STAGE-DISCHARGE RELATIONSHIP IN TWO-STAGE CHANNELS

by

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Dedication

To the people I love!

Abstract

Predicting the stage-discharge relationship in a flood event is an important concern. Once the flow exceeds the bank level in a two-stage channel, there is a momentum transfer that occurs at the interface between the main channel and its floodplain, which makes the problem more complicated. Several methods predict the stage-discharge relationship in two-stage channels; single-channel method (SCM), divided channel method (DCM), coherence method (COHM), weighted divided channel method (WDCM) and exchange discharge model (EDM). For analysis, all these methods were applied to the 18 m flume data collected in a symmetric smooth compound channel and the four cases of the symmetric rough compound channel. The SCM overestimated the stage for a given flow, whereas the DCM underestimated it. Although the WDCM is simple to use, it neglects the momentum transfer while calculating the stage-discharge, and it requires defining an appropriate weighing factor ξ to determine the stage-discharge relationship. On the other hand, the COHM and the EDM consider the momentum transfer; hence, showed better stage-discharge results. However, both COHM and EDM are very complex to use. Therefore, the aim of this study was to develop a simple method that can predict the stage-discharge relationship in symmetric compound channels accurately during flood events. In this study, the new method is proposed by improving the WDCM, and it is called improved weighted divided channel method (IWDCM), which includes the apparent shear force (ASF), wetted perimeters and B/b ratio. It was concluded that IWDCM is limited to all rigid symmetric compound channels with B/b ratios greater than or equal to 3. The IWDCM for smooth, symmetric compound channel led to percentage errors of 5.59%, 6.01% and 4.91% for total, main channel and floodplain discharges, respectively. On the other hand, for the rough symmetric compound channel, the results showed 1.85%, 7.74%, 10.75%, and 5.91% for total discharges for cases 1, 2, 3, and 4 respectively. Lastly, the IWDCM was applied to two datasets for validation purposes, and similar results were obtained. Therefore, the IWDCM can be used to predict the stage-discharge relationship in compound channels during flood events.

Keywords: Overbank flow; Momentum transfer, Stage-discharge; Weighted divided channel method; apparent shear stress.

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List of Abbreviations

ARF	Main Channel Aspect Ratio
ASF	Apparent Shear Force
ASSM	Apparent Shear Stress Method
COHM	Coherence Method
DCM	Divided Channel Method
DCM-$_H$	Horizontal Divided Channel Method
DCM-$_v$	Vertical Divided Channel Method
DISADF	Discharge Adjustment Factor
ECM	Energy Concept Method
EDM	Energy Discharge Method
FCF	Flood Channel Facility
IDCM	Interacting Divided Channel Method
IWDCM	Improved Weighted Divided Channel Method
LDA	Laser Doppler Anemometry
MTDCM	Momentum Transfer Divided Channel Method
SCM	Single Channel Method
SF	Shear Force
SKM	Shino-Knight Model
WDCM	Weighted Divided Channel Method

Chapter 1. Introduction

This chapter represents the flow mechanism in two-stage channels and their complexity during a flood event. It also addresses the flow characteristics of the channel and the interaction between the main channel and its floodplain during the overbank flow. In addition, this chapter briefly highlights the methods used to find the stage-discharge relationships in two-stage channels.

1.1. Overview

Many factors such as heavy precipitation, snow, coastal storms, severe winds over water, unusual high tides, tsunamis, overflow of dams may lead to flooding. Flooding is one of the most catastrophic disasters that damage property and endanger the lives of humans [1,2]. Therefore, floods have enormous detrimental effects on the economy as well as the environment. In 2011, the flood that occurred in the United States of America cost approximately 8.5 billion US dollars [2]. In addition, one of the most recent floods that occurred in Vietnam in June 2018 destroyed over 80 houses and over 700 hectares of rice fields. The cost of these damages amounted to around 23 million US dollars [3]. Therefore, methods and studies have been conducted for several years to control flood in order to minimize human and economic losses. Many different types of methods are available for flood control. Dams act as barriers against water flowing from rivers or reservoirs that are common water sources. Flood gates can be another method for flood control, as it adjusts the water flow from rivers. Moreover, if a temporary method is required in certain locations, flood walls can be used to act similar to dams [4]. In addition, areas around rivers can be re-engineered to have one or two floodplains and design two-stage channels.

Natural rivers mostly consist of a main channel combined with floodplains, which are known as two-stage channels or compound channels. Two-stage channels could be symmetric or asymmetric, depending on an adjacent number of floodplains. Engineers emphasize predicting the stage-discharge relationship in compound channels accurately due to the importance of the construction of hydraulic structures, prediction of sediment loads, water resource management, river engineering, hydraulic and hydrologic modeling, and especially flood risk management [5,6,7]. Over the years, the importance of two-stage channels in flood events has been highlighted. During low flow conditions, there is no flow in the floodplains; thus, the space provides an area for

agriculture [8,9]. Therefore, understanding the flow characteristics of rivers in-bank and over-bank flow conditions is essential. Hence, predicting the stage-discharge in compound channels is a requirement, especially to flood risk management in order to minimize human losses and environment, and economic consequences.

During flood events, when the water passes over the bank-full level, it affects the prediction of stage-discharge relationship, which causes the stage-discharge calculation to be complicated. It consequently, causes a difference in flow velocity between the main channel and the floodplain which leads to a disruption known as the lateral momentum exchange [5]. The lateral momentum transfer occurs due to a sudden change in the wetted perimeter when the floodplains get inundated, which occurs at the main channel-floodplain interface. The flow in the main channel accelerates the floodplain velocity, while the flow in the floodplain decreases the main channel velocity. Moreover, there are longitudinal exchanges at the interface of the main channel and the floodplain, which are known as the apparent shear stress. Therefore, the prediction of the stage-discharge relationship in two-stage channels during a flood event is more complicated due to the momentum transfer and the apparent shear stress that occurs at the interfaces [8].

Over the years, many different methods have been developed to calculate the stage-discharge relationship in compound channels. This present study mainly addresses the most commonly used one-dimensional (1D) methods, which are explained in detail in the literature review. The commonly used methods developed to determine the stage-discharge relationship are the single channel method (SCM) that uses the classical formulas such as Manning, Chezy, and Darcy-Weisbach, the divided channel method (DCM) that uses classical formulas on the cross section subsections, the weighted divided channel method by Lambert and Myers (WDCM), coherence method by Ackers (COHM), and exchange discharge method (EDM) by Bousmar [8-11]. Research has shown that these traditional and well-known models such as the SCM and the DCM are very simple to apply due to their assumptions, and hence predict the stage-discharge relationship inaccurately. On the other hand, models such as the WDCM, COHM, and EDM lead to more accurate results. However, the COHM and the EDM are very complex to use. Therefore, the gap that is currently available in

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available research is a simple model that can predict and calculate the stage-discharge relationship during flood events.

1.2.   Thesis Objectives

The purpose of the present research is to develop a model which can predict the stage-discharge relationship in two-stage channels during flood events accurately and easily. To be able to develop such models, already existing methods were studied and analysed.

1.3.   Research Contribution

During a flood, the flow structure in a river becomes more complex because the discharge increases rapidly, and the bank-full condition gets violated; therefore, there will be flow in the floodplains of the channel [3].

The following points have been considered in the present research:

1. Analysis of the symmetric smooth and rough compound channels and the rigid main channel with two identical adjacent floodplains to study current 1D methods and develop a new model.

2. The data that are used in this research is from the experiments that were done on two-stage channels in Birmingham University on an 18m flume with 1200 mm width, 400 mm depth, and fixed bed slope of 2.024×10^{-3} [4].

3. Two different data sets were used to validate the IWDCM. The first is Knight's data that were based on a 15m flume, with a fixed bed slope of 9.66×10^{-3} with three different B/b ratios (2, 3 and 4). The second is FCF data for a symmetric compound channel with different B/b ratios (Series 01, 02, 03, 07, 08, and 10) that were used to validate the new proposed method [32, 35].

1.4.   Thesis Organization

The thesis chapter organization is as follows:

Chapter 2 is the literature review. It presents the theoretical background of two-stage channels and the consequences of the discharge and interaction between the main channel and its floodplains during a flood event. It also describes the methods used to determine the stage-discharge relationship in two-stage channels. Chapter 3 describes

the steps for studying and analysing the 1D methods and includes the steps done for developing and validating the new method. Chapter 4 includes the mathematical analysis done in order to achieve and implement the new proposed method. Chapter 5 represents the results, discussion, and comparisons done between the new model and the WDCM. Chapter 5 concludes all the points mentioned and considered in the study.

