**Review Paper**

# Critical appraisal of various techniques used for flow modeling in non-prismaticcompound open channel flow

**B. Naik[1], K.K.Khatua[2]and S.S. Dash[3]**
Department of Civil Engineering, N.I.T. Rourkela, INDIA

## Abstract

*Each river in the world is unique. Some are gently curve, others meander, and some others are relatively straight and skewed. The size of river geometry also changes from section to section longitudinally due to different hydraulic and surface conditions called non -prismatic channel. Much works done on river hydraulics are found to bed non prismatic compound channels. There has also been significant progress of work in meandering channels. But an area which has been somewhat neglected is that of non-prismatic channels. This paper scrutinizes various phenomenon related to non-prismatic channel in different type of flow systems. As discharge prediction is a vital issue in flood risk management and more important for a river in changed geometry. Therefore, a critical appraisal of the various techniques developed by various researchers across the globe for the past few decades to predict the stage-discharge relationship of a non-prismatic compound channels is extremely essential. Because it will facilitate the researchers to focus on the area of river hydraulics and that may lead to solve for other related objectives. Many methods adopted and developed by earlier researchers for both prismatic and non-prismatic compound channel areanalysed in this paper.*

**Keywords:** Compound channel, prismatic, non-prismatic, stage, discharge, velocity, flood, geometry.

## Introduction

From source to sea, rivers play an integral part in the day to day functioning of our planet. Existence would not have been possible, at least not in the forms we know, unless there was a plentiful supply of fresh water. Water is necessary for the most basic of needs and for this reason; people have always flourished where there has been a ready supply of water. Rivers can mean a variety of different things to different people. They can bring prosperity and hardship. They give life, but in the worst of cases can take it in a second. Hence, the flow in natural rivers and manmade channels and conduits has been of great interest throughout the ages. Today, more than half the world's population live within 65 km of the coast, and most of the major cities are also located on main river systems. Open channel can be said to be as the deep hollow surface having usually the top surface open to atmosphere. Open channel flow can be said to be as the flow of fluid (water) over the deep hollow surface (channel) with the cover of atmosphere on the top. Open Channels are classified as: Prismatic open channels, Non prismatic channels.

The open channels in which shape, size of cross section and slope of the bed remain constant are said to be as the prismatic channels. Opposite of these channels are non-prismatic channels. Natural channels are the example of non-prismatic channels while manmade open channels are the example of prismatic channels. In non-prismatic channel occurs in sudden transition, Sub-critical flow through sudden transition etc. Some examples are flow through culverts, flow through bridge piers, high flow through bridge pier and obstruction, channel junction etc. It is seen that, the river

generally exhibit a two stage geometry (deeper main channel and shallow floodplain called compound section) having either prismatic or non-prismatic geometry (geometry changes longitudinally). Due to the rapidly growing population, and to the consequent demand for food and accommodation, more and more land on such areas has been used for agriculture and settlement. Therefore, due to improper estimation of floods, it has led to an increase in the loss of life, and properties. The modelling of such flows is of primary importance when seeking to identify flooded areas and for flood risk management studies etc. To face those modelling, the critical appraisal to study various techniques used for flow modelling in both prismatic and non-prismatic compound open channel flow are useful. Even for a prismatic compound channel, there lies difference in hydraulic and geometric conditionsbetween the main channel and floodplain components, causing strong interactions (figure 1) between the sub-sections (e.g.1 and 2).
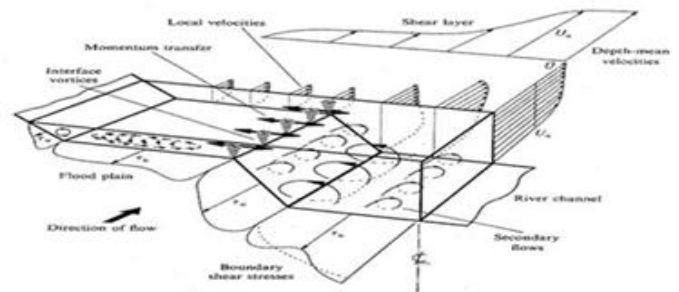


**Figure -1**
**Flow structure in a common compound channel section (after Shiono and Knight, 1991)**

In non-prismatic compound channels with converging/diverging floodplains (figure2), due to further continuous change in floodplain geometry along the flow path, the resulting interactions and momentum exchanges is further increased (3,4, and 5). This extra momentum exchange is very important parameter and should be taken into account in the overall flow modeling of a spatially varied river flow.
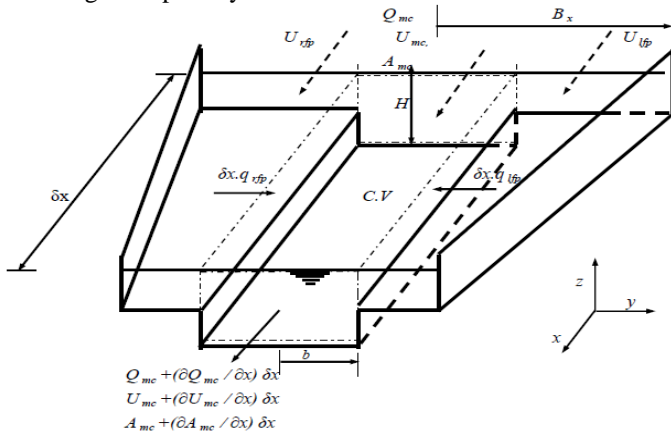


