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Heading Up and Head Losses Estimation Due to Rigid Bank Vegetation

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Abstract: Water surface profile is an important tool to design and manage hydraulic structures and watercourses flood control. However, limited studies focused on the effect of aquatic vegetation on the water depths in open channels. So the purpose of this paper is to investigate, how the density and distribution of the rigid bank vegetation affect the water depths in terms of heading up and head losses. Eighty-four tests were used, where tests were run for three vegetation densities (0.0113, 0.0028, and 0.0013) along 4.00 m fixed reach with varying Froude number. Water surface profiles were measured and plotted for all cases where it is observed that the water depth increased upstream the vegetated reach then lowered within it and gradually back to the normal depth downstream the vegetated reach. Empirical equations were deduced to determine the heading up and the head losses due to bank vegetation as a function in the vegetation density and the Froude number. The research presented empirical equations that assist in water management in vegetated open channels.

Keywords: Rigid bank vegetation, Water depth, Heading up, Head losses, Empirical equations.

1. INTRODUCTION

Behind the advantages of sided vegetation from increases bank stability, reduces erosion, provides habitat for aquatic life, and filters pollutants [1, 2], its excessive existence of it causes many hydraulic problems. Such as water velocity reduction, water level rising, decrease water flow, un-efficient water distribution, etc. [3, 4].

Many experimental studies [5-12] studied the effect of sided vegetation on velocity distribution and they agreed that increasing vegetation density at the channel side led to increasing the velocity at the main channel and reducing it near the channel side. On the other hand, few studies focused on the effect of sided vegetation on the water levels in open channels.

[10, 13] physically studied the effect of sided flexible vegetation on water surface profile, and concluded that water surface profile decreased within vegetation compared to the smooth case, in addition, to increasing energy losses due to vegetation. [13] Examined the effect of sided flexible vegetation density and concluded that there is no significant effect of the vegetation density on the water surface profile. So he deduced one manning equation for all vegetation densities as follows;

$$n_{eq} = 0.08\,(VR)^{0.30} \quad \text{Two}-\text{sided vegetation} \qquad (1)$$

$$n_{eq} = 0.02\,(VR)^{0.001} \quad \text{One}-\text{sided vegetation} \qquad (2)$$

Where n_{eq} = equivalent manning coefficient, V= average velocity (m/sec) and R = hydraulic radius (m).

[2] Experimentally deduced a water depth-discharge relationship for flow through different rigid emergent vegetation densities. It concluded that for the same discharge, the vegetation density has a direct relationship with the water depth upstream of the vegetated reach.

[14, 15] experimentally studied the effect of rigid vegetation distributed in a channel's bed on water level and concluded that the water level rose upstream of the vegetation patch and then lowered through it. [15] Proposed a water surface slope equation in terms of vegetation density as follows;

$$J_s = 0.0463\,\rho_i^2 + 1.9807\,\rho_i + 0.1792 \qquad (3)$$

Where J_s = water surface slope and ρ_i = integrated vegetation density.

Most studies focused on the impact of aquatic vegetation on velocity distribution a few of them were interested in its impact on water surface pro file, although, its importunacy in water management. So this paper is mainly to discuss the effect of rigid sided vegetation on change of water levels in terms of heading up and head losses.

Before the simulation of the rigid vegetation was done, a review for the previous simulations was done, [16- 24] presented the rigid vegetation using different materials, diameter and distribution. Finally, the experimental work was done under subcritical flow at different discharge and vegetation densities in trapezoid open channels.

2. EXPERIMENTAL PROGRAM

Experiments were performed in the hydraulic laboratory of Channel Maintenance Research Institute (CMRI) - sponsored by the National Water Research Center (NWRC). The experimental work was conducted in a recirculating lining trapezium flume with a horizontal bed, 0.6-m wide, 0.42-m deep, and 16-m long. The discharges were measured using Current-Flow-Meter (Fig.1 (a)) and the water depth was controlled using an end tailgate.

A summary review of the previous rigid vegetation simulation was done as shown in Table1. According to it, vegetation stems were represented in this study by 3 mm diameter steel rods set in a staggered grid pattern. Stems are distributed with a spacing of (2.50, 5.00 and 7.50 cm) in both the longitudinal and transversal directions, achieving three densities of vegetation (λ= 0.0113, 0.0028, and 0.0013). Vegetation was distributed to simulate one- and two-sided vegetation channels (Fig.2) with a fixed reach length of 4.00 m located at the center of the flume.

The effect of vegetation densities on heading up and head losses were tested using four different discharges (25, 30, 35, 40 lit/s) and three different tail water depths which related to three ranged Froude number for the unvegetated case (Fr_o); Fr_o = 0.11 to 0.15; Fr_o = 0.15 to 0.20 and Fr_o = 0.21 to 0.30, as shown in Table 2.

Through the 84 runs water depths were measured every 0.50 m along the artificial canal's centerline using an ultrasonic level meter (Sondar) as shown in Fig.1 (b).

