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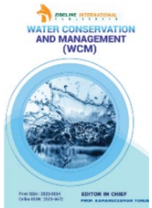
Water Conservation and Management (WCM)

DOI: http://doi.org/10.26480/wcm.02.2026.295.302



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ISSN: 2523-5664 (Print)
ISSN: 2523-5672 (Online)
CODEN: WCMABD

RESEARCH ARTICLE

INFLUENCE OF WATER CYCLE CONFIGURATION AND HEIGHT ON HYDRAULIC PERFORMANCE AND ENERGY DISSIPATION OF TRIANGULAR LABYRINTH WEIRS

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Article History:

Received 21 February 2026
Revised 04 March 2026
Accepted 24 April 2026
Available online 10 June 2026

ABSTRACT

Labyrinth weirs are widely used in hydraulic civil engineering due to their ability to increase discharge and flow velocity, thereby dispersing energy within specific channel widths. This study experimentally investigated the hydraulic performance and energy dispersion characteristics of triangular labyrinth weirs under the influence of weir height and number of water cycles. A single-, two-, and three-cycle labyrinth weir was tested at three different heights: 10 cm, 20 cm, and 30 cm, under various flow conditions. were tested under various flow conditions and crest heights**.** Upstream and downstream flow depths and velocities were measured to evaluate the specific energy, energy loss (ΔE), and energy dissipation efficiency (%η). The experimental results indicate that energy dissipation increases significantly with both the number of cycles and crest height. The three-cycle triangular labyrinth weir exhibited the highest performance, achieving energy dissipation efficiencies exceeding 50% at higher flow rates and crest heights. The results confirm that triangular labyrinth weirs provide effective downstream energy reduction and improved hydraulic control. The findings of this study can support the optimal design of labyrinth weirs in spillways, irrigation channels, and energy dissipation structures.

KEYWORDS

Labyrinth weir, triangular weir, energy dissipation, hydraulic performance, experimental study.

1. INTRODUCTION

Water is a limited and essential natural resource that supports all forms of life on Earth. Increasing demands from industrial, agricultural, municipal, and recreational sectors have placed significant pressure on available water resources. As water demand continues to rise, effective management and equitable distribution of water become increasingly important. However, efficient water management cannot be achieved without accurate knowledge of the quantity of water being utilized. Therefore, measuring water use is essential to ensure fair allocation among users and to promote sustainable water resource management. Furthermore, water measurement contributes to improved efficiency, accountability, environmental protection, and public confidence by reducing water losses and unnecessary drainage (Abbas, 2014).

Accurate flow measurement plays a fundamental role in the equitable distribution of water resources among users. This objective can be achieved through the use of flow-measuring structures, which are hydraulic devices installed in open channels to create predictable flow conditions. These structures establish a known relationship between water level and discharge, allowing flow rates to be determined from water level measurements taken at specified locations within the channel (Rickard et al., 2003).

A weir is a hydraulic structure consisting of an obstruction placed across the bottom of an open channel over which water flows. The hydraulic principle of weirs is based on forcing the flow to pass through critical depth conditions, thereby creating a unique relationship between upstream water depth and discharge. As a result, discharge can be accurately determined by measuring the water depth upstream of the structure, making weirs effective and widely used flow-measuring devices (Al-Baghdadi, 2012).

Weirs are among the oldest and most commonly used hydraulic structures employed by engineers for water resources management. They serve various functions, including discharge measurement, flow regulation, water diversion, and water level control. Consequently, weirs have been widely implemented in rivers, canals, irrigation systems, and reservoirs to support water management objectives.

Based on their geometric characteristics and flow conditions, weirs can be classified into several categories, including broad-crested, sharp-crested, and non-linear weirs such as ogee weirs. Sharp-crested weirs are further classified according to the shape of the opening into rectangular, triangular, trapezoidal, and compound weirs. Each configuration exhibits distinct hydraulic characteristics and is selected according to specific operational and design requirements (Cassidy and Christopher, 1985).

1.1 Methodology

Three models of labyrinth weirs; namely triangular, rectangular, and trapezoidal will be used in this investigation, created and tested in the Fluid Mechanics Laboratory at Qasim Green University's College of Engineering. Twenty-seven (27) actual hydraulic models after changing the geometric characteristics of the above models will be constructed. A total of (157) laboratory and numerical experiments will be done under the free flow conditions for the three labyrinth planforms.

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Cite The Article: Ali Sabah Toma, Hiba Ali Abba (2026). Influence Of Water Cycle Configuration and Height on Hydraulic Performance And Energy Dissipation of Triangular Labyrinth Weirs. Water Conservation and Management, 10(2): 295-302.

The current thesis schedule is set up as shown below:

2. Materials And Methods

2.1 Effective of Discharge

W is the cycle width (m), P is the weir height (m), B is the length of lateral wall (m), α is the angle of the lateral wall (degree), a is the half of cape width (m), H is the total upstream head on the weir (m) H=h+V2/2g and n is the number of cycles. Figure 1 shows a schematic view of the diagonal, duck-billed numerical modeling remain limited.

$$\mathbf{Q = Cd \cdot \sqrt{2y} \cdot H\ .\ Leff} \qquad \mathbf{(2.1)}$$

Q: Discharge (m^3/s)

- C_d: Discharge coefficient (depends on geometry & flow conditions)
- L_{eff}: Effective crest length (very important in labyrinth weirs)
- g: Gravitational acceleration (9.81 m/s^2)
- H: Total upstream head above crest (including velocity head if needed)

2.2 Effective of crest length for triangular labyrinth weir Triangular labyrinth increases crest length

$$\mathbf{Leff = N * Lc}$$

N: Number of cycles (1, 2, 3, …)

