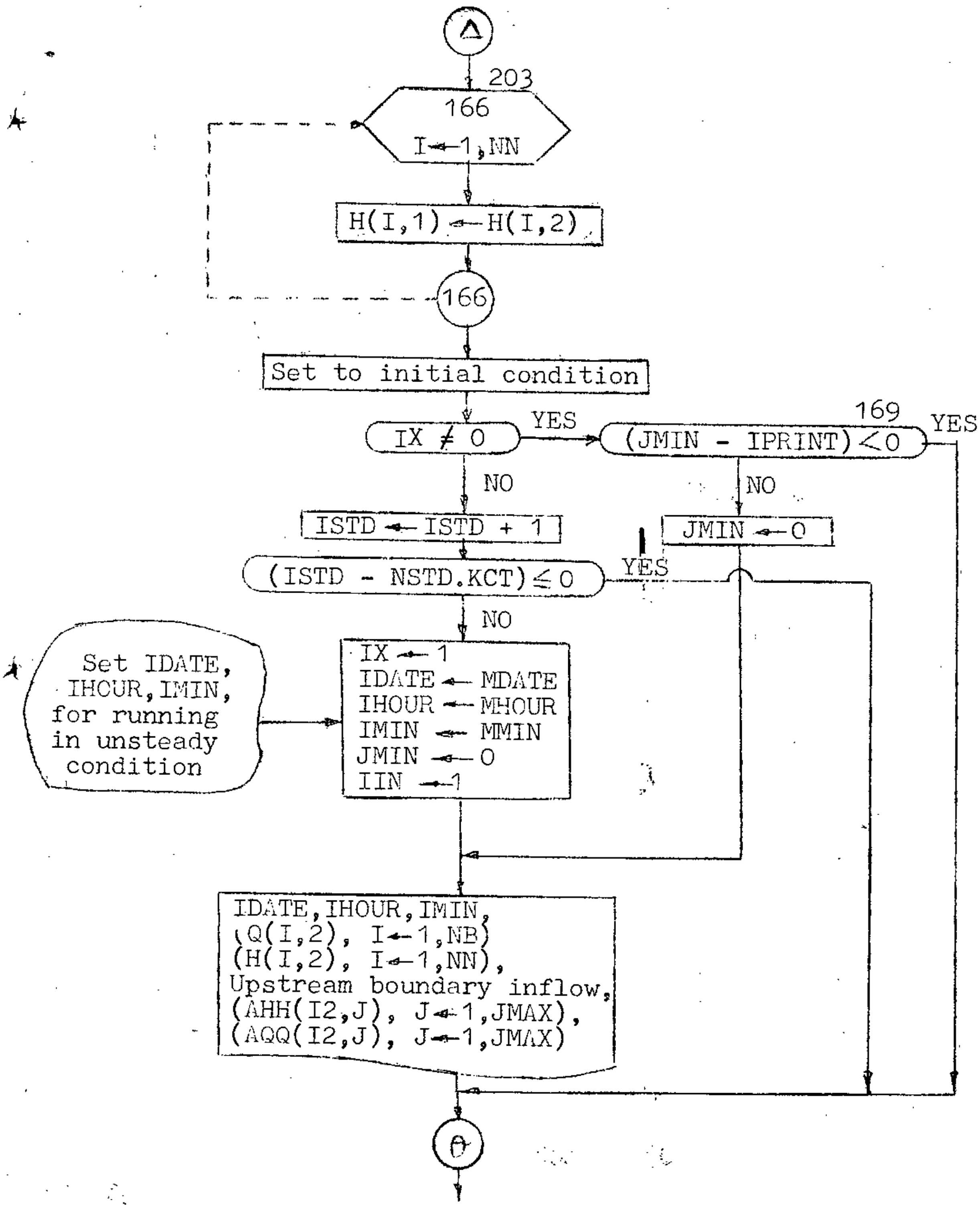
FLOW DIAGRAM OF MAIN PROGRAM (Continued)



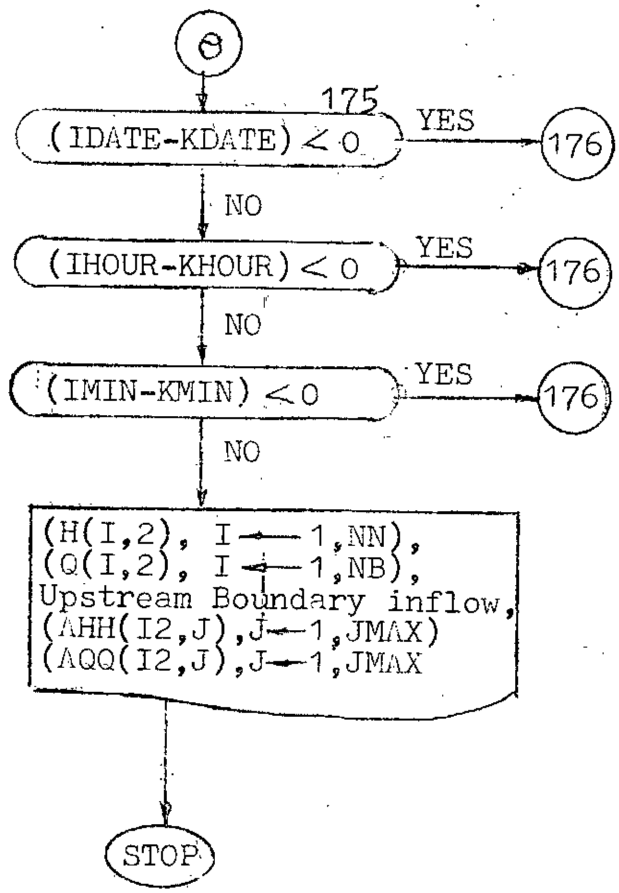
FLOW DIAGRAM OF MAIN PROGRAM (Continued)



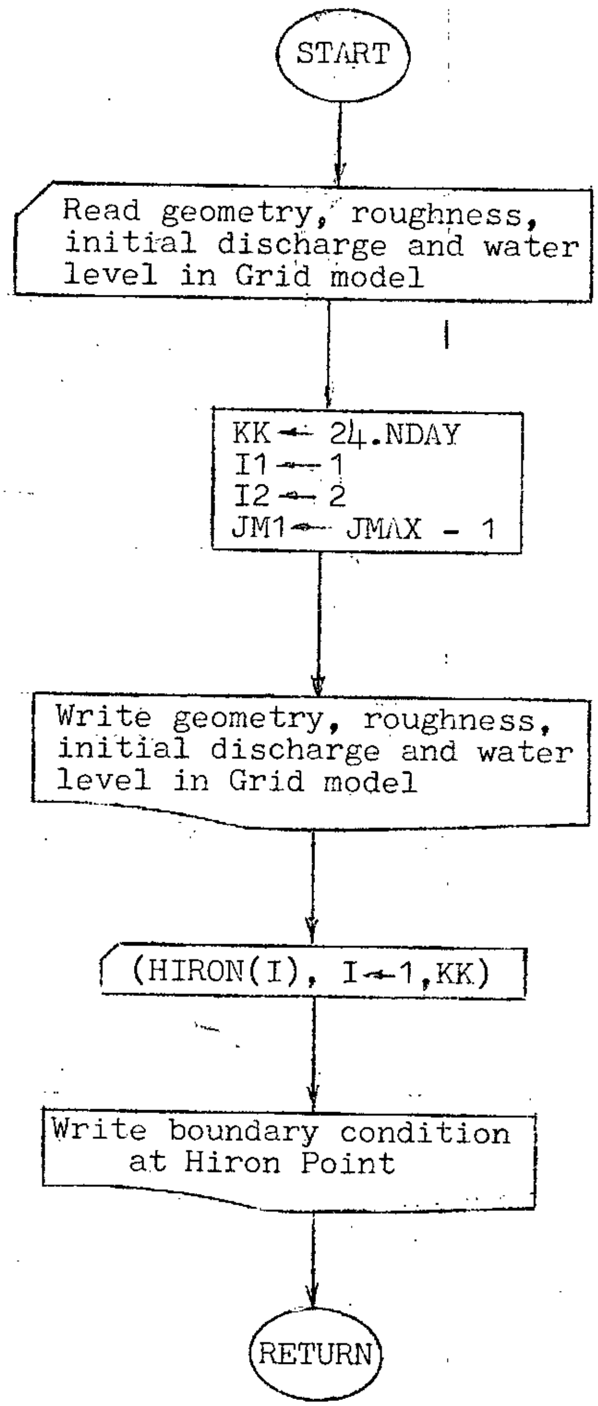
FLOW DIAGRAM OF MAIN PROGRAM (Continued)



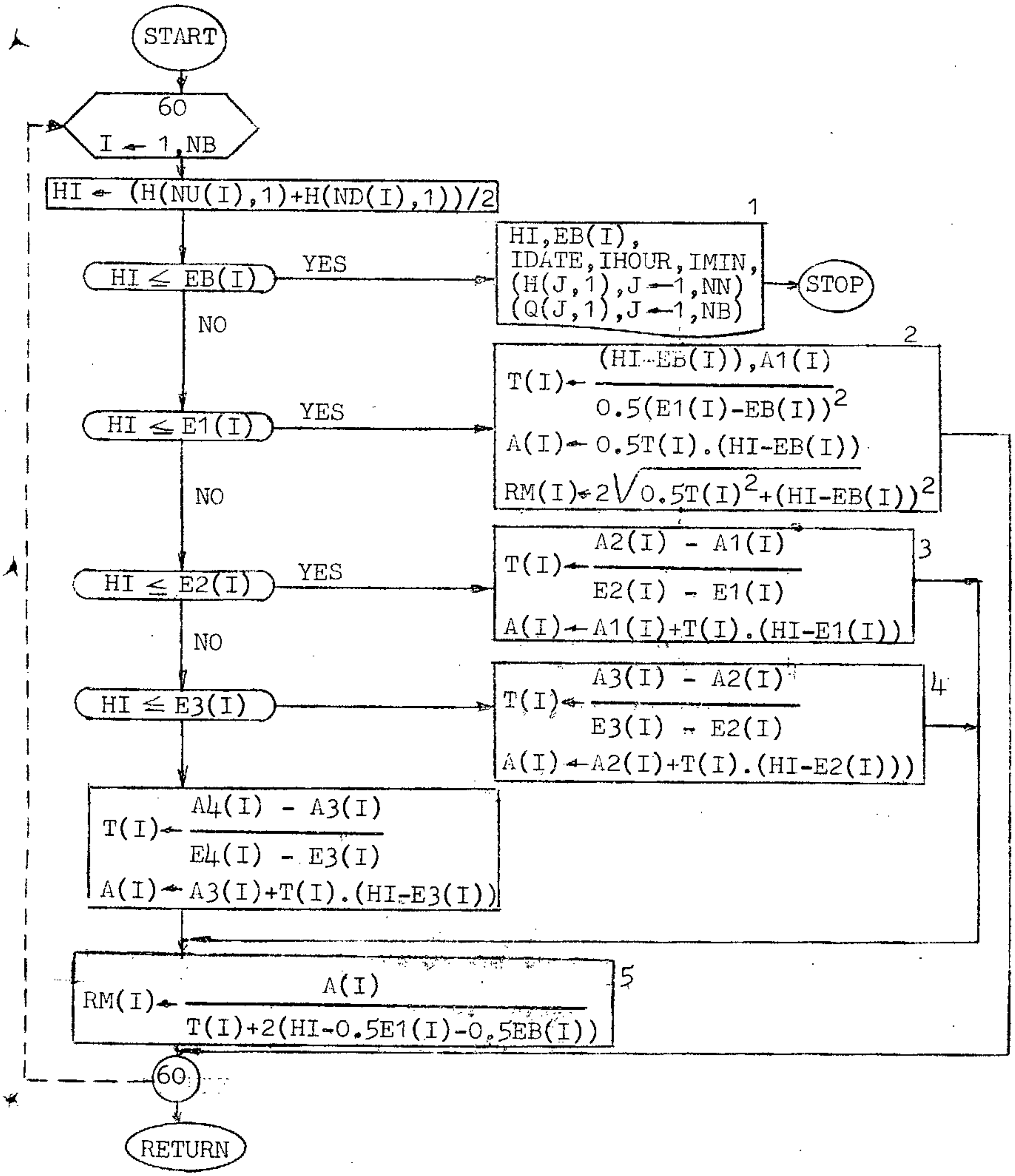
FLOW DIAGRAM OF MAIN PROGRAM (Continued)



