RN-21

EFFECT OF FLOODPLAIN ON FLOOD ROUTING

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1985-86

CONTENT

LIST OF FIGURES

ABSTRACT

Because of ever increasing human activities in the flood plains, the river environment gets affected. The movement of flood along the flood plains is quite complex. The flood plains act as conveying as well as storage medium for passage of floods. The valley storage naturally regulates the flood flow as it moves towards the downstream end of the reach. The flow over the flood plains is relatively slower than the main channel. This is mainly due to relatively low depth of flow and also due to the increased frictional resistance.

Civil constructions affect the flood plain accessibility, i.e. the relative ability of the water to leave or enter the flood plains. There are a few studies, made on the effect of encroachments on floods. Some studies suggest that flood height would not be substantially changed by urban development; since actual development is such that significant floodplain storage is still available for the passage of floods.

Routing of floods can be achieved either through black box models or through mathematical models. The data requirements for these modelling approaches differ significantly. Accuracy-wise both the methods are comparable. If channel processes have not altered the river environment very much from the past and if the available record of floods

of this period covers the movement on flood plain also, then black box method can be prefered. The Muskingum Cunge method appropriately takes into account the geometry of flood plains and channel while establishing the routing parameters, and hence it can be prefered over conventional Muskingum method. The Kalinin-Milyukov method is much simpler to use than other methods and at the same time it involves a physically meaningful establishment of parameters making it somewhat better approach for dealing with movement of floods in flood plains.

Sometimes, one dimensional mathematical models are used to route the floods in rivers with flood plains. The data requirement is largely on cross-section and roughness coefficients. There are three different approaches used to treat floodplains, viz.(i) Off channel storage, (ii) Composite channel, (iii) Channel-plain model. The off channel-storage model attenuates the hydrograph much more than the other two models.

The complexities involved in a meandering river with flood plain create problems in modelling. Experimental studies on the floodplain effects have been carried out at Hydraulic Research Laboratory in Belgrade. Certain empirical relationships on the channel flood plain interactions have been established by these studies. These, however, have limited scope in their application only to the river systems for which they have been developed.

1.0 INTRODUCTION

The floodplain is the area adjoining the main river channel which gets inundated when the water level increases beyond the bankfull stage. The floodplains have two main functions, viz. (i) transport of flood, (ii) temporary storage of flood discharge. It is this latter function which attenuates the flood significantly. The nature of flood flow in floodplains also causes the attenuation.

The human activities and encroachments in the flood plain affect the flood flow. Embankments are constructed in order to avoid disastrous inundations. But such activities drastically change the river environment, which has to attain new equilibrium under changed conditions. For instance, the floodplain level of the yellow river in China, at many locations lies more than three metres above the protected terrain.

During flood season, when the stream is in spate (sudden rush of water), the water level increases, the flow overtops the river channel banks and moves into the flood plains. In the case of wide floodplains the flood water gets stored and causes large attenuation. Over the floodplains the flood moves in relatively shallow depths. The vegetation and bed reoughness of the plains retard the flow and as such energy loss is different in the flood plains than that in the channel.

The streamflow measurement with floats in the case of large floods which inundate flood plain involves lot of error in the records. While using such records, care has to be taken to assess and possibly to remove such errors from the data used for the analysis. A careful analysis of stage-discharge relations would help to this end. A report entitled, 'Rating Curve Analysis' - UM-5 prepared by National Institute of Hydrology explains the relevant aspects.

The application of any flood routing method has to properly account for these factors, when dealing with high floods. The methods used to route a flood can be broadly classified into two categories, viz. (i) Black box models, (ii) Mathematical models. The Muskingum method belong to the former category and is used in many countries. This method uses the information on flood hydrographs observed in the past to arrive at the necessary routing parameters. If the observed floods are not large so as to include measurement in floodplains also, the parameters thus derived are of little use in routing large flood involving flood plains. The Kalinin-Milyukov method and Muskingum-Cunge method are also used for flood routing. These methods involve a physically meaningful establishment of flood routing parameters and would be somewhat more appropriate for routing of high floods.

The mathematical models involve geometry of river channels and do not need past flow records as much as the black box models. These models require data on the cross-section and bed roughness etc. to define river channel geometry and flow characteristics. Different approaches used in mathematical modelling have also been explained in subsequent sections.