Chapter 2. Background and Literature Review

Over the years, studies mostly concentrated on the importance of flood control. A flood occurs when water in a main channel passes over the bank-level and overflows onto the floodplains, which leads to a complexity in discharge calculation [5]. Due to the flow complexity of two-stage channels, it is essential to forecast both the total discharge in the channel and the zonal discharges in the main channel and the floodplains. Available research has shown the evaluation of different methods for the sake of predicting zonal and total discharge in compound channels [12]. The water from a flood event, that flows into floodplains with rough beds due to vegetation, is shallow. Hence, it causes the velocity to be slower compared to the main channel velocity, which leads to the occurrence of a shear layer at the interface of the main channel and its floodplains. The shear layer that arises due to the velocity gradient causes a disruption known as momentum exchange, as shown in Figure 2.1 [6,11,13]. The lateral momentum transfer occurs between the main channel and its floodplains, which causes the discharge capacity in compound channels to decrease. The decrease in the discharge capacity leads to a reduction in the main channel capacity. Hence, the total conveyance capacity of the whole channel decreases [11]. This decrease in the conveyance capacity is due to the wetted perimeter value that increases faster than the area; in other words, a decrease in the hydraulic radius results in a decrease in the conveyance capacity [6,7].
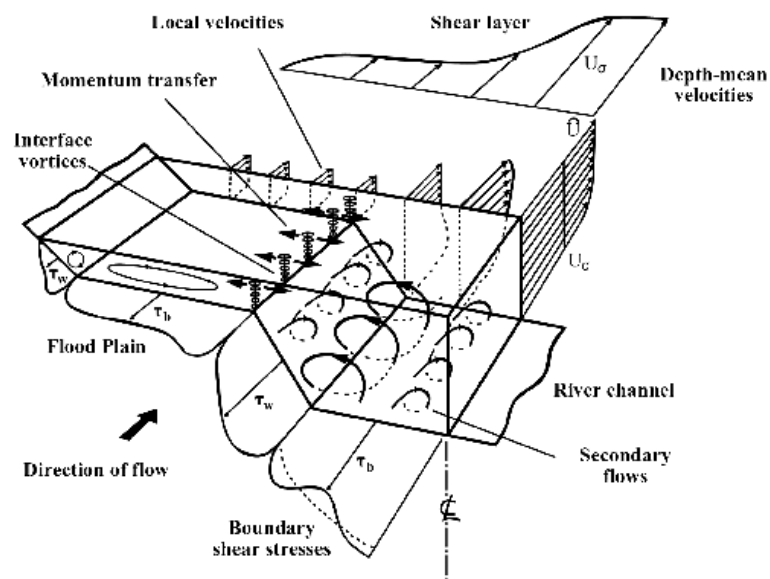

Figure 2.1. Hydraulic Parameters Associated with Overbank Flow [13]

Furthermore, the sudden change of the depth causes a longitudinal disruption at the interface, known as the apparent shear stress, that influences the flow structure of two-stage channels, as shown in Figure 2.2 [14]. Similar to the momentum exchange, the apparent shear stress also causes energy loss. Hence, it causes a decrease in the discharge capacity of the compound channels. There have been studies and experiments done to predict the boundary shear stress around the channel's wetted perimeter, which depends on the cross section of the channel, heterogeneous boundary roughness and longitudinal variation in planform geometry [15]. To measure the boundary shear stress in compound channels, direct and indirect techniques can be used. In 1954, a study on boundary shear stress distribution was done using the indirect techniques, and in 1970 other studies were done using direct techniques [16,17]. A study was done by Cruff on smooth compound channels with different aspect ratios (B/h); it aimed at determining the importance of aspect ratios in a boundary shear distribution. For different aspect ratios, the maximum and the mean boundary shear stresses on the walls and the bed were determined. The results showed that the boundary shear stress distribution is only affected by the aspect ratio, as the bed shear stress increases in parallel with an increase in aspect ratio [18]. Furthermore, other studies were done on rough symmetric and asymmetric compound channels; boundary shear distribution results appeared to be distinctly non-uniform [19-21]. A research paper was done on the momentum transfer mechanism, and the results showed that the apparent shear stresses were greater than the shear stresses on a solid boundary interface. The Laser Doppler Anemometry (LDA) technique confirms the study [22,23].
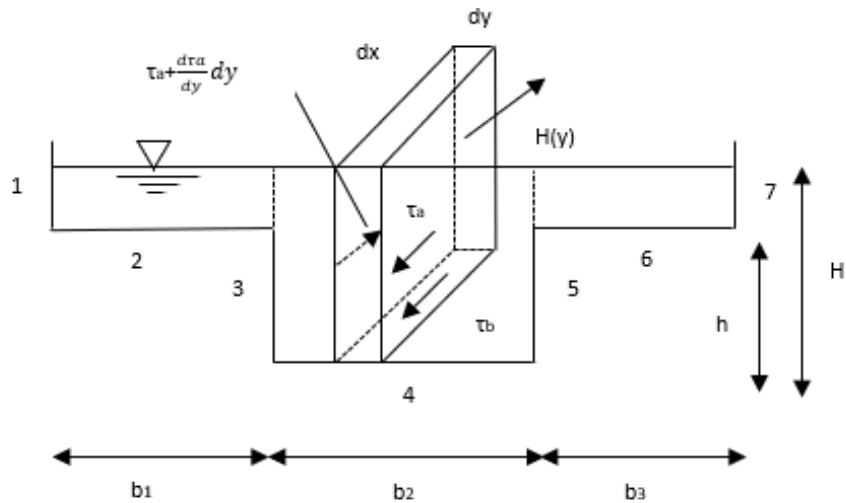

Figure 2.2. Symmetric Compound Channel with Boundary Elements [24]

A significant body of research has been done to identify the interaction effect at the interface between the main channel and the floodplain. Some researchers used a photographic technique and aluminium powder to identify the interface turbulence [19,21,26-29]. Moreover, the LDA technique considered the velocity and turbulence measurements to analyse the interaction between the main channel and the floodplain. The results showed that the momentum exchange at the main channel-floodplain interface depends on the relative depth and the channel geometry [30]. In addition, other studies used the logarithmic velocity distribution law to predict the floodplain's vertical velocity profiles [31]. Further studies have been done with varying flow velocity, flow depth, and roughness to evaluate the accuracy of the common methods that can be used to determine the discharge. Hence, on different imaginary interfaces, the apparent shear stress was determined [32]. A research paper measured the apparent shear forces between the divided channel sub-sections by considering different imaginary interface panes (inclined, horizontal and vertical) [33]. Another study considered a symmetric two-stage channel with varying floodplain roughness and studied the interaction that occurs at the main channel-floodplain interface. In addition, to determine the momentum transfer between the sub-section divisions, apparent shear force ASF was evaluated for an inclined, horizontal, and vertical interface, which resulted in a percentage for the apparent shear stress. Hence, the sub-section division of flow has an influence on the momentum transfer at the main channel-floodplain interface [34].

$$\%ASF_v = \frac{50}{(\propto-1)\beta+1} - 0.5\{100 - 2[\%(SF_1 + SF_2)]\} \tag{1}$$

$$\%ASF_H = \frac{100(1-\beta)}{(\propto-1)\beta+1} - \{100 - 2[\%(SF_1 + SF_2)]\} \tag{2}$$

$$\%ASF_i = \frac{25(2-\beta)}{(\propto-1)\beta+1} - 0.5\{100 - 2[\%(SF_1 + SF_2)]\} \tag{3}$$

During a flood event, and due to the sudden increase of the discharge, the bank-full condition gets violated, and the flow structure in a river becomes more complex [5]. It is very difficult to measure the velocity accurately during the flood event. To predict the stage-discharge relationship in two-stage channels, many studies focused on the experimental methods carried out in laboratories [35-43]. A few different experimental datasets are shown in Table 2.1.

Table 2.1. Experimental Datasets for Compound Channels [35-43]

Type of Experiment	S_o	Exp. No.	h (m)	Dr	B/b	Q_t (m³/s)
FCF	0.001027	Series 01	0.15	0.056-0.400	6.67	0.208-1.015
		Series 02	0.15	0.041-0.479	4.2	0.212-1.114
		Series 03	0.15	0.051-0.500	2.2	0.225-0.835
		Series 07	0.15	0.038-0.504	4.2	0.216-0.543
		Series 08	0.15	0.050-0.499	4	0.186-1.103
		Series 10	0.15	0.051-0.464	4.4	0.237-1.094
18 Flume	0.002024	Smooth	0.05	0.162-0.475	3.05	0.015-0.055
		Case 1	0.05	0.197-0.521	3.05	0.015-0.034
		Case 2	0.05	0.234-0.702	3.05	0.015-0.049
		Case 3	0.05	0.295-0.693	3.05	0.010-0.034
		Case 4	0.05	0.297-0.751	3.05	0.011-0.041
Knight et al.	0.000966	KD83A	0.076	0.108-0.409	2	0.005-0.017
		KD83B	0.152	0.131-0.491	3	0.005-0.023
		KD83C	0.229	0.106-0.506	4	0.005-0.029

As mentioned, predicting the stage-discharge relationship in two-stage channels is a significant factor, as it determines the discharge and the degree of flood accurately. A significant body of research has been done for developing different one-dimensional (1D) methods, two-dimensional (2D) methods, three-dimensional (3D) methods, and software in order to compute the stage-discharge relationship [44,45]. The 1D methods that were proposed ever since are the following: interacting divided channel method (IDCM), apparent shear stress method (ASSM), momentum-transfer divided channel method (MTDCM), modified divided channel method (MDCM), and energy concept method (ECM) [46-54]. Moreover, Shiono and Knight developed 2D methods: the quasi-analytical method such as SKM, and the modified methods proposed by Tang and Knight. In addition, 3D methods were developed by Krishnappan and Lau, Cater and Williams, and Marjang and Merkley which require different input data and turbulence parameters that are unavailable and require a lot of time to be determined [55-62]. Therefore, this study mainly focuses on the most common 1D methods: single-channel method (SCM), divided channel method (DCM), weighted divided channel method (WDCM), coherence method (COHM), and exchange discharge model (EDM). These methods are discussed in detail in the next section.

