Experimental Study of Flow in Lined Channels with Stepped Pervious Spillway

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Received: 1 April 2025
Revised : 1 August 2025
Accepted: 5 September 2025

Abstract. In this study, a laboratory flume was used to calculate the water depths upstream and downstream of stepped gabionade-spillway with five different mono-sized gravel samples. A total of 175 experimental tests has been conducted with variation of discharge values within a range of 0.0007-0.0150 m^3/s. Results indicated that the discharge has a positive effect and proportion on both upstream and downstream depths of water. Moreover, the detention depth value decreased with increasing the diameter of the gravel sample, while there is no effect of the gravel sample on the value of release depth. Obtained formulas for the detention and release depths can be usefully used for the design and scheduling actions in the field as it acknowledged a good matching between measured and calculated values. The errors percentage in average value for both detention and release tested values were 5.278% and -0.265% respectively.

Keywords: Open channels; Spillways; Gabion weirs; Detention depths; Release depths; Physical modeling.

1. INTRODUCTION

Controlling water level during scarcity seasons can be considered as a serious problem for water resources engineers as it is important for ensuring equity in water distributions during these seasons. One of the practical solutions is the use of hydraulic structures, as flow artificial movable obstructions, to decelerate the incoming low depth flow in the channels. Flow measurement structures, such as weirs and special spillways, are usually used to manage and control water flow within the water streams and measure water discharge by providing a relationship between the water depth and water discharge [1-3]. A weir can be defined as a barrier across the flow stream that is used to raise the water level upstream of its location and serve as a meter of the flow discharge by knowing the water depth at a certain distance upstream of the weir location [4,5]. Weirs can be porous (filtering water and trapping sediments), or impervious (dissipating flow energy and controlling water level) [6]. The alternative weir structures that made of loose stones such as gabion "Pervious" weir is preferred, since the latter can better meet natural and ecological requirements [7]. A rubble-mounded weir has more sustainable and environment-friendly fluid–structure interactions [8] than a solid weir due to its porosity that allows aquatic life and physical matter to move through it and due to the positive effects on river's water quality [9-11].

The hydraulic characteristics of flow for different flow conditions can be studied using weirs to calculate the dissipated energy of flow between its two sides [12-14]. Weirs help to allocate the distance of hydraulic jump that formed downstream these structures as an effective criterion of energy dissipation to find out a proper way to reduce the water damage on the sides and bed of the waterway [13,15,16]. Generally, the multiple skills of the spillway structures make it a useful hydraulic structure even for protection of the bed and sides of the natural and artificial channel from scouring process [17]. Several studies dealt with energy dissipation downstream hydraulic structures such as stepped spillway by changing water level upstream and downstream to reduce flow energy [18,19]. Spillways are characterized by a stage-discharge relationship which mainly depends on the shape and dimensions of the hydraulic structure [20]. Protection of the bed and sides of the natural and artificial channel from scouring process has been studied by Ali and Noori [21], where they discovered the relationship between the failure flowrate of protection layer and both of the weir weight and the number of protection layers, whereas the failure flowrate increases as the channel side slopes decreases.

A study conducted by Chilmeran and Noori [22] showed that the discharge coefficient has a direct relationship with the head to crest height ratio for normal weirs and for the same height of weir. While in the case of oblique weirs, this coefficient has an inverse relationship with the head of the crest height, the normal weirs of semi-circular crests perform better than those of sharp crest for all values of weir height, and weirs of small oblique angles give high discharge magnification factor and high performance than other types. New formulas relate flow in channels with weirs' have been illustrates by [23-26] to solve multi-issues in hydraulic engineering. Besides, weirs are good indicators that contribute to make the proper decisions related to improve the dimensions of the waterway, or the distribution of the whole irrigation system [27,28]. Protection of the bed and sides of the natural and artificial channel from scouring process has been studied by [21], where they discovered the relationship between the failure flowrate of protection layer and both of the spillway weight and the number of protection layers, whereas the failure flowrate increases as the channel side slopes decreases. Controlling the detention depth at the upstream side of the weir is very important to ensure justified supply of raw water during the dry season [29]. The prevalence of climate change phenomenon, and its effect on the policy of water distribution between the shared countries [28], the need to implement an effective design of weirs is increasing to keep save and control the reduced amount of pure water in the world. The growing demands on stored waters require intensive efforts from hydraulic engineers to develop rapid methods for weir design and construction. In this study, a laboratory flume was used to calculate the water depths upstream and downstream of a stepped gabioned weir, in order to evaluate the effect of using gabion weir on the flow characteristics.