Experimental works have been conducted to establish certain empirical relationships on the flood plain and channel interactions. These relationships have been used in flood routing models. Similar works carried out at the Hydraulic Research Laboratory, at Belgrade have been briefly given in section 7.0.

2.0 PHYSICAL ASPECTS OF FLOOD FLOW

There are several reasons for the floods to occur like heavy rain in the upstream catchment, landslides, dam break etc. Whatever be the cause of flood, its movement generally follows a similar pattern as it moves down. At a given site, the water level rises to reach a peak and then slowly decreases. As the water level increases discharge of water also increases, together with an increase in the storage of water in the channel and adjoining plains. Hence the flow entering in a reach may pass through the reach or may go into temporary storage. From this storage it will be released slowly. It is necessary that the continuity equation used in flood routing accounts such balance between inflow and outflow In this process of flow the peak discharge entering a reach gets lowered before leaving the reach. This acts as a natural regulator of flood, moderating it. Such decrease in peak flow is known as attenuation. This occurs in all cha-nels, although at varying extent. This aspect of the flow can be made clear from the figure 1.a to d.

The figure 1.a depicts the observed hydrograph at both the ends of a reach. The difference between inflow and outflow goes into storage until the time of maximum storage T as marked S. After this time T the outflow exceeds the inflow until both are equal at H for a single flood peak. During this period flood water is released from the temporary storage In general S should be equal to R but it may be noted that depending on the topographic nature some part of S may escape