Studies show that the known traditional methods, SCM and DCM, neglect the momentum transfer at the interface of the main channel and floodplain. In addition, these two traditional methods are based on the Manning's formula, which assumes the flow to be uniform and prismatic. Therefore, the SCM and the DCM cannot predict the stage-discharge accurately during real-life flood events. Furthermore, the DCM was improved to WDCM which is simple to use; this resulted considerable improvements and better accuracy in the stage-discharge relationship because WDCM calculates the stage-discharge of each zone (main channel and floodplain) separately before determining the stage-discharge capacity of the whole channel [9]. Later, studies were done, and more complex methods such as COHM and EDM were developed that lead to a better prediction of the stage-discharge relationship. COHM and EDM are the most accurate methods for calculating the stage-discharge relationship in two-stage channels compared to all the studied models [5,11]. However, due to their complexity, they are not preferred for use them when estimating the stage-discharge relationships in compound channels.

2.1. Single Channel Method

This method considers a unique cross-section for compound channels. Considering the given data, the stage-discharge was calculated using Manning's equation 4; the results showed that the single channel method overestimates the stage-discharge relationship at a given flow [63].

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{4}$$

in which,

n: Equivalent roughness

A: Cross-sectional area of the channel

R: Hydraulic radius

S: Slope of the channel bed

2.2. Divided Channel Method

In this method, the compound channel is divided into sub-areas as the main channel and the floodplain using different interfaces between them. This method also

uses the Manning's equation, but it is applied to the main channel and the floodplain separately. Based on adjustment of the sub-areas of wetted perimeters, Wormleaton and Knight developed the simple divided channel method [64-66]. Knight considered three different methods to calculate the stage-discharge: a vertical interface between the main channel and the floodplains while neglecting the interface length, a vertical interface while including the interface length, and an inclined interface while neglecting the interface length [67]. However, the sub-division methods were inaccurate because of the interaction between the main channel and floodplain flows. Wormleaton and Knight concluded that the inaccuracy of these sub-division methods is due to the floodplain water depth reduction because of the momentum transfer effects; Research results showed that the divided channel method underestimates the stage-discharge at a given flow [64,66].

2.3.   Coherence Method

Ackers developed a method in a straight compound channel that allows interaction effects between the main channel and the floodplain. The method is called the coherence method (COHM) that divides the main channel and the floodplain from each other; however, the imaginary division interface is not calculated in determining the wetted perimeters for the sub-areas. Using standard resistance formulas, the velocity and discharge for each zone were calculated and adjusted with the discharge adjustment factor (DISAF). The COH method considers four different regions to calculate the discharge, which means that four different correction factors are applied to calculate the discharge for each region. The total discharge is then determined by adding the discharge values calculated for each region [9,68]. This method takes into consideration changes in flow depth, the floodplain roughness being different from the main channel, the variation of floodplain width relative to the main channel, the channel being symmetric or asymmetric, the variation of side slope of main channel, and the variation of aspect ratio of main channel (B/h).

$$COH = \frac{Theoretical\ conveyance\ of\ single\ compound\ channel}{Sum\ of\ individual\ conveyances\ of\ each\ zone} \tag{5}$$

$$DISAF = \frac{Measured\ discharge}{Discharge\ computed\ for\ each\ zone} \tag{6}$$

$$COH(H) = \frac{\sum_{i=1}^{i=n} Ai \sqrt{\sum_{i=1}^{i=n} Ai \sum_{i=1}^{i=n}(fiPi)}}{\sum_{i=1}^{i=n}[Ai \sqrt{\left(\frac{Ai}{fipi}\right)}]} \tag{7}$$

$$COH(H) = \frac{(1+A*)\sqrt{\frac{1+A*}{1+f*P*}}}{1+A*\sqrt{\frac{A*}{f*P*}}} \tag{8}$$

$$COH(H) = \frac{(1+A*)^{\frac{3}{2}}\sqrt{\frac{1+P*^{\frac{4}{3}}n*^2}{A*^{\frac{1}{3}}}}}{1+\frac{A*^{\frac{5}{3}}}{n*P*^{\frac{2}{3}}}} \tag{9}$$

in which,

$A*=N_fA_f/A_c$; $P*=NP_f/P_c$; $H*=(H-h)/H$; $f*=f_f/f_c$; $n*=n_f/n_c$ and N_f = number of floodplains

     If the COH is less than one, the discharge adjustment factors are needed to adjust the individual discharges in the main channel and floodplain. If the COH is equal to, or greater than one, the channel can be treated as a single channel. There are four different regions and four different DISADF above the bank-full level.

     Region 1 has different velocities and flow depths in the main channel and floodplains; therefore, relative flow depths are low, and as depth increases, interaction increases as well.

For the main channel:

$$Q_c = Q_{bc} - \Delta Q_c \qquad V_c = Q_c/A_c \qquad DISADF_c = Q_c/Q_{bc} \tag{10}$$

For the floodplains:

$$Q_f = Q_{bf} - \Delta Q_f \qquad V_f = Q_f/A_f \qquad DISADF_f = Q_f/Q_{bf} \tag{11}$$

For the whole section:

$$Q_t = Q_{bt} - \Delta Q_t \qquad V_t = Q_t/A_t \qquad DISADF_t = Q_t/Q_{bt} \tag{12}$$

in which,

$$\Delta Q_c = Q*_c (V_{bc} - V_{bf}). H.h.ARF \tag{13}$$

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$$\Delta Q_f = Q^*_f (V_{bc} - V_{bf}). \ H.h.ARF \qquad (14)$$

$$\Delta Q_t = \Delta Q_c + N_f \Delta Q_f \qquad (15)$$

$$Q^*_c = -1.24 + 0.395(B/W_c) + GH^* \qquad (16)$$

$$Q^*_f = -1.00H^*/f^* \quad if \ Q^*_c < 0.5 \ then \ Q^*_c = 0.5; \ Q^*_f = 0 \qquad (17)$$

$$S_c \geq 1 \ \ G = 10.42 + 0.17f^* \qquad (18)$$

$$S_c < 1 \ \ G = 10.42 + 0.17S_c.f^* + 0.34(1-S_c) \qquad (20)$$

$$ARF = (2b/h)/10 \qquad (21)$$

Region 2 has a greater depth zone, and the flow calculations for this zone is based on DISADF of the considered part of the channel. In this region, the interference effect also decreases. The values of A^*, P^*, and f^* shown in the coherence equation are relation to the shifted value, $(H^*+shift)$.

For the main channel:

$$Q_c = DISADF_c{}^*Q_{bc} \qquad V_c = Q_c/A_c \qquad (22)$$

$$DISADF_c = DISADF_c \ (at \ the \ limit \ of \ region \ 1) \qquad (23)$$

For the floodplains:

$$Q_t = Q_t - Q_c \qquad V_f = Q_f/A_f \qquad DISADF_f = Q_f/Q_{bf} \qquad (24)$$

For the whole section:

$$Q_t = DISADF_t{}^*Q_{bt} \qquad V_t = Q_t/A_t \qquad DISADF_t = COH(H) \qquad (25)$$

where,

$$H = h/ \ [1-(H^* + shift)] \qquad (26)$$

$$S_c \geq 1 \qquad shift = 0.05 + 0.05N_f \qquad (27)$$

$$S_c < 1 \qquad shift = -0.01 + 0.05N_f + 0.6S_c \qquad (28)$$

Region 3 is a narrow region, where DISADF is a function of COH related to the actual relative depth,

$$DISADF_t = 1.567 - 0.667COH(H) \qquad (29)$$

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Region 4 is where the compound channel is treated like a single channel, DISADFt = COH(H)

Choice of region:

$$\text{If} \quad Q_t^{R1} \geq Q_t^{R2} \text{ then } Q_t = Q_t^{R1} \tag{30}$$

$$\text{If} \quad Q_t^{R1} < Q_t^{R2} \text{ and } Q_t^{R3} \geq Q_t^{R2} \text{ then } Q_t = Q_t^{R2} \tag{31}$$

$$\text{If} \quad Q_t^{R1} < Q_t^{R2} \text{ and } Q_t^{R3} < Q_t^{R2} \text{ then } Q_t = Q_t^{R3} \tag{32}$$

$$\text{unless } Q_t^{R4} > Q_t^{R3} \quad \text{then } Q = Q^{R4}$$

2.4. Weighted Divided Channel Method

To determine the stage-discharge capacity for compound channels, Lambert and Myers developed a model that is based on component mean velocities, using standard resistance equations in the main channel and floodplains [69]. This method is similar to the divided channel method, but as shown in Figure 2.3 it also uses the vertical and horizontal division lines; it is called the weighted divided channel method (WDCM) [9]. The velocity determined for the main channel is overestimated for the DCM with vertical divisions and underestimated for the DCM with horizontal divisions and vice versa for the floodplain velocities.