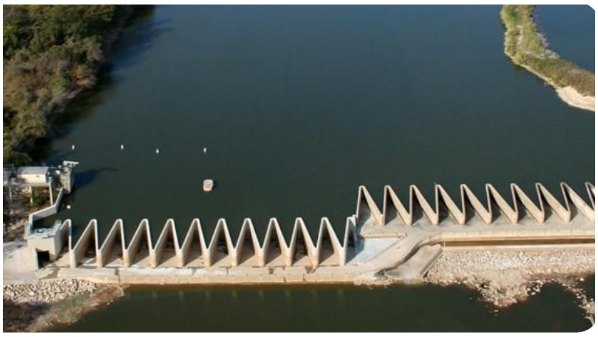
Lc: Crest length per cycle

2.3 Energy Equation for (upstream and dounstrem)

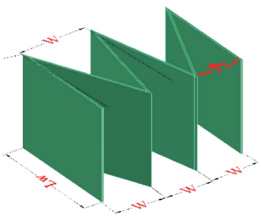
$$\mathbf{E = y1 + \frac{v1^2}{2g} - y2 + \frac{v2^2}{2g}} \qquad \mathbf{(2.2)}$$

And energy loss

$$\Delta E = E\mathbf{up} - E\mathbf{down}$$



(a)



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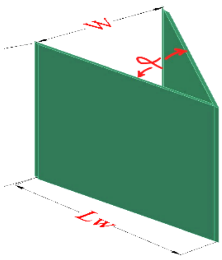

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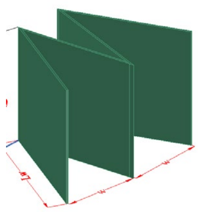


(d)

Figure 1: (1) (a) Lake Brazos Labyrinth Weir - Freese and Nichols. (b) 3 cycle Labyrinth weirs, (C) 1 cycle Labyrinth weirs and (d) 2 cycle Labyrinth weirs.

2.4 Dimensional analysis

The dimensional analysis method is well established in fluid mechanics and applies to engineering and physical fields of study (Alghazali, 2012). Since experimental studies are generally expensive, there is a need to reduce the number of experiments required so that variables are grouped into dimensionless smaller groups of the total number of variables (physical quantities) of a physical phenomenon in the mathematical technique "Dimensional analysis".

2.5 Energy Dissipation

In this study, the primary objective is investigating the effect of using different heights and number of cycles for three crest configurations (triangular, rectangular, and trapezoidal) of Labyrinth weir under the same hydraulic conditions on the energy dissipation ratio through a weir (EDR). For free flow conditions, the energy dissipation ratio (EDR) through a weir is depending mainly on the geometric characteristics of the flume and the models, the properties of the fluid, and the characteristics of the flow.

Utilizing dimensional analysis, the (EDR) can be written in functional form as:

$$EDR = f\{\rho, g, \sigma, \mu, P, W, L_w, N, \alpha, y_1, y_2, H, V_1, V_2\} \qquad (2\text{-}3)$$

The variables definitions are listed in Table (2-1).

$$\therefore f\,(EDR, \rho, g, \sigma, \mu, P, W, L_w, N, \alpha, y_1, y_2, H, V_1, V_2) \qquad (2\text{-}4)$$

Buckingham's π theorem was used. The number of the fundamental units (m) is 3; mass (M), length (L) and time (T). The total number of variables (n) involved is (15) as clear from equation (3.2). According to the above mentioned theorem, there should be n-m = 15-3 = 12 terms which are identified as the dimensionless parameters, thus;

$$f\,(\pi_1, \pi_2, \pi_3, \ldots\ldots\ldots\ldots\ldots\ldots, \pi_{12}) = 0 \qquad (2\text{-}5)$$

The number of variables in each term is (m+1) that is (3+1) = 4, By taking (□, g, y1) as the repeating variables:

$л_1 = \rho^{a1} g^{b1} y_1^{c1} EDR$, $л_2 = \rho^{a2} g^{b2} y_1^{c2} \sigma$, $л_3 = \rho^{a3} g^{b3} y_1^{c3} \mu$

$л_4 = \rho^{a4} g^{b4} y_1^{c4} P$, $л_5 = \rho^{a5} g^{b5} y_1^{c5} W$, $л_6 = \rho^{a6} g^{b7} y_1^{c8} Lw$

$л_7 = \rho^{a7} g^{b7} y_1^{c7} N$, $л_8 = \rho^{a8} g^{b8} y_1^{c8} \alpha$, $л_9 = \rho^{a9} g^{b9} y_1^{c9} H$

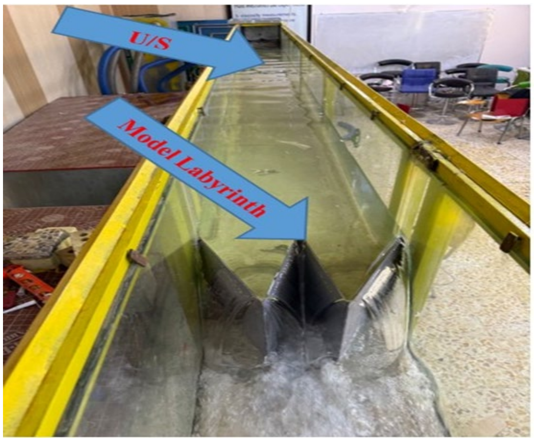
$л_{10} = \rho^{a10} g^{b10} y_1^{c10} y_2$, $л_{11} = \rho^{a11} g^{b11} y_1^{c11} V_1$, $л_{12} = \rho^{a12} g^{b12} y_1^{c12} V_2$