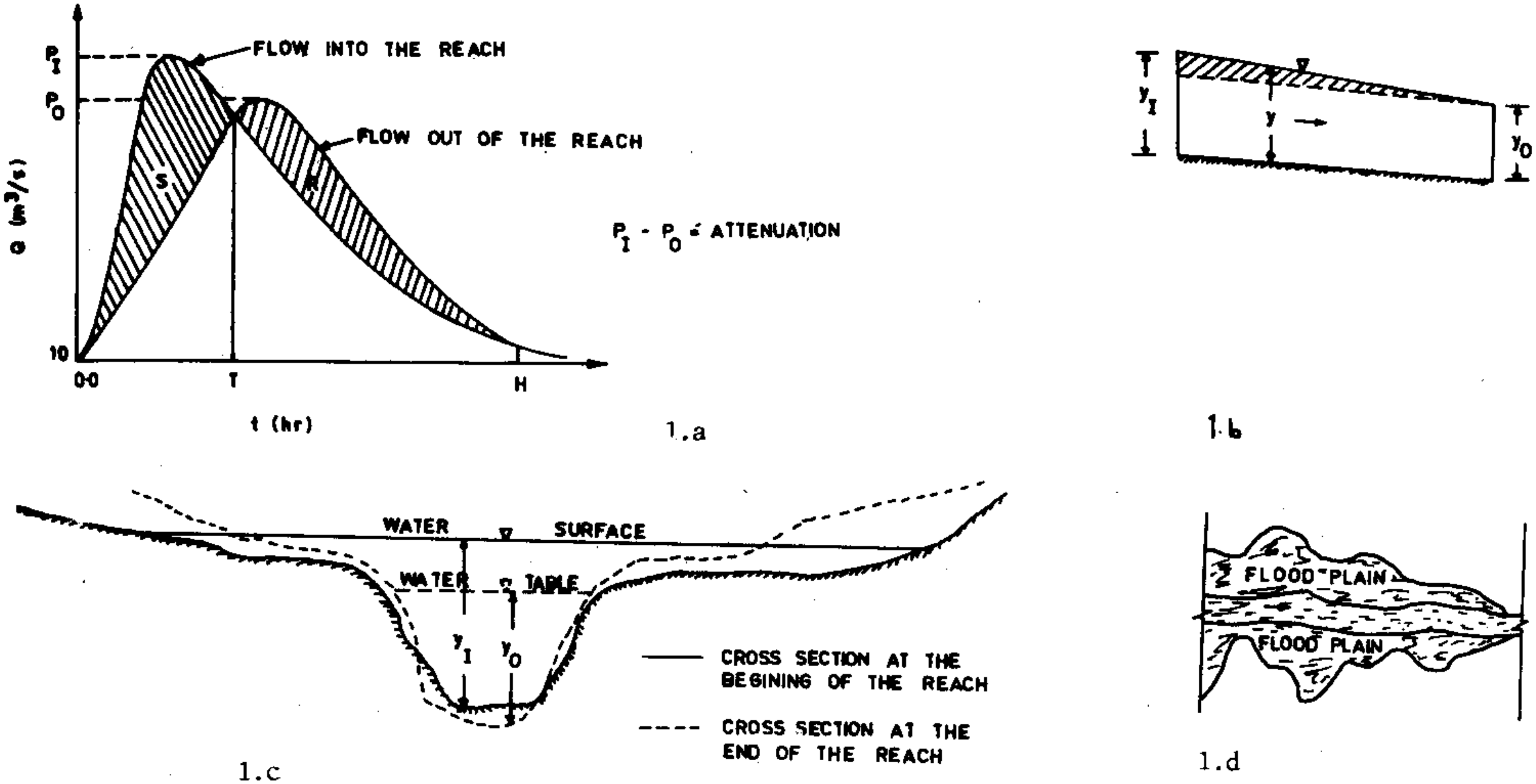

Figure 1.a - Flood hydrographs at both the ends of a river reach

1.b - Idealised water surface profile explaining the storage effect

1.c - Water level marked on a typical superimposed cross-section.
___ Cross-section at the beginning of the reach ; ---- cross-section at the end of the reach

1.d- Plan view of flood plain inundation the river system. This kind of escape is not treated in this report. The attenuation can be expressed as follows in percentage of inflow:

$$Q_{Att} = 100 \ (P_I - P_O)/P_I$$

Theoretical works on attentuations in the case of prismatic channels can be found in Forchheimer (1930), Hayami(1951), Hayashi (1965) and Di Silvio (1969).

The figure 1.b explains how flood waters enter into storage in the longitudinal point of view. The figure 1.d explains the plan view of flood movement.

Except for prismatic channel the superimposed cross-sections at various sites of a reach would look very similar to figure 1.c. This figure is only a typical situation.

Number of tributaries may join the river and the discharge increases as one moves downstream unless large withdrawals are made in between.

Any obstruction in the waterway causes backwater effect which may even extend upto 60 Km upstream and water spread area may get increased. Floodplains provide ample space for storage of flood water.

The velocity of flow in the floodplains are much different from that of channel. This is due to the fact that roughness present in floodplain is much larger and the depth of flow in the plains is shallower than that of channel. These characteristics complicate the flood routing.

3.0 EFFECT OF FLOOD PLAIN ENCROACHMENTS

Land development results in occupation of flood plains. This affects the functions (as given in section 2.0) of the same. In some countries limits are established to encroachments into flood plains to reduce damages due to flooding. The problem is of world wide concern. But no simple solution is available in the literature. The full unsteady flow equations are to be solved using numerical techniques to understand the effect of encroachments. In some cases physical models are used.. Although costly, they permit the study of detailed flow pattern.

Some observations of flood plain on flood waves for Russian rivers are reported by Grashevsky (1967). His studies indicated that flood plain 'accessibility' i.e., the relative ability of the water to leave the river and enter the flood plain, was an important factor in flood wave attenuation. If a flood wave moves part areas in which large amounts of potential flood plain storage exist, but the movement of water into these areas is restricted by high hydraulic roughness in over bank areas or by limited openings to the flood plains, thus full available storage of the flood plain may not be utilized. Grashevsky also observed that in channels with slopes of the order 0.001 the attenuation of the flood wave was observed to be less than with channels with flatter slopes.

Johnson and Senter (1977) evaluated the loss of flood plain storage on the Ohio river for long river reaches. They simulated different amounts of storage loss ranging from complete removal of valley storage with levees to partial loss. They also examined the effect of varying Manning's n value by 20%. They concluded that for the reach of the Ohio river the flood height would not be substantially changed by complete loss of valley storage or by substantial variation in Manning's n. Effects of encroachments in the flood plain of the Connecticut river were studied by Dewey and Kropper (1964). They examined the consequences of removing major volumes of valley storage along 40 miles of the Connecticut river. Their general findings are as follows:

1. A 10 to 40 per cent increase in peak discharge downstream as a result of the loss of 10 to 30 per cent of the valley storage.
2. An increase in water surface elevations for major flood discharges as a consequence of the decrease in waterway cross-sectional areas.

There are number of hydraulic model studies involving the effects of levees and other types of encroachments on river water levels have been made by the US Army Crops of Engineers, Waterways Experiment Station (WES).