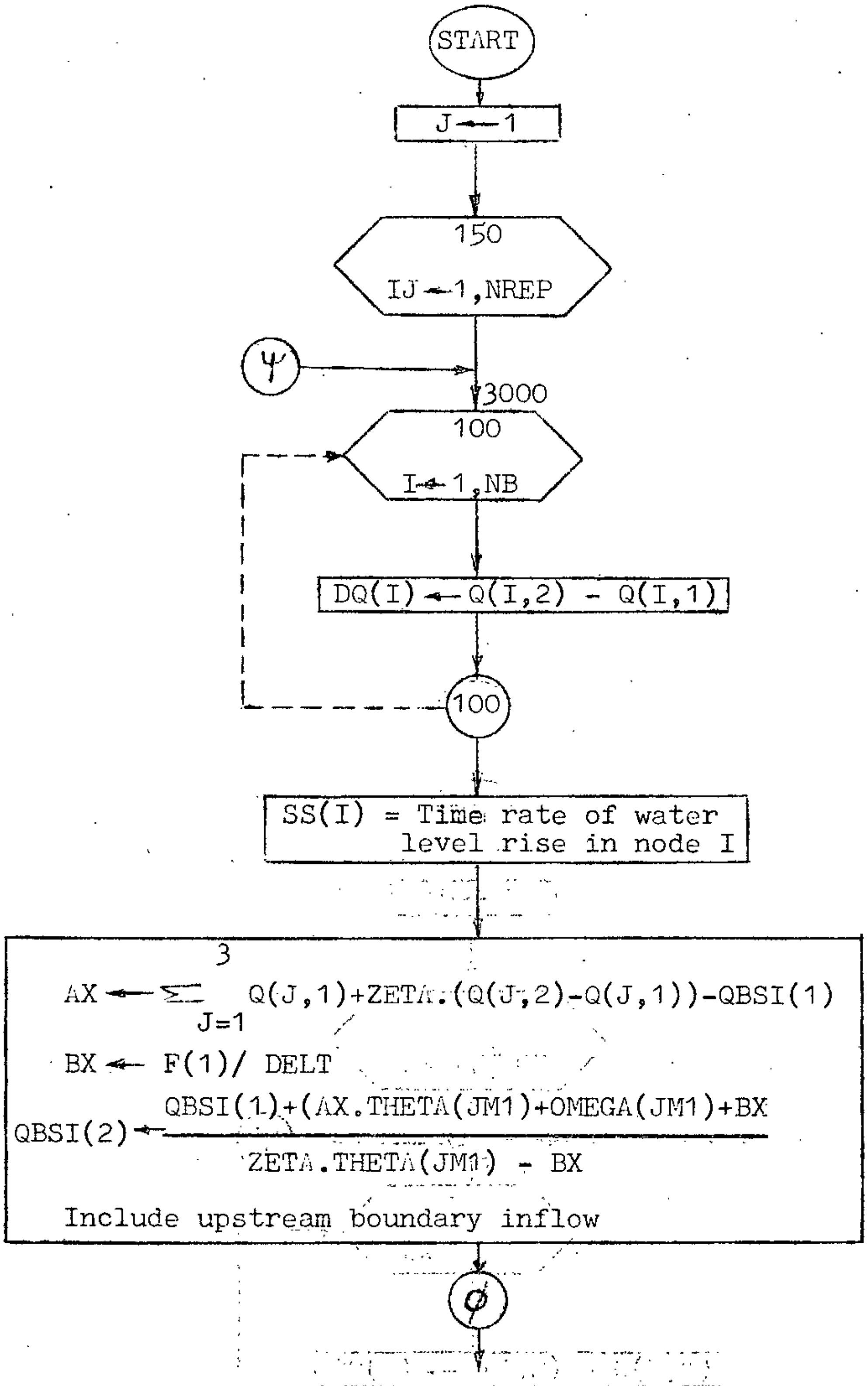
FLOW DIAGRAM OF MAIN PROGRAM (Continued)