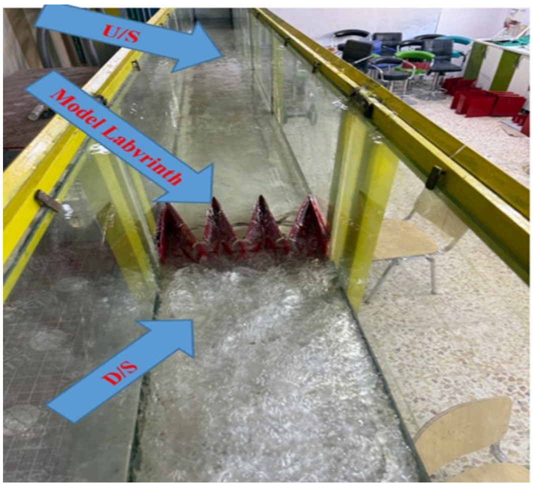
Variable	Quantity	Dimension
	Geometric characteristics	
W	The width of the water cycle	L
P	Height of the weir from the flume bed	L
Lw	Sidewall length of Labyrinth weir	L
N	Number of cycles of the Labyrinth weir	-
α	Sidewall angle	-
	Flow characteristics	
y1	Depth of the flow U/S the weir	L
y2	Depth of the flow D/S the weir	L
H	Depth of flow above the weir from the weir crest	L
V1	Average flow velocity U/S the weir	LT^{-1}
V2	Average flow velocity D/S the weir	LT^{-1}
	Fluid properties	
ρ	Density of fluid	ML^{-3}
μ	Dynamic viscosity of fluid	$MT^{-1}L^{-1}$
g	Gravitational acceleration	LT^{-2}
σ	Surface tension	MT-2
Hu		

3. The Experimental Work Purposes

As listed in table 1, The flow through a labyrinth dam is a complex process dependent on several factors, including the dam's geometry, upstream water pressure, and downstream water level. However, the general methodology for calculating the flow through a labyrinth dam can be summarized as determine the labyrinth weirs geometry. This includes the height, crest length, and the number of cycle and Calculate the energy dispersion using the dispersion ratio and compare this ratio with the difference in height between the three shapes and the number of cycle.

Water resources science is an applied science that requires laboratory simulations of real water flow conditions in canals and rivers. The use of mathematical equations in hydraulic calculations is derived from laboratory experiments. Therefore, a hydraulic canal is essential for understanding the principles of water movement, its hydraulic behavior, and the equations that govern it. A gate at the beginning of the canal controls the water level and remains open in all experiments. A Labyrinth weir made of 2 mm thick steel plates, coated with water and salt-resistant paint, is placed in the canal. It consists of three different crest heights and three different water flow rates, and is fixed with silicone adhesive at a distance of 3 meters from the upstream side of the canal, as shown in Figure (2).





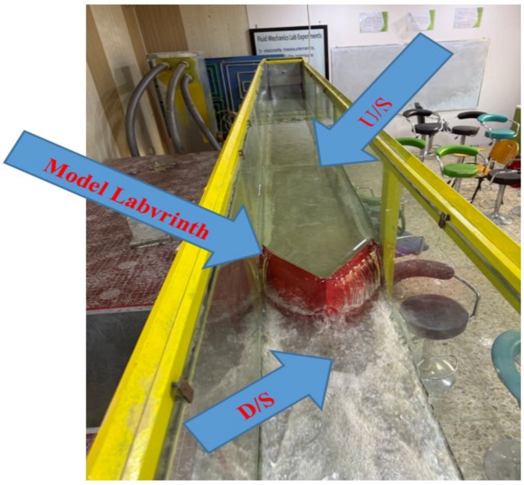


Figure 2: Experimental work Labyrinth weirs

3.1 Descriptions of flume

The flume used in this study is illustrated in. It was designed based on Manning's equation and was engineered to safely and economically convey the required discharge, while taking into consideration several design criteria related to the channel dimensions and the flow rates passing through it. It is located in University of Babylon / Al-Qasim Green University, College of Civil Engineering, Fluid Mechanics Laboratory.

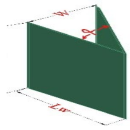
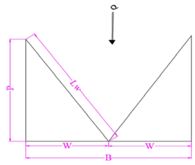
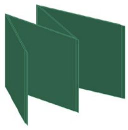
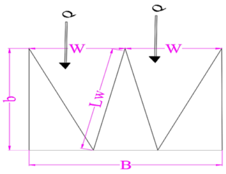
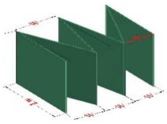
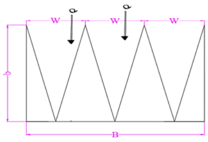
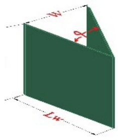
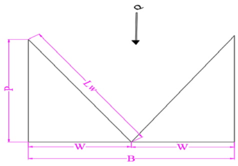
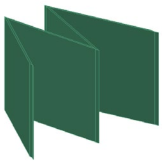
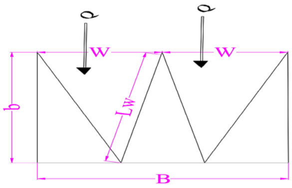
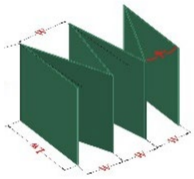
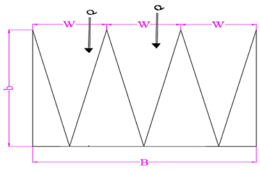
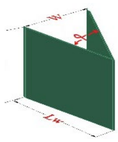
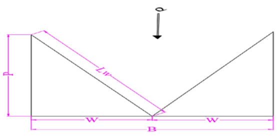
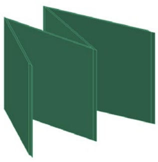
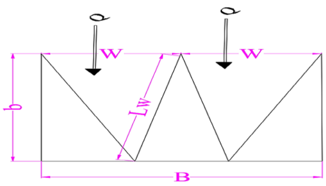
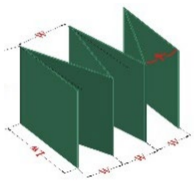
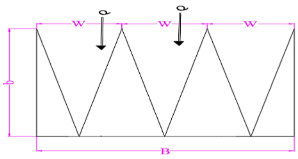
The flume is composed of three parts; first part includes the flume basin which made of painted iron to resist the moisture with tempered glass walls to facilitate visual observations and has a total length of 11.75 m. The flume height is 60 cm and the acrylic glass base is 40 cm as a width. This part represents the working section where in the middle of it the physical model is installed, from visual observation; there is enough distance from the upstream basin to the model (about 4 m) to ensure the stability of the flow before gets over the weir.