De Vries (1980) analysed the effect of effects of encroachments on floods. He used a one-dimensional model to solve complete equations of motion. He has routed a hypothetical flood input in the form of a triangle. As a result the following are found:

1. The narrow valleys the hydrograph shape is an important factor in flood wave attenuation for a flatter river slope (S=0.0001). An early peak gets attenuated more than the peak occuring later in the flood. This is precisely because major portion of the flood plain storage would have already been occupied by earlier flows, leaving less room for later peak.
2. Water depths on the flat plain are greater for flatter slopes and the narrower valleys. But water depths are greater for steep slopes in the case of wider valleys.
3. The flood peak is strongly affected by the encroachments. In general, the flood peak arrives significantly earlier as a result of a reduction of flood plain storage.
4. In general a maximum rise of 1 foot in water level is noticed due to encroachments. It has been pointed out that the actual development on a flood plain is such that significant flood plain storage is still available.

4.0 FLOOD ROUTING MODELS

Routing of floods can be achieved either through black box models or through mathematical models. The black box models require data of a number of past high floods involving movement in flood plains. More the availability of data of such floods, better is the establishment of the routing parameters, assuming that channel processes have not significantly altered the river environment. The mathematical models require data on cross-section of the river at close intervals and estimates of roughness coefficient. Their requirement on data of past floods is minimal. Based on the data availability any one of the methods can be choosen, since accuracy wise both are similar.

4.1 Black Box Models

Muskingum method is widely used in many countries. This makes use of the past recorded floods and finds the set of routing parameter that would best produce the out flow given the inflow. These parameters takes care of the translation and storage characteristics of the flood and the geometry of the river. In case the floods, used in computing the parameters are large such that movement in flood plains occurred, the parameters could conveniently be used to route the flood taking flood plains into account. Otherwise the routing parameters cannot be used and Muskingum method is of little use. In such cases, a variance of this method, originally proposed by Kalinin and Milyukov (1958) can be used which involves use of physically meaningful approach for estimation of the parameters. The Muskingum Cunge method takes the geometrical features of the flood plain and channel for establishing the flood routing parameters, and is therefore, preferred over Muskingum method.

4.2 Mathematical Models

There are three kinds of models available in the literature to treat flood plains. They are described briefly below:

1. Off-channel storage

This model assumes that floodplains function only as a storage. The velocity of flow in the floodplain is assumed to be negligible and momentum effects are not considered.

2. Composite channel

This treats the channel and flood plains as one unit. A single Manning's n value is assumed. An excellent text on this Manning's n is given in Chow (1959). This model takes the carrying capacity of the plains also in lumped form.

3. Channel-plain model

This model distinguishes the two functions of the flood plains and accounts both of them. These functions are storage and conveyance. As such the wetted area A is the sum of area of flow in the channel, area of flow in the plains and the area of dead storage.

5.0 FLOOD ROUTING IN MEANDERING RIVERS WITH FLOOD PLAINS

The natural rivers always have a tendency to meander. No river can be found to be straight more than 10 time its width. River channels meander through wide flood plains. In addition to the complexities mentioned in section 2.0, the following further complications are associated with meandering rivers:

1. The flood flow over the plains need to travel only short distance to reach the downstream site where as the flow in the channel need to take longer route through meanders to reach the same site.
2. The slope of the flood plain will be larger than the main channel.
3. The lateral exchange of flow between them.
4. The presence of helicoidal flow at river bends and the travelling eddies.

At present there is no model which could simulate unsteady flow with above complexities. A one dimensional mathematical model has been proposed by Fread (1976). An approximate ratio (ψ) of flow was defined using Manning's equation applied to channel and flood plain as follows:

$$\psi = Q_f/Q_c \qquad \ldots(1)$$

where, Q_f is flood flow through the flood plain and Q_c is flow through channel. He derived following one dimensional equations:

$$\frac{\partial A}{\partial t} + \frac{\partial(\phi Q)}{\partial x_c} + \frac{\partial(TQ)}{\partial x_f} - q = 0 \qquad \ldots(2)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial(\phi^2 Q^2/Ac)}{\partial x_c} + \frac{\partial(T^2 Q^2/A_f)}{\partial x_f}$$

$$+ gA_c\{\frac{\partial h}{\partial x_c} \pm S_c\}$$

$$+ gA_f\{\frac{\partial h}{\partial x_f} + S_f\} - qV_{1x} = 0 \qquad \ldots(3)$$