The weighted divided channel uses the divided channel method (DCM) with vertical divisions and with horizontal divisions. The method uses a weighting factor (ξ) that defines the transition between vertical and horizontal velocity. Firstly, the method calculates the mean velocity in the main channel and floodplain. Secondly, it divides them by the observed mean velocity for the whole channel cross-section to determine dimensionless velocity values. The DCM with vertical divisions overestimates the main channel velocity and underestimates the horizontal division and vice versa for the floodplain velocities.

$$V_{mc} = \xi V_{mc\text{-}DCM\text{-}V} + (1-\xi)V_{mc\text{-}DCM\text{-}H} \tag{33}$$

$$V_{fp} = \xi V_{fp\text{-}DCM\text{-}V} + (1-\xi)V_{fp\text{-}DCM\text{-}H} \tag{34}$$

in which,

V_{mc}: improved estimates of the main channel velocity

V_{fp}: improved estimates of the floodplain velocity

$V_{mc\text{-}DCM\text{-}V}$: mean velocity in the main channel by vertical division, divided channel method

$V_{fp\text{-}DCM\text{-}V}$: mean velocity in the floodplain by vertical division, divided channel method

$V_{mc\text{-}DCM\text{-}H}$: mean velocity in the main channel by horizontal division, divided channel method

$V_{fp\text{-}DCM\text{-}V}$: mean velocity in the main channel by vertical division, divided channel method

The horizontal division method is determined by adding the bank-full discharge and the discharge in the region above the horizontal division line with the same velocity as the floodplain, and then dividing this sum by the total shaded area. The WDCM neglects the interaction effects that happen between the main channel and floodplains. This method is successful because the floodplain is over-predicted, and the main channel discharge is under-predicted to compensate for the errors [9]. However, the disadvantage of using this method is that it requires trial and error for choosing the best weighting factor for compensating channel discharge errors.

Figure 2.3. Division of a Compound Channel [9]

2.5. Exchange Discharge Model

To predict the stage-discharge relationship in two-stage channels, Bousmar and Zech improved the divided channel method and developed a model by estimating the momentum transfer as the product of the velocity gradient by the mass of water flowing through the interface of the main channel and floodplain. This method is developed for non-prismatic and non-uniform flows; however, it neglects the sinuosity and associated

secondary current in compound channels. EDM improved the stage-discharge prediction compared to the previously mentioned methods and gave similar accuracy to the coherence method. The EDM is much simpler than the COHM, as it does not require many parameters. However, it requires iterations until the final discharge value is reached [5].

$$Q = K \left(\frac{Se}{1+\chi i}\right)^{\frac{1}{2}} = KiSf^{\frac{1}{2}} = \frac{AiRi^{\frac{2}{3}}}{ni}Sf^{\frac{1}{2}} \tag{35}$$

in which,

K_i: conveyance factor for each subsection

S_f & $S_{e:}$ friction & energy slope respectively

A_i & Ri: area & hydraulic radius of each subsection

$\chi_{i:}$ subsection ratio

Chapter 3. Methodology

This chapter describes the methodology that was adopted for this study. First, the accuracy and simplicity of the one-dimensional models described in the literature review were investigated. Second, the advantages and disadvantages of the 1D models were defined. Third, based on the analysis, the new method was decided to be either an improvement of one of the 1D models or a new development. Lastly, the new proposed method was validated using two different sets of data: FCF and Knight.

3.1. Investigation of the One-Dimensional Models

First, the SCM, DCM, WDCM, COHM, and EDM were studied and analysed by applying them on the available 18 m flume data. All the methods were applied on smooth and rough symmetric compound channels. The Manning's coefficients for the smooth, symmetric channel were assumed to be 0.01 for both main channel and floodplains. Moreover, for the rough, symmetric channels, the Manning's coefficients are shown in Table 3.1. Based on the experiments done at the University of Birmingham for four different roughness cases, the symmetric channels were roughened using A-frames of aluminium wire grids, placed at various longitudinal intervals, λ along the channel. For all the four cases, the floodplains were roughened (λ = 1.0, 0.5 and 0.25 m) and the roughness for the main channel was varied from smooth to rough (λ = 3.0 and 2.0 m); hence, the Manning's n values were determined [35].

Table 3.1. Manning's Coefficients n for Rough Symmetric Channels [35]

Case 1		Case 2		Case 3		Case 4	
n_{mc}	n_{fp}	n_{mc}	n_{fp}	n_{mc}	n_{fp}	n_{mc}	n_{fp}
0.01	0.017	0.01	0.022	0.023	0.026	0.020	0.038
0.01	0.021	0.01	0.026	0.023	0.036	0.021	0.056
0.01	0.024	0.01	0.032	0.024	0.039	0.021	0.065
0.01	0.026	0.01	0.036	0.024	0.042	0.021	0.072
0.01	0.028	0.01	0.041	0.024	0.045	0.021	0.079
0.01	0.029	0.01	0.044	0.024	0.047	0.022	0.085
0.01	0.031	0.01	0.047	0.024	0.048	0.022	0.096

3.2. Advantages and Disadvantages of the 1D Models

As mentioned earlier in the literature review, the SCM and DCM are both simple to use; however, SCM overestimates the stage at any given discharge, while DCM underestimates it [17-18]. The COHM and EDM take into account the momentum transfer at the main channel-floodplain interface. However, COHM has a very complicated procedure and requires many steps, while EDM requires many iterations to determine the stage-discharge relationship [5, 9, 68]. Although the WDCM is simple to use, it neglects the momentum transfer. In addition, WDCM requires defining the value for its weighting factor, ξ. In other words, the value of ξ is chosen from a range of values suggested by Lambert and Myers based on trial and errors which cannot easily be applied to the real-life cases [9]. Therefore, after investigation and analysis, the WDCM was chosen to be improved.

3.3. Development of the New Proposed Model

It is known that the apparent shear forces (ASF) can be used to calculate the interface interactions (momentum transfer) between the vertical and horizontal sub-sections of the cross-sections [65]. Therefore, the shear forces (ASF) done by Knight et al. were investigated to somehow take into account these interactions for the new model. Moreover, for more accuracy of some cases, the wetted perimeter of the main channel and the floodplains and the B/b ratio were also introduced into the method. Furthermore, the results of the new model were compared with the WDCM to assure that the new method improves the stage-discharge relationship results. Throughout this study, the new proposed model is called the improved weighted divided channel method (IWDCM). The development of IWDCM is the major part of this study. Therefore, it is explained in the following chapter.

3.4 Validation of the New Proposed Model

After developing IWDCM, for validation purposes, two different datasets were used; FCF and Knight. Six series of data were used for FCF (series 01, 02, 03, 07, 08 and 10), where all are data collected on a smooth, symmetric compound channel except series 07 which is from a rough symmetric compound channel. Similarly, three sets of data were collected by Knight et al. on a smooth symmetric, compound channel based on B/b ratio (B/b = 2, 3 and 4).

Chapter 4. Mathematical Analysis

As mentioned, the main objective of this study was to develop a simple model to predict the stage-discharge relationship accurately. Therefore, for developing the new method, the current one-dimensional methods were analysed, the apparent shear forces formulas were studied, the new method results were compared with the WDCM, and at last, the FCF and Knight's data was used to validate the new model.

4.1.   One-Dimensional Methods Analysis

During a flood event, the conveyance capacity increases as the wetted perimeter of the channel increases faster than its area. Hence, the value of the conveyance capacity is not very accurate, as it is treating a two-stage channel as a single channel. However, increasing the value of the flow depth helps to improve the accuracy of the methods [10]. Furthermore, the coherence, exchange discharge and weighted divided channel methods were also studied and analyzed. The results showed that the three methods predicted the total discharge accurately enough for smooth, symmetric compound channels; however, the zonal discharges did not show very accurate results. The results are discussed in detail in the following chapter.

4.2   New Method's Development

As mentioned before, the WDCM does not take the momentum transfer into account and requires defining a value for the weighting factor. The weighting factor was initially suggested to be 0.5; however, a different value was required when the roughness value of the compound channel changes. For instance, in case of a smooth, symmetric compound channel, a 0.7 weighting factor lead to the most accurate results while in case of a rough symmetric compound channel, a 0.3 weighting factor lead to an accurate stage-discharge relationship. In order to overcome this problem, the different sets of parameters such as the apparent shear force (ASF) between the main channel and floodplain interface, the zonal wetted perimeters of the symmetric compound channel, the Manning's n coefficients and B/b ratio were somehow introduced to WDCM instead of ξ as a new method for better accuracy. One way to calculate the momentum transfer is to calculate the apparent shear forces. Therefore, the first parameter that was considered was the apparent shear force formulas developed by Knight et al. [33,34]. However, introducing the ASF formulas alone, as

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dimensionless parameters, into the new method did not lead to accurate results for all smooth and rough cases. Hence, the wetted perimeter and the B/b ratios were introduced as dimensionless parameters into the new method as well. The new method was named to be the improved weighted divided channel method (IWDCM).