2. MATERIALS AND METHODS

2.1 Experimental Tests

Experimental tests were conducted in the laboratory of fluid mechanics of College of Engineering in University of Babylon-Iraq. The laboratory has an ARMFIELD tilting flume of 10.00 m length, 0.30 m width and 0.50 m height. The physical models that are used, have lengths 0.4, 0.6, 0.8, 1.0, and 1.2 m, and named as GWNo.I, Gabion Weir Number I, GWNo.II, GWNo.III, GWNo.IV, and GWNo.V respectively, whereas the length of the forth step of the tested gabions was focus on in order to elongate the path of the flowing water inside the body of the weir and get resistance to get more depth of water before the weir. All models have constant cross-section, width 0.3 m and height 0.4 m. in contrast, the gravel samples that used as filling material for the physical models were five monosized gravel samples with diameters ranged between 9.5-14.0 mm, 14.0-19.0 mm, 19.0-25.0 mm, 25.0-37.5 mm, and 37.5-50.0 mm, and numbered as GSNo.I, Gravel Sample Number I, GSNo.II, GSNo.III, GSNo.IV, and GSNo.V respectively. The body of the weir was made of thin steel plates, covered by metal mesh. The dimensions of the used hydraulic models of gabion weir and the gravel samples diameters are listed in Table 1. A total of 175 experimental tests were conducted. Figures 1 and 2 show the detailed shape of the hydraulic models of gabion weir.

Table 1. The dimensions of the used hydraulic models of gabion weir, the gravel samples, and test runs.

Gabion Number	Gabion dimensions	First step (m)	Second step (m)	Third step (m)	Forth step (m)
G1	Length	0.40	0.20	0.20	0.08
	Width	0.30			
	Height	0.15	0.05	0.10	0.10
G2	Length	0.40	0.20	0.20	0.16
	Width	0.30			
	Height	0.15	0.05	0.10	0.10
G3	Length	0.40	0.20	0.20	0.24
	Width	0.30			
	Height	0.15	0.05	0.10	0.10
G4	Length	0.40	0.20	0.20	0.32
	Width	0.30			
	Height	0.15	0.05	0.10	0.10
G5	Length	0.40	0.20	0.20	0.40
	Width	0.30			
	Height	0.15	0.05	0.10	0.10
Gravel sample number	GRS.01	GRS.02	GRS.03	GRS.04	GRS.05
Gravel sample diameter (m)	0.0095- 0.0140	0.0140- 0.0190	0.0190- 0.0250	0.0250- 0.0375	0.0375- 0.0500
Test runs range (m^3/s)	0.0007-0.0150				

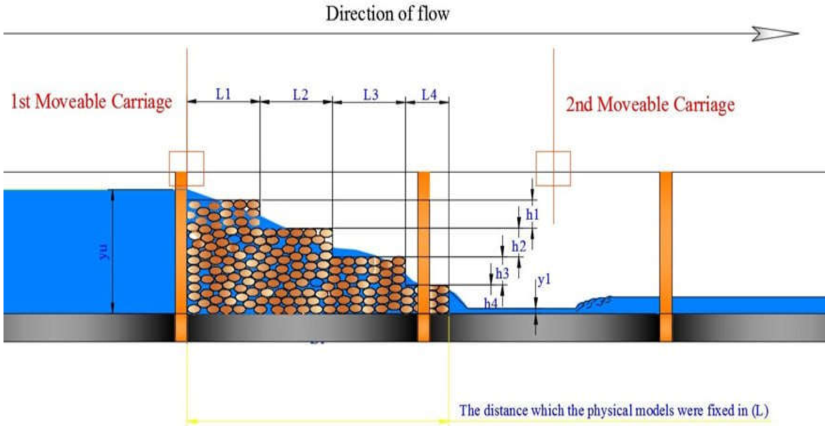
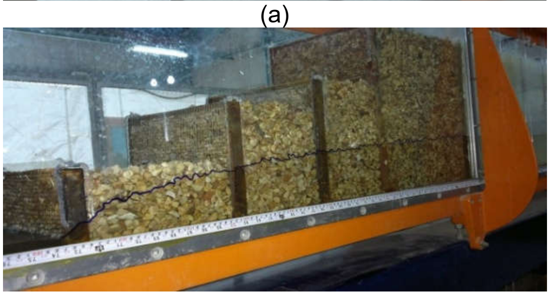


Figure 1. The detailed shape of the hydraulic models of gabion weir.


(a)

(b)

(c)

(d)

(e)

Figure 2. Experimental models of gabion weirs: a) G1 with GRS.02, b) G2 with GRS.02, c) G3 with GRS.01, d) G4 with GRS.01, and e) G5 with GRS.05.

