AN EXPERIMENTAL STUDY OF BRANCHING FLOW IN OPEN CHANNELS

Tarek Sayed

Assistant Professor, Department of Civil Engineering, Assiut University, Assiut,
and High Institute for Engineering and Technology, Sohag, Egypt
Email: tareksayed1986@aun.edu.eg; tareksayed1986@gmail.com

ABSTRACT

Branching channel flow indicates to any side water withdrawals from rivers or main channels. Branching channels have spacious application in many practical projects, such as irrigation and drainage network systems, water and waste-water treatment plants, and many water resources projects. Therefore, in this research, a comprehensive analysis of laboratory data has been carried out to reach the best angle of branching. Also, this study aims to introduce simple, practical equations to help engineers of water resources to fix the percentage of discharge diverted to the branch channel. The study was carried out in the Irrigation and hydraulics laboratory of the civil department, Faculty of Engineering, Assiut University. A laboratory channel consists of two parts, the main channel, and a branch channel was used. The main channel has 8.0 m. long, 20 cm wide, and 20 cm depth. The division corner to the branch channel was sharped edged and located 5.0 m downstream from the main channel inlet. The branch channel has 3.0 m. long, 20 cm depth and its width was changed three times (10, 15, and 20 cm) respectively. A total of 84 runs were carried out. Investigations of the flow into the branching channel show that the branching discharge depends on many interlinked parameters. It increases with the decreasing of the main channel flow velocity and Froude number at the upstream of the branch channel junction. Also, it increases with the increasing of (Y_b/Y_u). In subcritical flow, water depth in the branch channel is always lower than the main channel water depth. The flow diversion to the branch channel leads to a decrease in water depth at the downstream of the main channel. The study also, showed that the highest discharge rate obtained when the angle of branching equal 45^o and then angle 60^o. While the lowest discharge rate obtained at angle 90^o. Furthermore, at (B_r=1.0), using the branching angle equal 45^o increases the discharge ratio (Q_r) with about (4.21 to 14.91)% more than that obtained with using the branching angle equal 90^o. While the discharge ratio (Q_r) increases with about (19.67 to 49.96) % and (12.23 to 15.38) %, at (B_r=0.75), and (B_r=0.5) respectively.

Keywords: Diversion flow, Main channel, Branch channel, Froude number, Branching angle.

NOMENCLATURE

a_1: Coefficient depend on the angle of branching;
a_2: Coefficient depend on the angle of branching;
a_3: Coefficient depend on the angle of branching;
B: Main channel bed width;
B_r: Bed width ratio, the branch channel to main channel bed width;
b: Branch channel bed width;
F_b: Froude number of the branch channel;
F_d: Froude number downstream of the main channel;
F_u: Froude number upstream of the main channel;
g: Gravitational acceleration;
Q_b: Branch channel discharge;
Q_d: Main channel downstream discharge;
Q_t: Total discharge, and its equal Q_u;
Q_u: Main channel upstream discharge;
Q_r: Discharge ratio;
S: Bed slope of the main channel;
S_b: Bed slope of the branch channel;
Y_b: Water depth in the branch channel;
Y_d: Water depth downstream of the main channel;
Y_u: Water depth upstream of the main channel;
θ: Branching angle; and
R^2: Determination coefficient.

1 INTRODUCTION

In recent decades, extensive theoretical and experimental investigations of the branching open channels have been performed to understand the characteristics of this branching flow. Branching channel flow has been studied in the last decades and still garners the attention of water resources engineering researchers as it commonly exists in many water engineering related projects, and due to the complexity of branching flow involving many interlink factors thus making the generalization of the phenomenon much difficult to achieve (Lama et al., 2002). Studying the flow in the diversion channel has a direct application in water supply plants, water treatment plants, as well as irrigation and drainage network system design (Ramamurthy et al., 1990). Constructing a branch channel to divert some part of the water from the main flow affects the main channel flow and river bed mechanics, changing the bed form, especially in the junction region (Yonesi et al., 2008). These changes lead to many problems, such as changes in the main channel slope due to erosion and sedimentation in the main channel as well as on the branch channel.

Previous studies on branching channel flow were focused on the flow characteristics, such as branching flow discharge and regimes. For example, the earliest study conducted by Taylor (1944) investigated ways to appreciate a flow discharge in the branch channel. Based on experimental results, he proposed a graphical trial and error procedure for free flow branching flow discharge. Grace and Priest (1958) investigated branching flow with a different branch to main bed width ratio with free overflow and classified the flow into two regimes, without standing waves for relatively small Froude number flow and with local standing waves near the branch channel.

The research on the branching channel flow later advanced with the exploration of theoretical equations. Ramamurthy and Satish (1988), Ramamurthy et al. (1990), and Hsu et al. (2002) deduced a theoretical model for branching flow into a right angle and short branch channel. Based on energy, momentum, and mass conservation principles and on the assumption that there is no energy loss along the main channel. Hager (1987), Kesserwani et al. (2010) and Ghostine et al. (2013) deduced their theoretical equations by treating the branching flow as a lateral flow over zero high side weirs. To the best of the author knowledge, most of the branching channel flow studies have been done with rigid boundary and 90˚ branching angle, while only a few researchers studied different branching angles (e.g. Keshavarzi and Habibi, 2005; Al Omari and Khaleel, 2012; Khaleel et al., 2015) or with movable bed condition (e.g. Kerssens and Van Urk, 1986). Herrero et al. (2015), for example, studied a right angle diversion flow with movable sand bed. He observed a scour hole constructed at the downstream edge of the branch channel entrance.