**Figure - 2**
**Geometry of a non-prismatic compound channel**

In the present work, an attempt will be made to study different methods for flow analysis of both prismatic and non-prismatic compound channels.Previous work done so far in prismatic and non-prismatic compound channel:-

**Single Channel Method:** During recent decades, a major area of uncertainty in river channel analysis is that of accurately predicting the discharge capability of compound channel i.e. river channel with flood plains. Cross sections of these compound channels are generally characterized by deep main channel bounded by one or both sides by a relatively shallow flood plain. Chow suggested that, Manning's or Chezy or Darcy-Weischbach equations (shown in Equations (1), (2) and (3) respectively) are used to predict discharge capacity at low depths when the flow is only in main channel.

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where, $Q$ = Overall discharge of the compound channel, $A$ = Area of the compound channel, $R$ = Aspect ratio of the compound channel, $S$ = Slope of the main channel, $f$ =Darcy-Weischbach friction factor of the compound channel, and $n$ = composite Manning's coefficient of the compound channel.

When over bank flow occurs, these classical formulae either overestimate or underestimate the discharge. Composite roughness methods are essentially flawed when applied to compound channels because compound channel is considered as single entity through the process of refined one dimensional methods of analysis6.Thus, the carrying capacity is underestimated because the single channel method suffers from a sudden reduction in hydraulic radius as the main channel discharge inundates to flood plains.

**Divided Channel Method:** The simple sub-division and composite roughness methods are not appropriate to predict discharge and flow resistance in a compound channel6. In the light of the knowledge gained about flow structure in compound channels, a number of suggestions have been made to account the interaction process in straight compound channels more accurately. The usual practice of calculating discharge in a compound channel is the use of 'divided channel method'. Assumed vertical, horizontal or diagonal interface planes running from the main channel-floodplain junctions are used to divide the compound section into subsections and the discharge for each subsection is calculated using Manning's or Chezy's or Darcy-Weisbach equation and added up to give the total discharge carried by the compound section. Generally, Manning's formula are used for discharge calculation in compound channels and written as.

$$Q = \sqrt{S}\left( \frac{1}{n_{mc}} A_{mc}^{5/3} P_{mc}^{-2/3} + \frac{1}{n_{fp}} A_{fp}^{5/3} P_{fp}^{-2/3} \right)$$

Where, S = longitudinal slope of the channel, $P_{mc}$ = main channel perimeters, $P_{fp}$ = flood pain perimeters, $A_{mc}$= main channel area, $A_{fp}$ = flood plain areas, $n_{mc}$= main channel Manning's coefficient, and $n_{fp}$ = flood plain Manning's coefficient. Mainly, the divided channel method is divided into three methods such as horizontal, vertical and diagonal division methods. Horizontal division method, although a realistic approach, but it neglects the main channel and flood plain interface. In the diagonal division method, division lines for all shapes and flow depths cannot be accurately drawn because uncertainty is gleaned into prediction of zero-shear line due to three dimensional nature of velocity flow field. Therefore, vertical division method is considered to predict discharge in straight compound channel in this study. There are several vertical division methods which are based on altering the wetted perimeter of the sub-area to account for the effect of interaction. Typically, the vertical division lines between the main channel and the flood plain is included in the wetted perimeter for the discharge calculation in the main channel flow. This is intended to have the effect of retarding the flow in main channel and enhancing it in the flood plain. However, simply altering the wetted perimeter by the vertical line does not completely reflect the interaction effect in a simple function7. It is found that this approach generally over predicts flow rate and conceptually, it is flawed since it applies an imbalance of shear forces at the interface. A typical example of vertical division method is shown in figure 3.
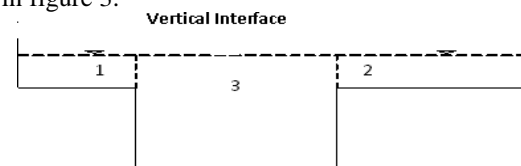
$$Q = CA\sqrt{RS} \quad (1) \quad (2)$$



**Figure -3**
**Vertical division of the compound channel cross-sectional view**

**Coherence method (Cohm):** It is based on the principle of adjusting the discharges calculated separately for each sub-area by an appropriate method. The coherence method (COHM) is now well established 1-D approaches for dealing with overbank flow and the related problems of heterogeneous roughness and shape effects8. The 'coherence', *COH*, is defined as the ratio of the basic conveyance calculated by treating the channel as a single unit with perimeter weighting of the friction factor to that calculated by summing the basic conveyances of the separate zones.

$$COH = \frac{\sum A_i \sqrt{\sum A_i / \sum (f_i P_i)}}{\sum \left[ A_i \sqrt{A_i / (f_i P_i)} \right]}$$

Where, i identifies each of the n flow zones, A is the sub-area, *P* is the wetted perimeter and *f* is the Darcy-Weisbach friction factor. As *COH* approaches unit, it is appropriate to treat the channel as a single unit using the overall geometry and discharge is estimated as per single channel method. In extreme cases, *COH* may be as low as 0.5. When coherence is much less than unity then discharge adjustment factors are required in order to correct the individual discharges in each sub-area and calculations are similar to divided channel method. The experimental data of flood channel facility (FCF) hasbeen suggestedfor four distinct levels of flow regions above the main channel level existing in straight compound channel flow and different discharge adjustment factors to be evaluated by methodologies for each region to estimate the overall discharge of the compound channel8.