The second part is a steel supporting structure designed as an engineering truss system capable of carrying the flume and water loads uniformly. The structure is supported by two bases, one fixed and the other adjustable in height, in order to obtain the required slope during flume operation. The third Part includes four water storage tanks with a combined storage capacity of 10,000 liters, manufactured from galvanized steel, three of them in the upstream side with a setup that maintains a fixed head and one in the downstream side to collect water where the flow is discharged into it after passing the first part of the flume.

The flume equipped with three pumps connected to the last tank in the upstream side. These pumps can be operated separately or simultaneously. Each pump has different value for the maximum discharge, i.e. the maximum discharge values were (15, 20, & 32 l/sec) respectively. The flume has a closed water system where the water is supplied from the downstream tank to the upstream tanks through three pipes having a 3 in diameter. The water withdraws using the three pumps that located at the upstream of the flume and placed on a metal base. It is worth noting that the upstream storage tanks were designed with a depth significantly greater than that of the channel, such that the tank bases are located lower than the channel bed and closer to the ground surface. This design was adopted to ensure that the tanks retain a sufficient volume of water even after the pumps are shut down, thereby preventing air entrainment and protecting the pumps from drawing air during the initial start-up of the channel.

There are two gates in the canal, one at the front of the canal to control the amount water entering and the other at the back to control the water levels (Bulle, 1926).

Table 1: Dimensions and models of Labyrinth weir

Tyeps Models	P cm	L cm	W cm	n No.cycle	Shape	shape of Model top view
A1	**10**	**30**	**39.80**	1		
A2	**10**	**30**	**19.90**	2		
A3	**10**	**30**	**13.26**	3		
A4	**20**	**30**	**39.80**	1		
A5	20	30	19.90	2		
A6	20	30	13.26	3		
A7	30	30	39.80	1		
A8	30	30	19.90	2		
A9	30	30	13.26	3		

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3.2 The Measuring Equipment

I-Point gauge

Measuring the water level in open channels is one of the important fundamentals in hydraulic studies, as it is used to calculate the discharge, discharge coefficient, and velocity. The point gauge is one tool used for this. In hydraulic labs, this instrument is used to measure the water level both before and after the maze model. As seen in Figure (3), this tool was utilized in the channel to determine the water levels both before and after the model.

Figure 3: Point gauge

II-Velocity current meter

It measures the velocity at pointing place.

Working: water with rotate fins, the fins movement send signal to instrument to convert the fins rotation to velocity show figure (4)

Figure 4: Velocity current meter

3.3 RESULTS AND DISCUSSION

The results of laboratory tests in order to achieve the primary objective of this study. Data study includes models operating in free flow circumstances at different discharges (starting from 15 to 31 l/s). The impact of the parameter (H/P) on the weir discharge coefficient is analyzed. The dimensional analysis indicates that the discharge coefficient can be expressed as follows:

$$C_w - \mathbf{f}(\frac{\mathbf{Ht}}{\mathbf{p}},\frac{\mathbf{w}}{\mathbf{p}},\frac{\mathbf{d}}{\mathbf{L}},\boldsymbol{\alpha}) \text{ --(3-1)}$$

These are geometry-related parameters. The impact of the parameters (w/P) and h/p on the discharge coefficient, the height of the weir to energy dissipation, and the number of water cycles to energy dissipation for three weirs—triangular, rectangular, and trapezoidal—are discussed in the sections that follow

3.1 Effect of labyrinth Weir H/P on discharge coefficient for Triangular labyrinth weir One cycle ,Two cycle and Three cycle for p=10, 20 and 30 cm

The impact of water height above the dam and the dam height-to-height ratio (H/P) on the flow coefficient at heights of 10, 20, and 30 cm for one, two, and three cycles is shown in Figures 5, 6, and 7. During one, two, and three cycles, five experiments were carried out at five distinct flow rates, and the outcomes were recorded. For two cycles at a height of 10 cm, the maximum discharge coefficient was 0.88 m^3/s at the highest H/P ratio of 0.5, while the lowest discharge coefficient was 0.21 at the lowest H/P ratio of 0.4. The findings demonstrate that when flow rate increases, increased flow above the dam crest and less hydraulic shrinkage result in a greater H/P ratio. On the other hand, reduced flow rates, greater viscosity, and energy loss result from a lower H/P ratio. The discharge coefficient rises as the H/P ratio rises because of better flow conditions above the dam crest and decreased shrinking effects. However, at greater H/P ratios, the coefficient tends to stabilize or slightly drop due to increased turbulence and flow interference.