Another aspect that influences the branching channel system is the branching angle. Lama et al. (2002) noticed that the separation zone in the branch channel occurs in the downstream wall of a 30˚ branching angle. On the other hand, it occurs in the upstream wall of a 90˚ branching angle (e.g. Keshavarzi and Habibi, 2005; Ramamurthy, 2007; Herrero Casas, 2013) found from a laboratory study and by comparing separation zone sizes in different diversion angles (45˚, 56˚, 67˚, 79˚, and 90˚) that the optimum angle of the diversion is 55˚ according to separation zone size in the intake channel. Based on the maximum branch channel discharge, the best angle for the diversion channel is 60˚ from among 30˚, 60˚, and 90˚ (Al Omari and Khaleel, 2012). An experimental study of the diversion channel from a 180˚ bend main channel showed that a 45˚ branching channel angle gave maximum (Q_r), for (F_u) = 0.47 from among 45˚, 60˚, 75˚, and 90˚ (Masjedi and Taeedi, 2011). Furthermore, a 60˚ bend for the maximum diversion flow and 45˚ bend for other discharges gave a minimum amount of diverted sediment from among 45˚, 60˚, and 75˚ (Pirestani et al., 2011). In addition, Dehghani et al. (2009) recommended using an 115^o branching channel from the bend flow because the upstream scour length is shorter than it in 150^o. Moreover, many researchers have studied the distribution of velocity components in the branching channel system experimentally (e.g. Ramamurthy et al., 2007; Bagheri and Heidarpour, 2012) and numerically (e.g. Shamloo and Pirzadeh, 2007a, b).

Lastly, branching channel flow is considered a very complex flow, as this flow depends on many factors such as controlling gates at the end of the main and branch channel, velocity, Froude number and momentum in both the main and branch channels, and the geometry of the branching channel system. From this review, it is important to study the effect of the different branching channel geometries, such as branching angle on the flow in the main and branch channel.

2 MATERIAL AND METHODS

Experiments were conducted in the irrigation and hydraulics laboratory of the Civil Engineering Department at Assiut University, Egypt. A laboratory channel consists of two parts, the main channel, and a branch channel. A schematic layout of the experimental channel was shown in figure 1. The main channel was 8.0 m. long, 20 cm. wide and 20 cm depth. The division corner to the branch channel was sharped edged and located 5.0 m downstream from the main channel inlet. The branch channel was 3.0 m. long, 20 cm depth, and its width have been changed three times (10, 15, and 20 cm) respectively. The water flow was issued from an underground source. To assure the flow expansion as well as low turbulence, a honeycomb was set up at the entrance of the main channel. The discharges from the main and branch channels were measured by using the volumetric weight method. The water depths were measured at several cross-sections (Figure .1) with three vertical measurements in each cross-section. At the end of each channel, it is necessary to make sure that the downstream flows were subcritical. All sections of the main and branch channels were taken at a distance equal ten times the main channel width from the branch entrance.

The discharge in all observations varied between 1.28 and 7.47 lit/s. The downstream to upstream discharge ratios ranged from 0.42 to 0.76. Froude number in the main channel upstream of the junction (measured 2 m. upstream) varied from 0.34 to 0.74, the corresponding Froude number in the main channel measured at 2 m. downstream of the junction varied between 0.34 and 0.73, respectively. The branch channel Froude number well downstream of the junction (measured 2 m. away ranged from 0.31 to 0.87. For each run, the discharge in the branch channel, the discharge downstream of the main channel, the total discharge, the depths of flow at various sections were measured. The laboratory experiments were performed using three different values for the bed width ratio (B_r) the branch channel to the main channel bed width (b/B) (B_r=0.5, 0.75, and 1.0). For each bed width ratio, four different angles (45^o, 60^o, 75^o and 90^o) were used to connect the branch channel to the main channel. For each branch angle, seven different discharges were passed through the main channel. All experiments were carried out with steady flow condition. The flow downstream the main and branch channel was free and subcritical. The total number of runs was 84.

To perform any case of experiments, runs were started by connecting the branch channel to the main channel with any diversion angle. The storage, feeding tank was filled with water. The intake valve of the feeding pipeline was opened slowly to give a definite value of discharge by adjusting both the intake valve and the water manometer reading. The downstream tailgate was removed to obtain the free flow conditions, after a period of about 20 to 30 minutes, the flow was steady. The discharges from the main and branch channels were measured by using the volumetric weight method. Afterward, the diversion flow ratios were calculated. The water depths in the main and branch channels were measured at cross-sections shown in figure 1.

Investigations of the flow into branching channel show that the branching discharge depends on many interlinked parameters such as the main channel upstream discharge (Q_u), the main channel downstream discharge (Q_d), the branch channel discharge (Q_b), the water depths upstream and downstream in the main channel and in the branch channel (y_u, y_d, and y_b, respectively), the bed slope (S), the branching angle (θ), the bed width ratio, the branch channel to main channel bed width (B_r), the bed roughness, and the gravitational acceleration. Applying the dimensional analysis yields:

$$Q_r = \emptyset\left(\frac{Y_u}{Y_d}, F_u, F_d, F_b, \theta, B_r\right) \quad (1)$$

Where $Q_r = \frac{Q_b}{Q_u} < 1.0)$, $F_u = \frac{Q_u}{B \times Y_u \times \sqrt{g \times Y_u}}$, $F_d = \frac{Q_d}{B \times Y_d \times \sqrt{g \times Y_d}}$, $and\ F_b = \frac{Q_b}{b \times Y_b \times \sqrt{g \times Y_b}}$.

Equation 1 states that subcritical, free, branching channel flow over a horizontal bed can be characterized by $\frac{Y_u}{Y_d}, F_u, F_d, F_b, \theta,\ and\ B_r$.