**Region 1:** Here, the depth of flow is low; hence the velocities in flood plain and main channel are very dissimilar. This region is characterized by the relative depth $H_r<0.2$.

$$H_r = \frac{(H-h)}{H}$$

Where, $H$ = water level above channel bottom and $h$ = bank level above channel bottom.
$Q = Q_{basic}$-DISDEF
Where, *DISDEF* = Discharge deficit factor

**Region 2:** This zone is also of greater depth where interaction effect again disappears and flow computation depends on discharge adjustment factor *DISADF* in each part of the channel under consideration.
$Q = Q_{basic} \times DISADF_2$
(8)
$DISADF_2$ = Discharge adjustment factor for region 2.
**Region 3:** This zone appears when the relative depth is around 0.5 which again increase the interference effect.
$Q = Q_{basic} \times DISADF_3$
(9)
$DISADF_3$ = Discharge adjustment factor for region 3.
**Region 4:** This zone is of greater than relative depth of 0.6 and behaves as single unit due to the coherence character that obeys both the main channel and flood plains.
$Q = Q_{basic} \times DISADF_4$ (10)

$DISADF_4$= Discharge adjustment factor for region 4.
Where, $Q_{basic}$= basic total discharge calculated using zones separated by vertical divisions (omitted from the wetted perimeter). The coherence method is based originally on laboratory data from the FCF. At very shallow depth on flood plain i.e. at depth $H_r<0.0625$, this model disregards. The COHM is more difficult to apply when the roughness of the main channel river bed varies with discharge as is the case in sand bed rivers. Also Ackers8has pointed out that the zonal discharge adjustment factors are not well established because of lack of data when the flow is in region 2, 3, and 4.
(5)

**Exchange discharge method (edm):** This 1-D model of compound channel flows is developed by Bousmar and Zech9and modeled for straight and skew channel with maximum skew angle of $9^0$ by taking the interaction between main channel and flood plain into consideration. EDM also divides the channel as subsections but computes the total discharge by summing up the corrected discharge in each subsection discharge. The EDM requires geometrical exchange correction factor ($\psi^g$) and turbulent exchange model co-efficient ($\psi^t$) for evaluating discharge. Here, momentum transfer is proportional to the product of velocity gradient at the interface with the mass discharge exchanged through this interface due to turbulence. The main channel and each subsection of a compound channel can be considered as a single channel submitted to a lateral flow per unit length $q_l$. By assuming the head loss is the same in all subsections and applying the conservation of mass andthe momentum equations, the subsection discharge can be evaluated as shown below.

$$Q = \frac{A_i R_i^{2/3}}{n_i} S_f^{1/2} = K_i S_f^{1/2} = K \left( \frac{S_e}{1+\chi_i} \right)^{1/2}$$
(6)
where subscript 2 stands for the main channel; subscripts 1 and 3 stands for the floodplains; $h_1$ and $h_3$ are main-channel bank level on floodplain 1 and 3 side respectively; $K_i$ = conveyance factor for each subsection; $S_f$= friction slope; $S_e$= Energy slope; $A_i$= area of each subsections; $R_i$ = hydraulic radius of each subsections.
(7)

The factor $\chi_i$ calculated by equations provided in Bousmar and Zech9for each subsection of the flow. The system of equations is function of water depth, geometry and roughness. An analytical solution for straight symmetrical uniform flow is given by them and proposed a numerical solution procedure for the general case. When developing these solutions, it is assumed that the main channel velocity is larger than the floodplain velocity. This hypothesis enables the absolute values to be replaced by the difference without any sign change. After calculating $\chi_i$ for each subsection by iterative procedure, it can be used in equation (4.11) to obtain overall discharge of the compound channel.

**Lateral distribution methods (Ldms):** There are a number of lateral distribution models which are based on the depth

averaged Reynolds Averaged Navier-Stokes equations (RANS), given as

$$\frac{\partial u}{\partial t} + U\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) - \left(\frac{\partial u'^2}{\partial x} + \frac{\partial u'v'}{\partial y} + \frac{\partial u'vw'}{\partial z}\right) \quad (12)$$

As these methods are derived from fundamental fluid flow equations, they are physically based and theoretically sound. The channel is divided into a number of "panels" and the unit flow rate (or depth-averaged velocity) is calculated at these locations and summed to give the overall discharge in the channel as shown in equation

$$Q = \int_0^B q\,dy = \int_0^B U_d\,dA \quad (13)$$

These models are not strictly 1-D or 2-D and are perhaps best described as 1-D models with 2-D terms describing 3-D effects. There are a number of methods which fall into this classification but include the flood discharge assessment by Wark10 and Cuge11, the k-method by Ervine 12 and the Shiono-Knight method 13.Each of these methods has differing assumptions, emphasize the importance of different terms, but all somehow model the processes as opposed to directly evaluating them. The calibration coefficients and turbulence closure model is specific to a given method. A full review of the Shiono and Knight Method (SKM) is given in the following section.