2.2 Dimensional Analysis

Using of the dimensional analysis technique comes to bond all the variables of the studied case in one formula, whereas the resulted dimensionless formula helps both of engineers and researchers to understand the behaviour of variable with other ones [20]. In this study, the total flow state which consists of a combination between the free surface flow state over the top of the weir, and seepage flow state through the weir structure was depended basically because the actual upstream water depth before the weir is an important parameter for field management of water shares by using of this structure, and the main goal is to keep the water at a certain depth which is not raise above the head of the weir structure, in most of cases, before the farmers can irrigate their lands which lies before the structure position of the irrigation canal. For the detention process of water, the upstream water depth y_{us}, measured directly in front of the weir represents the detention depth, and the parameters affect it can be expressed as follows:

$y_{us} = F_1 \{q, d, L_T, L_4, \rho, g\}$ (1)

Where q is the discharge per unit width ($m^3/s/m$), d is the mean diameter of the gravel sample (m), L_T is the total length of gabion weir (m), L_4 is the length of the 4th step in the gabion weir (m), g is the gravitational acceleration (m/s^2), and ρ is the mass density (kg/m^3). For the release process, the downstream water depth, yd, measured near the weir toe represents the release depth, and the variables affect it are as follows:

$y_{ds} = F_2 \{q, d, L_T, L_4, \rho, g\}$ (2)

Based on Buckingham Pi-Theorem, the public expression can be formulated to correlate the dependent and independent variables as:

$$\frac{y_{us}}{L_T} = F_3 \{\frac{q}{g^{0.5}L_T^{1.5}}, \frac{d}{L_T}, \frac{L_4}{L_T}\}$$

where the term $(\frac{y_{us}}{L_T})$ is the detention dimensionless variable, the term $(\frac{q}{g^{0.5}L_T^{1.5}})$ is the unit discharge dimensionless variable, the term $(\frac{d}{L_T})$ is the gravel diameter dimensionless variable, and the term $(\frac{L_4}{L_T})$ is the gabion length ratio. For release depth, the equation can be expressed as:

$$\frac{y_{ds}}{L_T} = F_3 \{\frac{q}{g^{0.5}L_T^{1.5}}, \frac{d}{L_T}, \frac{L_4}{L_T}\} \quad (4)$$

Where the term $(\frac{y_{ds}}{L_T})$ is the release dimensionless variable. The gabion length ratio $(\frac{L_4}{L_T})$ has not been discussed in this study as the first tested length of the gabion weir in the canals of the irrigation network is more easiness in setup, removing, and relocation along the targeted canal. Hence, the equations (3) and (4) can be reduced to:

$$\frac{y_{us}}{L_T} = F_3 \{\frac{q}{g^{0.5}L_T^{1.5}}, \frac{d}{L_T}\} \quad (5)$$

$$\frac{y_{ds}}{L_T} = F_3 \{\frac{q}{g^{0.5}L_T^{1.5}}, \frac{d}{L_T}\} \quad (6)$$

3. RESULTS AND DISCUSSION

3.1 Effect of discharge on the detention depth

The discharge and water depth have a positive correlation in most flow cases [26,30,31]. Hence, this relationship is necessary for weirs' designing [32]. For this study, controlling the detention depth at the upstream side of the weir is very important to ensure justified supply of raw water during the dry season. The relationship between discharge and water depth is shown in Figure 3. From Figure 3, the detention depth of water increases as the value of discharge increased for all gravel samples and for all gabion weir models. The representation equation of this relationship is as follows:

$$y_{us} = a(us) \times q^{b(ds)} \quad (11)$$

Where a(us) and b(us) are constants, and Table 2 presents the values of these constants.

Table 2. Values of constants a(us) and b(us).

Gabion Number	Gravel Sample Number	q ($m^3/s/m$)		y_{us} (m)		a(us)	b(us)	R^2
		from	to	from	to			
G1	GRS.01	0.00233	0.02800	0.115	0.441	03.2422	0.5352	0.9760
	GRS.02	0.00233	0.03168	0.086	0.440	03.9801	0.6117	0.9759
	GRS.03	0.00233	0.03237	0.084	0.440	03.7962	0.6191	0.9951
	GRS.04	0.00233	0.03990	0.074	0.444	03.6479	0.6352	0.9929
	GRS.05	0.00233	0.05000	0.068	0.442	03.3274	0.6540	0.9787
G2	GRS.01	0.00233	0.02167	0.107	0.417	04.7856	0.6239	0.9965
	GRS.02	0.00233	0.02333	0.084	0.407	05.6896	0.6839	0.9270
	GRS.03	0.00233	0.04333	0.078	0.451	03.6357	0.6373	0.9918
	GRS.04	0.00233	0.04667	0.052	0.417	03.6479	0.6352	0.9929
	GRS.05	0.00233	0.05000	0.042	0.428	03.3274	0.6540	0.9787
G3	GRS.01	0.00233	0.02600	0.128	0.435	02.8195	0.4929	0.9660
	GRS.02	0.00233	0.03168	0.103	0.443	03.2772	0.5554	0.9823
	GRS.03	0.00233	0.03633	0.089	0.444	03.2093	0.5716	0.9775
	GRS.04	0.00233	0.03990	0.079	0.456	03.6479	0.06352	0.9929