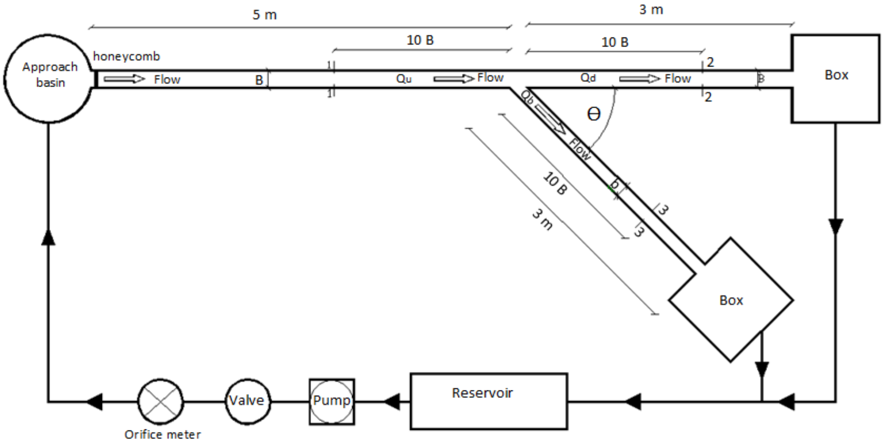

Figure 1. Experimental Set-up

3 RESULTS AND DISCUSSION

In the branching channel flow, some of the total discharge diverts towards the branch channel. The discharge ratio (Q_r) is always used to describe a diversion flow in the branching channel. (Q_r) is considered one of the most relevant parameters in the analysis of branching channel flow. This ratio depends on many factors, such as Froude number upstream and downstream of the main channel and in the branch channel (F_u, F_d, and F_b, respectively), the water depths upstream and downstream in the main channel and in the branch channel (y_u, y_d, and y_b, respectively), the branching angle (θ), the bed width ratio, the branch channel to main channel bed width (B_r), and, if there is a side weir, the shape of the crest and weir height. Therefore, in this research, a comprehensive analysis of laboratory data has been carried out to reach the best angle of branching. Also, one of the main aims of this study is to introduce simple, practical equations to help engineers of water resources to fix the percentage of discharge diverted to the branch channel.

Experimental results were expressed in dimensionless forms and represented graphically to study the efficiency of using different angles of branching to connect the branch channel with the main channel on the discharge, velocity, depths of flow, and surface streamlines.

4 Relationship between Discharge Ratio and Bed Width Ratio

In this study, fixed bed width of the main channel of 20 cm was taken in all laboratory experiments. While in the branch channel, the bed width was changed three times (10, 15 and 20 cm). To illustrate the effect of the change in the bed width ratio on the flow, the relationship between the discharge ratio (Q_r) and the bed width ratio (B_r) at different values of the Froude number downstream of the main channel (Fr_d) for all understudy angles of branching, was plotted as shown in the following figures (2) through (5). Generally, for all understudy angles of branching, there is a reverse relationship between (Q_r) and (Fr_d). Furthermore, (Q_r) increases as the bed width ratio (B_r) increases, For ($Fr_d \geq 0.2$).

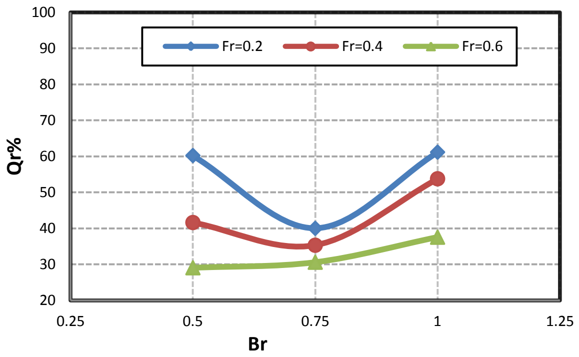

Figure 2. Effect of (B_r) on Division of flow at (ɵ=90)

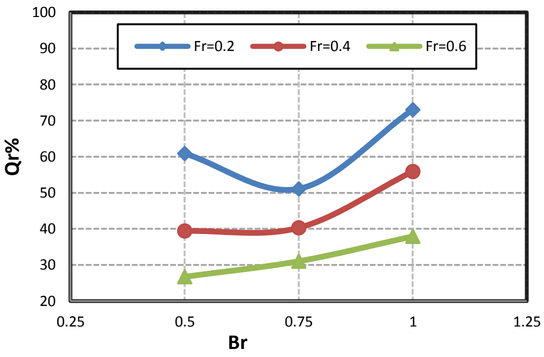

Figure3. Effect of (B_r) on Division of flow at (ɵ=75)

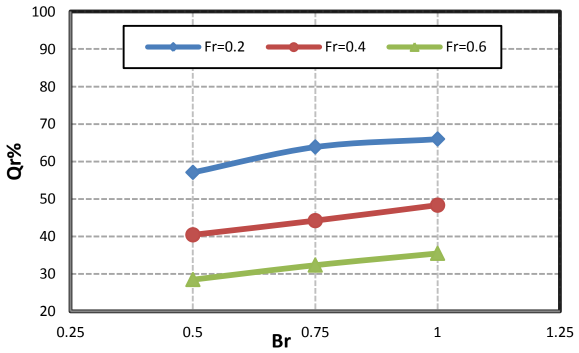

Figure 4. Effect of (B_r) on Division of flow at (ɵ=60)

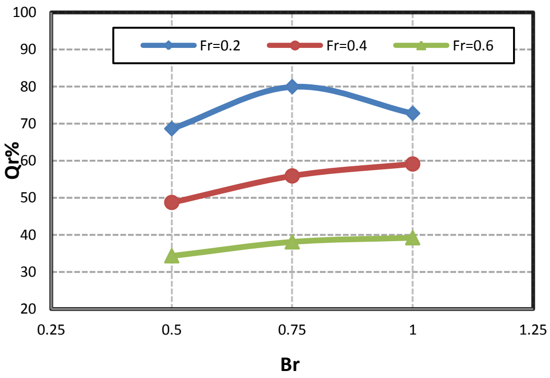

Figure 5. Effect of (B_r) on Division of flow at (ɵ=45)

Based on the experimental data and using the simple and multiple linear regression analysis, the best equation for predicting the discharge ratio for all understudy angles of branching can be written in the following form:

$$Q_r\% = a_1(B_r)^2 + a_2(B_r) + a_3 \tag{2}$$

In which (a_1, a_2, and a_3) are coefficients depend on the angle of branching their values are given in the following table (1)