**Interacting Divided Channel Method:** A new method that is the interacting divided channel method (IDCM) was developed by Fredrik Hut off et al14 to calculate flow in compound channels, based on a new parameterization of the interface stress between adjacent flows.
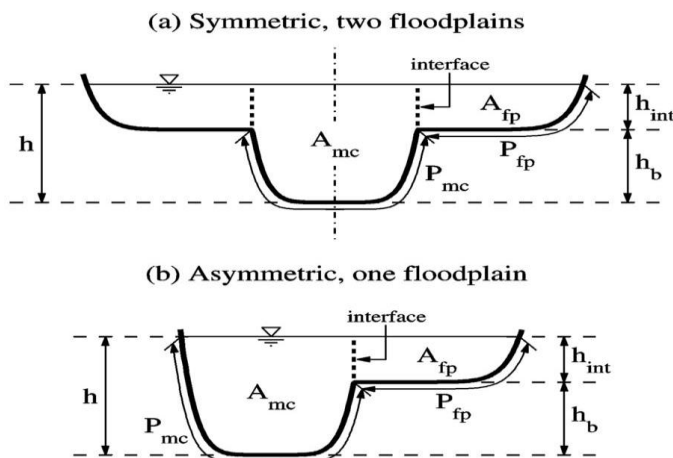


**Figure-4**
**Cross section of a two-stage channel: (a) symmetric with two identical floodplains (b) asymmetric with one flood plain**

They considered the channel geometries as depicted in figure 4, consisting of a main channel with either two identical floodplains $(N_{fb}=2)$ or a single floodplain $(\_N_{fb}=1)$. The total channel discharge $Q$equals the sum of the discharges in the main

channel and the floodplain(s)
$$Q = A_{mc} U_{mc} + N_{fp} A_{fp} U_{fp} \quad (14)$$

Where$A_{mc}$_cross-sectional area (of the main channel "mc") and $U_{mc}$ (cross-sectional averaged flow velocity) (Likewise for the floodplain "$f_p$"). The flow velocities $U_{mc}$ and $U_{fp}$ assumed steady and longitudinally uniform, follow from the stream wise force balances in both the main channel and the floodplains

**Rezaei1 et.al method:** Rezaei1 et.al[16,17,18] presented the experimental results of overbank flow in compound channels with non-prismatic flood plains and different convergence angles. The depth-averaged velocity, the local velocity distributions, and the boundary shear stress distributions were presented along the converging flume portions for different relative depths. Using the experimental data, various terms in the momentum equation were also calculated. They compared the results with the prismatic cases. The energy balance in non-prismatic compound channel sis also investigated by using the water surface elevation. They performed forthreenon-prism at ic configurations, of convergence angles of θ = 11:31°, θ= 3:81°, and θ=1:91°. The plan views of three non-prismatic compound channel configurations used by them are shown in Fig. 4.
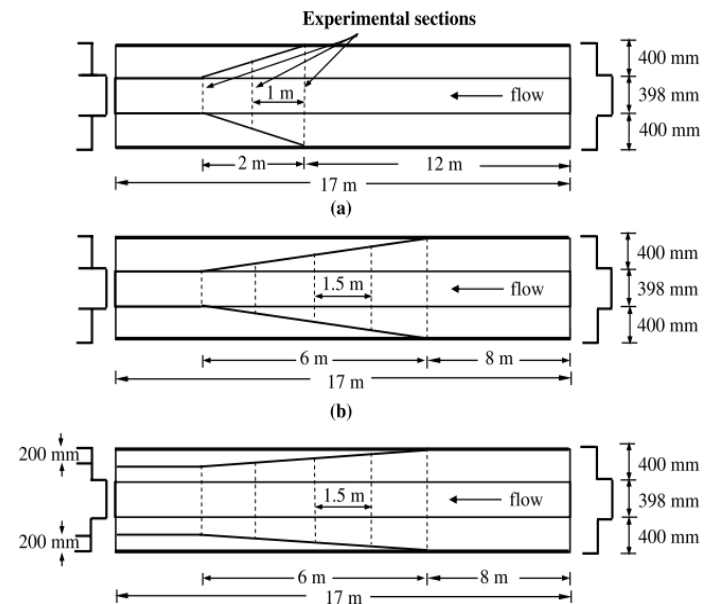


**Figure-5**
**Plan view of some non-prismatic channel**

They have used the force balance equation to get the surface profile. Here for the control volume in the main channel was taken as

$$F_{p1mc} - F_{p2mc} + W_{mc}S_o - \int \tau_b\,dp - \int \tau_a\,dp = \rho\beta_{2mc}U_{2mc}Q_{2mc} - \rho\beta_{1mc}U_{1mc}Q_{1mc} - 2\rho\bar{U}_{mf}q_1L$$