	GRS.05	0.00233	0.05000	0.071	0.395	03.3274	0.6540	0.9787
G4	GRS.01	0.00233	0.01613	0.123	0.423	12.4900	0.8050	0.9758
	GRS.02	0.00233	0.02000	0.098	0.390	07.6279	0.7287	0.9813
	GRS.03	0.00233	0.03167	0.074	0.410	04.6019	0.6755	0.9929
	GRS.04	0.00233	0.03000	0.062	0.456	03.4679	0.06352	0.9929
	GRS.05	0.00233	0.04000	0.057	0.348	03.3274	0.6540	0.9787
G5	GRS.01	0.00233	0.02600	0.105	0.426	03.7032	0.5634	0.9482
	GRS.02	0.00233	0.03168	0.113	0.443	02.7596	0.5281	0.9794
	GRS.03	0.00233	0.03633	0.095	0.444	03.1521	0.5692	0.9878
	GRS.04	0.00233	0.03990	0.075	0.438	03.6479	0.6352	0.9929
	GRS.05	0.00233	0.05000	0.069	0.360	03.3274	0.6540	0.9787

3.2 Effect of gravel samples on the detention depth

Figure 3 shows that the detention depth decreases as the diameter of the gravel sample increased for all gabion weir models. The relationship between the detention depth dimensionless variable and the unit discharge dimensionless variable used in all physical models is represented by the following equation:

$$\frac{y_{us}}{L} = f_3\left(\frac{q}{g^{0.5}L_T^{1.5}}\right) \tag{8}$$

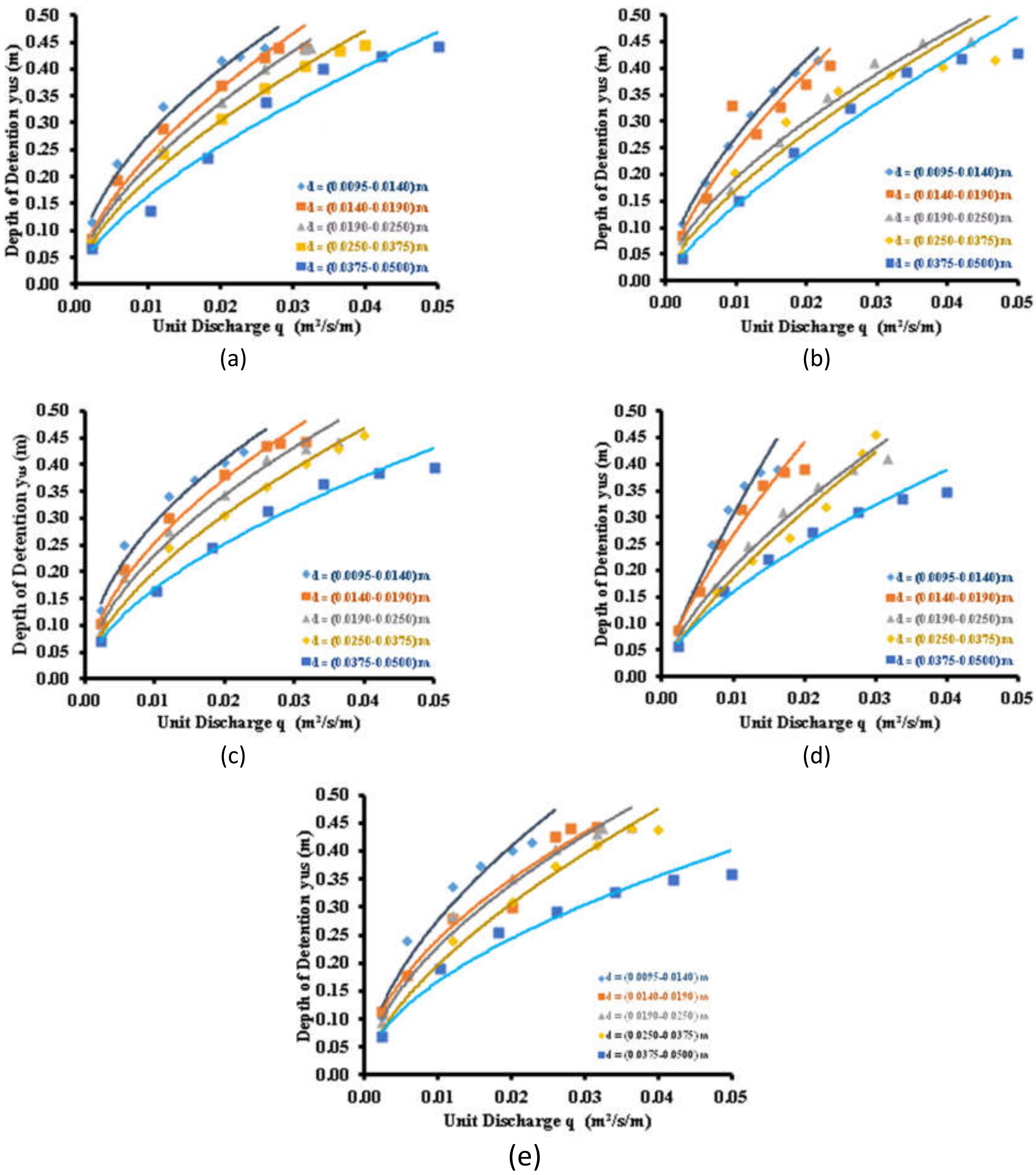


Figure 3. The discharge-detention depth relationship for gabion weirs: a) G1, b) G2, c) G3, d) G4, and e) G5.