Table 1.Values of coefficients (a_1, a_2 and a_3) in Eq. (2)

Fr_d	ɵ											
	ɵ = 90^{o}			ɵ = 75^{o}			ɵ = 60^{o}			ɵ = 45^{o}		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
0.2	198.24	-273.	128.58	254.1	-357	175.8	-37.4	73.86	29.49	-148.	230.3	-9.52
0.4	43.23	-47.8	42.17	117.74	-144	81.80	2.71	11.76	33.85	-31.4	67.9	22.63
0.6	331.23	-494.9	224.89	20.80	-8.8	25.93	-5.65	22.45	18.68	-21.2	41.51	18.87

3.2 Relationship between Discharge Ratio and Froude Number

To illustrate the effect of the velocity on the discharge of the branch channel (Q_b), the relationship between the discharge ratio (Q_r) and the Froude number upstream and downstream of the main channel and in the branch channel (F_u, F_d, and F_b, respectively) for all understudy angles of branching, at different bed width ratios, was plotted as shown in figures (6) through (14). From these figures, it is observed that there is a strong linear relationship between discharge ratio (Q_r) and the Froude number in all cases. As well, there is a reverse relationship between (Qr) and (F_u), Which is consistent with the results of (Krishnappa and Seetharamiah, 1963; Hager, 1987; Bejestan, et al., 2013) and (F_b). Furthermore, (Q_r) decreases as (F_d) increases which is agree with the study of (Hsu, et. al., 2002). Also, based on the maximum branch channel discharge, the best angle for the diversion channel is 45˚ from among 45˚, 60˚, 75°, and 90˚

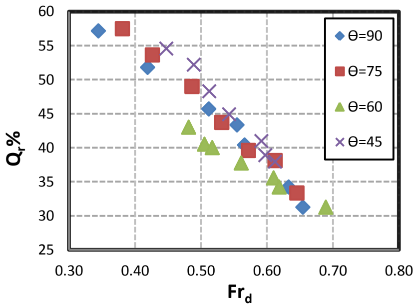

Figure 6. Effect of Fr_d on Division of flow at (B_r=1.0)

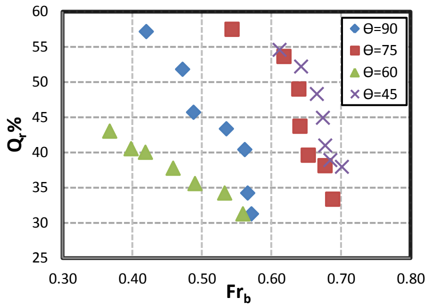

Figure 7. Effect of Fr_b on Division of flow at (B_r=1.0)

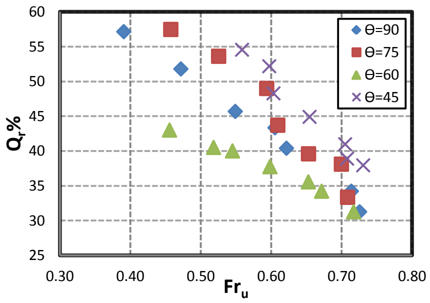

Figure 8. Effect of Fr_u on Division of flow at (B_r=1.0)

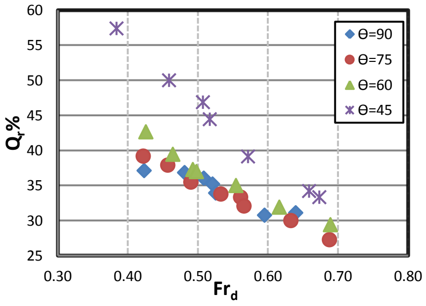

Figure 9. Effect of Fr_d on Division of flow at (B_r=0.75)

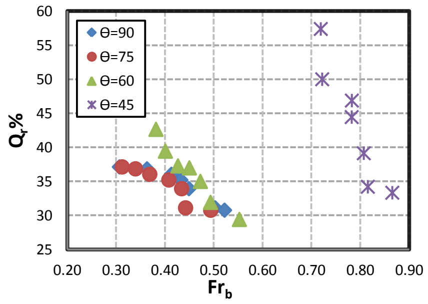

Figure 10. Effect of Fr_b on Division of flow at (B_r=0.75)

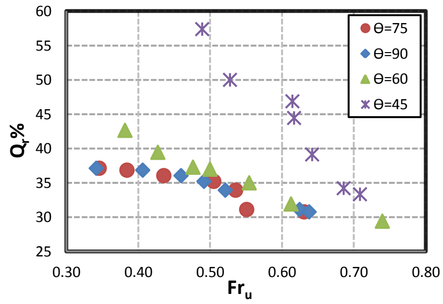

Figure 11. Effect of Fr_u on Division of flow at (B_r=0.75)

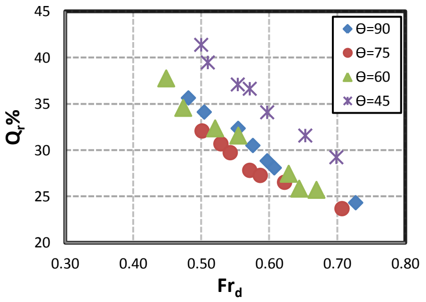

Figure 12. Effect of Fr_d on Division of flow at (B_r=0.5)

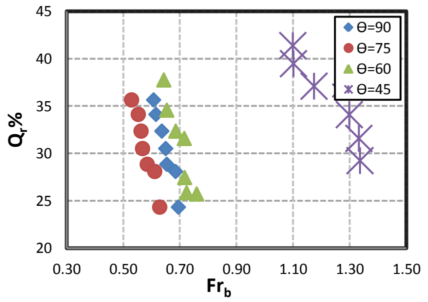

Figure 13. Effect of Fr_b on Division of flow at (B_r=0.5)