(15)

Where the subscripts mc and fp = main channel and floodplain, respectively; a = apparent parameters; and b = bed. Hence,

$$-(F_{p1mc} - F_{p2mc}) - \rho g \bar{A}_{mc} L S_0 + (2\overline{SF_3} + \overline{SF_4})L +$$
$$(\rho \beta_{2mc} U_{2mc} Q_{2mc} - \rho \beta_{1mc} U_{1mc} Q_{1mc}) - 2\rho \bar{U}_{mf} q_1 L + 2ASF_v = 0$$

(16)

in which ρ = the water density; β = the momentum correction coefficient; $\bar{U}_{mf}$ = the average velocity at interface between the main channel and the floodplain; Q = the flow discharge; $q_1$ = the lateral flow per unit length; L = the distance between selected sections; $F_p$ = the hydrostatic pressure force; W = the weight force; $\tau_a$ = the apparent shear stress; $\tau_b$ = the shear stress; p = the wetted perimeter; A = the average cross-sectional area; So = the average bed slope; g = the gravitational acceleration; SF3 = the boundary shear force per unit length acting in the main channel walls; SF4 = the boundary shear force per unit length acting in the main channel bed; and $ASF_v$ = the apparent shear force at the vertical interface between the main channel and floodplains. For the whole Channel, the Control Volume equation is written as:

$$-(F_{p1t} - F_{p2t}) - \rho g \bar{A}_t L S_0 + (2\overline{SF_1} + 2\overline{SF_2} + 2\overline{SF_3} + \overline{SF_4})L +$$
$$(\rho \beta_{2t} U_{2t} Q_{2t} - \rho \beta_{1t} U_{1t} Q_{1t}) - 2R_x = 0$$

(17)

In which the subscripts = total cross section; $SF_1$ = boundary shear force per unit length acting on the flood plain walls; $SF_2$ = boundary shear force per unit length acting on the floodplain bed; and Rx = component of wall reaction on the x-direction. The only unknown term in Eq. (17) is $R_x$, which also can be calculated using hydrostatic pressure force as follows:

$$R_x = \gamma \bar{h}_x A_{wx}$$

(18)

Where γ = specific gravity of water; $\bar{h}_x$ = depth of the centroid of the area; and $A_{wx}$ = projection of the floodplain wall area onto a plan perpendicular to x. The results of those two methods may be used to justify the accuracy of bed shear stress measurements and to correct them. Different terms in Eq. (15) are calculated for the various relative depths and the convergence angles of θ = 11:31° and θ = 3:81°

**Bousmar et.al method:** They have presented the experimental data for flow in compound channels with symmetrically narrowing floodplains. In such geometry, the flow behaviour presents similarities with the more complex flow in a meandering compound channel, yet without the curvature effects, because of mass transfers between the floodplains and the main channel, and secondary currents induced in the main channel. An estimation of the momentum transfer generated by the mass transfer is found significant compared to the frictional losses. It mainly depends on the geometrical parameters and is practically independent of the friction slope. Free-surface profile computations are performed with the exchange discharge model

EDM to incorporate the effects of the momentum transfer in terms of an additional head loss. Agreement was found between measured and computed water surfaces, thus validating the EDM approach.

**Exchange Discharge Model:** The exchange discharge model developed by Bousmar and Zech9 have presented the flow in a compound channel by taking into account the momentum transfer at the interface between the main channel and floodplains due to both turbulent exchanges in a prismatic channel and mass transfer generated by geometrical changes in a non-prismatic channel. The momentum transfer is estimated as the product of the lateral discharge through the interface by the velocity difference between the subsections. For computational purposes, the momentum transfer is then converted in an additional head loss to be added to the usual frictional losses, and the total discharge is obtained by summation of the so-corrected sub sectional discharges. Governing equations of EDM are summarized here, as they are used for subsequent analysis. The momentum equation for a subsection of the compound channel may be demonstrated by Bousmar and Zech9

$$\frac{\partial}{\partial t}(\rho A U) + \frac{\partial}{\partial t}(\rho A U^2) + \rho g A \frac{\partial H}{\partial x} = \rho g A (S_o - S_f) + \rho q_{in} u_l - \rho q_{out} U$$

(19)

Where ρ = density of water; g = gravity constant; A = cross-section area; U = Q/A = mean velocity with Q = discharge; H = flow depth; $q_{in}$ and $q_{out}$ = lateral inflow and outflow per unit length, respectively; $u_l$ = velocity component of the lateral inflow in the main-flow direction; and $S_o$ and $S_f$ = bottom and friction slopes, respectively. The friction slope $S_f$ is derived from Manning's equation, using the classical assumption that the head loss for a specific reach is equal to the head loss in the reach for a uniform flow having the same hydraulic radius and averaged velocity20.

$$S_f = \left( \frac{Q}{\frac{AR^{\frac{2}{3}}}{n}} \right)^2 = \left( \frac{Q}{K} \right)^2$$

(20)