The IWDCM has three scenarios as shown below:

Scenario 1: This scenario is for symmetric compound channels, with both the main channel and floodplains as smooth. Where, the velocity of each zone is calculated separately using dimensionless parameters, θ and λ, which represent the ratio of the vertical and horizontal ASF ratio and the ratio of the main channel and floodplains wetted perimeter respectively.

$$V_{mc} = \theta\lambda V_{mc-v} + (1 - \theta\lambda)V_{mc-H} \qquad (36)$$

$$V_{fp} = \theta\lambda V_{fp-v} + (1 - \theta\lambda)V_{fp-H} \qquad (37)$$

Scenario 2: This scenario is for symmetric compound channels with a smooth main channel and rough floodplains. Where, the velocity of the main channel is the same as scenario 1, equation 46, while the floodplain's equation is changed by introducing another dimensionless parameter, α, which represents the B/b ratio of the symmetric compound channel.

$$V_{mc} = \theta\lambda V_{mc-v} + (1 - \theta\lambda)V_{mc-H} \qquad (38)$$

$$V_{fp} = \alpha(\theta - \lambda)V_{fp-v} + (1 - \alpha(\theta - \lambda))V_{fp-H} \qquad (39)$$

Scenario 3: This scenario is for symmetric compound channels, with both the main channel and floodplains as rough. Where, the velocity of the main channel is changed to a different formula as it is roughened, and the velocity of the floodplain is the same formula as scenario 2 as a new formula was already developed in case of a roughened floodplain.

$$V_{mc} = \theta\lambda V_{mc-v} + (1 - \lambda)V_{mc-H} \qquad (40)$$

$$V_{fp} = \alpha(\theta - \lambda)V_{fp-v} + (1 - \alpha(\theta - \lambda))V_{fp-H} \qquad (41)$$

The following are the formulas to calculate the dimensionless parameters of the improved weighted divided channel method (IWDCM):

$\theta = ASF_v/ASF_H$ (refer to equations 1 and 2)

$\lambda = P_{mc}/P_{fp}$, and $\alpha = B/b$

SF_1 and SF_2 = the shear forces on the floodplain wall and bed respectively

B and b = semi-width of the compound channel and main channel bed respectively.

4.3   FCF and Knight's Data Validation

After comparing the results for the IWDCM with the results for the original WDCM, different sets of data were used to validate the new proposed method further. The FCF data included six series of data sets, while the Knight's data included three sets of data. All datasets were obtained from smooth, symmetric compound channels except series 7 from FCF which was obtained from a rough, symmetric compound channel.

Chapter 5. Results and Discussion

This chapter presents the results of the new proposed model, IWDCM, for predicting the stage-discharge relationship. In addition, it shows the comparison with the WDCM and the experimental results.

5.1 Analysis of the One-Dimensional Methods

As mentioned earlier, the one-dimensional methods were first studied and analysed. First, the accuracy of the stage-discharge relationship in smooth, symmetric compound channels for SCM and DCM were studied. Second, the COHM and the EDM were compared in one graph for both total and zonal discharges. Lastly, the accuracy of the IWDCM was compared to the original WDCM in one graph for all cases: total and zonal discharges for smooth and rough symmetric compound channels. In addition, the absolute percentage errors of all methods analysed are mentioned.
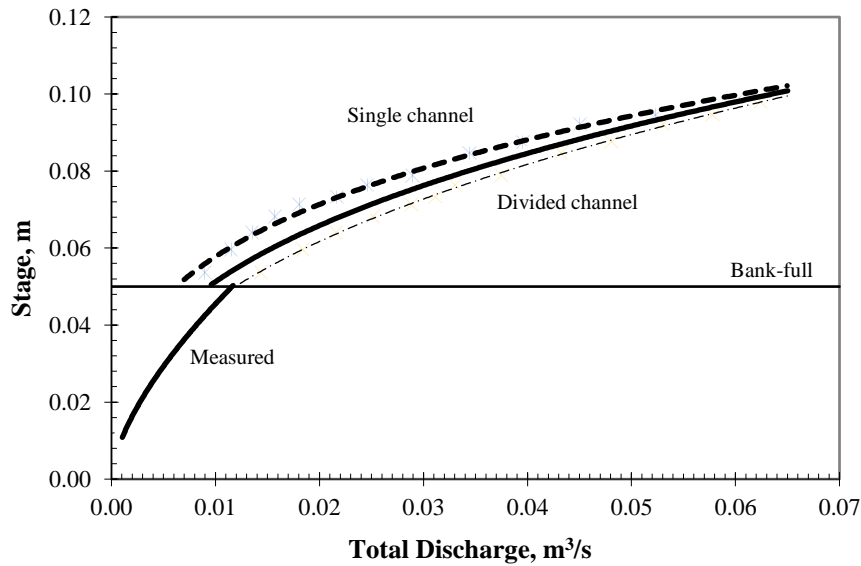

Figure 5.1. Stage-Discharge Relationship for SCM and DCM in a Smooth, Symmetric Compound Channel

Similarly, Figure 5.2 also shows the stage-discharge relationships that were calculated by using different 1-D models; the coherence, exchange discharge, and weighted divided channel methods. As mentioned earlier, the three methods predicted the total discharge accurately enough for smooth, symmetric compound channels. The total percentage error for smooth, symmetric compound channel was determined to be

2.48% and 10.07% for the COHM and EDM respectively. In addition, the COHM was applied on the rough datasets, and the total absolute percentage error are as follows: 6.78%, 4.16%, 8.33% and 23.02% for cases 1, 2, 3 and 4, respectively. As EDM requires many iterations, for simplicity, the EDM was only evaluated for the smooth, symmetric compound channel. The percentage of errors for the WDCM are mentioned later.
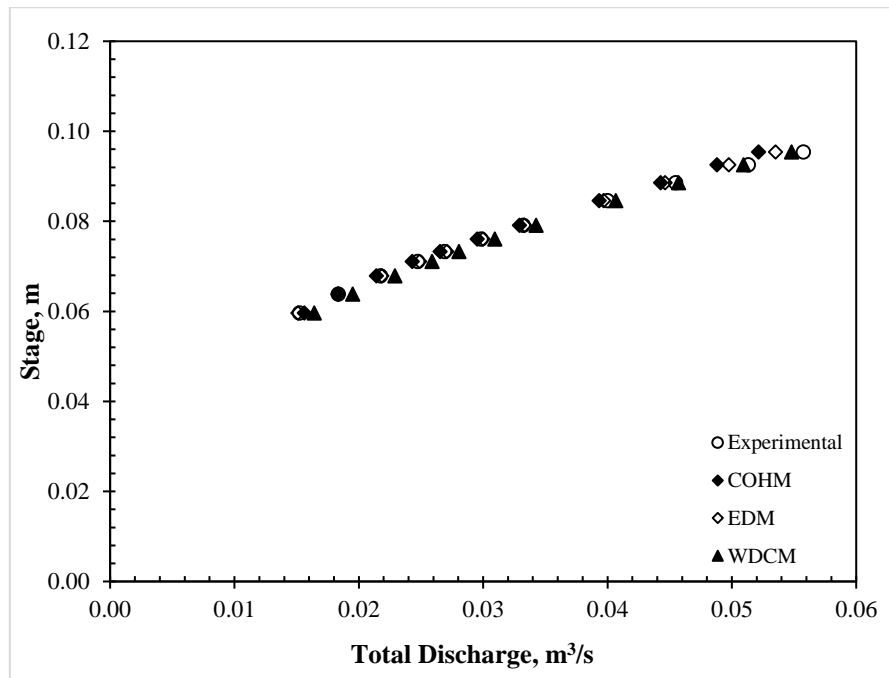

Figure 5.2. Stage-Discharge Relationship for 1D models in a Smooth, Symmetric Compound Channel