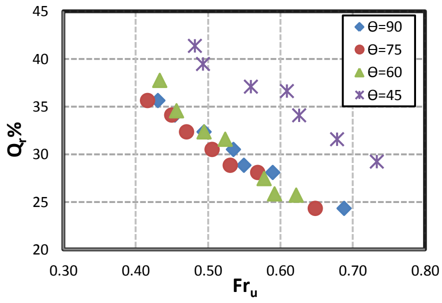

Figure 14. Effect of Fr_u on Division of flow at (B_r=0.5)

Based on the experimental data and using the simple and multiple linear regression analyses, the best equation for predicting the discharge ratio for all understudy angles of branching at (B_r = 0.75) as example, can be written in the following form:

$$Q_r\% = a_1[Fr_u] + a_2 \qquad (3)$$

$$Q_r\% = a_1[Fr_d] + a_2 \qquad (4)$$

$$Q_r\% = a_1[Fr_b] + a_2 \qquad (5)$$

The values of R^2 ranged from 0.85 to 0.98. The coefficients (a_1 and a_2) are constants depending on the angle of branching their values are given in the following table (2)

Table 2. Values of coefficients (a_1, a_2) in Eqns. (3, 4, and 5)

Fr	ɵ							
	ɵ = 90°		ɵ = 75°		ɵ = 60°		ɵ = 45°	
	a_1	a_2	a_1	a_2	a_1	a_2	a_1	a_2
Fr_u	- 23.46	46.11	- 24.12	46.11	- 36.27	55.23	- 106.5	108.83
Fr_d	- 34.26	52.51	- 44.28	57.69	- 47.75	61.61	- 82.89	88.26
Fr_b	- 32.52	48.31	- 38.46	49.80	-75.04	70.14	-156.11	166.12

3.3 Relationship between Discharge Ratio and Water Depth Ratio

From the laboratory investigation, it is noted that, in the main channel, the highest level of water occurs in the first half of the junction region, and the lowest water level occurs just downstream of the junction region near the downstream edge of the branch channel. Also, in the branch channel, the water surface drops at the upstream corner at the entrance of the branch channel. The lowest water depth in the branch channel happens in the contraction zone and starts to increase as the separation zone decreases, which is agreeable with the study results of Ramamurthy et al. (2007). The following figures (15, 16, and 17) were plotted for the relation between the discharge ratio (Q_r) and the ratio between the water depths upstream and downstream of the main channel. From these figures, it is clear that there is an appositive relationship (Q_r) and (y_b/y_u). While, there is a reverse relationship between (Q_r) and (y_d/y_u) as shown in the figures (18, 19, and 20). Moreover, it is noticed, the main factors that have an effect on the water depths in the branch channel system are discharge ratio and the Froude number. Also, from these figures, it is clear that for the same value of (y_d/y_u) or (y_b/y_u) the optimum angle of the diversion is 45°, which ensures that the largest amount of water is diverted to the branch channel.

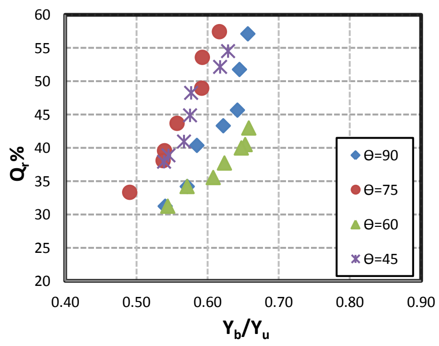

Figure 15. Effect of $\left(\frac{Y_b}{Y_u}\right)$ on Division of flow at (B_r=1.0)

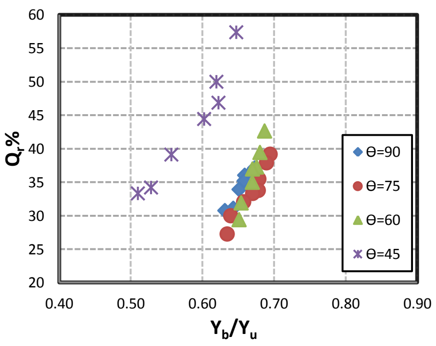

Figure 16.Effect of $\left(\frac{Y_b}{Y_u}\right)$ on Division of flow at (B_r=0.75)

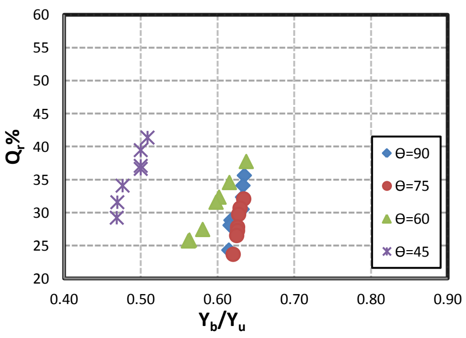

Figure 17. Effect of $\left(\frac{Y_b}{Y_u}\right)$ on Division of flow at (B_r=0.5)

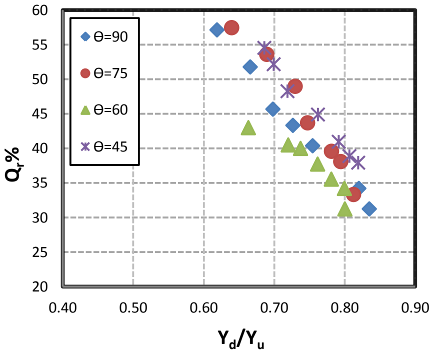

Figure 18. Effect of $\left(\frac{Y_d}{Y_u}\right)$ on Division of flow at (B_r=1.0)

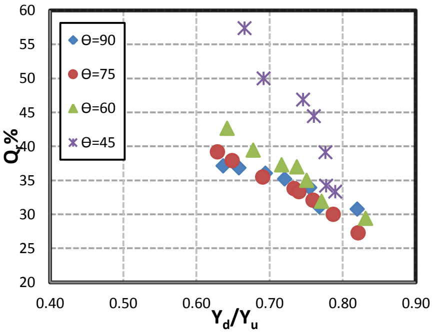

Figure 19. Effect of $\left(\frac{Y_d}{Y_u}\right)$ on Division of flow at (B_r=0.75)