Where R = cross-sectional hydraulic radius; K = cross-sectional conveyance; and n = roughness coefficient. In the momentum equation (21) inflow and outflow convey different momentum since their initial velocities are different. For steady flow, the total head loss per unit length Se is obtained from Eq. (22), associated to the continuity equation

$$S_e = -\frac{\partial}{\partial x}\left( z + \frac{v^2}{2g} \right) = S_f + \frac{q_{in}(U - u_l)}{gA} = S_f + S_a = S_f(1 + X)$$

(21)

where the slope Sa is defined as the additional head loss due to the exchange discharges at the interface, to be added to the friction slope; and X = $S_a/S_f$ is the ratio of this additional loss and the friction loss, depending only on geometrical parameters. In a compound channel, an additional loss ratio Xi and a friction slope $S_{fi}$ are defined in each subsection i, while the total energy

slope Se is the same in all subsections for a one-dimensional model. The exchange discharge q was subdivided into two parts: (1) $q_{cf}^t$ related to turbulent momentum flux; and (2) $q_{fc}^g$ associated to the mass transfer due to geometrical changes. The turbulent exchange discharge was estimated by a turbulence model analogous to a mixing-length model in the horizontal plane

$$q_{cf}^t = q_{fc}^t = |\overline{v'}|(H - h_f) = \varphi^t |U_c - U_f|(H - h_f) \quad (22)$$

Where $q_{cf}^t$ and $q_{fc}^t$ = lateral inflows from the main channel to a floodplain and from this floodplain to the main channel, respectively $v'$ =fluctuating part of transverse velocity; $h_f$ = bank level above the main-channel bottom. ($U_c$ and $U_f$ = longitudinal velocity in the main channel and floodplains, respectively; and $\varphi^t$ proportionality factor. This proportionality factor was calibrated as $\varphi^t$=0.16using the available experimental data (BousmarandZech9). The geometrical transfer discharge $q_g$ was estimated by considering conveyance change in the floodplain subsection. For decreasing floodplain conveyance

$$q_{fc}^g = -\varphi^g \frac{dQ_f}{dx} = -\varphi^g \frac{dK_f}{dx} S_{ff}^{\frac{1}{2}} \quad \text{and} \quad q_{cf}^g = 0 \quad (23)$$

Where the frictionslope variation $\frac{ds_{ff}}{dx}$ were neglected against $dK_f$ /dx. The geometrical transfer discharge was then multiplied by a proportionality factor $\varphi^g$ to adjust the momentum transfer.

**Proust et.al method:** Their study was focused on the analysis of flow parameters onthe channels with abrupt floodplain contraction (mean angle 22°). They applied some one-dimensional (1D) models, developed for straight and slightly converging geometry, and tested the validity for such geometry. Experiments on a contraction model were carried out in an asymmetric compound channel flume. They observed, severe mass and momentum transfers from the floodplain towards the main channel, giving rise to a noteworthy transverse slope of the water surface and different head loss gradients in the two subsections. Three 1D models and one 2D simulation were compared to experimental measurements. Each 1D model incorporates a specific approach for the modeling of the momentum exchange at the interface boundary between the main channel and the floodplain. The increase of the lateral mass transfer generates moderate errors on the water level values but significant errors on the discharge distribution. Erroneous results arise because of incorrect estimations of both momentum exchange due to lateral mass transfers and boundary conditions which are imposed by the tested 1D model.

**Presentation of Different 1D Model:** There are many studies found in literatures related to the flow of simple channels andflow of water in other media with application to computational fluid dynamics (e.g. 20,21,22,23 and24). There are less study found for compound channels and very less study

for non-prismatic cases. The relevance of 1D approach for a compound channel is related to the accuracy of interfacial transfer modeling. The significanceof these interfacial shear stresses and lateral discharges betweensubsections was investigated for backwater profilescomputation in a straight compound channel Yen15, and more recently for slightly non-prismatic geometries Bousmar and Zech4 andBousmaret.al 9. Both approaches distinguish the mass exchange and turbulence exchange contributions in the interfacial momentum transfer. The first 1D modeling considered in the following analysis is the classical divided channel method (DCM), which ignores both turbulent and mass transfer betweensubsections. TheBousmar and Zech9 model, called exchange dischargemethod (EDM) is the second modeling investigated. EDMis based on a theoretical modeling of the interfacial momentum transfer, tested for flows in slightly skewed compound channels and for a compound channel with narrowing floodplains. The interfacialshear on the subsection boundary is evaluated by using a mixing length model in the horizontal plane, and by expressing aturbulent exchange lateral discharge, noted $q^t$ , and modelledas

$$q^t = 0.16.h_{fp}(U_{mc} - U_{fp}) \quad (24)$$

Where $h_{fp}$ = mean flow depth on the floodplain, and the value 0.16 is a coefficient that was calibrated from nine series of uniform flows in the FCF of HR Wallingford Bousmar and Zech9.