where,

Q is discharge, L^3/T

q is lateral flow, L^2/T

A is the cross-sectional area of flow L^2 and $A=A_c+A_f+A_s$

A_s is the off channel dead storage L^2

x is distance along the longitudinal axis of either flood plains or channel

g is acceleration due to gravity L/T^2

S is friction slope

V_{1x} is the velocity of lateral flow L/T

$$\phi = \frac{1}{1+\Psi} \qquad \ldots(4)$$

$$T = \frac{\Psi}{1+\Psi} \qquad \ldots(5)$$

The subscrip C denotes variables pertaining to the channel and f denotes similarly the flood plain. The equation 3 neglects the momentum exchange between channel and flood plains. These equations (2 and 3) are hyperbolic type. Finite difference schemes were used to solve them together with appropriate boundary conditions. The idealized meandering river with a significant flood plain used by Fread (1976) is shown in the figure 2.

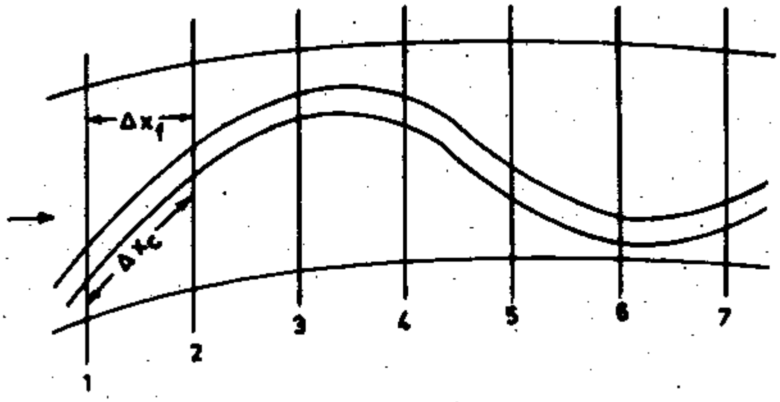

Figure 2 - Idealised meandering river with flood plains used by Fread

Fread (1976) has used all the three models mentioned in the section 4.0. The composite model produced computational problem when simulating the sudden change in top width as the flow spills onto the flat flood plains. The results of Fread's analysis are briefly mentioned here. Details can be seen from the original paper.

The off channel-storage attenuates the hydrograph much more than other two models. This can be an obvious conclusion. The composite channel behaved very similar to channel-plain model for sinuosity (Length of the channel/ length of the valley) equal to unit. However, as this ratio increases the composite channel model attenuate more than the other. As far as the travel time is concerned, the off channel-storage required larger travel time. The other two models are compared in the similar way as in the case of attenuation.

Although composite section model has certain computational problem of simulating when the flow spills onto a wide flat flood plain, its simulation characteristics approach to those of the channel-flood plain model as per Fread when the sinuosity is one and when the flood plain width is small.

6.0 THE PARANA-PARAGUAY MODEL

A mathematical model has been developed jointly by Delft Hydraulic Laboratory and NEDECO (Netherlands Engineering Consultants) for a flood control study of the rivers Parana and Paraguay. This model was used to study the rivers and flood plains under different floods with elements of human interference. Implicit finite difference scheme is used to solve continuity and momentum equations in a one dimensional form.

The cross-section with flood plain is divided into number of subsections as shown in Figure 3. The slope of the water surface is taken to be the same for the whole cross-section.

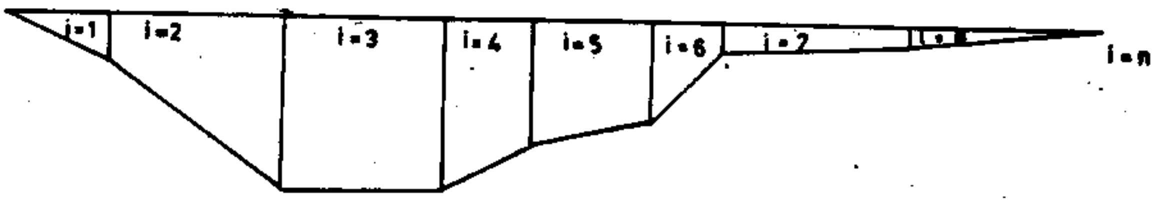

Figure 3 - Non-uniform flow in a cross-section

The hydraulic radius is defined (Engelund 1964) as follows:

$$R = \frac{\{ \sum_{i=1}^{n} C_i \; A_i \; \sqrt{R_i} \; \}^2}{C^2 \; A^2} \qquad \ldots (6)$$

$$S_f = Q^2/(C^2 \; R \; A^2) \qquad \ldots (7)$$

where,

R is an equivalent hydraulic radius,

C is Chezy's coefficient,

A is the area of flow,

Q is the discharge, and

S_f is energy slope.