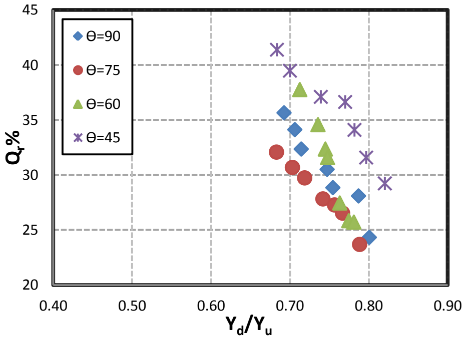

Figure 20. Effect of $\left(\frac{Y_d}{Y_u}\right)$ on Division of flow at (B_r=0.5)

Based on the experimental data and using the simple and multiple linear regression analysis, the best equation for predicting the discharge ratio for all understudy angles of branching at (Br = 1.0) for example, can be written in the following form:

$$Q_r\% = a_1\left(\frac{y_d}{y_u}\right)^2 + a_2\left(\frac{y_d}{y_u}\right) + a_3 \quad (6)$$

$$Q_r\% = a_1\left(\frac{y_b}{y_u}\right)^2 + a_2\left(\frac{y_b}{y_u}\right) + a_3 \quad (7)$$

The values of R^2 ranged from 0.92 to 0.99. The coefficients (a_1, a_2, and a_3) are constants depending on the angle of branching their values are given in the following table (3)

Table 3. Values of coefficients (a_1, a_2, and a_3) in Eqns. (6, and7)

	ɵ											
	ɵ = 90°			ɵ = 75°			ɵ = 60°			ɵ = 45°		
	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3	a_1	a_2	a_3
(y_d/y_u)	112.2	-280.3	187.7	-388	424.2	-54.9	-505	664.5	175.9	196	-416	246.8
(y_b/y_u)	1125	-1152	326.1	824	-715	185.7	424	-421	135	-435.9	696	211

3.3 Relationship between Discharge Ratio and Discharge in Upstream Main Channel

The following figures (20, 21 and 22) show the relation between the discharge ratio (Q_r) and the total discharge in upstream of the main channel (Q_t= Q_u). From these figures, it is noted that the highest discharge rate obtained when the angle of branching is 45° and then angle 60°. While the lowest discharge rate obtained at angle 90°, and this is due to the way of connection between the branch channel and the main, the extent of disturbance in the flow, and loss of energy in the branch region. When the use of branching angle equal 45°, it allows better flow from the main channel to the branch channel, thus reducing the disturbance in the flow, and the loss of energy. When the angle of branching is 90°, there is a greater difficulty in diverting the water to the branch channel due to the phenomenon of continuity that makes the water continue in the first direction (towards the downstream of the main channel) and decreases the amount of water that goes to the branch channel.

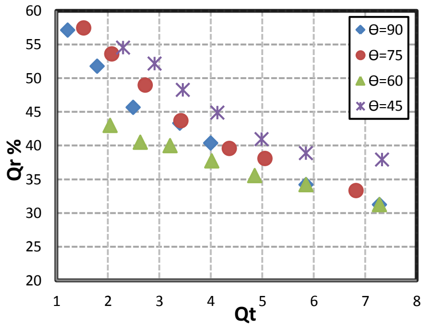

Figure 21.Effect of (Q_t) on Division of flow at (B_r=1.0)

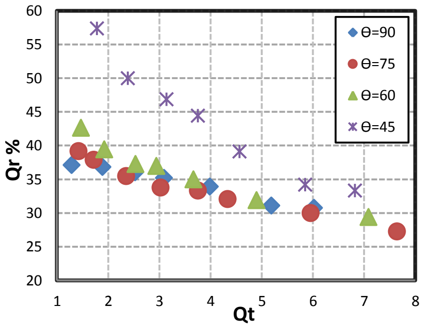

Figure 22. Effect of (Q_t)on Division of flow at (B_r=0.75)

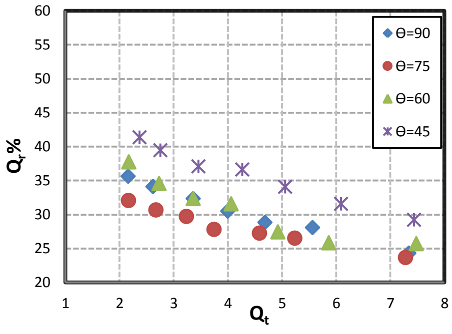

Figure 23.Effect of (Q_t)on Division of flow at (B_r=0.5)

3.4 Relation between Discharge Ratio and Angle of Branching

Figures (24, 25 and 26) show the relationship between the discharge ratio (Q_r) and the branching angle for different values of Froude number, at all understudy bed width ratios. These figures show the percentage of increase in the discharge ratio (Q_r), using the branching angle 45°, 60°, and 75° more than that obtained using the branching angle 90°.

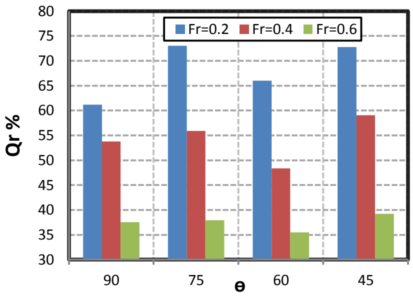

Figure 24. Effect of (ɵ) on Division of flow at (Br=1.0)

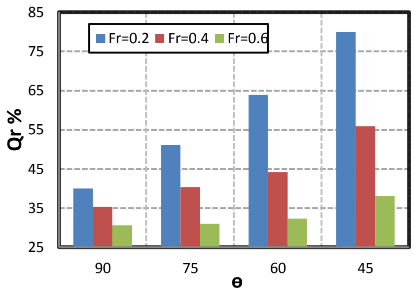

Figure 25. Effect of (ɵ) on Division of flow at (B_r=0.75)

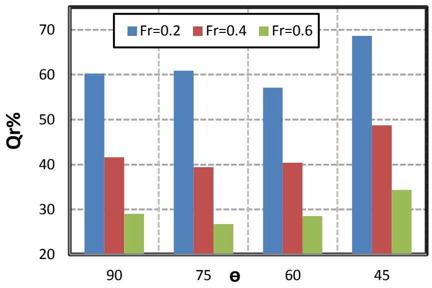

Figure 26. Effect of (ɵ) on Division of flow for at (B_r=0.5)

From these figures it is clear that, at (B_r=1.0), using the branching angle equal 45° increases the discharge ratio (Q_r) with about (4.21 to 14.91)% more than that obtained with using the branching angle equal 90°. While the discharge ratio (Q_r) increases with about (19.67 to 49.96) % and (12.23 to 15.38) %, at (B_r=0.75), and (B_r=0.5) respectively.