Debord formula presented an empirical method that was developed on the basis of large experimental data sets in a60 m x 3 m straight compound-channel flume. The Debord formula gives an estimate of the conveyance on the whole crosssection, K *, by modifying one of the DCM asfollow

$$K^* = \varphi \frac{1}{n_{mc}} R_{hmc}^{\frac{2}{3}} A_{mc} + \frac{1}{n_{fp}} \sqrt{\left(A_{fp}^2 + A_{mc} A_{fp}(1 - \varphi^2)\right)} R_{hfp}^{\frac{2}{3}} \quad (25)$$

Where $\varphi$ = parameter that accounts for turbulent exchanges, modeled by

$$\varphi = \varphi_0 = 0.9\left(n_{mc}/n_{fp}\right)^{1/6}$$
$$\varphi = \frac{1}{2}\left\{[1 - \varphi_o]\cos\left(\frac{\pi r}{0.3}\right) + [1 + \varphi_o]\right\} \quad (26)$$

If $r = R_{hfp}/R_{hmc} \geq 0.3$ and $r = R_{hfp}/R_{hmc} \leq 0.3$

In that way, it is close to more recent empirical formulas such as Ackers8 or to previous expressions proceeding from the computation of apparent shear stress acting at the interfacial boundary, Knight and Demetriou[1]. The Debord method has been extensively used for more than 20 years by French modelers 24. It accounts for turbulent transfers but not for mass exchanges in the momentum transfers.

**Total Interfacial Exchanges:** As mentioned above, some 1D models developed for slightly non prismatic geometry take into account momentum transfer due to the mass exchange. The complete EDM can be used as a framework to evaluate this contribution. As suggested, the momentum equation can be written for the main channel as an energy balance by introducing the mass conservation

$$\frac{\partial}{\partial x}(Z_{mc}) + \frac{1}{g} U_{mc} \frac{\partial U_{mc}}{\partial x} + S_{f_{mc}} + S_{a_{mc}} = 0$$

$$S_{amc} = (q^t + q^m) \frac{(U_{mc} - U_{fp})}{gA_{mc}} \quad (27)$$

Where no inflow $(q^m = \text{lateral discharge due to mass transfer})$; due to mass transfers is considered as the water only leaves the converging floodplain.

**2D Computations:** 2D simulations were made by means of the numerical program Mac2D, Bousmar et.al 09. Mac2D solves the shallow water equations using a finite-difference method based on a Mac-Cormack scheme. The grid is made up of quadrilaterals of mean size (5cm x 4.5 cm).The momentum equation in x -direction, at a lateral position y, can be written as an energy equation by introducing the mass conservation.

$$\frac{dz}{dx} + \frac{1}{g} U_d \frac{dU_d}{dx} + \frac{1}{g} V_d \frac{dU_d}{dy} + S_{fx} - T_{xx} - T_{xy} = 0$$

$$(28)$$

Where the terms $T_{xx}$ and $T_{xy}$ are related to depth-averaged Reynolds stresses.

**Charles Bong HinJoo et.al method:** It had been long realized that traditional hydraulic methods of channel subdivision were inadequate for discharge calculation due to the significant interaction between main channel and flood plain that previously rarely taken into account of. So Charles et al 19 presented the results of experimental investigations carried out on a small scale non-symmetrical compound channel with rough flood plain in order to compare the different methods available for discharge prediction in a compound channel. The weighted divided channel method (WDCM) had been used to check the validity of the horizontal division method and the vertical division method in predicting discharge. Results from this experimental investigations had shown that for non-symmetrical compound channel with wider flood plain, the horizontal division method provide the more accurate predictions of discharge while for narrower flood plain, the vertical division is more accurate.

**Weighted Divided Channel Method (WDCM):** The weighted divided channel method (WDCM) was proposed to provide improved results to the conventional approach. The WDCM method uses a weighting factor ($\xi$) to allow a transition between the velocity given by the vertical division channel method (DCM-V) and the velocity predicted by the horizontal division

channel method (DCM-H). The weighting factor value varies between zero and unity that represents an infinite range of channel subdivisions between the traditional vertical division ($\xi$ = 1) and the horizontal division ($\xi$ = 0). The weighting is applied to both the main channel and the flood plain areas to give improved mean velocity estimates for these areas. The new velocity estimates are then used to determine the overall discharge. For the main channel region, the application of the weighting coefficient yields

$$V_{mc} = \xi V_{mc}DCM–V + (1 – \xi) V$$

$$(29)$$

Where$V_{mc}$ is the improved estimate of the main channel mean velocity, $V_{mc}$DCM-V is the mean velocity in the main channel given by the vertical division channel method, $V_{mc}$DCM-H is the mean velocity given by the horizontal division channel method and $\xi$ is the weighting coefficient. A similar equation was used for the flood plain velocity and the "mc" subscript representing the main channel was replaced by "fp" for the flood plain region. The use of a single parameter to account for the momentum interaction has allowed this method to be quickly and easily applied in designs situations and could also be easily incorporated in water surface profile calculations**.**

## Conclusion

The following conclusions can be drawn. There are different 1D, 2D and 3 D methods for predicting flow variables in compound open channel flow during flood. Most of the models are found to be suitable for prismatic compound channels only. Though the SCM and DCM are the traditional methods, the methods are found to give satisfactory results only for prismatic compound channels with limited field condition.The EDM, LDM, MDCM are found to give good results for prismatic compound channels with uniform surface roughness. Very limited research has been done on non-prismatic compound channels, the contributions as reported here is highly appreciated for non-prismatic compound channels. Further study and analysis are required to model for non-prismatic compound channels to predict surface profiles, boundary shear stress, discharge distributions etc.