The subscript i denotes subsection values. The equations 6 and 7 are valid only for quasi steady flow situations.

6.1 The Description of the River

The studies by Grijsen and Meijer (1979) covered a length of 1700 km of the river Parana as shown in Figure 4.

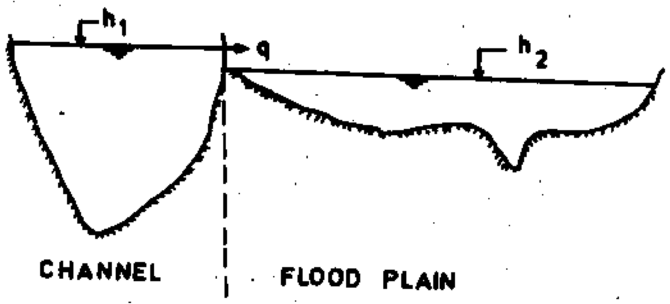

Figure 4 - Composite section

They have treated the flood plains and the main river as separated channels. The river was defined by 475 cross sections. The cross-section details of plains have been derived from topographic maps. Large portion of the river in the upper reaches consisted of narrow deep channel. In these part composite sections have been used with two roughness coefficients. Downstream of Corrientes, small streams run parallel to the main river as shown in figure 4. These secondary channels are said to be dry during low river stages and hence require special numerical treatment.

6.2 Interaction Between Flood Plain and Channel

Introducing short transverse channel connections flood plains and river channel these interactions could be modelled But because of increased complexity an explicit scheme is used by Grijen and Meijer. This is to compute the exchange flow using the results of the last time step, to introduce them as lateral flows into and from the channels during the next time step. Two physical situations have been noticed in the field as follows. The flood plains are sloping outward from the river as shown in figure 4. The second situation is that the narrow plains slope towards the rivers. This later situation is seen along the river Paraguay. A time lag of Δt is assumed between water levels in the river and the valley in the same location:

$$h_2 \ (t + \Delta t) = h_1(t) \qquad \ldots (8)$$

The storage in the plains are also accounted by the following equation:

$$q = -B \ \partial h_2 / \partial t - \partial Q_2 / \partial x \qquad \ldots (9)$$

Here,

q is the storage in flood plain,

B is the width of flood plain,

h_2 is the depth of flow in the flood plain,

Q_2 is the flow in flood plain.

6.3 Application

The model has been used to route flood of varying magnitude experienced between September 1964 to August 1968. A large value of the Manning's n equal to 0.1 was used for the flood plains. It was found by Grijen and Meijer that the attenuation of normal prolonged floods by storage in the plains is rather small and partly compensated by inflows from tributaries. It is expected that the opposite may occur in case of extreme floods.

7.0 HYDRAULIC LABORATORY MODELS

Movement of flood in rivers with flood plain is highly complicated as explained earlier due to fluid and the associated energy exchange between plains and the channel. A number of studies mainly on hypothetical river system have been made in the past. These studies aim at throwing light up on the underlying the physical principles of flow. At few places experimental works have been conducted to establish certain empirical relationships on the flood plain and channel interactions.

7.1 Hydraulic Research Laboratory Belgrade

The quantitative analysis of energy transfer process between main channel and flood plain has been carried out through experimental study at Hydraulic Research Laboratory at the Faculty of Civil Engineering in Belgrade, Yugoslavia. In these studies measurements of sheer stress along the walls of the main channel and flood plain in uniform flow were maid. The following parameters were proposed by Miodrag Radojkovic (1976).

$$\theta_{mc} = \tau_{mc} / \gamma R_{mc} S_o \qquad \text{... (10)}$$

$$\theta_{fp} = \tau_{fp} / \gamma R_{fp} S_o \qquad \text{... (11)}$$

and $$\psi_{mc} = (1- \theta_{mc}) / \theta_{mc} \qquad \text{...(12)}$$

where,

where, τ_{mc}, τ_{fp} are mean boundary sheer stress along solid boundary of channel and flood plain respectively,

γ is specific gravity of water,

R_{mc}, R_{fp} are hydraulic radius of channel and flood plain respectively,

S_o is the bed slope, and

ψ_{mc}, θ_{mc}, θ_{fp} are empirical parameters defining the energy transfer processes.