On the other hand, the zonal discharges (the main channel and floodplain discharges) that were calculated by using the COHM, EDM, and WDCM were also compared. The percentage of zonal discharge values were plotted against the relative depth of the compound channel in Figure 5.3, in which the results do not show very high accuracy. For example, the EDM overestimates the floodplain discharge and underestimates the primary channel discharge at a given stage; therefore, they compensate the total discharge value. Hence, Figure 5.2 shows more accuracy, compared to Figure 5.3. The percentage errors for COHM are 5.29% and 6.21% for main channel and floodplain respectively. In addition, the main channel absolute percentage errors were 4.13%, 4.00%, 13.72%, and 29.12% for cases 1, 2, 3, and 4,

respectively. Similarly, the floodplain absolute percentage errors were determined to be 16.12%, 8.46%, 7.57%, and 7.55% for cases 1, 2, 3, and 4, respectively.
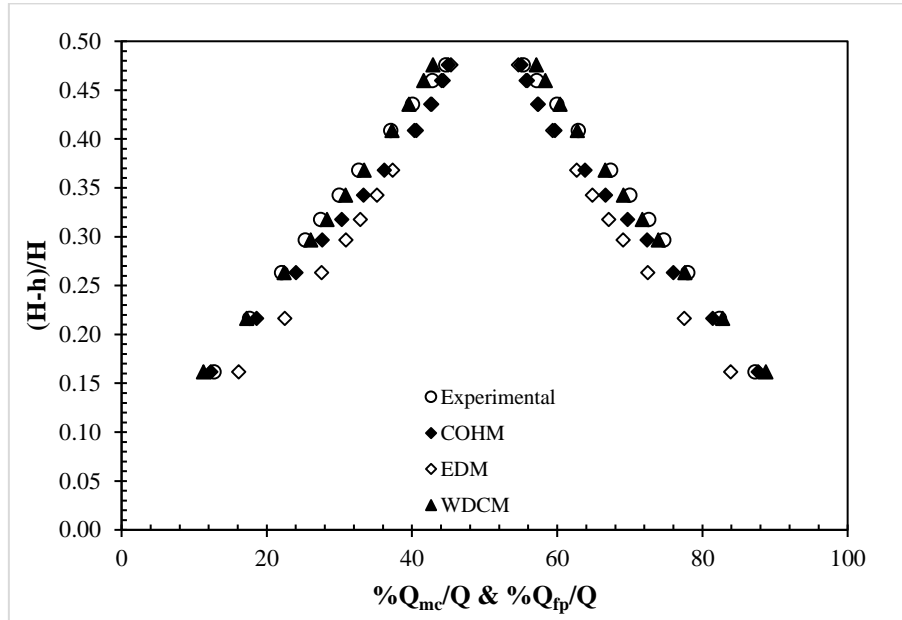

Figure 5.3. Zonal Discharge Comparison of 1D Models in Smooth, Symmetric Compound Channel

5.2   Development of the New Model

Similar to the WDCM, the zonal velocities of the 18m flume symmetric compound channel were computed using Manning's equation. The zonal velocities were calculated based on the vertical division once, and another time based on the horizontal division of the compound channel. Furthermore, to determine the total velocity of the compound channel, the vertical and horizontal velocities were each determined, based on the IWDCM formulas proposed for each scenario, where the zonal velocities are in terms of vertical and horizontal velocities, vertical and horizontal ASF, the main channel and floodplain wetted perimeters and B/b ratio of the compound channel. The total and zonal discharge values were then computed by multiplying the velocity results with the total and zonal area values, respectively. The IWDCM was then compared with the WDCM for evaluation and analysis Figure 5.4 and Figure 5.5 show the comparison between WDCM and IWDCM for total and zonal discharges, respectively.

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Figure 5.4 shows the stage-discharge relationship results for WDCM and IWDCM in smooth, symmetric compound channels, which led to a total absolute percentage error of 5.03% and 5.91% for WDCM and IWDCM, respectively.
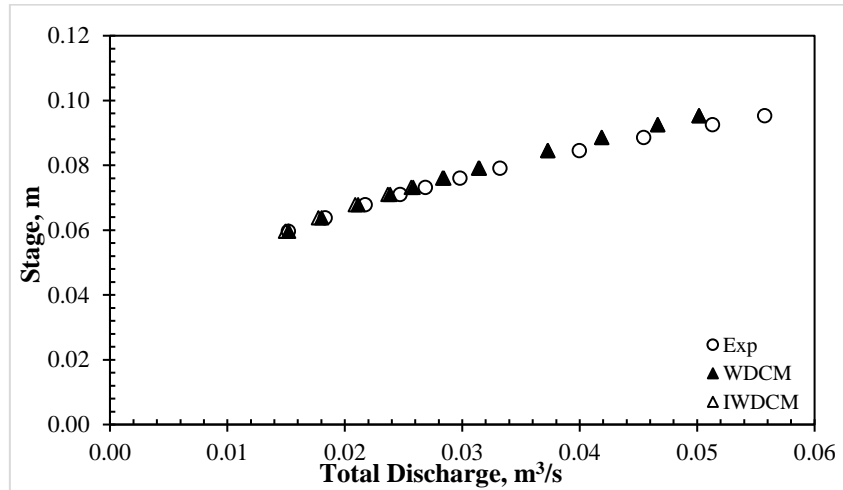

Figure 5.4. Stage-Discharge Relationship for WDCM and IWDCM in a Smooth, Symmetric Compound Channel

On the other hand, Figure 5.5 shows the results of the zonal discharges for the IWDCM compared to the WDCM using percentages of each zone with respect to the relative depth of the compound channel. The results were as the following: WDCM with 5.11% and 5.75% and IWDCM with 6.01%, and 4.91% for the main channel and floodplain, respectively.
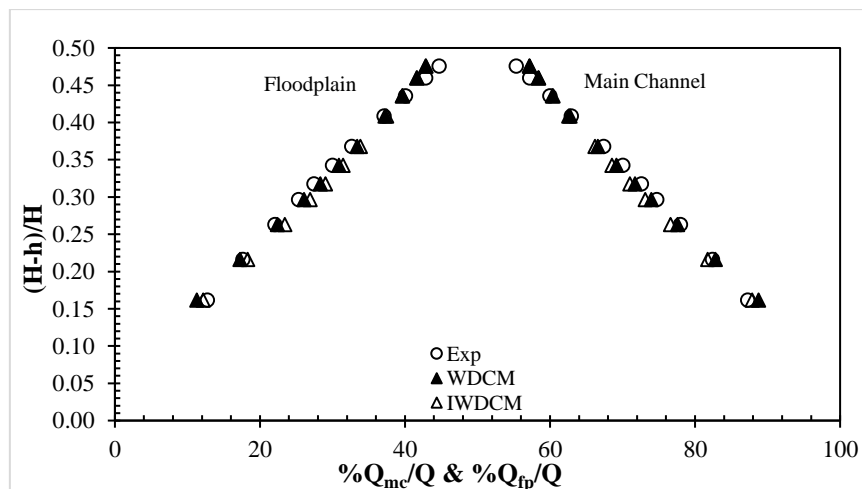

Figure 5.5. Zonal Discharge Comparison for WDCM and IWDCM in a Smooth, Symmetric Compound Channel

Similarly, the studies were done for the rough datasets, and the results are shown in Figure 5.1, and the comparisons were done for each case, as shown in Figure 5.4 and Figure 5.5. In some cases, the percentage errors increased; for example, in the case of having a smooth, symmetric compound channel. However, the IWDCM predicts the stage-discharge relationship better compared to the WDCM, as it considers the apparent shear forces, the wetted perimeter formulas, and the B/b ratio. As mentioned in the methodology, Lambert and Myers suggested a range of values for the weighting factor, and the weighting factor value differs for each case when the roughness of the compound channel changes. Therefore, the IWDCM with dimensionless parameter introduced in the original method leads to direct results while the WDCM can lead to different stage-discharge results, based on which value was considered for the weighting factor.

On the other hand, the results for having rough symmetric compound channels show more improvement compared to the WDCM. The IWDCM computes the zonal discharges more accurately, hence, leads to improved results for the total discharges. It should be noted that Table 5.1 shows the best results obtained for the WDCM based on the weighting factor value.

Table 5.1. Absolute Percentage Error Comparison Between the WDCM and the IWDCM

Method	Type of channel	%$Q_{t-error}$	%$Q_{mc-error}$	%$Q_{fp-error}$
WDCM	Smooth	3.19	2.99	3.58
	Case 1	11.23	15.80	4.26
	Case 2	27.63	34.92	8.66
	Case 3	5.49	16.13	40.49
	Case 4	4.78	9.36	14.17
IWDCM	Smooth	5.59	6.01	4.91
	Case 1	1.85	1.60	11.09
	Case 2	7.74	10.27	4.12
	Case 3	10.75	9.71	12.12
	Case 4	5.91	7.66	5.24

As mentioned earlier, the results of the IWDCM for the rough symmetric compound channel were also compared to the original WDCM. Figure 5.6 shows the stage-discharge relationship for case 1, where the main channel was smooth while an aluminium grid roughened the floodplains at 1.0m interval. As shown in Figure 5.6, the IWDCM shows a significant improvement in the stage-discharge relationship. The IWDCM computed the absolute percentage error of the total discharge for case 1 to be 1.85% while the original WDCM obtained 11.23%.
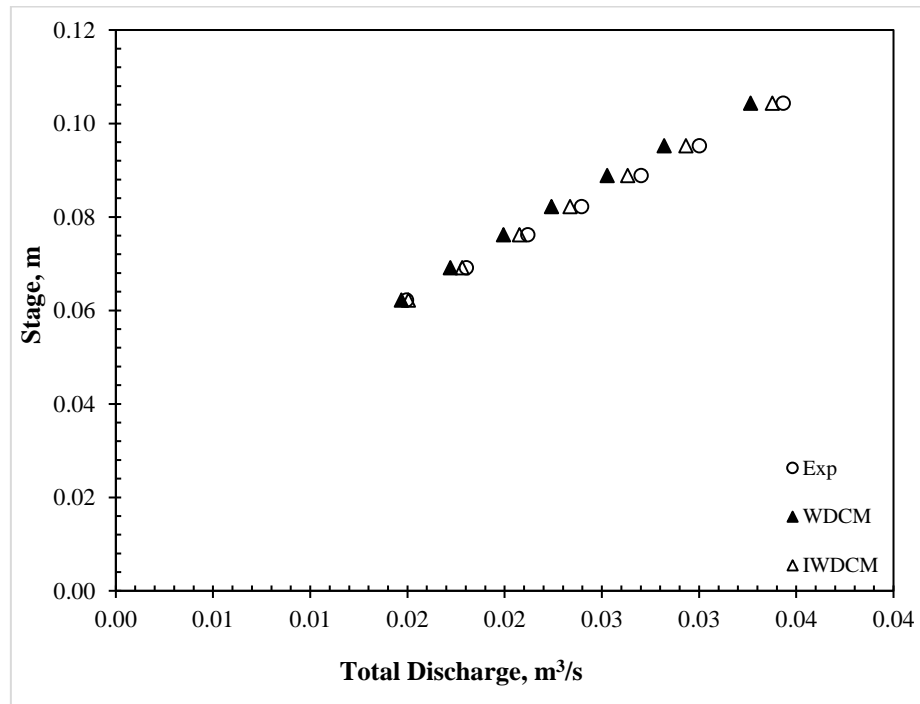