## References

**1.** Knight D.A. and Demetrious J.D., Flood Plain and Main Channel Flow interaction. *J.Hydr.Engg*, ASCE, **109, 8,** 1073-1092 **(1983)**

**2.** Khatua K.K, Patra K.C, and Mohanty P.K., Stage-Discharge Prediction for Straight and Smooth Compound Channels with Wide Floodplains, *J. Hydr. Engg., ASCE,* **(2012)**

**3.** Bousmar D., Wilkin N., Jacquemart J.H., Zech Y., Overbank flow in symmetrically narrowingfloodplains. *J. Hydraul. Eng*., ASCE, **130(4),** 305-312 **(2004)**

4.  Bousmar D. and Zech Y., Discussion of two-dimensional solution for straight and meandering overbank flows*., J. Hydraul. Eng.,* **128(5),** 550-551 **(2002)**

5.  Proust S., Rivière N., Bousmar D., Paquier A. and Zech, Y., Flow in compound channel with abrupt flood plain contraction, *J. Hydraul. Eng.*, **132(9),** 958-970 **(2006)**

6.  Chow V.T., Open-channel hydraulics, New York, Mc. Graw-Hill Book Co, *Hydraul. Eng.,* **137(8),** 815-824 **(1959)**

7.  Shiono K., Al-Romaih J.S. and Knight D.W., Stage-Discharge Assessment in Compound Meandering Channels, *Hydraul. Eng, ASCE,* **125(1),** 66-77**(1999)**

8.  Ackers P., Stage–discharge functions for two-stage channels, the impact of new researches, *Inst Water Environ Manage*, **7,** 52–61 **(1993)**

9.  Bousmar D., and Zech Y., Momentum transfer for practical flow computation in compound channel, *J. Hydraul. Eng.,* **125(7),** 696-706 **(1999)**

10. Wark J.B., Samuels P.G. and Ervine D.A., A practical method of estimating velocity and discharge in compound channels, *Proc., Int. Conf. on River Flood Hydraulics, Wallingford, U.K.,Wiley, Chichester*, U.K., 163–172 **(1990)**

11. Cunge J.A., Holly F.M. Jr and Verwey A., Practical Aspects of Computational River Hydraulics. Pitman, London **(1980**)

12. Ervine D.A., Babaeyan-Koopaei K. and Sellin R.H.J., Two dimensional solution for straight and meandering overbank flows, *J. Hydraul. Eng.*, **126(9),** 653–669 **(2000)**

13. Shiono K. and Knight D.W., Turbulent open channel flows with variable depth across the channel, *J. Fluid Mech.*, **222,** 617–646 **(1991)**

14. Huthoff F.P.C., Roos D.C.M., Augustijn S.J.M. and Hulscher H., Interacting Divided Channel Method for Compound Channel Flow., *J. Hydraul. Eng, ASCE*, **134 (8),** 1158-1165 **(2008)**

15. Yen B.C., Hydraulics of floodplains: Methodology for backwater computation., *Institutfür Wasserbau, Univ. Stuttgart, Stuttgart, Germany*. *Rep. No.* **84(5),** (HWV053) **(1984)**

16. Rezaei B. and Knight, D.W., Overbank flow in compound channels with non-prismatic floodplains *J. Hydraul. Research* **(2011)**

17. Rezaei B., Overbank flow in compound channels with prismatic and non-prismatic floodplains, *PhD Thesis, Univ. of Birmingham, U.K.(*2006**)**

18. Rezaei B. and Knight D.W., Application of the Shiono and Knight Method in compound channel with non-prismatic floodplains, *J. Hydraul. Research,* **47 (6),** 716-726 **(2009)**

19. Charles B., Hin J. And Darrien Mah Yau S**.,** Study of flow of a non-symmetrical compound channel with rough flood plain**,** *Journal, The Institution of Engineers, Malaysia* **69(2),** **(2008)**

20. Thermal and Hydrodynamic Analysis of the Impingement Cooling inside a Backward Facing Step Flow Khudheyer S. Mushatet, *Res. J. Recent Sci.,* **1(ISC-2011),** 304-309 **(2012)**

21. Numerical Investigation of External Flow around the Ahmed Reference Body Using Computational Fluid Dynamics Chauhan Rajsinh B. and Thundil Karuppa Raj R., *Res.J.Recent Sci.,***1(9),** 1-5**(2012)**

22. Numerical study of fluid flow and effect of inlet pipe angle In catalytic converter using CFD Thundil Karuppa Raj R. and Ramsai R., *Res.J.Recent Sci.,***1(7),** 39-44 **(2012)**

23. Discharge Characteristics of Sharp Crested Weir of Curved Plan-form Kumar S., Ahmad Z., Mansoor T. and Himanshu S.K., *Research J. Engineering Sci.,***1(4),** 16-20 **(2012)**

24. French R.H., *Open-channel hydraulics*, McGraw-Hill, New York **(1985)**