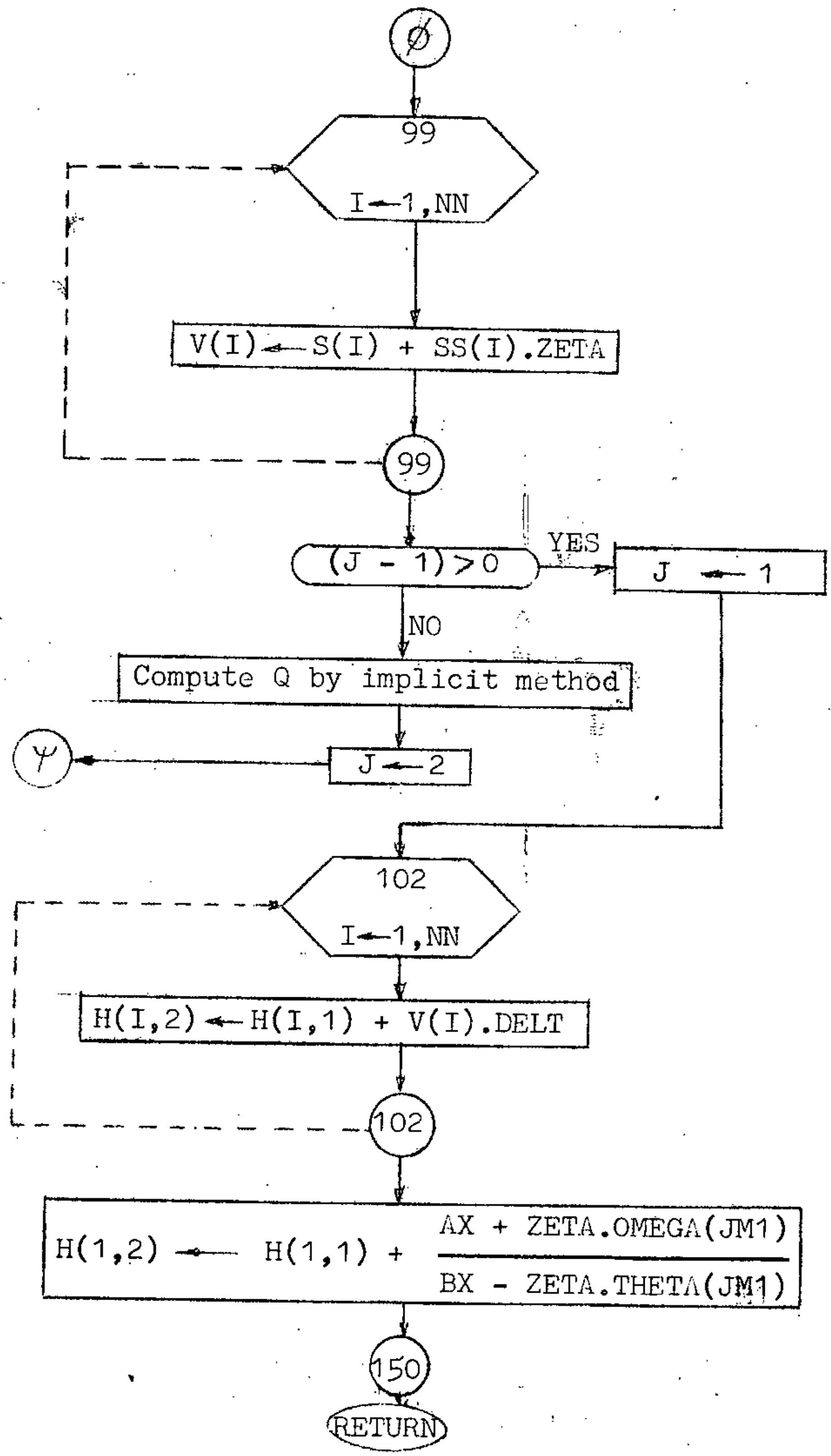
FLOW DIAGRAM OF SUBROUTINE GEOM



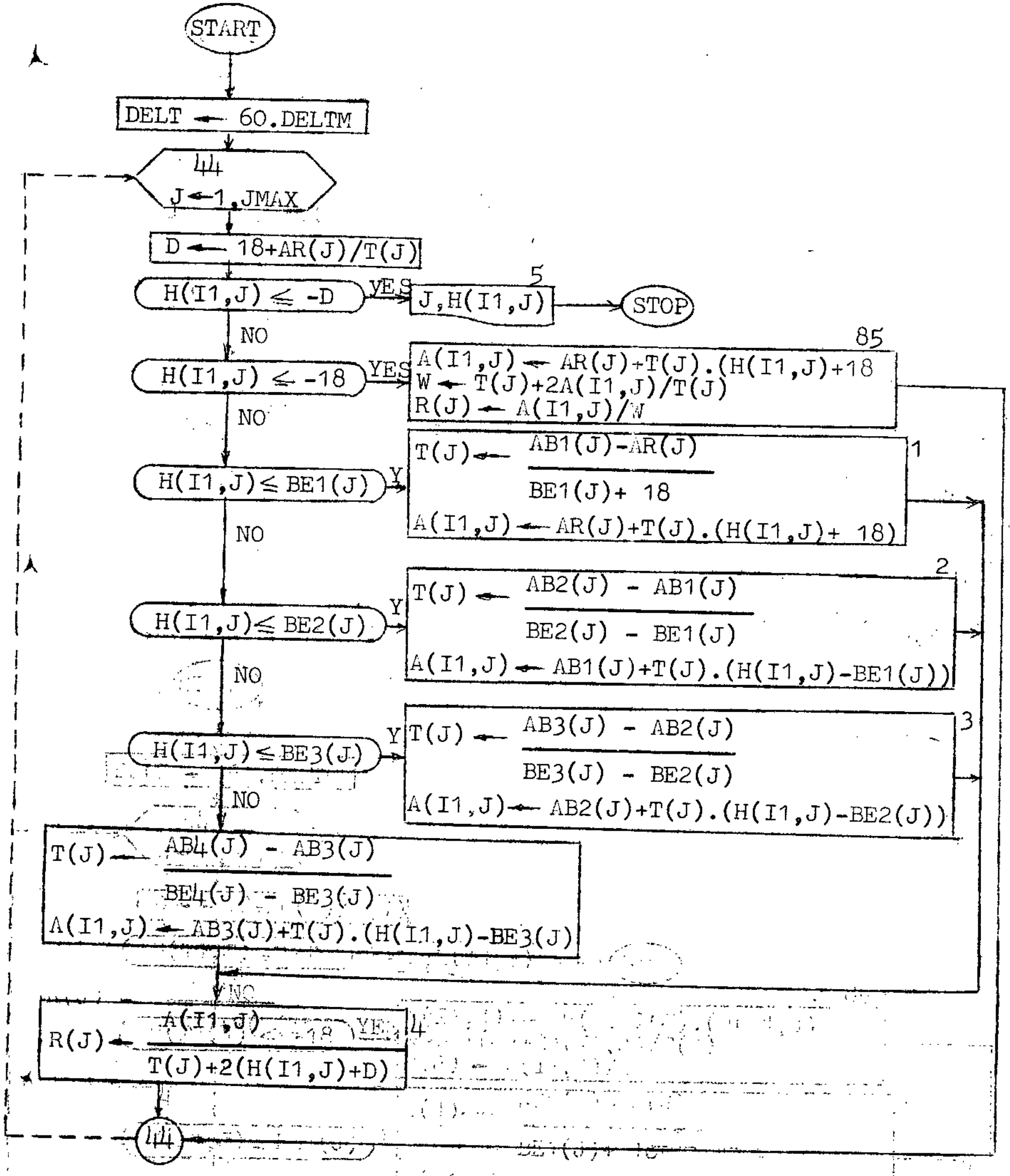
FLOW DIAGRAM OF SUBROUTINE AREA



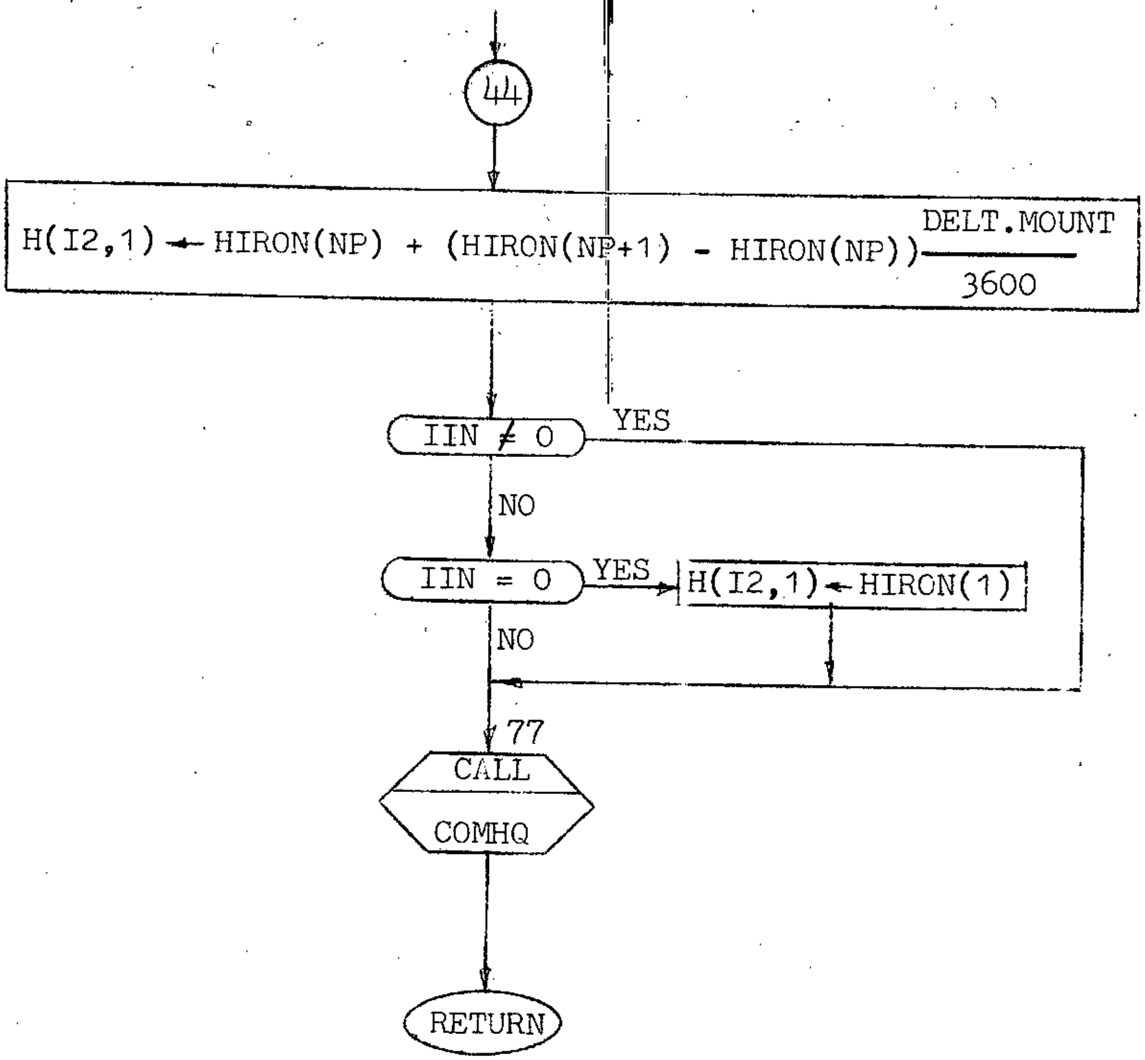
FLOW DIAGRAM OF SUBROUTINE REP



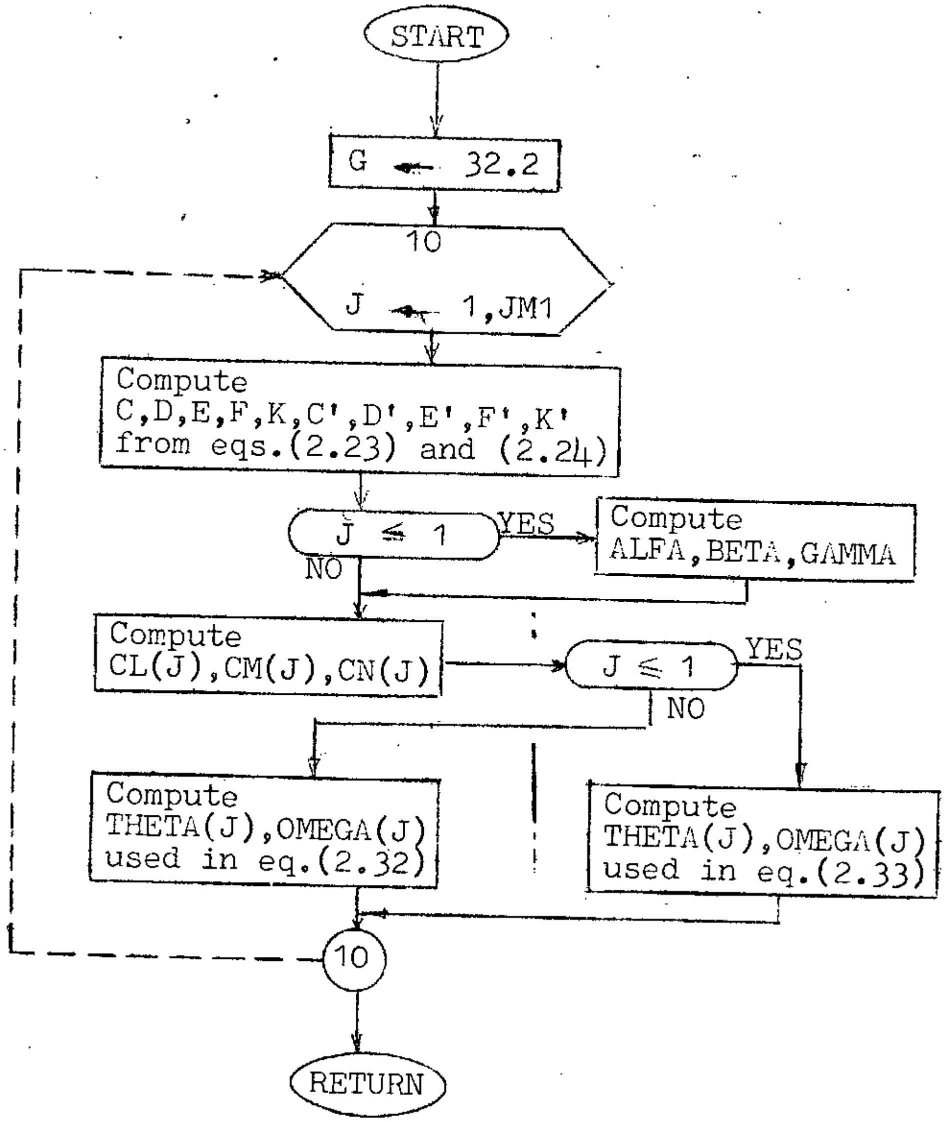
FLOW DIAGRAM OF SUBROUTINE REP (Continued)