For predicting an equation to determine the discharge ratio (Q_r) which describe the diversion flow in the branching channel, as a function of the Froude number upstream and downstream of the main channel, and the ratio between the water depths upstream and downstream in the main channel. The simple and multiple linear regression analysis was used, and the equation as derived from the statistical program SPSS can be written in the following form:

$$Q_r\% = a_1(Fr_d) + a_2(Fr_u) + a_3\left(\frac{y_d}{y_u}\right) + Constant \qquad (8)$$

In which (a_1, a_2, and a_3) are coefficients depend on the angle of branching. The values of these coefficients and the values of R^2 are given in the following table (4).

Table 4. Values of coefficients (a_1, a_2, a_3, constant, and R^2) in Eq. (8)

θ	**a_1**	**a_2**	**a_3**	**constant**	**R^2**
$\theta = 90^o$	- 114.782	118.324	- 130.249	130.199	0.996
$\theta = 75^o$	- 115.862	114.195	- 118.263	123.982	0.998
$\theta = 60^o$	- 112.741	110.689	- 122.621	127.842	0.998
$\theta = 45^o$	- 106.642	98.289	- 117.67	128.142	0.999

For verifying the results, Figures (27) through (30) show a comparison between the measured discharge ratio (Q_r) and the calculated one using the developed equation (8). It can be noticed that the predicted data have a good agreement with the measured ones.

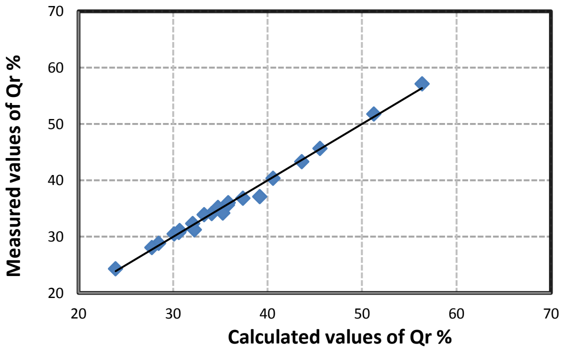

Figure 27. Comparison between measured and calculated values of discharge ratio using equation (8) at (θ=90)

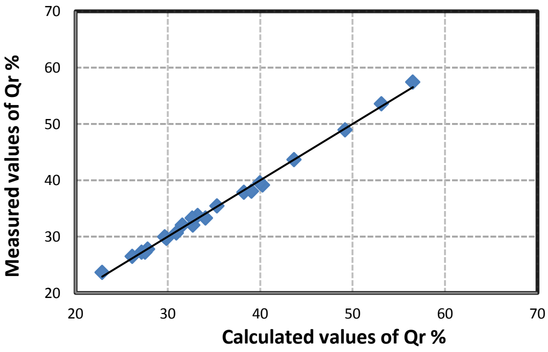

Figure 28. Comparison between measured and calculated values of discharge ratio using equation (8) at (θ=75)

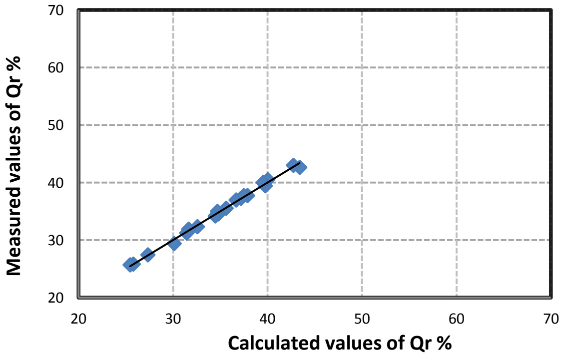

Figure 29. Comparison between measured and calculated values of discharge ratio using equation (8) at (θ=60)

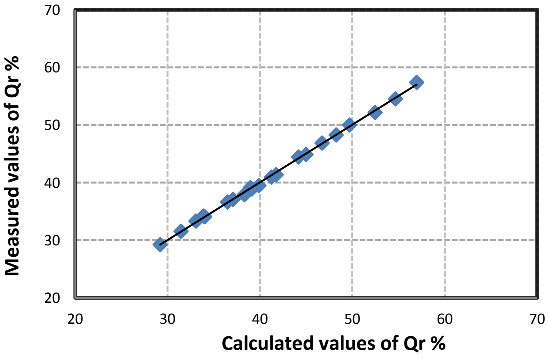

Figure 30. Comparison between measured and calculated values of discharge ratio using equation (8) at (θ=45)

5 CONCLUSIONS

Through the present study and its experimental results, the following main conclusions can be obtained:

- Regarding flow characteristics, the branching discharge decreases as velocity, Froude number and momentum in the upstream main channel flow increases. Moreover, it increases by increasing the upstream main channel water depth and branch channel bed width.
- In subcritical flow, the water depth in the main channel decreases downstream diversion area. On the other hand it decreases in its depth in the branch channel.