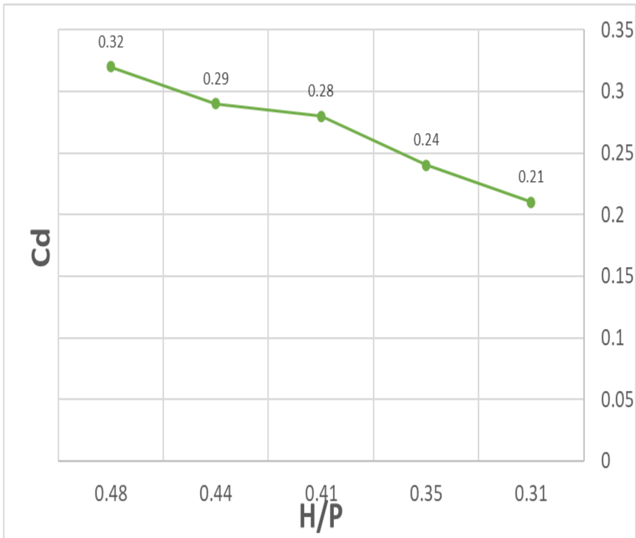

Figure 5: The relationship between H/p and Cd One cycle

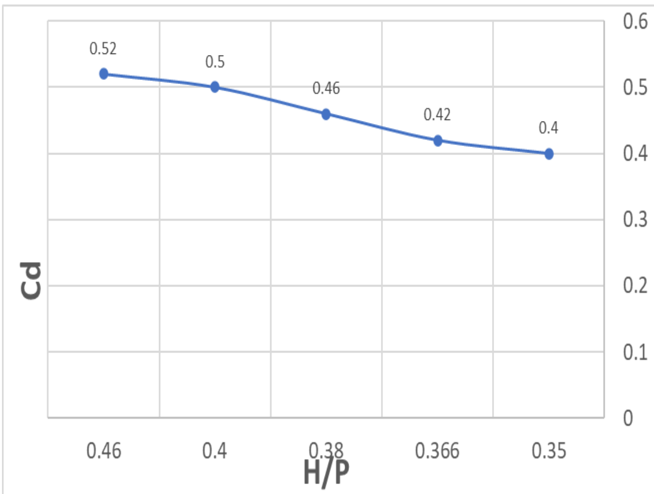

Figure 6: The relationship between H/p and Cd Two cycle

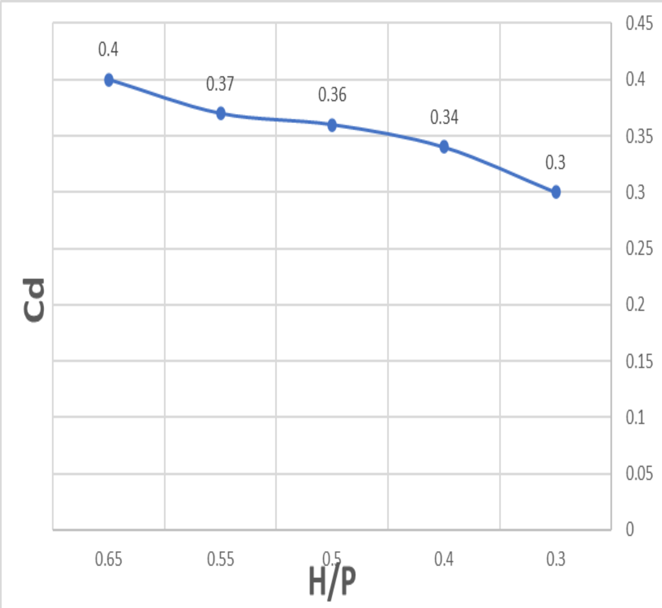

Figure 7: The relationship between H/p and Cd Two cycle

3.2 Effect number of water cycle ratio W/P on Energy dissipation

The impact of weir height and the water cycle w/p ratio on energy dissipation is depicted in Figures (8), (9), and (10). The tested models were set up as one-cycle, two-cycle, and three-cycle labyrinth weirs with three cycle (39.8,19.8,13.266) cm and three height (10,20,30) cm configurations. The triangle labyrinth weir's w/p ratio is (w/p = 1.32,1.99,3.98) for one cycle with W = 39.8 cm, (w/p = 0.66,0.99,1.98) for two cycles with W = 19.8 cm, and (w/p = 0.44,0.66,1.326) for three cycles with W = 13.266 cm. The In the lab, hydraulic performance was assessed experimentally while taking crest height into account. The results showed that one cycle with w/p = 3.98 provided the least amount of energy dissipation, while the three-cycle design with w/p = 0.44 produced the most because of the longer crest and stronger interaction between flow jets. As the flow moves along a longer crest path, increasing the number of cycles in tandem with the rising weir increases the effective crest length within a certain channel width, improving discharge capacity. Nevertheless, more cycles also result in increased flow turbulence and jet interference, which increases energy loss. Although the geometry is straightforward, jet interference is negligible, and the discharge coefficient is comparatively larger in the single-cycle arrangement, the effective crest length and discharge capacity are still constrained. The double-cycle arrangement offers better energy dissipation, mild turbulence, and balanced hydraulic performance. The triple-cycle arrangement, on the other hand, provides the highest and longest crest length. (Crookston and others, 2010).