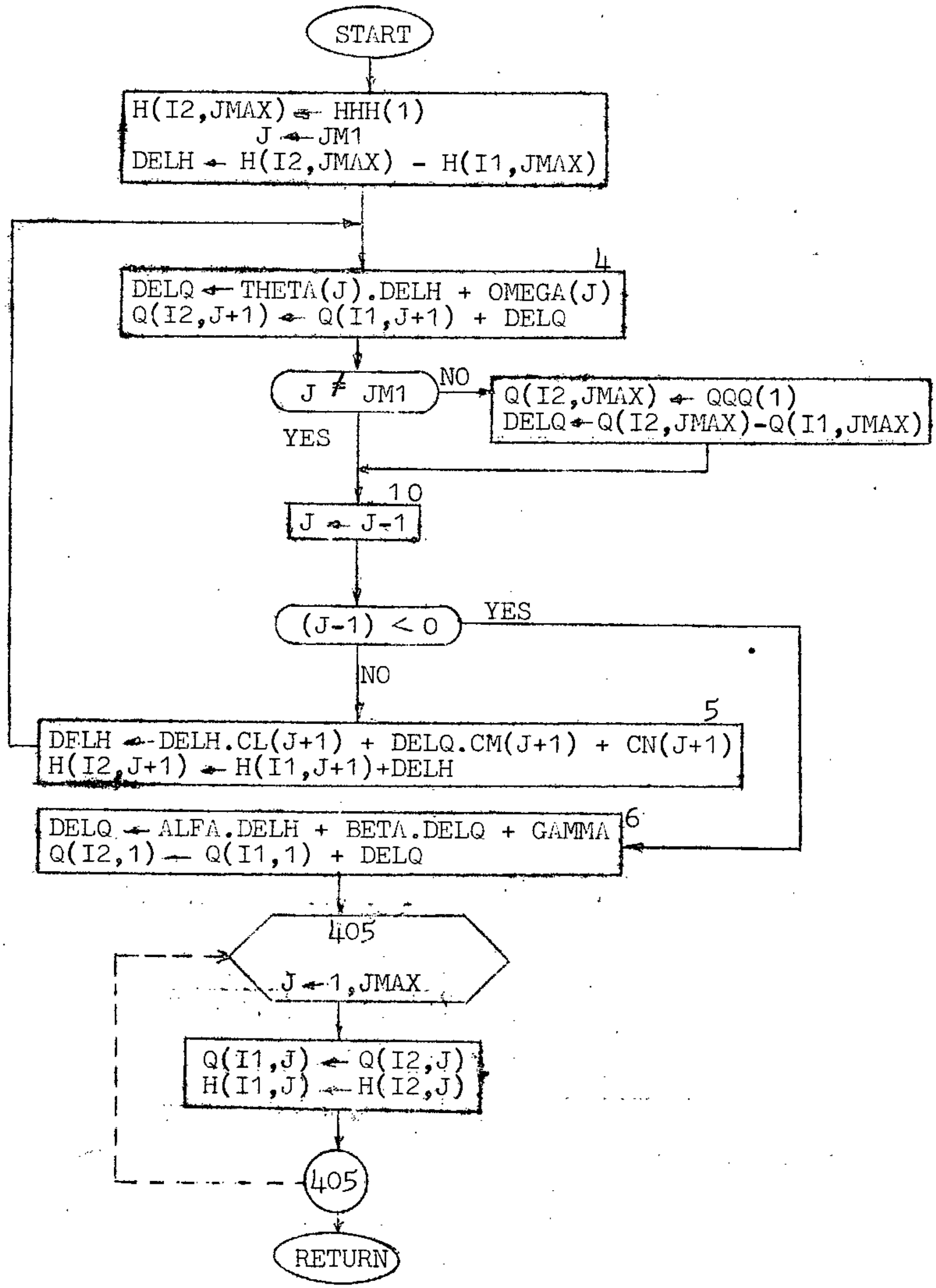
FLOW DIAGRAM OF SUBROUTINE TIDE2



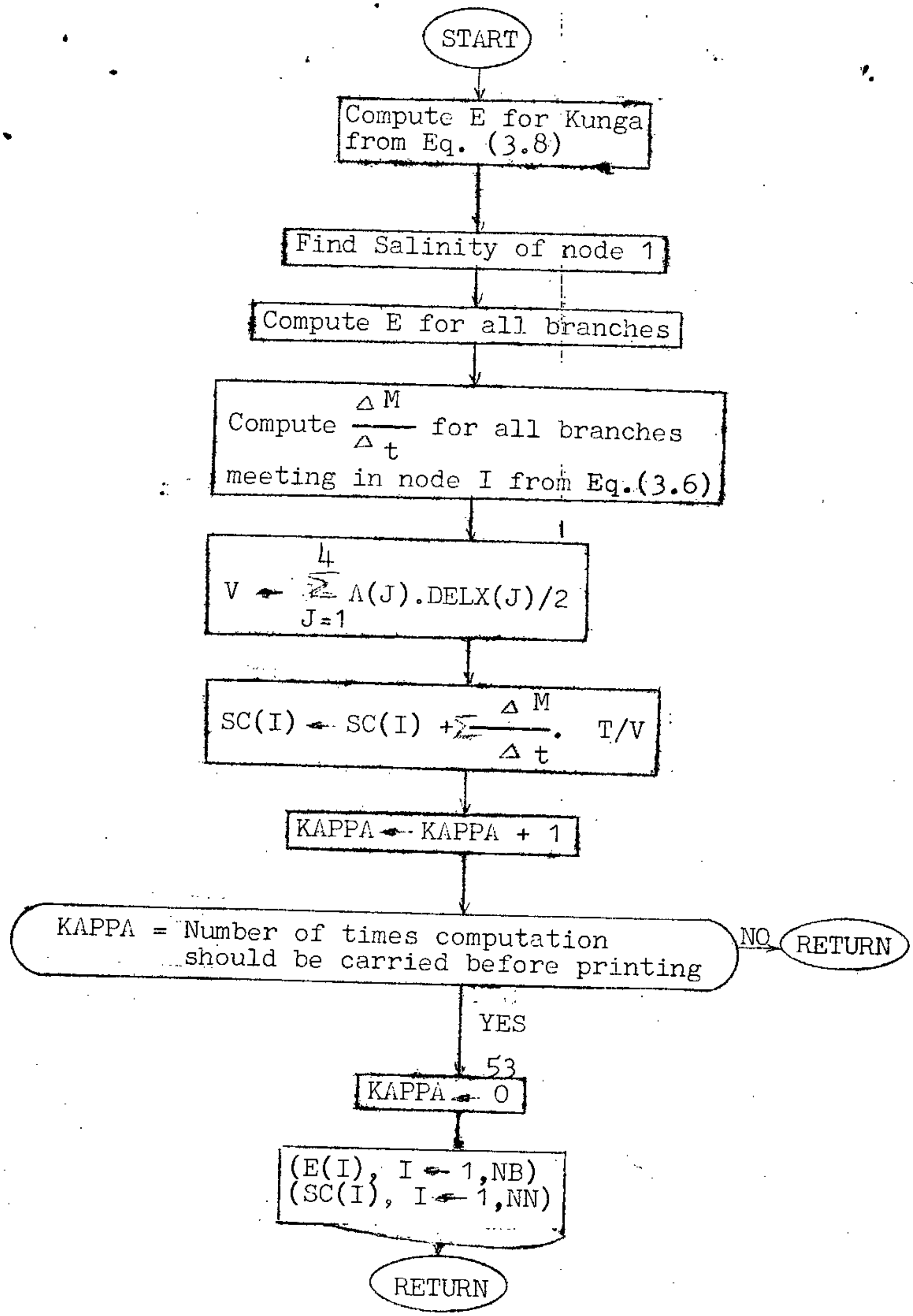
FLOW DIAGRAM OF SUBROUTINE TIDE2 (Continued)