- . In subcritical flow, water depth in the branch channel is always lower than the main channel water depth.
- The flow diversion to the branch channel leads to a decrease of water depth at the downstream of the main channel.
- There is a stagnation point that occurs in the downstream corner of the branch channel entrance.
- Two separate zones form in the branching channel system: one in the downstream main channel, in front of the branching junction, which occurs when a branch channel takes an important amount of water, and another at the beginning of the branch channel.
- In the branch channel, the water surface drops at the upstream corner at the entrance of the branch channel. The lowest water depth in the branch channel happens in the contraction zone and starts to increase as the separation zone decreases.
- The highest discharge rate obtained when the angle of branching is 45^o and then angle 60^o. While the lowest discharge rate obtained at angle 90^o
- At (Br=1.0), using the branching angle equal 45^o increases the discharge ratio (Q_r) with about (4.21 to 14.91)% more than that obtained with using the branching angle equal 90^o. While the discharge ratio (Q_r) increases with about (19.67 to 49.96) % and (12.23 to 15.38) %, at (B_r=0.75), and (B_r=0.5) respectively.

REFERENCES

Al Omari, N. K., and Khaleel, M. S. (2012). Laboratory study of the effect of the branching angle and the branching channel slope on flow. Al-Rafadain Engineering Journal, 20(5), 33-41.

Bagheri, S., and Heidarpour, M. (2012). Characteristics of flow over rectangular sharp-crested side weirs. Journal of Irrigation and Drainage Engineering, 138(6), 541-547.

Bejestan, S. M., Moghaddam, Karami M. and Seyedian, M. (2013). Best flow condition for lateral intakes of irrigation canals. The 14Th TSAE National Conference and the 6Th International Conference: TSAE 2013, Thailand. 170-174.

Dehghani, A., Ghodsian, M., Suzuki, K., and Alaghmand, S. (2009). Local scour around lateral intakes in 180 degree curved channel. In advances in water resources and hydraulic engineering (pp. 821-825) Springer Berlin Heidelberg.

Ghostine, R., Vazquez, J., Terfous, A., Rivière, N., Ghenaim, A., and Mosé, R. (2013). A comparative study of 1D and 2D approaches for simulating flows at right angled dividing junctions. Applied Mathematics and Computation, 219(10), 5070-5082. doi:http://dx.doi.org/10.1016/j.amc.2012.11.048.

Grace, J. L., and Priest, M. S. (1958). Division of flow in open channel junctions. Auburn, Ala: Engineering Experiment Station, Alabama Polytechnic Institute.

Hager, W. (1987). Lateral outflow over side weirs. Journal of Hydraulic Engineering, 113(4), 491504.

Herrero Casas, A. (2013). Experimental and theoretical analysis of flow and sediment transport in 90degree fluvial diversions. (PhD dissertation).

Herrero, A., Bateman, A., and Medina, V. (2015). Water flow and sediment transport in a 90° channel diversion: an experimental study. Journal of Hydraulic Research, 53(2), 253-263.

Hsu, C., Tang, C., Lee, W., and Shieh, M. (2002). Subcritical 90˚ equal-width open-channel dividing flow. Journal of Hydraulic Engineering, 128(7), 716-720.

Kerssens, P., and van Urk, A. (1986). Experimental studies on sedimentation due to water withdrawal. Journal of Hydraulic Engineering, 112(7), 641-656.

Keshavarzi, A., and Habibi, L. (2005). Optimizing water intake angle by flow separation analysis. Irrigation and Drainage, 54(5), 543-552. doi:10.1002/ird.207

Kesserwani, G., Vazquez, J., Rivière, N., Liang, Q., Travin, G., and Mosé, R. (2010). New approach for predicting flow bifurcation at right-angled open-channel junction. Journal of Hydraulic Engineering, 136(9), 662-668.

Khaleel, M. S, Taha, K. Y., and Alomari, N. K. (2015). Effect of Main Channel Roughness on the Branching Flow. Al-Rafadain Engineering Journal, 23(1), 51-61.

Krishnappa, G., and Seetharamiah, K. (1963). A new method of predicting the flow in a 90 branch channel. La Houille Blanche, (7), 775-778.

Lama, S. K., Kuroki, M., and Hasegawa, K. (2002). Study of flow bifurcation at the 30˚ open channel junction when the width ratio of branch channel to main channel is large. Annual Journal of Hydraulic Engineering, JSCE, Vol.46, February, 583-588.

Masjedi, A., and Taeedi, A. (2011). Experimental investigations of effect intake angle on discharge in lateral intakes in 180 degree bend. World Applied Sciences Journal, 15(10), 1442-1444.

Pirestani, M. R., Vosoghifar, H. R., and Jazayeri, P. (2011). Evaluation of optimum performance of lateral intakes. World Academy of Science, Engineering and Technology, 5(8), 301-305.

Ramamurthy, A., and Satish, M. (1988). Division of flow in short open channel branches. Journal of Hydraulic Engineering, 114(4), 428-438.

Ramamurthy, A., Minh Tran, D., and Carballada, L. (1990). Dividing flow in open channels. Journal of Hydraulic Engineering, 116(3), 449-455.

Ramamurthy, A., Qu, J., and Vo, D. (2007). Numerical and experimental study of dividing open channel flows. Journal of Hydraulic Engineering, 133(10), 1135-1144.

Shamloo, H., and Pirzadeh, B. (2007b). Numerical investigation of velocity field in dividing open channel flow. Proceedings of the 12th WSEAS International Conference on APPLIED MATHEMATICS", Cairo, Egypt, Desember29-31, 194-198.

Shamloo, H., and Pirzadeh, B. (2007a). Investigation of characteristics of separation zones in T-junctions. Proceedings of the 12th WSEAS International Conference on APPLIED MATHEMATICS", Cairo, Egypt, Desember29-31, 189-193.

Taylor, E. H. (1944). Flow characteristics at rectangular open-channel junctions. Transactions of the American Society of Civil Engineers, 109(1), 893-902.

Yonesi, H. A., Omid, M. H., and Haghiabi, A. H. (2008). A study of the effects of the longitudinal arrangement sediment behavior near intake structures. Journal of Hydraulic Research, 46(6), 814-819.