Figure 4 shows the relationship between these variables, whereas every single trend line represents the assembled data of the gravel sample that used in all gabion weir models. This figure confirms the fact that the detention depth increases by decreasing the mean diameter of gravel sample in all physical models. These results give a vision that changing the gabion filling material should be synchronized with the increases of the degree of scarcity, whereas it changes from courser to finer when the scarcity degree increases to ensure a safe elevation of water depth inside the canal. From Figure 4, it's obvious that power form is a good mathematical expression for the variables of equation (8).

$$\frac{y_{us}}{L} = A\left(\frac{q}{g^{0.5}L_T^{1.5}}\right)^B \tag{9}$$

where, A and B are constants, and Table 3 presents the values of these constants.

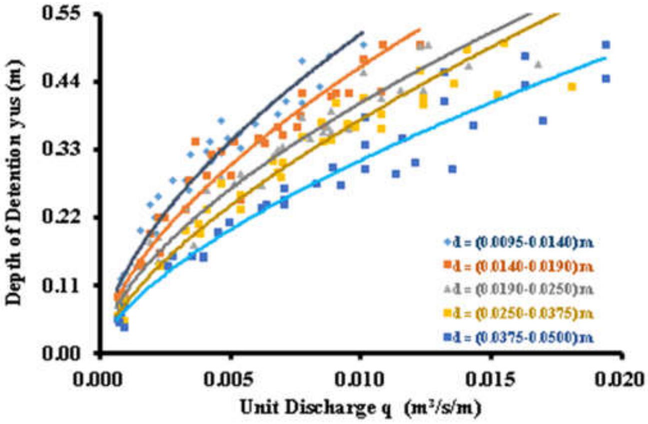


Figure 4. The discharge-detention depth relationship all for gabion weir and gravel samples used.

Table 3. Values of constants A and B.

Gravel Sample Number	q (m^3/s/m)		L_T (m)		y_{us} (m)		A	B	R^2
	from	to	from	to	from	to			
I	0.00233	0.02800	0.88	1.20	0.115	0.441	7.9121	0.5921	0.9456
II	0.00233	0.03168	0.88	1.20	0.086	0.443	7.5764	0.6064	0.9527
III	0.00233	0.04333	0.88	1.20	0.084	0.451	6.7062	0.6089	0.9703
IV	0.00233	0.04667	0.88	1.20	0.074	0.456	8.0683	0.6640	0.9704
V	0.00233	0.05000	0.88	1.20	0.068	0.442	6.0718	0.6439	0.9646

The final form of equation (5) after applying the regression process (with R^2 = 0.846958) is:

$$\frac{y_{us}}{L_T} = 0.214842064 + 27.86011099\left(\frac{q}{g^{0.5}L_T^{1.5}}\right) - 4.221891875\left(\frac{d}{L_T}\right) \tag{10}$$

3.3 Effect of Discharge on the Release Depth

The power form was used to draw the relationship between the discharge and the release depth of water in Figure 5. From results presented in Figure 5, the same results and relationship of the discharge-detention depth was found for the release water depth. This relation can be shown as:

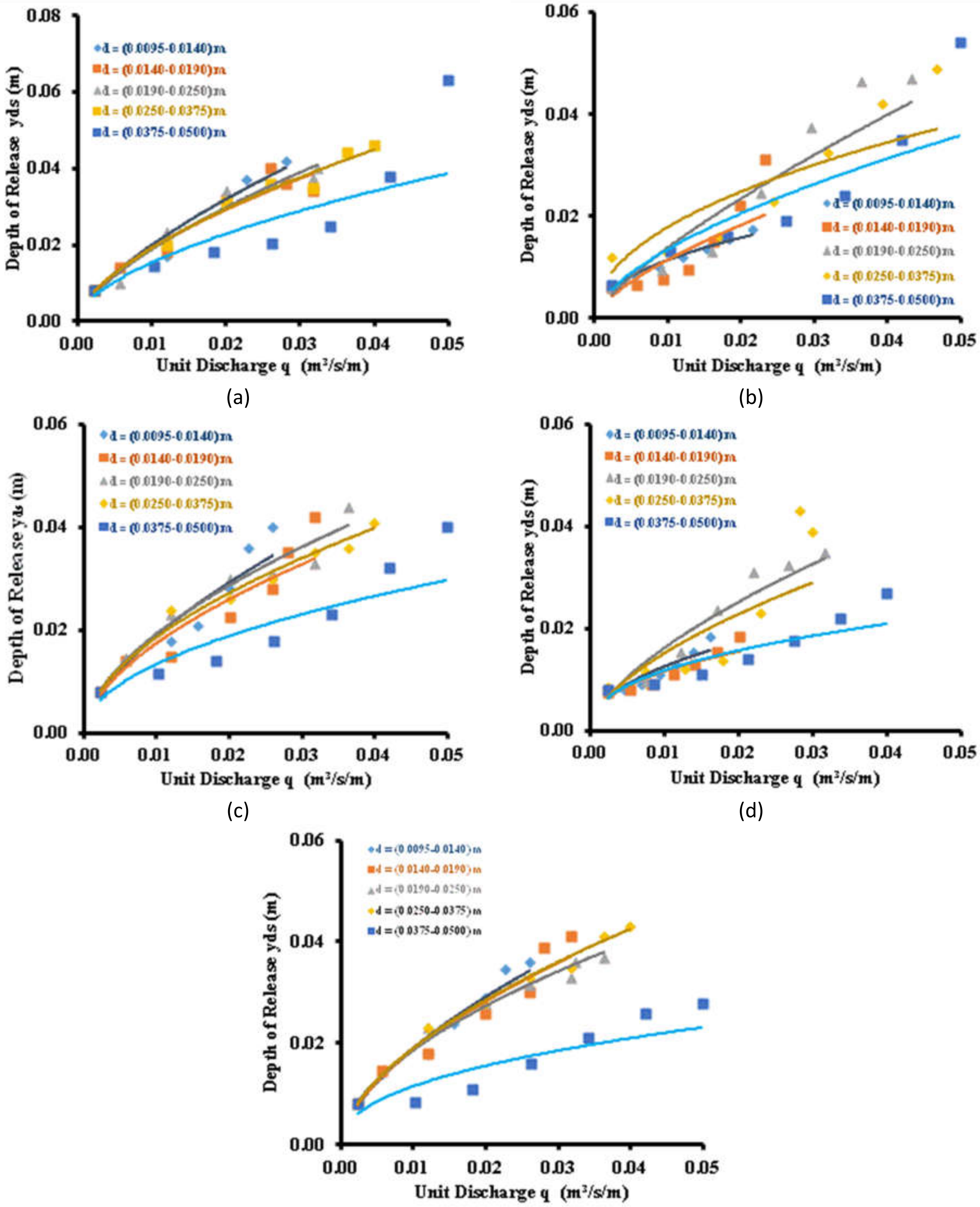
$$y_{ds} = a(ds) \times q^{b(ds)} \tag{11}$$

Where, a(ds) and b(ds) are constants, and Table 4 presents the values of these constants.

Table 4. Values of constants a(ds) and b(ds).

Gabion number	Gravel sample number	q (m^3/s/m)		y_{ds} (m)		a(ds)	b(ds)	R^2
		from	to	from	to			
G1	GRS.01	0.00233	0.02800	0.008	0.042	0.4498	0.6761	0.9611
	GRS.02	0.00233	0.03168	0.008	0.034	0.3160	0.6089	0.9635
	GRS.03	0.00233	0.03237	0.008	0.040	0.3971	0.6620	0.9588
	GRS.04	0.00233	0.03990	0.008	0.046	0.3238	0.6136	0.9896
	GRS.05	0.00233	0.05000	0.008	0.063	0.2156	0.5731	0.8370
G2	GRS.01	0.00233	0.02167	0.006	0.018	0.0992	0.4705	0.9836
	GRS.02	0.00233	0.02333	0.006	0.031	0.2604	0.6798	0.7374
	GRS.03	0.00233	0.04333	0.006	0.047	0.4680	0.7655	0.8915
	GRS.04	0.00233	0.04667	0.012	0.049	0.1592	0.4757	0.7602
	GRS.05	0.00233	0.05000	0.007	0.054	0.2210	0.6077	0.8852

G3	GRS.01	0.00233	0.02600	0.008	0.040	0.3409	0.6278	0.9449
	GRS.02	0.00233	0.03168	0.008	0.042	0.2449	0.5734	0.9194
	GRS.03	0.00233	0.03633	0.008	0.044	0.2674	0.5716	0.9810
	GRS.04	0.00233	0.03990	0.008	0.041	0.2326	0.5485	0.9816
	GRS.05	0.00233	0.05000	0.008	0.040	0.1309	0.4951	0.8540
G4	GRS.01	0.00233	0.01613	0.008	0.019	0.1067	0.4645	0.8546
	GRS.02	0.00233	0.02000	0.008	0.019	0.0783	0.4144	0.8348
	GRS.03	0.00233	0.03167	0.008	0.035	0.3030	0.6356	0.9011
	GRS.04	0.00233	0.03000	0.009	0.039	0.2271	0.5873	0.7086
	GRS.05	0.00233	0.04000	0.008	0.027	0.0794	0.4147	0.8056
G5	GRS.01	0.00233	0.02600	0.008	0.036	0.3243	0.6159	0.9755
	GRS.02	0.00233	0.03168	0.008	0.041	0.2880	0.5939	0.9665
	GRS.03	0.00233	0.03633	0.008	0.037	0.2361	0.5510	0.9888
	GRS.04	0.00233	0.03990	0.008	0.043	0.2754	0.5798	0.9941
	GRS.05	0.00233	0.05000	0.008	0.028	0.8479	0.4330	0.7845