Now using the Manning's equation the following are derived:

$$\frac{Q_{mc}}{Q_{fp}} = \frac{n_{fp}}{n_{mc}} \; \frac{A_{mc}}{A_{fp}} \; \frac{R_{mc}^{2/3}}{R_{fp}^{2/3}} \left(\frac{\theta_{mc}}{\theta_{fp}} \right)^{1/2} \qquad \ldots(13)$$

These above parameters could be used in flood routing models while the following equations are solved. These equations are as given in Miodrag Radojkovic (1976).

Momentum equation:

main channel:

$$\frac{1}{g} \frac{\partial V_{mc}}{\partial t} + \frac{V_{mc}}{g} \frac{\partial V_{mc}}{\partial x} + \frac{\partial z_{mc}}{\partial x}$$

$$= - \frac{\tau_{mc}}{\gamma R_{mc}} \theta_{mc} + (1-m) \frac{V_{mc}\, q}{gA_{mc}}, \qquad \ldots(14)$$

Flood plains:

$$\frac{1}{g}\frac{\partial V_{fp}}{\partial t} + \frac{V_{fp}}{g}\frac{\partial V_{fp}}{\partial x} + \frac{\partial z_{fp}}{\partial x} = \frac{\tau_{fp}}{\gamma R_{fp}}\,\theta_{fp} + m\,\frac{V_{fp}}{g}\,\frac{q}{A_{fp}} \qquad \ldots(15)$$

Continuity:

Main channel

$$B_{mc}\frac{\partial z_{mc}}{\partial t} + V_{mc}B_{mc}\frac{\partial z_{mc}}{\partial x} + A_{mc}\frac{\partial V_{mc}}{\partial x_{mc}}$$

$$+ V\left(\frac{\partial A}{\partial x}\right)^{z=c}_{mc} + kq \qquad \ldots(16)$$

Flood plain:

$$B_{fp}\frac{\partial z_{fp}}{\partial t} + V_{fp}B_{fp}\frac{\partial z_{fp}}{\partial x} + A_{fp}\frac{\partial V_{fp}}{\partial x_{fp}}$$

$$+ V\left(\frac{\partial A}{\partial x}\right)^{z=c}_{fp} + kq \qquad \ldots(17)$$

where, the index mc refers to main channel and fp refers to flood plain,

A is area of cross-section

B is width

V is mean velocity

g is gravitational acceleration

k is parameter defining lateral flow

q is lateral flow per unit length determined separately as spillway discharge

z is water level

Further details of the deviation of these equations can be seen in Strelkoff (1969).

7.2 Waterways Experiment Station, Vicksburg

In order to study geometric parameters that influence flood plain flow, experiments were conducted by Maurice James at the US Army Engineer Waterways Experiment Station at Vicksburg. The investigations consisted of three basic parts. The first was stage-discharge relationship for various channel flood plain configurations. The second was determining the parameters that describe increased flow resistance. Finally to characterize the general flow in channel meanders outside or separates from the flood plain and returns.

Tests were carried out in a tilting flume. The configurations used include symmetrical, asymmetrical flood plain of different dimensions and meandering channel within a flood plain. Different roughness characteristics were used. The venturi meter, pitot tube were used to measure discharge, velocity respectively. Surface current pattern, velocity vectors were recorded by time lapse photography.

Treating channel and plain as single channel the Manning's n was computed and plotted from the measurements. It is found from the plots that the value of Manning's n at just bankfull flow decreased suddenly to some minimum value and then increased with depth approaching a constant value which was nearly equal to that of bankfull stage.

8.0 CONCLUSIONS

The effect of flood plain complicates the routing of high floods mainly due to the following characteristics:

i) Larger roughness than that of channel bed

ii) Shallow depth of flow.

The problem of flood plain encroachment have been studied by hydraulic models as well by mathematical models. Studies on Connecticut river showed that a 10% to 40% increase in peak discharge downstream as a result of the loss of 10 to 30% of the valley storage. It has also been noticed that the flood peak is strongly affected by the encroachments and in general the flood peak arrives significantly earlier as a result of a reduction of flood plain storage due to encroachments.