FLOW DIAGRAM OF SUBROUTINE COMHQ



FLOW DIAGRAM FOR SUBROUTINE TIDE3



FLOW DIAGRAM OF SUBROUTINE COMS

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APPENDIX - D

COMPUTER PROGRAMS

```
      C     A MATHEMATICAL MODEL FOR SALINITY INTRUSION IN THE
      C     SIBSA-PUSSUR RIVER SYSTEM
      C     MAIN PROGRAM FOR SALINITY INTRUSION (1979)
      C
      C
01          DIMENSION FGORAI(15),FMADHU(15),FRPUR(15),FDLUTI(15),
           $ FMONGL(15),DIFH(76)
02          COMMON/BLOCK1/ Q(76,2),H(60,2),NB,NN,NU(76),ND(76),QGORAI(2),
           $ QMADHU(2),QRPUR(2),QDLUTI(2),QMONGL(2),QBSI(2),DELX(76)
03          COMMON/BLOCK2/ ZETA,L1(60),L2(60),L3(60),L4(60),DQ(76),
           $ G,DIFA(76),CK(76),IX,DELT,F(60),S(60),C(76),SS(60)
04          COMMON/BLOCK3/ A(76),T(76)
05          COMMON/BLOCK4/ DELTM,MOUNT
06          COMMON/BLOCK5/ EB(76),E1(76),E2(76),E3(76),E4(76),A1(76),
           $ A2(76),A3(76),A4(76),RM(76)
07          COMMON/BLOCK6/ V(60),SQ(76),NREP
08          COMMON/BLOCK7/ SM,SC(60),ENM(76),EK1,EK2,KAPPA
09          COMMON/BLOCK8/ JM1,NP,NDAY,QQQ(2),HHH(2)
10          COMMON/BLOCK9/ADELX,AB1(7),AB2(7),AB3(7),AB4(7),BE1(7),BE2(7),
           $      BE3(7),BE4(7)
11          COMMON/BLOCKA/CL(7),CM(7),CN(7),THETA(7),MCT,OMEGA(7),
           $   ALFA,BETA,GAMMA,AHH(2,7),ACQ(2,7)
12          COMMON/BLOCKB/AMANCO(7),HIRON(370),JMAX,I1,I2,IIN,ADD(7),TAD(7)
13          COMMON/BLOCKF/MDATE,IDATE,IHOUR,IMIN
      C     COMPUTATIONAL PROCEDURE
      C     READ NO OF BRANCHES AND NODES
14          READ(1,1000) NB,NN
      C     READ TIME INTERVAL IN MINUTES FOR COMPUTATION
15          READ(1,1001) DELTM
      C     READ DISTANCE INTERVAL IN MILES ALONG BRANCHES
16          READ(1,1004) (DELX(I),I=1,NB)
      C     READ NODE UPSTREAM AND NODE DOWNSTREAM OF EACH BRANCH
      C     AND ROUGHNESS COEFFICIENT
17          READ(1,1000)(NU(I),ND(I),I=1,NB)
18          READ(1,1004) (ENM(I),I=1,NB)
      C     READ INITIAL AND FINAL DAY, HOUR AND MINUTE ALSO
      C     READ NO OF DAY FOR RUNNING SALINITY COMPUTATION
19          READ(1,1000) IDATE,IHOUR,IMIN,KDATE,KHOUR,KMIN,NDAY
      C     READ TIME IN MINUTES FOR PRINTING THE COMPUTED RESULT
20          READ(1,1000) IPRINT
      C     READ NO OF STEADY DAY
21          READ(1,1000) NSTD
      C     READ DAILY UPLAND DISCHARGES FROM GORAI, MADHUMATI, ETC
22          READ(1,1004) (FGORAI(I),I=1,NDAY)
23          READ(1,1004) (FMADHU(I), I=1,NDAY)
24          READ(1,1004)(FRPUR(I),I=1,NDAY)
25          READ(1,1004)(FDLUTI(I),I=1,NDAY)
26          READ(1,1004)(FMONGL(I),I=1,NDAY)
      C     READ INITIAL WATER LEVEL AND DISCHARGE FOR ALL NODES AND BRANCHES
27          READ(1,1004)(H(I,1),I=1,NN)
28          READ(1,1004)(Q(I,1),I=1,NB)
      C     READ INITIAL DISCHARGE AT THE BOUNDARY
29          READ(1,1004) QGORAI(1),QMADHU(1),QRPUR(1),QDLUTI(1),QMONGL(1)
30          QBSI(1)=QGORAI(1)+QMADHU(1)+QRPUR(1)+QDLUTI(1)+QMONGL(1)
```

```
C     READ ELEVATION AND CORRESPONDING CROSS-SECTIONAL AREA
      DO 30 I=1,NB
      READ(1,1004) EB(I),E1(I),E2(I),E3(I),E4(I)
      READ(1,1004) A1(I),A2(I),A3(I),A4(I)
   30 CONTINUE
C     READ BRANCH NUMBERS WHICH ISSUE FROM EACH NODE
      READ(1,1000)(L1(I),L2(I),L3(I),L4(I),I=1,NN)
C     READ SALINITY AT SEA AND NODES
      READ(1,1120) SM,(SC(I),I=1,59)
C     READ PARAMETERS FOR LONGITUDINAL DISPERSION COEFFICIENT
      READ(1,1004) EK1,EK2
      WRITE(3,4000)
      WRITE(3,2000) NB,NN
      WRITE(3,2001) DELTM
      WRITE(3,2002)(DELX(I),I=1,NB)
      WRITE(3,2005)
      WRITE(3,2003)(I,NU(I),ND(I),I=1,NB)
      WRITE(3,2008)
      WRITE(3,2009)(ENM(I),I=1,NB)
      DO 132 I=1,NB
C     CHANGE DELX(I) TO FEET
      DELX(I)=DELX(I)*5280.
  132 CONTINUE
      WRITE(3,2010)
      WRITE(3,2011)IDATE,IHOUR,IMIN,KDATE,KHOUR,KMIN,NDAY
      WRITE(3,2012) IPRINT
      WRITE(3,2013) NSTD
      WRITE(3,2014) IDATE,(FGORAI(I),I=1,NDAY)
      WRITE(3,2015) IDATE,(FMADHU(I),I=1,NDAY)
      WRITE(3,2016)IDATE,(FRPUR(I),I=1,NDAY)
      WRITE(3,2017)IDATE,(FDLUTI(I),I=1,NDAY)
      WRITE(3,2018)IDATE,(FMONGL(I),I=1,NDAY)
      WRITE(3,2020)(H(I,1),I=1,NN)
      WRITE(3,2021)(Q(I,1),I=1,NB)
      WRITE(3,2023)QGORAI(1),QMADHU(1),QRPUR(1),QDLUTI(1),QMONGL(1)
      WRITE(3,3005)
      DO 536 I=1,NB
      WRITE(3,2028)I,EB(I),E1(I),A1(I),E2(I),A2(I),E3(I),A3(I),E4(I),
     $ A4(I)
  536 CONTINUE
      WRITE(3,2034)
      WRITE(3,2035)(I,L1(I),L2(I),L3(I),L4(I),I=1,NN)
      WRITE(3,2004) EK1,EK2
 1000 FORMAT(16I5)
 1001 FORMAT(F10.2)
 1004 FORMAT(8F10.2)
 1120 FORMAT(8F10.2)
 2000 FORMAT(//10X,'NB=NO OF BRANCHES =',I5,5X,'NN=NO OF NODES =',
     $I5)
 2001 FORMAT(//10X,'DELTM=TIME INTERVAL IN MINUTES=',F8.2)
 2002 FORMAT(//20X,'LENGTH OF EACH BRANCH IN',1X,'MILE',//,
     $40X,'DELX(I)',//,(10X,8F9.2))
 2003 FORMAT(3(10X,'(',I2,')',1X,2I5))
 2004 FORMAT(10X,'EK1=',F12.1,10X,'EK2=',F12.1)
```

```
77        2005 FORMAT(//15X,'BRANCH NO.,    NODE UPSTREAM AND NODE DOWNSTREAM O
               $EACH BRANCH')
78        2008 FORMAT(/20X,'ROUGHNESS COEFFICIENT OF BRANCH= MANNING''S N',//)
79        2009 FORMAT(3(3X,3F9.4))
80        2010 FORMAT(//6X,'INITIAL  DAY  HOUR  MINUTE          FINAL  DAY  HOUR
               $MINUTE          NO OF DAY FOR RUNNING')
81        2011 FORMAT(/13X,3I5,17X,3I5,16X,I5)
82        2012 FORMAT(//6X,'IPRINT= TIME INTERVAL FOR PRINTING THE COMPUTED WA
               $LEVEL, SALINITY & DISCHARGE IN MINUTE= ',I5)
83        2013 FORMAT(//6X,'NSTD= NO OF STEADY DAY =',I5)
84        2014 FORMAT(/6X,'FGORAI=DAILY INFLOW FROM GORAI FROM DAY NO',I3,//,
               $(8F9.2))
85        2015 FORMAT(/6X,'FMADHU= DAILY INFLOW FROM MADHUMATI AND BIL ROUTE
               $ FROM DAY NO',I3,//,(8F9.2))
86        2016 FORMAT(/6X,'FRPUR= DAILY INFLOW IN SIBSA AT RAIPUR FROM DAY NO'
               $,//,(8F9.2))
87        2017 FORMAT(/6X,'FDLUTI=DAILY INFLOW IN SIBSA AT DELUTI FROM DAY NO'
               $I3,//,(8F9.2))
88        2018 FORMAT(/6X,'FMONGL=DAILY INFLOW IN MONGLA NALA FROM DAY NO',I3,
               $//,(8F9.2))
89        2020 FORMAT(6X,'INITIAL WATER LEVEL IN EACH NODE ABOVE CHART DATUM'
               $(8F9.2))
90        2021 FORMAT(/6X,'INITIAL DISCHARGE (CFS) IN EACH BRANCH',//,(8F9.2)
91        2023 FORMAT(/6X,'INFLOW (CFS) AT UPSTREAM MODEL BOUNDARIES',//6X,'Q
               $I=',F8.2,5X,'QMADHU=',F8.2,5X,'QRPUR=',F8.2,5X,'QDLUTI=',F8.2,
               $5X,'QMONGL=',F8.2)
92        2028 FORMAT(10X,'(',I2,')',1X,9F10.1)
93        2034 FORMAT(/10X,'NUMBERS OF BRANCH ISSUING FROM EACH NODE',//
               $5X,' NODE NO.',7X,'L1(I)',5X,'L2(I)',5X,'L3(I)',5X,'L4(I)')
94        2035 FORMAT(6X,'(',I2,')',5X,4I10)
95        3005 FORMAT(//6X,'SPECIFIC ELEVATION AND CORRESPONDING CROSS-SECTION
               $ AREA OF BRANCH',/6X,'BRANCH NO',7X,'EB',8X,'E1',8X,'A1',8X,
               $'E2',8X,'A2',8X,'E3',8X,'A3',8X,'E4',8X,'A4')
96        4000 FORMAT(1H1,10X,'DATA FOR NODE AND BRANCH MODEL')
     C         INITIALIZE INDICES USED IN THE PROGRAM
97             G=32.2
98             KAPPA=0
99             NREP=3
100            NO=1
101            IF(QGORAI(1).GE.2000.0) DELTM=10.0