(a) (b) (c) (d) (e)

Figure 5. The discharge-release depth relationship for gabion weirs: a) G1, b) G2, c) G3, d) G4, and e) G5.

3.4. Effect of Gravel Samples on the Release Depth

Experimental tests show that there is no effect of increasing the diameter of gravel sample on the release depth of water for all gabion weir tested models (See Figure 5). The relationship between the release depth dimensionless variable and the unit discharge dimensionless variable for all physical models is represented by:

$$\frac{y_{ds}}{L} = f_4\left\{\frac{q}{g^{0.5}L_T^{1.5}}\right\} \tag{12}$$

From Figure 6, the power form gives a good and precise mathematical representation for the variables of Equation (12):

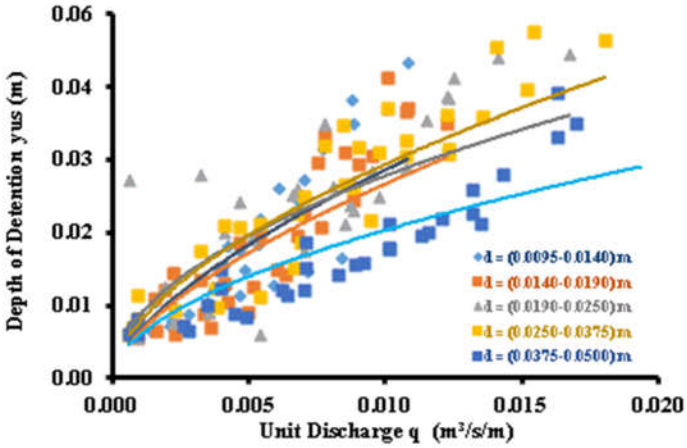


Figure 6. The discharge-release depth relationship all for gabion weir and gravel samples used.

$$\frac{y_{ds}}{L} = A_1\left(\frac{q}{g^{0.5}L_T^{1.5}}\right)^{B_1} \tag{13}$$

A1 and B1 are constants, and their variables are listed in Table 5.

Table 5. Values of constants A1 and B1.

Gravel Sample Number	q (m^3/s/m)		L_T (m)		y_{ds} (m)		A1	B1	R^2
	from	to	from	to	from	to			
GRS.01	0.00233	0.02800	0.88	1.20	0.115	0.441	0.6039	0.6414	0.7758
GRS.02	0.00233	0.03168	0.88	1.20	0.086	0.443	0.5319	0.6289	0.7550
GRS.03	0.00233	0.04333	0.88	1.20	0.084	0.451	0.3146	0.5059	0.5686
GRS.04	0.00233	0.04667	0.88	1.20	0.074	0.456	0.4619	0.5774	0.8517
GRS.05	0.00233	0.05000	0.88	1.20	0.068	0.442	0.2671	0.5382	0.7689

The final form of Equation (6) after applying the regression process (with R^2 = 0.737579) is:

$$\frac{y_{ds}}{L_T} = 0.0006747946 + 2.502605555\left(\frac{q}{g^{0.5}L_T{}^{1.5}}\right) - 0.032891787\left(\frac{d}{L_T}\right) \tag{14}$$

The previous results give an indication that changing the diameter of filling materials of the gabion weir affects the detention depth more than the release depth. The variation in impact plays an important role in scheduling process for the irrigation canal during the scarcity seasons.

3.5 Results Evaluation

The calculated and measured values of detention and release depths of water were drawn in Figure 7. The data of the first gabion weir model was used to draw this relationship for practical considerations by making elimination for the data of the second and fifth test runs of each used gravel sample. Final calculations are presented in Equations (15-18) with R^2 = 0.914448, 0.903007, 0.9795 and 0.8628 respectively.

$$\frac{y_{us}}{L_T} = 0.246053958 + 29.37438167\left(\frac{q}{g^{0.5}L_T{}^{1.5}}\right) - 4.462720536\left(\frac{d}{L_T}\right) \tag{15}$$

$$\frac{y_{ds}}{L_T} = 0.013333632 + 3.128334189\left(\frac{q}{g^{0.5}L_T{}^{1.5}}\right) - 0.238162855\left(\frac{d}{L_T}\right) \tag{16}$$