Figure 5.6. Stage-Discharge Relationship for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 1

Moreover, the zonal discharges for case 1 were also compared. The zonal discharges were compared using the percentages of each zone with respect to the relative depth of the compound channel. Figure 5.7 shows that the IWDCM overestimates the main channel and underestimates the floodplain discharges; hence, it compensates when computing the total discharge. The IWDCM computed the absolute percentage error of the main channel and the floodplain to be 1.60% and 11.09%, while the original WDCM obtained 15.8% and 4.26% respectively.
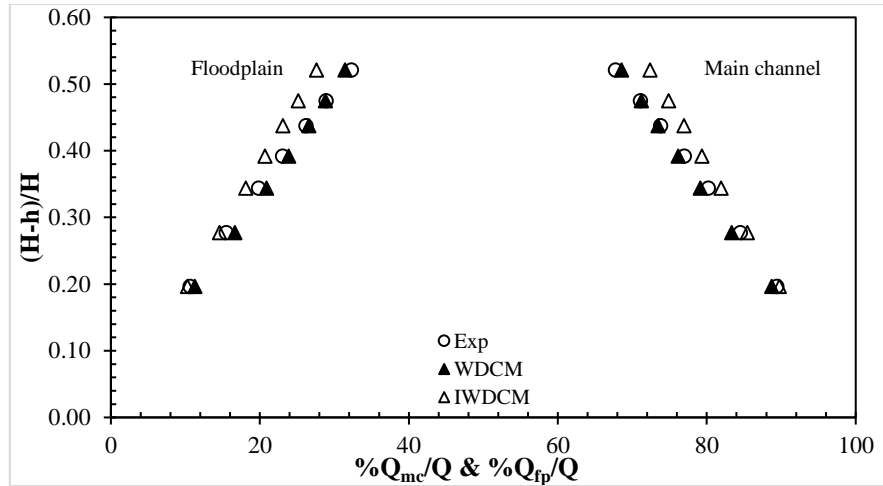
Figure 5.7. Zonal Discharge Comparison for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 1

Similarly, the stage-discharge relationship for case 2 of the rough, symmetric compound channel was studied. Case 2 had a smooth main channel, and two floodplains that were roughened by grids at 0.5m intervals. As Figure 5.8 shows, both the IWDCM and the original method show close estimation for the stage-discharge relationship. However, as the stage increases the accuracy of the relationship decreases. The IWDCM computed the absolute percentage error of the total discharge for case 2 to be 7.74% while the original WDCM obtained 27.63%. Therefore, it can easily be concluded that the overall prediction of the stage-discharge relationship was improved by the proposed method.
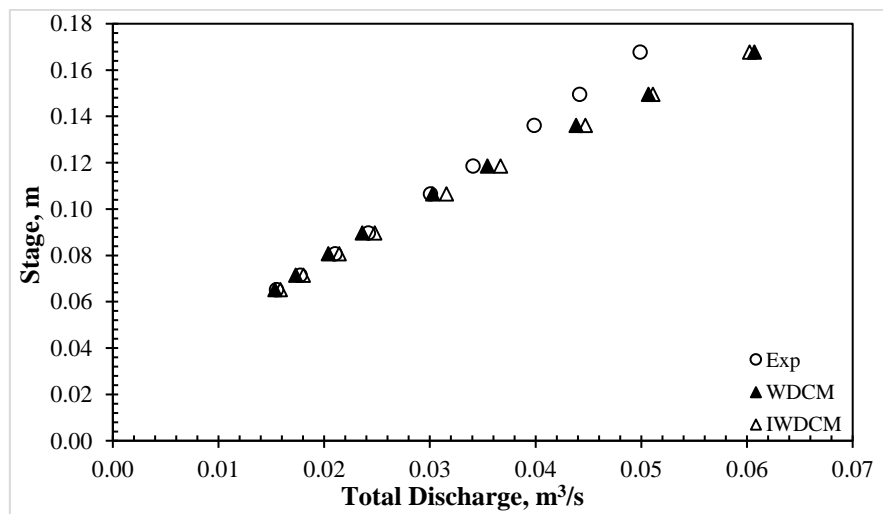

Figure 5.8. Stage-Discharge Relationship for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 2

The zonal discharges of the IWDCM for case 2 were also compared to the original WDCM. The IWDCM computed the absolute percentage error of the main channel and the floodplain to be 10.27% and 4.12% while the original WDCM obtained 34.92% and 8.66% respectively. Hence, the results showed an overall improvement for predicting the discharge value for each zone.

Figure 5.9. Zonal Discharge Comparison for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 2

Figure 5.10 shows the results for case 3 in which the main channel and the floodplain were roughened. As Figure 5.10 shows, the IWDCM estimated the stage-discharge relationship more accurately than the original WDCM. The IWDCM computed the absolute percentage error of the total discharge for case 3 to be 10.75%, while the original WDCM obtained 5.49%.

Figure 5.10. Stage-Discharge Relationship for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 3

In addition, the zonal discharges of the IWDCM for case 3 also showed higher accuracy of results compared to the original WDCM, shown in Figure 5.11. The IWDCM computed the absolute percentage error of the main channel and the floodplain to be 9.71% and 12.12%, while the original WDCM obtained 16.13% and 40.49%, respectively. Hence, the results showed a significant improvement in predicting the discharge value for each zone.
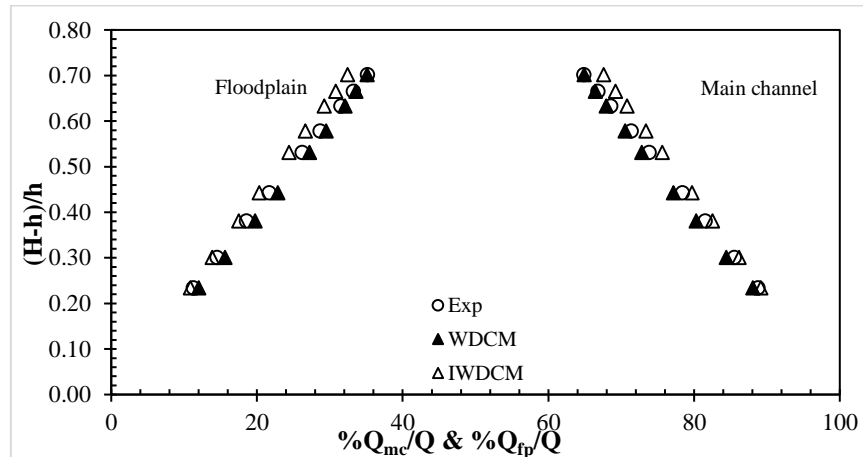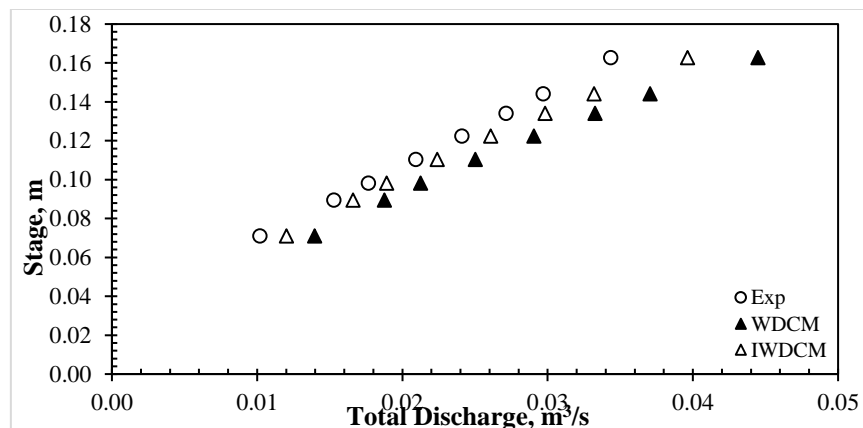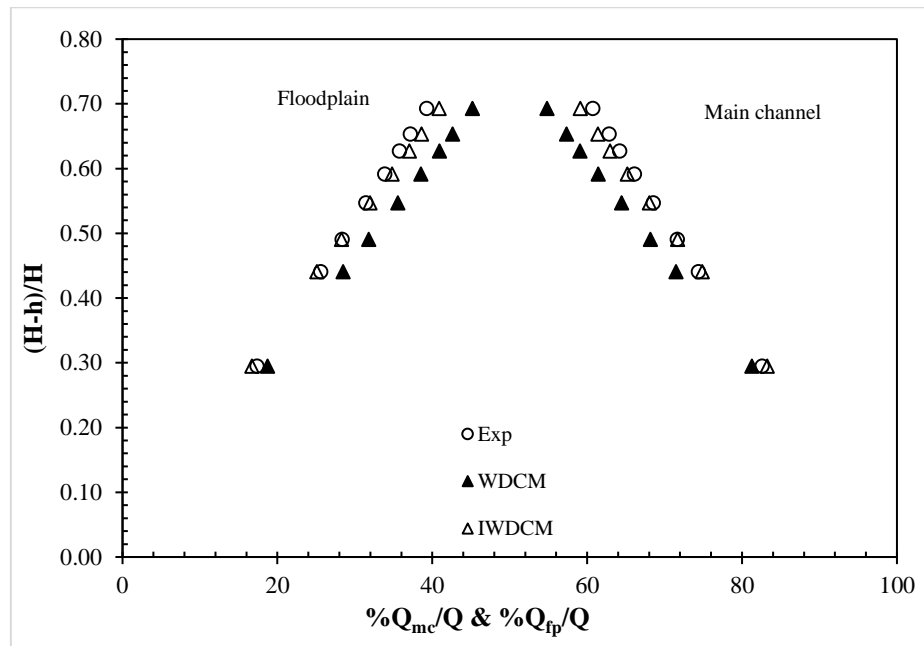