For routing of floods in rivers with flood plains, two kinds of models are used viz. (i) Black base models and (ii) Mathematical models. The data requirements are different for each of the above models. The Kalinin-Milyukov method or the Muskingum-Cunge method may be preferred to conventional Muskingum method since physically meaningful establishment of routing parameters are done in these two methods.

Mathematical models for flood routing differs in the manner in which they treat the effect of flood plains. Some models treat the flood plain as a storage space only, while some other as a conveying medium along with channel. There are also models where flood plain and channel are separately accounted. For instance the mathematical model developed by Delft Hydraulic Laboratory and NEDCO for flood control study of the river Parana and Paraguay is a channel-plain model using finite difference approach.

Because of the complexity of the flood flow mathematical formulations are usually inadequate to describe all physical processes. Modelling studies involving scale models of river systems have also been conducted to establish certain empirical relationships. Results of such studies are however only useful for particular situation and can not be applied elsewhere. There is a need to develop numerical models to deal with the complex flow involving movement of floods in flood plain as well as channel section. Embankments are needed to be designed to cater for the increase in flood level as a consequence of reduction in flow section. The studies made at U.S. Waterways Experiment Station regarding effects of flood plain encroachment indicate suitable procedure for similar studies in India.

REFERENCES

1. Chow, V.T. (1959), 'Open Channel Hydraulics',McGraw Hill, New York.

2. De Vries, J.J.,(1980),'Effects of flood plain encroachments on peak flow',The Hydrologic Engineering Centre,Davis,CA.

3. Dewey and Kropper, Engineers ,(1964),'Effects of loss of Valley Storage Due to Encroachment - Connecticut River', Report to Connecticut Water Resources Commission, Hartford, Connecticut,April, 15 pp.

4. Di Silvio,G.,(1969), 'Flood Wave Modification along Channels' Jour.of the Hydraulic Dn.ASCE,95,HY9,1589-1614.

5. Engelund,F,(1964),'Flow resistance and hydraulic radius', Acta Polytechnica Scandinavia.

6. Forchheimer,P,(1930),'Hydraulic 3rd edn.Teubner, Leipzig and Berlin'.

7. Fread, D.L.,(1976),'Flood routing in meandering rivers with flood plains', In Symposium on Inland Waterways for Navigation, Flood Control and Water diversions, Vol. 1, Colorado State University, August , pp.16-35.

8. Grijsen, J.G. and Meijer, Th.J.G.P.,(1979), 'On the modelling of flood flow in large river systems with flood plains', IAHR, Vol.5, Sub.D. pp 227-235.

9. Grushevsky, M.S.,(1967),'Flood plain influence on flood wave propagation along a river', International Symp. on floods and their computation, Vol.II, IASH-UNESCO-WMO, Publication on 85, pp 745-754.

10. Hayami,S.,(1951),'On the propagation of flood waves', Bull.No.1,Disaster Prevention Research Institute, Kyoto University, Japan.

11. Hayashi, T.,(1965), 'Propagation and Deformation of flood waves of natural channels', pp 67-80, 80th Anniversary Bulletin, Chuo Univ. ,Japan.

12. Johnson, B.H. and P.K. Senter, (1977),'Effect of loss of valley storage in the Cannelton Pool on Ohio river Flood Heights', Misc. paper, H-77-7, U.S. Army River Engineer Waterways Experiment Station, Vicksburg, Mississippi, June, 33 pp.

13. Kalinin, G.P. and P.I. Milukov, (1958), 'Approximate calculation of nonsteady state flow of water masses', Trudy Ts IP, No.66.

14. Liggett, J.A. (1969), 'Mathematical flow determination in open channel', Jour. Engr. Mech. Dn.,ASCE,Vol. 94, No.EM4, August, pp 947-963.

15. Maurice James and Bobby J. Brown, (1977), 'Geometric parameters that influence flow', Research Report H-77-I, Hydraulic Laboratory, US Army Engineers Waterways Experiment Station.

16. Miodrag Radoj Kovic, (1976),'Mathematical modelling of rivers with flood plains', In Symposium on Inland Waterways for Navigation, Flood Control and Water Diversions, Vol.I, 1976, ASCE, pp 56-64.

17. Strelkoff, T, (1969), 'One dimensional equations of open channel flow', JHD, ASCE, HY.3.