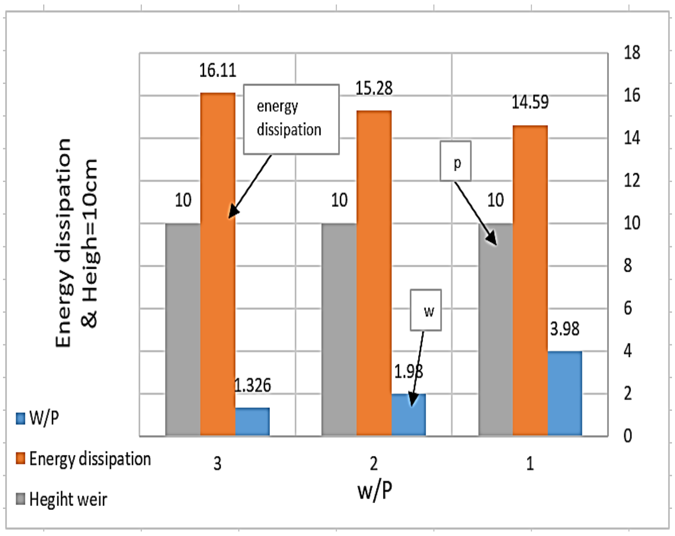

Figure 8: The relationship between model height and energy dissipation & water cycle

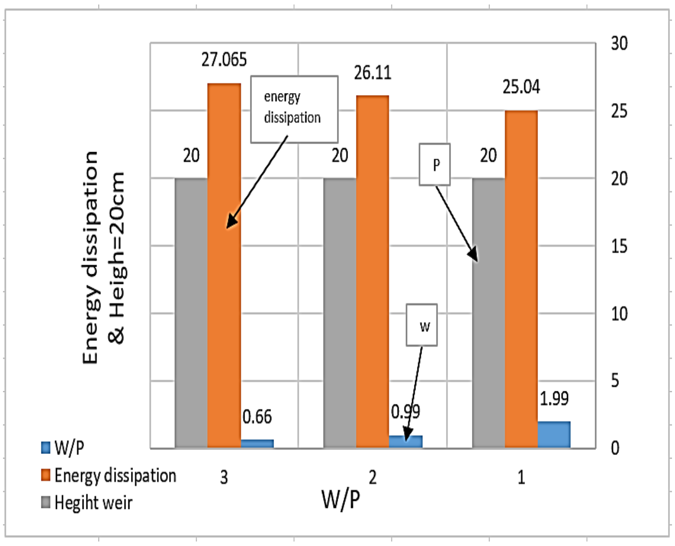

Figure 9: The relationship between model height and energy dissipation & water cycle

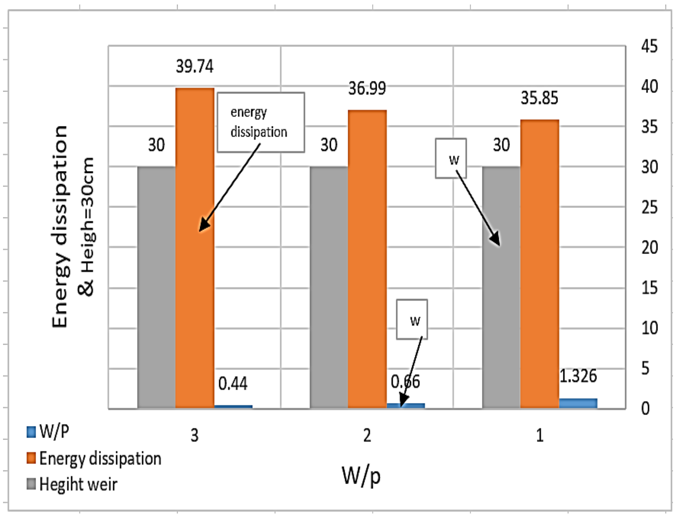

Figure 10: The relationship between model height and energy dissipation& water cycle

3.3 Effect of Labyrinth Weir Geometry on Discharge Coefficient and Relative Energy of Height weir (p)=10 cm

Figure (11) illustrates how the drainage coefficient Cd and the energy dissipation upstream are affected by the labyrinth weir's dimensions, specifically the ratio of the weir's height (p) to the water's height above it (H).

The theoretical discharge equation was used to determine the discharge coefficient of a triangular weir, where Cd stands for the ratio of the actual discharge to the theoretical discharge. The findings demonstrated that the water height above the weir (H), the design of the weir, and the number of cycles in the labyrinth weir all affect the discharge coefficient values. In general, the discharge increases as the water height above the weir rises, creating more turbulence in the flow over the edge and increasing the effectiveness of water transfer through the weir. The discharge coefficient, which tends to stabilize at specific values when the flow becomes more uniform, reflects this trend. Additionally, changes in the number of cycles and the shape of the weir result in differences in the weir's effective crest length, which has an immediate impact on the discharge coefficient. A low Cd denotes more eddies and turbulence in the flow, which increases energy loss and, consequently, energy dissipation. The findings show that three-cycle labyrinth weirs provide a good trade-off between energy dissipation efficiency and drainage throughput. While frequent changes in flow direction promote downstream energy dissipation, increasing the effective edge length enhances the drainage coefficient. In order to maximize the hydraulic performance of triangular labyrinth weirs, the number of cycles can be regarded as a crucial design element. For the labyrinth weir, the lowest discharge coefficient(Cd) was 0.32 with an energy dissipation value of 26% and a height of 10 cm, while the greatest discharge coefficient was 0.46 with three cycles and an energy dissipation value of 27.65. This indicates that increasing the discharge coefficient increases the amount of energy dissipation.