102            KOUNT=1
103            IX=0
104            HHH(1)=H(1,1)
105            DELT=DELTM*60.
106            IDELT=DELTM
107            NP=1
108            JMIN=0
109            JJMIN=0
110            KCT=24.*3600./DELT
111            ISTD=0
112            DQ(NB+1)=0
113            Q(NB+1,1)=0
114            DELX(NB+1)=0.
115            T(NB+1)=0.
```

```
              A(N3+1)=0.
              MDATE=IDATE
              MHOUR=IHOUR
              MMIN=IMIN
              ZETA=0.55
              MO=1
              MOUNT=1
              MCT=3600./DELT
C             CALL SUBROUTINE GEOM TO READ DATA IN FIXED GRID FINITE DIFFER
              CALL GEOM
              IIN=0
              QOO(1)=-QBSI(1)
          176 IMIN=IMIN+IDELT
              JMIN=JMIN+IDELT
              JJMIN=JJMIN+IDELT
              CALL AREA
              IF((IMIN-60).LT.0) GO TO 101
              IMIN=IMIN-60
              IHOUR=IHOUR+1
              IF((IHOUR-24).LT.0) GO TO 101
              IHOUR=IHOUR-24
              IDATE=IDATE+1
          101 DO 3 I=1,NN
              IF(L2(I).EQ.0) L2(I)=NB+1
              IF(L3(I).EQ.0) L3(I)=NB+1
              IF(L4(I).EQ.0) L4(I)=NB+1
C             COMPUTE SURFACE AREA OF EACH NODE
              F(I)=(DELX(IABS(L1(I)))*T(IABS(L1(I)))+
             $DELX(IABS(L2(I)))*T(IABS(L2(I)))+
             $DELX(IABS(L3(I)))*T(IABS(L3(I)))+
             $DELX(IABS(L4(I)))*T(IABS(L4(I))))/2.
C             COMPUTE CONSTANT OF CONTINUITY EQUATION
              S(I)=(Q(IABS(L1(I)),1)*L1(I)/IABS(L1(I))
             $+Q(IABS(L2(I)),1)*L2(I)/IABS(L2(I))
             $+Q(IABS(L3(I)),1)*L3(I)/IABS(L3(I))
             $+Q(IABS(L4(I)),1)*L4(I)/IABS(L4(I)))/F(I)
            3 CONTINUE
C             INCLUDING BOUNDARY CONDITION INTO NODES
              S(2)=S(2)+QG RAI(1)/F(2)
              S(3)=S(3)+QMADHU(1)/F(3)
              S(4)=S(4)+QRPUR(1)/F(4)
              S(5)=S(5)+QDLUTI(1)/F(5)
              S(6)=S(6)+QMONGL(1)/F(6)
              S(1)=S(1)-QBSI(1)/F(1)
C             COMPUTE WATER ELEVATIONS OF ALL NODES
              DO 20 I=1,NN
              H(I,2)=H(I,1)+S(I)*DELT
           20 CONTINUE
C             COMPUTE DIFFERENCE IN WATER SURFACE ELEVATION BETWEEN NODES
              DO 5 I=1,NB
              DIFH(I)=H(ND(I),1)-H(NU(I),1)
C             COMPUTE CONVEYANCE OF CHANNELS
              CK(I)=A(I)*(RM(I)**.667)*1.486/ENM(I)
C             COMPUTE CONSTANT OF MOMENTUM EQUATION IN BRANCH
```

```
      SQ(I)=S(NU(I))+S(ND(I))
    5 CONTINUE
      DO 700 I=1,NB
      DIFA(I)=T(I)*DIFH(I)/DELX(I)
      C(I)=Q(I,1)*T(I)/A(I)*SQ(I)+(Q(I,1)**2)*DIFA(I)/(A(I)**2)
     $-G*A(I)*DIFH(I)/DELX(I)-G*A(I)*Q(I,1)*ABS(Q(I,1))/(CK(I)**2)
      Q(I,2)=Q(I,1)+C(I)*DELT
  700 CONTINUE
C     CHECK STEADY STATE CONDITION
      IF(IX.NE.0) GO TO 201
C     SET TO STEADY STATE BOUNDARY CONDITION
      QGORAI(2)=QGORAI(1)
      QMADHU(2)=QMADHU(1)
      QRPUR(2)=QRPUR(1)
      QDLUTI(2)=QDLUTI(1)
      QMONGL(2)=QMONGL(1)
      H(1,2)=H(1,1)
      HHH(1)=H(1,1)
C     COMPUTE TIDAL CONDITION FROM DOWNSTREAM (JEFFORD POINT)
      CALL TIDE2
C     SOLVE WATER LEVEL AND DISCHARGE BY IMPLICIT METHOD
      CALL REP
      HHH(1)=H(1,2)
      QQQ(1)=-QBSI(2)
C     SOLVE THE SOLUTION BY BACK UP  IN MARHJATA
      CALL TIDE3
      GO TO 203
C     COMPUTE NEXT BOUNDARY INFLOW INTO  NODE
  201 QGORAI(2)=FGORAI(NO)+(FGORAI(NO+1)-FGORAI(NO))/24./3600.*
     1DELT*KOUNT
      QMADHU(2)=FMADHU(NO)+(FMADHU(NO+1)-FMADHU(NO))/24./3600.*
     1DELT*KOUNT
      QRPUR(2)=FRPUR(NO)+(FRPUR(NO+1)-FRPUR(NO))/24./3600.*DELT*KOUNT
      QDLUTI(2)=FDLUTI(NO)+(FDLUTI(NO+1)-FDLUTI(NO))/24./3600.*
     $DELT*KOUNT
      QMONGL(2)=FMONGL(NO)+(FMONGL(NO+1)-FMONGL(NO))/24./3600.*
     $DELT*KOUNT
      KOUNT=KOUNT+1
      IF(KOUNT.LE.KCT) GO TO 181
      KOUNT =1
      NO=NO+1
C      COMPUTE TIDAL CONDITION FROM DOWNSTREAM BOUNDARY
  181 CALL TIDE2
C     COMPUTE SALINITY INTRUSION
      CALL COMS
      MOUNT=MOUNT+1
      IF(MOUNT.LE.MCT) GO TO 165
      MOUNT=1
      MO=MO+1
      NP=NP+1
CSOLVE WATER LEVEL AND DISCHARGE BY IMPLICIT METHOD
  165 CALL REP
      HHH(1)=H(1,2)
      QQQ(1)=-QBSI(2)
```

```
C     CALL TIDE3 TO SOLVE BY BACK UP
      CALL TIDE3
C     SET TO INITIAL CONDITION
  203 DO 166 I=1,NN
      H(I,1)=H(I,2)
  166 CONTINUE
      QGORAI(1)=QGORAI(2)
      QMADHU(1)=QMADHU(2)
      QRPUR(1)=QRPUR(2)
      QDLUTI(1)=QDLUTI(2)
      QMONGL(1)=QMONGL(2)
      QBSI(1)=QBSI(2)
      DO 167 I=1,NB
      Q(I,1)=Q(I,2)
  167 CONTINUE
      IF(IX.NE.0) GO TO 169
       ISTD=ISTD+1
      IF((ISTD-NSTD*KCT).LE.0) GO TO 175
      IX=1
C     SET IDATE,IHOUR, IMIN FOR RUNNING IN UNSTEADY CONDITION
      IDATE=MDATE
      IHOUR=MHOUR
      IMIN=MMIN
      JMIN=0
      IIN=1
      WRITE(3,3055)
      GO TO 477
  169 IF((JMIN-IPRINT).LT.0) GO TO 175
      JMIN=0
C     WRITE WATER LEVEL AND DISCHARGE FOR ALL NODES AND BRANCHES
      WRITE(3,3050)
  477 WRITE(3,3008) IDATE, IHOUR, IMIN
      WRITE(3,3009)(H(I,2),I=1,NN)
      WRITE(3,3009) (Q(I,2),I=1,NB)
      WRITE(3,2023)QGORAI(2),QMADHU(2),QRPUR(2),QDLUTI(2),QMONGL(2)
      WRITE(3,3060)
      WRITE(3,3009)(AHH(I2,J),J=1,JMAX)
      WRITE(3,3009)(AQQ(I2,J),J=1,JMAX)
  175 IF((IDATE-KDATE).LT.0) GO TO 176
      IF((IHOUR-KHOUR).LT.0) GO TO 176
      IF((IMIN-KMIN).LT.0) GO TO 176
C     WRITE WATER LEVEL AND DISCHARGE IN NODE AND BRANCH
      WRITE(3,3050)
      WRITE(3,3010)(I,I=1,NB)
      WRITE(3,3009)(H(I,2),I=1,NN)
      WRITE(3,3009)(Q(I,2),I=1,NB)
      WRITE(3,2023) QGORAI(2),QMADHU(2),QRPUR(2),QDLUTI(2),QMONGL(2)
      WRITE(3,3009)(AHH(I2,J),J=1,JMAX)
      WRITE(3,3009)(AQQ(I2,J),J=1,JMAX)
      STOP
 3008 FORMAT(//6X,'DATE=',I2,2X,'HOUR=',I2,2X,'MIN=',I2)
 3009 FORMAT(6X,10F12.2)
 3010 FORMAT(6X,12I8)
 3050 FORMAT(1H1,/6X,'COMPUTED WATER LEVEL AND DISCHARGE IN NODES 'AND
```

```
     $BRANCHES',///,20X,'***UNSTEADY CONDITION***')
45   3055 FORMAT(1H1,/6X,'INITIAL CONDITION OF WATER LEVEL & DISCHARGE IN
     $NODES AND BRANCHES',   ///,20X,'***STEADY UPSTREAM BOUNDARY
     $CONDITION***')
46   3060 FORMAT(//6X,'WATER LEVEL AND DISCHARGE IN MARJATA')
47        END
```

```fortran
      SUBROUTINE AREA
      COMMON/BLOCK1/ Q(76,2),H(60,2),NB,NN,NU(76),ND(76),QGORAI(2),
     $ QMADHU(2),QRPUR(2),QDLUTI(2),QMONGL(2),QBSI(2),DELX(76)
      COMMON/BLOCK3/ A(76),T(76)
      COMMON/BLOCK5/ EB(76),E1(76),E2(76),E3(76),E4(76),A1(76),
     $ A2(76),A3(76),A4(76),RM(76)
      COMMON/BLOCKE/MDATE,IDATE,IHOUR,IMIN
C     C IMPUTE TOP WIDTH, C IROSS-SECTIONAL AREA
      DO 60 I=1,N3
      HI=(H(NU(I),1)+H(ND(I),1))/2.
      IF(HI.LE.EB(I)) GO TO 1
      IF(HI.LE.E1(I)) GO TO 2
      IF(HI.LE.E2(I)) GO TO 3
      IF(HI.LE.E3(I)) GO TO 4
      T(I)=(A4(I)-A3(I))/(E4(I)-E3(I))
      A(I)=A3(I)+T(I)*(HI-E3(I))
      GO TO 5
    1 WRITE(3,150) I,HI,EB(I)
      WRITE(3,151) IDATE,IHOUR,IMIN
      WRITE(3,152)(J,H(J,1),J=1,NN)
      WRITE(3,153)(J,Q(J,1),J=1,NB)
      WRITE(3,154)QGORAI(1),QMADHU(1),QRPUR(1),QDLUTI(1),QMONGL(1),
     $QBSI(1)
      STOP
  150 FORMAT(5X,'AT BRANCH NO',2X,I2,3X,'H=',F10.2,' AND EB=',F10.2,