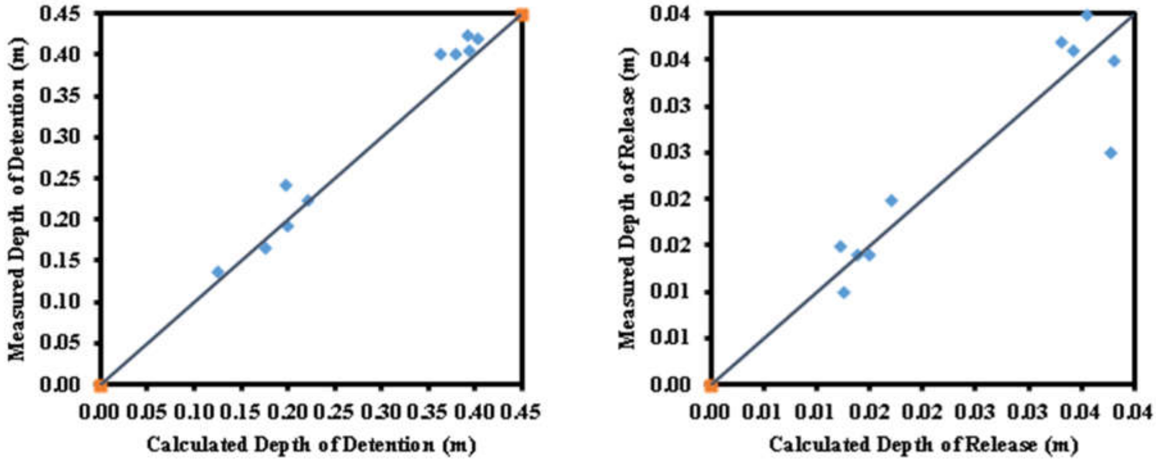
$$y_{us} \text{ measured} = 1.0657 * y_{us} \text{ calculated} - 0.0013 \tag{17}$$

$$y_{ds} \text{ measured} = 0.7692 * (y_{ds} \text{ calculated})\ \text{^}0.9343 \tag{18}$$

To evaluate the error percentages for both detention and release depths, measured and calculated, Equations (19) and (20) were used for the first length of the gabion weir model, and these values are presented in Tables 6 and 7.

$$y_{us}\ \% = \frac{y_{us,\text{Measured}} - y_{us,\text{Calculated}}}{y_{us,\text{Measured}}} \tag{19}$$

$$y_{ds}\ \% = \frac{y_{ds,\text{Calculated}} - y_{ds,\text{Measured}}}{y_{ds,\text{Calculated}}} \tag{20}$$



(a) (b)

Figure 7. The measured-calculated relationship of the (a) detention depth of water (b) the release depth of water.

The average values of the data listed in tables 6 and 7 were 5.278% and -0.265% respectively.

Table 6. Errors percentage for detention depth in the first gabion weir length.

Gravel Sample Number	$y_{us,measured}$ (m)		$y_{us,calculated}$ (m)		Error %	
	2nd q	5th q	2nd q	5th q	2nd q	5th q
GRS.01	0.224	0.425	0.221	0.391	0.0145	0.0807
GRS.02	0.194	0.421	0.200	0.403	-0.0285	0.0431
GRS.03	0.166	0.401	0.175	0.378	-0.0542	-0.0566
GRS.04	0.243	0.405	0.197	0.394	0.1891	0.0276
GRS.05	0.138	0.401	0.124	0.362	0.1020	0.0967

Table 7. Errors percentage for release depth in the first gabion weir length.

Gravel Sample Number	$y_{ds,measured}$ (m)		$y_{ds,calculated}$ (m)		Error %	
	2nd q	5th q	2nd q	5th q	2nd q	5th q
GRS.01	0.014	0.037	0.015	0.033	0.0647	-0.1188
GRS.02	0.014	0.040	0.014	0.035	-0.0117	-0.1271
GRS.03	0.010	0.036	0.012	0.034	0.2017	-0.0533
GRS.04	0.020	0.035	0.017	0.038	-0.1718	0.0794
GRS.05	0.015	0.025	0.012	0.037	-0.2249	0.3354

4. CONCLUSIONS

Gabion weirs, nowadays, have attracted the attention of many researchers due to their environment suitability, positive effects on river's water quality and simple design and implementation. In this study, experimental tests were conducted using a laboratory flume to calculate the water depths upstream and downstream of a stepped gabion weir. The results confirmed that the discharge has a positive effect and proportion on both depths of water. Moreover, the detention depth value decreases with increasing the diameter of the gravel sample, while there is no effect of the gravel sample on the value of release depth. Obtained formulas for the detention and release depths can be used for the design as they confirmed a good matching when comparing measured and calculated values of these depths. The errors percentage in average value for both detention and release tested values were 5.278% and -0.265% respectively.

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