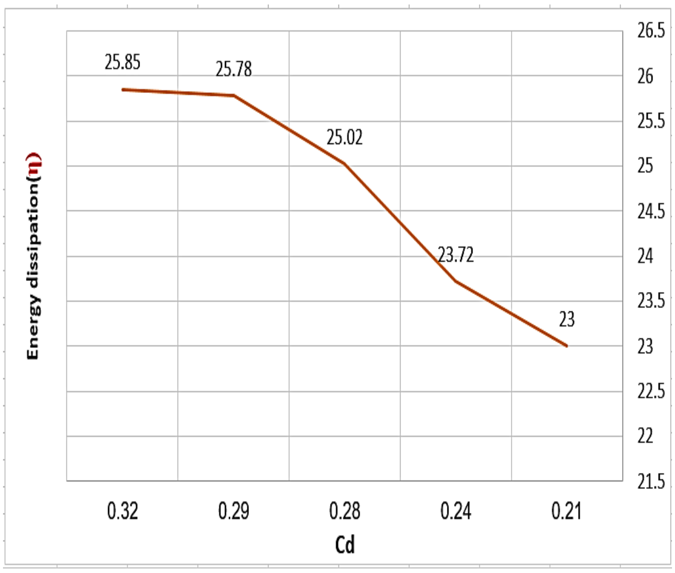

Figure 11: The relationship between energy dissipation& Cd

3.4 Effect of Labyrinth Weir Geometry on Discharge Coefficient and Relative Energy of Height weir (p)=20 cm

Figure (12) shows how the dimensions of the labyrinth weir—that is, the ratio of the weir's height (p) to the height of the water above it (H)—affect the drainage coefficient Cd and the upstream energy dissipation. The results demonstrate that three-cycle labyrinth weirs offer a good trade-off between discharge throughput and energy dissipation efficiency. Increasing the effective edge length improves the drainage coefficient, but frequent changes in flow direction encourage downstream energy dissipation. The number of cycles might be considered an important design factor in order to optimize the hydraulic performance of triangular labyrinth weirs. The highest discharge coefficient for the labyrinth weir was 0.46 with three cycles and an energy dissipation value of 26.11 Rises, while the lowest discharge coefficient was 0.35 with an energy dissipation value of 21.9% at a height of 20 cm. This demonstrates that, in comparison to one water cycle, the percentage increase in energy dissipation with three water cycles rose by 16%.

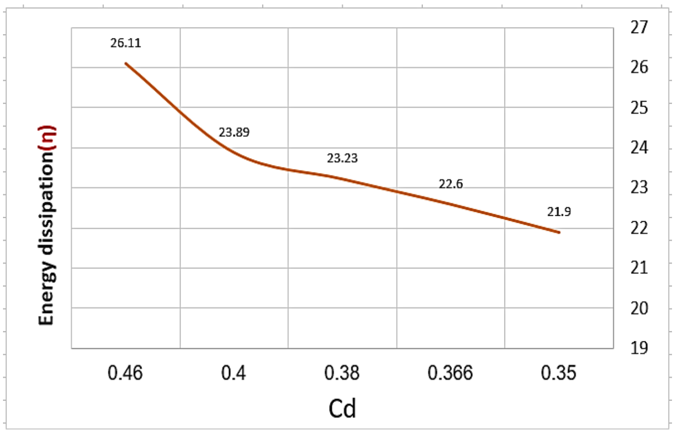

Figure 12: The relationship between energy dissipation& Cd

3.5 Effect of Labyrinth Weir Geometry on Discharge Coefficient and Relative Energy of Height weir (p)=30 cm

Figure (13) illustrates how the drainage coefficient Cd and the upstream energy dissipation are influenced by the labyrinth weir's dimensions, specifically the ratio of the weir's height (p) to the height of the water above it (H). The findings show that three-cycle labyrinth weirs provide a fair trade-off between energy dissipation efficiency and discharge throughput. The drainage coefficient is improved by increasing the effective edge length, although frequent flow direction changes promote downstream energy dissipation. To maximize the hydraulic efficiency of triangular labyrinth weirs, the number of cycles may be regarded as a crucial design element. For the labyrinth weir, the lowest discharge coefficient was 0.32 with an energy dissipation value of 0.198 at a height of 20 cm, while the greatest discharge coefficient was 0.51 with three cycles and an energy dissipation value of 0.208 Rises. This shows that the percentage increase in energy dissipation with three water cycles increased by 10% as compared to one water cycle.

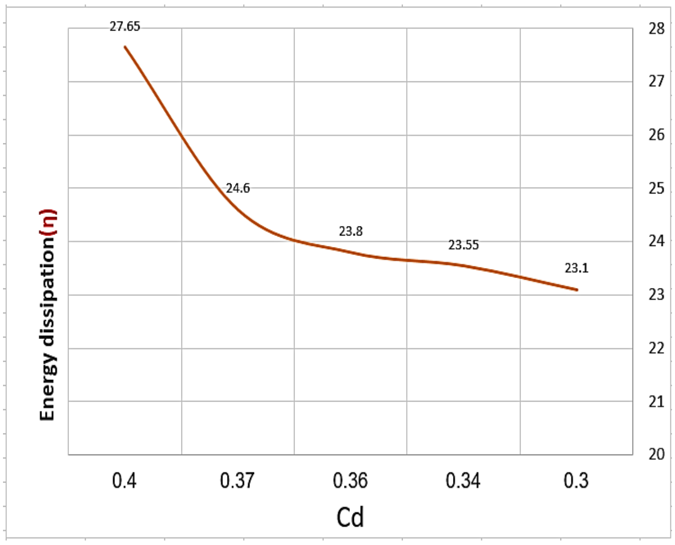

Figure 13: The relationship between energy dissipation& Cd

3.6 Effect of Discharge and Discharge coefficient for Triangular labyrinth weir with height 10 ,20and 30 cm ,for Three cycle,Two and One Cycle