     1'WATER LEVEL FALLS BELOW RIVER BED')
  151 FORMAT(10X,I2,'DAY',I2,'HOUR',I2,'MIN')
  152 FORMAT(7(2X,'H(',I2,')=',F8.2))
  153 FORMAT(6(2X,'Q(',I2,')=',F11.0))
  154 FORMAT(2X,'QGORAI=',F9.1,2X,'QMADHU=',F9.1,2X,'QRPUR=',F9.1,2X,
     $'QDLUTI=',F9.1,2X,'QMONGL=',F9.1,2X,'QBSI=',F10.2)
    2 T(I)= (HI-EB(I))*A1(I)/(0.5*(E1(I)-EB(I))**2)
      A(I)=T(I)*(HI-EB(I))*0.5
      RM(I)=2.*SQRT((T(I)/2.)**2+(HI-EB(I))**2)
      GO TO 60
    3 T(I)=(A2(I)-A1(I))/(E2(I)-E1(I))
      A(I)=A1(I)+T(I)*(HI-E1(I))
      GO TO 5
    4 T(I)=(A3(I)-A2(I))/(E3(I)-E2(I))
      A(I)=A2(I)+T(I)*(HI-E2(I))
C     COMPUTE HYDRAULIC RADIUS FOR EVERY ELEVATION
    5 RM(I)=A(I)/(T(I)+2.*(HI-0.5*E1(I)-0.5*EB(I)))
   60 CONTINIE
      RETURN
      END
```

```
      SUBROUTINE REP
      COMMON/BLOCK1/ Q(76,2),H(60,2),NB,NN,NU(76),ND(76),QGORAI(2),
     $ QMADHU(2),QRPUR(2),QDLUTI(2),QMONGL(2),QBSI(2),DELX(76)
      COMMON/BLOCK2/ ZETA,L1(60),L2(60),L3(60),L4(60),DQ(76),
     $ G,DIFA(76),CK(76),IX,DELT,F(60),S(60),C(76),SS(60)
      COMMON/BLOCK3/ A(76),T(76)
      COMMON/BLOCK4/ DELTM,MOUNT
      COMMON/BLOCK6/ V(60),SQ(76),NREP
      COMMON/BLOCK8/ JM1,NP,NDAY,QQC(2),HHH(2)
      COMMON/BLOCKA/CL(7),CM(7),CN(7),THETA(7),MCT,OMEGA(7),
     $ ALFA,BETA,GAMMA,AHH(2,7),AQQ(2,7)
C     COMPUTE CHANGE IN DISCJARGE
      J=1
      DO 150 IJ=1,NREP
 3000 DO 100 I=1,NB
      DQ(I)=Q(I,2)-Q(I,1)
  100 CONTINUE
   55 DO 101 I=1,NN
      IF(L2(I).EQ.0) L2(I)=NB+1
      IF(L3(I).EQ.0) L3(I)=NB+1
      IF(L4(I).EQ.0) L4(I)=NB+1
      SS(I)=(DQ(IABS(L1(I)))*L1(I)/IABS(L1(I))
     $+DQ(IABS(L2(I)))*L2(I)/IABS(L2(I))
     $+DQ(IABS(L3(I)))*L3(I)/IABS(L3(I))
     $+DQ(IABS(L4(I)))*L4(I)/IABS(L4(I)))/F(I)
  101 CONTINUE
      AX=Q(1,1)+ZETA*(Q(1,2)-Q(1,1))+Q(2,1)+ZETA*(Q(2,2)-Q(2,1))+
     $    Q(3,1)+ZETA*(Q(3,2)-Q(3,1))-QBSI(1)
      BX=F(1)/DELT
      QBSI(2)=QBSI(1)+(AX*THETA(JM1)+OMEGA(JM1)*BX)/(ZETA*THETA(JM1
      SS(1)=SS(1)-(QBSI(2)-QBSI(1))/F(1)
      SS(2)=SS(2)+(QGORAI(2)-QGORAI(1))/F(2)
      SS(3)=SS(3)+(QMADHU(2)-QMADHU(1))/F(3)
      SS(4)=SS(4)+(QRPUR(2)-QRPUR(1))/F(4)
      SS(5)=SS(5)+(QDLUTI(2)-QDLUTI(1))/F(5)
      SS(6)=SS(6)+(QMONGL(2)-QMONGL(1))/F(6)
      DO 99 I=1,NN
      V(I)=S(I)+SS(I)*ZETA
   99 CONTINUE
      IF(J-1) 1001,1001,1002
 1002 J=1
C     COMPUTE NEW WATER LEVEL OF ALL JUNCTIONS
      DO 102 I=1,NN
      H(I,2)=H(I,1)+V(I)*DELT
  102 CONTINUE
      H(1,2)=H(1,1)+(AX+OMEGA(JM1)*ZETA)/(BX-THETA(JM1)*ZETA)
      GO TO 150
 1001 DO 103 I=1,NB
      I3=NU(I)
      I4=ND(I)
      FCT1=ZETA*T(I)*Q(I,1)/A(I)
      FCT2=ZETA*G*A(I)/DELX(I)
      C3R=-C(I)-FCT2*V(I3)*DELT+FCT2*V(I4)*DELT-FCT1*(SS(I3)+DQ(I
     $)-FCT1*(SS(I4)-DQ(I)/F(I4))
```

```
0045          COR=COR-ZETA*DQ(I)*DELT*FCT2*(1./F(I3)+1./F(I4))
0046          IF(Q(I,1).EQ.0.) SIGN=1.
0047          IF(Q(I,1).EQ.0.) GO TO 1
0048          SIGN=ABS(Q(I,1))/Q(I,1)
0049        1 COL=-1./DELT+FCT1*(-1./F(I3)+1./F(I4))+2.*ZETA*Q(I,1)*(DIFA(I)
             $(A(I)**2)-G*A(I)*SIGN/(CK(I)**2))+ZETA*T(I)/A(I)*SQ(I)
0050          COL=COL-ZETA*FCT2*DELT*(1./F(I3)+1./F(I4))
0051          Q(I,2)=Q(I,1)+COR/COL
0052      103 CONTINUE
0053          J=2
0054          GO TO 3000
0055      150 CONTINUE
0056          RETURN
0057          END
```

```
      SUBROUTINE GEOM
      COMMON/G/ T(7),AR(7),R(7)
      COMMON/ONE/ DELT,DELX
      COMMON/X/ A(2,7),H(2,7),Q(2,7),B(7)
      COMMON/BLOCK4/ DELTM,MOUNT
      COMMON/BLOCK8/ JM1,NP,NDAY,QQC(2),HHH(2)
      COMMON/BLOCK9/ADELX,AB1(7),AB2(7),AB3(7),AB4(7),BE1(7),BE2(7),
     $     BE3(7),BE4(7)
      COMMON/BLOCKA/CL(7),CM(7),CN(7),THETA(7),MCT,OMEGA(7),
     $     ALFA,BETA,GAMMA,AHH(2,7),ACQ(2,7)
      COMMON/BLOCKB/AMANCO(7),HIRON(370),JMAX,I1,I2,IIN,ADD(7),TAD(7
C     READ NO OF GRID POINT,DISTANCE, DISTANCE INTERVAL
      READ(1,101) JMAX, XL, DELX
      WRITE(3,200)
      WRITE(3,201) XL,DELX
      READ(1,102)(T(J),AR(J),J=1,JMAX)
      DO 10 J=1,JMAX
      DIST=(J-1)*DELX/5280.
      IF(J.EQ.1) DIST=1.
      WRITE(3,202) DIST,T(J),AR(J),J
      ADD(J)=AR(J)
      TAD(J)= T(J)
   10 CONTINUE
C       READ ROUGHNESS COEFFICIENT OF ALL GRID POINTS
      READ(1,103)(AMANCO(J),J=1,JMAX)
      WRITE(3,203)( AMANCO(J),J=1,JMAX)
  102 FORMAT(8F10.2)
  101 FORMAT(I5,2F10.3)
  200 FORMAT(///20X,'DATA FOR GRID MODEL')
  201 FORMAT(//10X,'LENGTH OF ESTUARY MARJATA=',F10.0,' FEET',//10X,
     1'SEGMENT LENGTH',F10.0,'FEET',//30X,'***SCHEMATIZATION***'/1
     2'MILE',13X,'B',11X,'AREA',5X,'SECTION')
  202 FORMAT(10X,F8.1,2F15.0,5X,I5)
  103 FORMAT(8F10.4)
  203 FORMAT(//10X,'ROUGHNESS CO-EFFICIENT AT THE GRID POINT',/,
     $(5X,8F10.3))
      KK=NDAY*24
      I1=1
      I2=2
      JM1=JMAX-1
      ADELX=DELX
      DO 20 J=1,JMAX
      READ(1,120) BE1(J),BE2(J),BE3(J),BE4(J)
      READ(1,120) AB1(J),AB2(J),AB3(J),AB4(J)
   20 CONTINUE
      WRITE(3,250)
      WRITE(3,252)
      DO 30 J=1,JMAX
      WRITE(3,256)J,BE1(J),AB1(J),BE2(J),AB2(J),BE3(J),AB3(J),BE4(
     $ AB4(J)
   30 CONTINUE
C     READ INITIAL CONDITION, WATER LEVEL & DISCHARGE
      READ(1,120)(H(I1,J),J=1,JMAX)
      READ(1,120)(Q(I1,J),J=1,JMAX)
```

```
C      READ BOUNDARY CONDITION AT HIRON POINT
       READ(1,120)( HIRON(I) ,I =1 ,KK)
   120 FORMAT( 8F10.2)
       WRITE( 3,150)
       WRITE( 3,211)(H(I1 ,J) , J=1 ,JMAX)
       WRITE( 3,212)(Q(I1 ,J) , J=1 ,JMAX)
       WRITE( 3,260) NDAY
       WRITE( 3,255)(HIRON(I) ,I =1 ,KK)
       DO 15 J=1,JMAX
       AHH(I1,J)=H(I1,J)
       AQQ(I1,J)=Q(I1,J)
    15 CONTINUE
   150 FORMAT( /6X,'INITIAL CONDITION, WATER LEVEL& DISCHARGE AT GRID
      $POINTS IN MARJATA')
   255 FORMAT( 6X,12F8.2)
   260 FORMAT( /6X,'HOURLY WATER LEVEL AT HIRON POINT',I4,2X,'DAY',2X,
      $ MSL')
   211 FORMAT( 5X,'WATER LEVEL (FEET)',8F9.2)
   212 FORMAT( 5X,'DISCHARGE (CFS)',8F9.2)
   250 FORMAT( //15X,'CHANNEL CROSS-SECTION ADJUSTMENT ABOVE MSL')
   252 FORMAT( /6X,'SPECIFIC ELEVATION AND CORRESPONDING CROSS-SECTIO
      $ AREA',16X,'OF MAIN CHANNEL IN FEET AND SQ. FT.',/6X,'GRID NO
      $'BE1',5X,'AB1',5X,'BE2',5X,'AB2',5X,'BE3',5X,'AB3',5X,'BE4',
   256 FORMAT( /8X,'(',I2,')',8F10.0)
       RETURN
       END
```

```
      SUBROUTINE TIDE2
      COMMON/G/ T(7),AR(7),R(7)
      COMMON/ONE/ DELT,DELX
      COMMON/X/ A(2,7),H(2,7),Q(2,7),B(7)
      COMMON/BLOCK4/ DELTM,MOUNT
      COMMON/BLOCK8/ JM1,NP,NDAY,QQQ(2),HHH(2)
      COMMON/BLOCK9/ADELX,AB1(7),AB2(7),AB3(7),AB4(7),BE1(7),BE2(7),
     $      BE3(7),BE4(7)
      COMMON/BLOCKA/CL(7),CM(7),CN(7),THETA(7),MCT,OMEGA(7),
     $  ALFA,BETA,GAMMA,AHH(2,7),AQQ(2,7)
      COMMON/BLOCKB/AMANCO(7),HIRON(370),JMAX,I1,I2,IIN,ADD(7),TAD(7
      DELT=DELTM*60.
      DO 44 J=1,JMAX
      H(I1,J)=AHH(I1,J)
      Q(I1,J)=AQQ(I1,J)
      AR(J)=ADD(J)
      T(J)=TAD(J)
      D=AR(J)/T(J)+18.
      IF(H(I1,J).LE.(-D)) GO TO 5
      IF(H(I1,J).LE.(-18.)) GO TO 85
      IF(H(I1,J).LE.BE1(J)) GO TO 1
      IF(H(I1,J).LE.BE2(J)) GO TO 2
      IF(H(I1,J).LE.BE3(J)) GO TO 3
      T(J)= (AB4(J)-AB3(J))/(BE4(J)-BE3(J))
      A(I1,J)=AB3(J)+T(J)*(H(I1,J)-BE3(J))
      GO TO 4
    1 T(J)=(AB1(J)-AR(J))/(BE1(J)+18.)
      A(I1,J)=AR(J)+T(J)*(H(I1,J)+18.)