Figure 5.11. Zonal Discharge Comparison for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 3

Lastly, the stage-discharge relationship for case 4 was studied, where the main channel and the floodplains were roughened. Figure 5.12 shows that the IWDCM estimated the stage-discharge relationship more accurately than the original WDCM. However, as shown in Figure 5.12, when the stage increases, the accuracy to determine the total discharge decreases. For example, at the stage of 0.07 m the IWDCM computes the total discharge to be 0.012 m^3/s, while the experimental discharge was known to be 0.011 m^3/s. However, at the stage of 0.20 m, the total discharge was estimated to be 0.037m^3/s, while the experimental value was determined as 0.042 m^3/s. The IWDCM computed a (5.91%) absolute percentage error of the total discharge for case 4, while the original WDCM obtained 4.78%.

Figure 5.12. Stage-Discharge Relationship for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 4

Figure 5.13 represents the comparison for the zonal discharges for the new proposed method and the original method; it shows similar results for each method. The IWDCM computed the absolute percentage error of the main channel and the floodplain to be 7.66% and 5.24% while the original WDCM obtained 9.36% and 14.17% respectively. Again, the overall prediction of the stage-discharge relationship for the compound channel was dramatically improved by the proposed method.
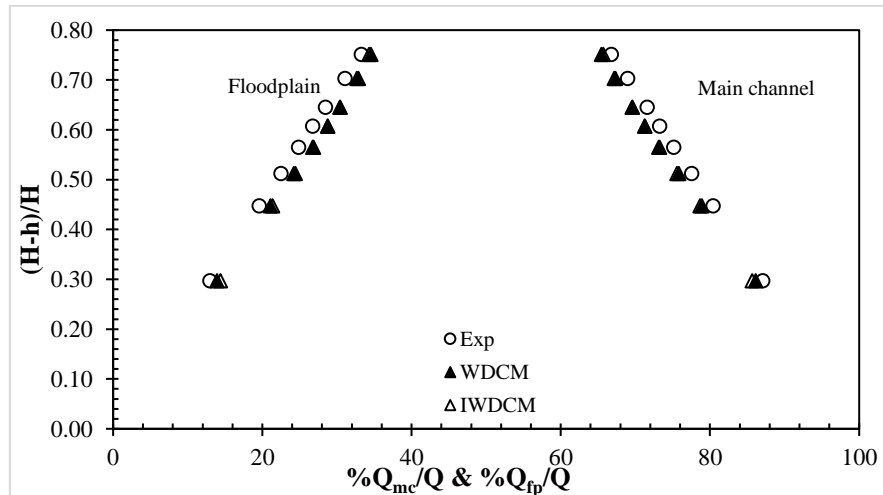

Figure 5.13. Zonal Discharge Comparison for WDCM and IWDCM in a Rough, Symmetric Compound Channel, CASE 4

5.3 Validation of the New Model

As mentioned before, the new method was applied to all sets of the FCF and Knight's data for validation purposes. There were 6 sets of data available for FCF

(Series 01, 02, 03, 07, 08 and 10) and 3 sets of data for Knight (B/b = 2, 3 and 4). Series 03 with B/b ratio less than 3 from FCF and B/b = 2 from Knight's data were rejected as they did not lead to acceptable results for the stage-discharge relationship. Therefore, the new proposed model was concluded to be a simple method for cases of compound channels with B/b ratio greater than or equal to 3. Table 5.2 and Table 5.3 show the absolute percentage errors of the total and the zonal discharges of the new method when applied for Knight and FCF data, respectively.

Table 5.2. Validated Result for the Symmetric Compound Channel, Knight's Data

	B/b	%$Q_{t\text{-error}}$	%$Q_{mc\text{-error}}$	%$Q_{fp\text{-error}}$
Knight	2	1.76	2.31	4.22
WDCM	3	4.95	5.55	3.86
	4	5.14	4.76	3.81
	2	X	X	X
IWDCM	3	5.55	5.53	8.89
	4	2.63	2.41	3.38

Table 5.3. Validated Result for the Symmetric Compound Channel, FCF Data

	Series	%$Q_{t\text{-error}}$	%$Q_{mc\text{-error}}$	%$Q_{fp\text{-error}}$
FCF	1	4.74	5.47	2.89
WDCM	2	2.01	1.70	4.53
	3	3.34	1.72	12.92
	7	1.68	4.02	17.36
	8	5.13	5.06	4.39
	10	2.03	0.72	11.98
IWDCM	1	3.42	8.43	6.01
	2	2.66	4.66	6.09
	3	X	X	X
	7	9.41	7.92	28.80
	8	2.25	2.00	8.79
	10	5.05	9.30	8.96

It is important to note that, the best results of the WDCM are presented in Table 5.2 and Table 5.3. In other words, the results are for when 0.5 is used for the weighting factor, ξ, to predict the stage-discharge relationship for smooth symmetric compound

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channels. However, in case of the rough symmetric compound channel 0.3 is used for ξ, in which it validates the point mentioned earlier; the accuracy the WDCM results vary with changing the value of weighting factor according to the roughness of the symmetric compound channel. On the other hand, direct formulas can be used to determine the value of the dimensionless parameters to predict the stage-discharge relationship with the IWDCM. Therefore, the new proposed method can confidently be used in case of a real flood event.

Chapter 6. Conclusion

As discussed, predicting the stage-discharge in flood events is an important concern in engineering. However, the currently available methods either have low accuracy due to neglecting the momentum transfer or have a complicated procedure of determining the stage-discharge value during flood events. Therefore, the main objective of this study was to develop a new simple method of predicting the stage-discharge relationship in compound channels accurately.

In the present study, the current 1D methods were analysed and compared, and the advantages and disadvantages of each were evaluated, which led to narrowing down the methods to WDCM as the base method in order to carry out further evaluation for developing the new model. The WDCM method has a simple procedure for determining the discharge in compound channels; however, as mentioned in the literature review, it neglects all the interaction effects that occur between the main channel and the floodplains. In addition, the WDCM uses a weighting factor to adjust the velocity values between the vertical and the horizontal divisions which has a range of values that are used as trial and errors to determine the final estimated stage-discharge relationship. However, the new proposed method introduced formulas instead of the weighting factor, which leads to more reliable and accurate predictions in flood events. The new model includes the apparent shear force formulas, the wetted perimeters for the main channel and the floodplains and the B/b ratio in addition to the Manning's equation for determining the velocity values.

The new method was developed based on the 18m flume data that is valid for symmetric compound channels with B/b ratio greater than or equal to 3. The IWDCM results for smooth, symmetric compound channel were 5.59%, 6.01% and 4.91% for total, main channel and floodplain discharges, respectively. On the other hand, for the rough, symmetric compound channel, the results were 1.85%, 7.74%, 10.75%, and 5.91% for total discharges for cases 1, 2, 3, and 4, respectively. At last, the IWDCM was applied to two datasets for validation purposes. The FCF data results were as follows: 3.42%, 2.66%, 9.41%, 2.55% and 5.05% for the total percentage errors of series 1, 2, 7,8 and 10, respectively. Similarly, the Knight data results were 5.55% and

2.63% for total percentage errors of compound channels with B/b ratios of 3 and 4, respectively. The zonal percentage errors of each dataset were also determined.

As a final point, the present study met the objective of developing a new simple method since the results for the IWDCM were accurate and were validated with different datasets. Therefore, the IWDCM can be used for predicting the stage-discharge relationship simply and accurately during flood events.

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