For one, two, and three cycles, Figure (14),(15)and (16) shows the connection between discharge and discharge coefficient at three water levels (10, 20, and 30 cm). Five experiments were carried out over three cycles, and five flow rates were recorded for each of the three water cycles in the lab. At a height of thirty centimeters, three water cycles produced the highest discharge coefficient. Increased turbulence and a lower discharge coefficient are the results of the longer rim and higher velocity. It was found that the discharge coefficient (Cd) and discharge (Q) had an inverse relationship. At the greatest discharge coefficient of 0.63, the discharge rate was 0.069 m^3/s, while at the lowest discharge coefficient of 0.41, the discharge rate was 0.0184 m^3/s. The research raising the water level improves flow conditions, lowers viscosity, and minimizes losses, all of which raise the discharge coefficient (Cd) (Henry et al., 2003). Conversely, the dam's water transfer efficiency diminishes when discharge declines. The discharge coefficient (Cd) is lowered when the water level above the dam is lower because there is more control over viscosity, which reduces flow efficiency and increases losses. Additionally, more twists result in a lower discharge coefficient because to the longer hydraulic path, increased friction, and the creation of more eddies, which dissipate more energy. According to Kabiri-Samani, the discharge coefficient falls as energy dissipation rises.

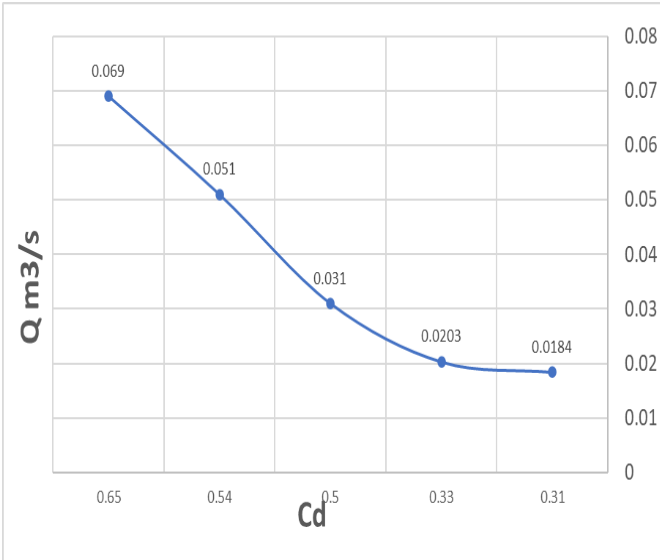

Table 14: Practical results of energy dissipation for 10 cm height three cycle labyrinth wire.

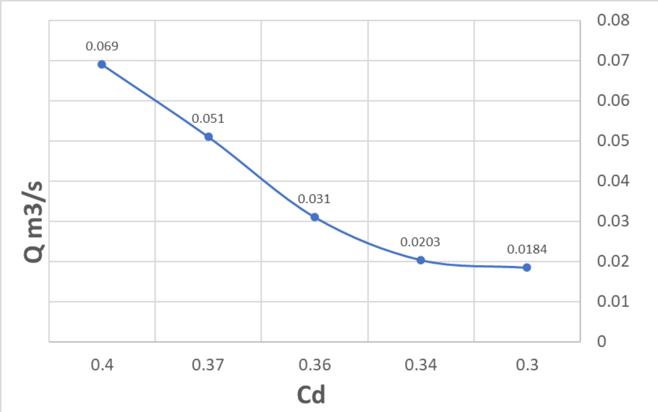

Table 15: Practical results of energy dissipation for 20 cm height three cycle labyrinth wire

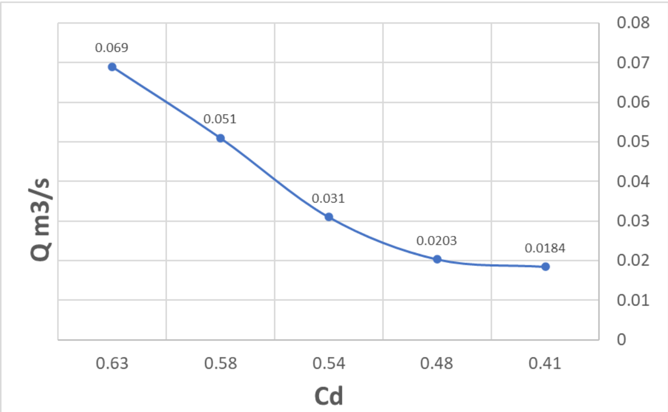

Table 16: Practical results of energy dissipation for 30 cm height three cycle labyrinth wire

4. Conclusions

The following conclusions can be made in light of the experimental investigation:

- Triangular labyrinth weirs are useful structures for controlling flow and dissipating energy.
- The efficiency of energy dissipation is greatly increased by increasing the number of labyrinth cycles.
- With a maximum energy dissipation efficiency of more than 50%, the three-cycle triangular labyrinth weir showed exceptional performance.
- Increased energy loss and enhanced hydraulic efficiency are associated with higher crest heights.
- The findings offer helpful direction for labyrinth weir design and optimization in real-world hydraulic engineering applications.

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Cite The Article: Ali Sabah Toma, Hiba Ali Abba (2026). Influence Of Water Cycle Configuration and Height on Hydraulic Performance And Energy Dissipation of Triangular Labyrinth Weirs. Water Conservation and Management, 10(2): 295-302.