      GO TO 4
    2 T(J)=(AB2(J)-AB1(J))/(BE2(J)-BE1(J))
      A(I1,J)=AB1(J)+T(J)*(H(I1,J)-BE1(J))
      GO TO 4
    3 T(J)=(AB3(J)-AB2(J))/(BE3(J)-BE2(J))
      A(I1,J)=AB2(J)+T(J)*(H(I1,J)-BE2(J))
    4 R(J)=A(I1,J)/(T(J)+2.*(H(I1,J)+D))
      GO TO 44
   85 A(I1,J)=AR(J)+(H(I1,J)+18.)*T(J)
      W=T(J)+2.*A(I1,J)/T(J)
      R(J)=A(I1,J)/W
   44 CONTINUE
      H(I2,1)=HIRON(NP)+(HIRON(NP+1)-HIRON(NP))/3600.*DELT*MOUNT
      IF(IIN.NE.0) GO TO 77
      IF(IIN.EQ.0) H(I2,1)=HIRON(1)
   77 CALL COMHQ
      RETURN
    5 WRITE(3,200) D,J,H(I1,J)
  200 FORMAT(5X,'IN GRID MODEL THE WATER LEVEL FALLS BELOW CHANNEL
     $ BOTTOM',//,'D=',F10.2,15X,'H(I1,',I2,')=',F10.2)
      STOP
      END
```

```
      SUBROUTINE COMHO
      COMMON/ONE/ DELT,DELX
      COMMON/G/ T(7),AR(7),R(7)
      COMMON/X/ A(2,7),H(2,7),Q(2,7),B(7)
      COMMON/BLOCK4/ DELTM,MOUNT
      COMMON/BLOCK8/ JM1,NP,NDAY,QCQ(2),HHH(2)
      COMMON/BLOCK9/ADELX,AB1(7),AB2(7),AB3(7),AB4(7),BE1(7),BE2(7),
     $    BE3(7),BE4(7)
      COMMON/BLOCKA/CL(7),CM(7),CN(7),THETA(7),MCT,OMEGA(7),
     $    ALFA,BETA,GAMMA,AHH(2,7),AQQ(2,7)
      COMMON/BLOCKB/AMANCO(7),HIRON(370),JMAX,I1,I2,IIN,ADD(7),TAD(7)
      G=32.2
      DELX=ADELX-1000.0
      DO 10 J=1,JM1
      IF(J.GT.1) DELX=ADELX
      ASUM= A(I1,J+1)+A(I1,J)
      QSUM= Q(I1,J+1)+Q(I1,J)
      RSUM= R(J+1)+R(J)
      ADIF= A(I1,J+1)-A(I1,J)
      QDIF= Q(I1,J+1)-Q(I1,J)
      B(J)= T(J)
      B(J+1)= T(J+1)
      C=DELX*(B(J)+B(J+1))/2.0
      D=C
      E=-2.*DELT
      F=-E
      DELH=H(I2,1)-H(I1,1)
      PK=2.*DELT*QDIF
      CP=-G*DELT*ASUM
      DP=-CP
      IF(QSUM.LE.100.) SIGN=1.0
      IF(QSUM.LE.100.) GO TO 5
      SIGN= ABS(QSUM)/QSUM
    5 EP1=8.0*DELT*Q(I1,J)/ASUM
      EP2=5.04*G*DELT*DELX*QSUM*AMANCO(J)**2*SIGN/(2.22*ASUM*RSUM**1
     $)
      EP3=4.*DELT*ADIF*QSUM/ASUM**2
      EP=DELX-EP1+EP2-EP3
      FP=DELX+EP1+EP2-EP3
      PKP1=4.*QSUM*QDIF*DELT/ASUM
      PKP2=G*DELT*ASUM*(H(I1,J+1)-H(I1,J))
      PKP3=2.52*G*DELT*DELX*(AMANCO(J)*QSUM)**2*SIGN/(2.22*ASUM*RSUM
     $).33)
      PKP4=2.*DELT*ADIF*(QSUM**2)/ASUM**2
      PKP=PKP1+PKP2+PKP3-PKP4
      IF(J.GT.1) GO TO 8
      ENOM=E*CP-C*EP
      ALFA=(C*DP-D*CP)/ENOM
      BETA=(C*FP-F*CP)/ENOM
      GAMMA=(C*PKP-PK*CP)/ENOM
    8 CL(J)=(DP*E-D*EP)/(C*EP-CP*E)
      CM(J)=(FP*E-F*EP)/(C*EP-CP*E)
      CN(J)=(PKP*E-PK*EP)/(C*EP-CP*E)
      IF(J-1)1,1,2
```

```
      3 PJ=PK+C*DELH
        PJP=PKP+CP*DELH
        THETA(J)=(DP*E-D*EP)/(F*EP-FP*E)
        OMEGA(J)=(PJP*E-PJ*EP)/(F*EP-FP*E)
        GO TO 10
      2 DENO=F*(CP+EP*THETA(J-1))-FP*(C+E*THETA(J-1))
        IF(ABS(DENO).LE.1.) GO TO 6
        THETA(J)=(DP*(C+E*THETA(J-1))-D*(CP+EP*THETA(J-1)))/DENO
        OMEGA(J)=((PKP+EP*OMEGA(J-1))*(C+E*THETA(J-1))-(PK+E*OMEGA(J-1))
       $(CP+EP*THETA(J-1)))/DENO
     10 CONTINUE
        RETURN
        END
```

```
      SUBROUTINE TIDE3
      COMMON/ONE/ DELT,DELX
      COMMON/G / T(7),AR(7),R(7)
      COMMON/X/ A(2,7),H(2,7),Q(2,7),B(7)
      COMMON/BLOCK8/ JM1,NP,NDAY,QQQ(2),HHH(2)
      COMMON/BLOCK9/ADELX,AB1(7),AB2(7),AB3(7),AB4(7),BE1(7),BE2(7),
     $      BE3(7),BE4(7)
      COMMON/BLOCKA/CL(7),CM(7),CN(7),THETA(7),MCT,OMEGA(7),
     $   ALFA,BETA,GAMMA,AHH(2,7),AQQ(2,7)
      COMMON/BLOCKB/AMANCO(7),HIRON(370),JMAX,I1,I2,IIN,ADD(7),TAD(7)
C     COMPUTE Q(2), AND H(2) FOR EVERY GRID POINT IN MARJATA
      H(I2,JMAX)=HHH(1)
      J=JM1
      DELH=H(I2,JMAX)-H(I1,JMAX)
    4 DELQ=THETA(J)*DELH+OMEGA(J)
      Q(I2,J+1)=Q(I1,J+1)+DELQ
      IF(J.NE.JM1) GO TO 10
      Q(I2,JMAX)=QQQ(1)
      DELQ=Q(I2,JMAX)-Q(I1,JMAX)
   10 J=J-1
      IF(J-1)6,5,5
    5 DELH=DELH*CL(J+1)+DELQ*CM(J+1)+CN(J+1)
      H(I2,J+1)=H(I1,J+1)+DELH
      GO TO 4
    6 DELQ=ALFA*DELH+BETA*DELQ+GAMMA
      Q(I2,1)=Q(I1,1)+DELQ
      DO 405 J=1,JMAX
      AQQ(I2,J)=Q(I2,J)
      AHH(I2,J)=H(I2,J)
      AQQ(I1,J)=Q(I2,J)
      AHH(I1,J)=H(I2,J)
      Q(I1,J)=Q(I2,J)
      H(I1,J)=H(I2,J)
  405 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE COMS
      DIMENSION D( 5) ,E( 76)
      COMMON/BLOCK1/ Q(76,2) ,H(60,2) ,NB,NN,NU (76),ND(76), QGORAI(2),
     $  QMADHU(2) ,QRPUR(2) ,QDLUTI(2) ,QMONGL(2) ,QBSI(2), DELX(76)
      COMMON/BLOCK2/ ZETA,L1(60) ,L2(60) ,L3(60) ,L4(60), DQ(76),
     $  G,DIFA(76) ,CK(76) ,IX,DELT,F(60) ,S(60) ,C(76) ,SS(60)
      COMMON/BLOCK3/ A(76) , T(76)
      COMMON/BLOCK5/ EB(76) ,E1(76) ,E2(76) ,E3(76), E4(76), A1(76),
     $  A2(76) ,A3(76) ,A4(76) ,RM(76)
      COMMON/BLOCK7/ SM,SC(60) ,ENM(76) ,EK1 ,EK2,KAPPA
      COMMON/BLOCKA /CL(7) ,CM(7) ,CN(7) ,THETA(7) ,MCT, CMEGA(7),
     $   ALFA,BETA,GAMMA ,AHH(2,7) ,AQQ(2,7)
      COMMON/X/ ALTAF(2,7) ,HAM(2,7) ,QADE(2,7) , BELA(7)
      COMMON/G/ TAREQ(7) ,ARIF(7) ,RATS(7)
      E7= EK2*ABS( SM-SC(1))
      V=AQQ(1,4)/ALTAF(1,4)
      E6=EK1*0.02*V*RATS(4)**0.8333
      E(1)=E6+E7
      D(1)=(3.*SC(1)+SM)/4.*AQQ(1,4)-ALTAF(1,4)*E(1)*(SC(1)-SM)/4800
      V=(A(1)*DELX(1)+A(2)*DELX(2)+A(3)*DELX(3)+ALTAF(1,4)*24000.)/2
      SC(1)= SC(1)+D(1)*DELT/V
      IF( SC(1).GT.20000.0)  SC(1)=20000.0
      IF( SC(1).LT.15000.0)  SC(1)=15000.0
      DO 5 I=1,NB
      E7=EK2*ABS( SC(NU(I))-SC(ND(I)))
      V=Q(I,1)/A(I)
      E6=EK1*ENM(I)*V*RM(I)**0.8333
      E(I)= E6+E7
      IF (E(I).LT.1.) E(I)=1.
    5 CONTINUE
      DO 40 I=1,NN
      J =IABS(L1(I))
      K =IABS(L2(I))
      M =IABS(L3(I))
      N =IABS(L4(I))
      J1=IABS(L1(I))/L1(I)
      K1=IABS(L2(I))/L2(I)
      M1=IABS(L3(I))/L3(I)
      N1=IABS(L4(I))/L4(I)
      IF(NU(J).NE.I)  MA=ND(J)
      IF(NU(J).NE.I)  MB=NU(J)
      IF(NU(J).NE.I)  GO TO 41
      MA= NU(J)
      MB=ND(J)
   41 D(1)=(3.*SC(MA)+SC(MB))/4.*Q(J,1)*J1-A(J)*E(J)*(SC(MA)-SC(MB))/
     $   DELX(J)
      IF(K.EQ.NB+1)   D(2)=0.0
      IF(K.EQ.NB+1)   GO TO 44
      IF(NU(K).NE.I)   MC=ND(K)
      IF(NU(K).NE.I)  MD=NU(K)
      IF(NU(K).NE.I)  GO TO 43
      MC= NU(K)
      MD= ND(K)
   43 D(2)=(3.*SC(MC)+SC(MD))/4.*Q(K,1)*K1-A(K)*E(K)*(SC(MC)-SC(MD))/
```

```
     $      DELX(K)
   44 IF(M.EQ.NB+1)   D(3)=0.0
      IF(M.EQ.NB+1)   GO TO 46
      IF(NU(M).NE.I)   MG=ND(M)
      IF(NU(M).NE.I)    MH=NU(M)
      IF(NU(M).NE.I)   GO TO 47
      MG=NU(M)
      MH= ND(M)
   47 D(3)=(3.*SC(MG)+SC(MH))/4.*Q(M,1)*M1-A(M)*E(M)*(SC(MG)-SC(MH))/
     $      DELX(M)
   46 IF(N.EQ.NB+1)    D(4)=0.0
      IF(N.EQ.NB+1)    GO TO 48
      IF(NU(N).NE.I)    ME=ND(N)
      IF(NU(N).NE.I)   MF=NU(N)
      IF(NU(N).NE.I)   GO TO 45
      MF=NU(N)
      MF=ND(N)
   45 D(4)=(3.*SC(ME)+SC(MF))/4.*Q(N,1)*N1-A(N)*E(N)*(SC(ME)-SC(MF)),
     $      DELX(N)
   48 IF(I.EQ.1) GO TO 40
      V=(A(J)*DELX(J)+A(K)*DELX(K)+A(M)*DELX(M)+A(N)*DELX(N))/2.
      SC(I)=SC(I)+(D(1)+D(2)+D(3)+D(4))*DELT/V
      IF( SC(I).LE.0.0)  SC(I)=0.0
   40 CONTINUE
      KAPPA= KAPPA+1
      IF(KAPPA.EQ.6) GO TO 53
      RETURN
   53 KAPPA= 0
      WRITE(3,202) EK1,EK2
      WRITE(3,200)(E(I),I=1,NB)
      WRITE(3,201)(SC(I),I=1,NN)
      RETURN
  200 FORMAT(9X,'LONGITUDINAL DISPERSION COEFFICIENT = E(I)'/,(10F12
  201 FORMAT(10X,'SALINITY AT JUNCTIONS',//,7(5X,F12.2))
  202 FORMAT(10X,'EK1=',F10.2,10X,'EK2=',F10.2)
      END
```