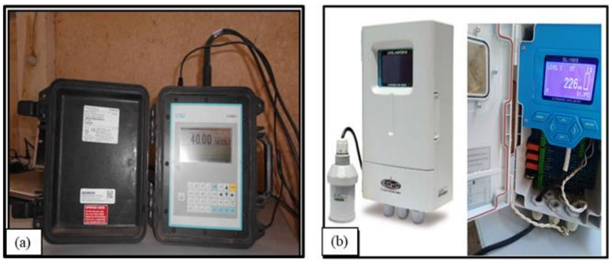


Fig 1. The experimental tools. (a) Current flow meter and (b) Ultrasonic level meter (Sondar).

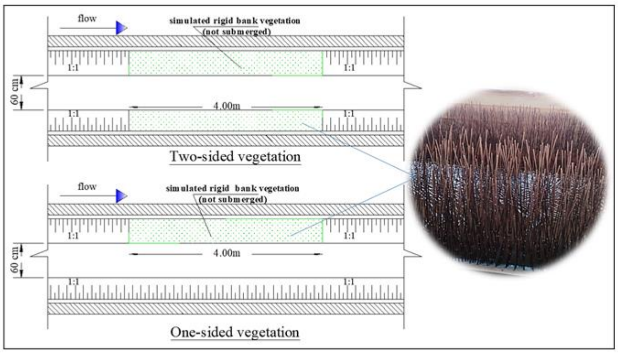


Fig 2. *The artificial canal, rigid* vegetation on the channel side slopes (a) Two-sided vegetation and (b) One-sided vegetation.

Table 1. Summary review of rigid vegetation simulations

Authors	**Stem simulation**				
	Shaped		**Diameter (mm)**	**Spacing (Δx)**	**Distributio**
[16]		Wood	3.18, 6.35 and	3.8, 4.6 and 7.6	Staggered
[17]		Steel	5	2.5, 5, and 7.5 cm	Staggered
[18]		Metallic	3	10 cm	Linear
[19]		Stainless	10	3.2 to 20.3 cm	Staggered
[20]		Steel	3.2, 6.6 and 8.3	3 and 6 cm	Staggered
[21]		Iron	6.5	10 cm	Both linear
[22]		PVC	10	22.72, 11.9, and	Linear
[23]		PVC	6	Random Distribution	
[24]		PVC	8	10 cm	Linear
Current	cylindrical	Steel	3	2.5, 5, and 7.5 cm	Staggered

Table 2. Experimental setup

	Vegetation properties			Flow condition	Passing discharge (Q)	(Tail water depth)**	N^{O} of runs
	arrangement	Spacing (cm)	density (λ)				
Non-vegetation	-----------------	-----------	----------	Sub-critical	40,35,30,25 l/s	Three different depths for each discharge	12
High vegetation density	Staggered One- and Two-side vegetation channel		0.0113		40,35,30,25 l/s		24
Medium vegetation density			0.0028		40,35,30,25 l/s		24
Low vegetation density			0.0013		40,35,30,25 l/s		24
Total Number of Runs							84

**The tail water depths are related to three Froude number ranges for the unvegetated case (Fr_o); 1. $Fr_o = 0.11$ to 0.15; 2. $Fr_o = 0.15$ to 0.20 and 3. $Fr_o = 0.21$ to 0.30.

3. DIMENSIONAL ANALYSIS

Dimensional analysis is used in the derivation of a general equation to compute the change in the water depths as a function in the vegetation density and the flow parameter before infestation.

The following function was obtained using Buckingham's – theorem, using water depth (Y_o)and velocity ($\bar{u}$) that were measured in the unvegetated case, in addition to fluid density (ρ) as repeated variables. Figure 3 shows a definition sketch of the dimensional parameter.

$$f\left(\frac{Y_u}{Y_o}, \frac{Y_d}{Y_o}, \lambda, \frac{gY_o}{\bar{u}}\right) = 0 \qquad (4)$$

The finally obtained hypothetical relationships may be written as follow:

$$\left(\frac{(Y_u - Y_o)}{Y_o} * 100, \frac{(Y_u - Y_d)}{Y_o} * 100\right) = (h_u\%, h_L\%) = f(\lambda, Fr_o) \qquad (5)$$

Where, (Y_u) is the average water depth measured upstream the vegetation reach (m)(Y_u measured upstream at a distance equal to 25% from the vegetation length to avoid the flow turbulence), (Y_d) is the water depth measured just downstream the vegetated reach (m), (Y_o) is the water depth in the unvegetated case (m), h_u% is the upstream heading up percentage, h_L% is the head losses percentage (λ) is the vegetation density (the cross-sectional area of cylinders (stems) per unit bank area, $\lambda = \Pi N^0 d^2/4$, where N^0 is the number of stems per unit side area and (d) is the stem diameter in m), and (Fr_o) is the Froude number in unvegetated case $Fr_o = \bar{u}/\sqrt{gY_o}$ where $\bar{u}$ is the average velocity in the unvegetated case (m/s) and (g) is the gravitational acceleration (m/s^2).

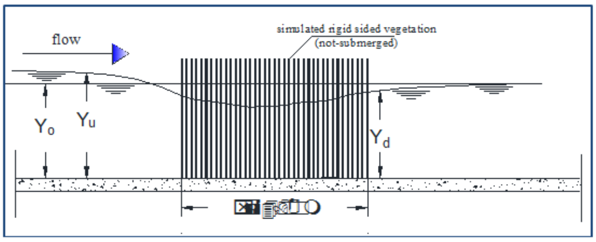
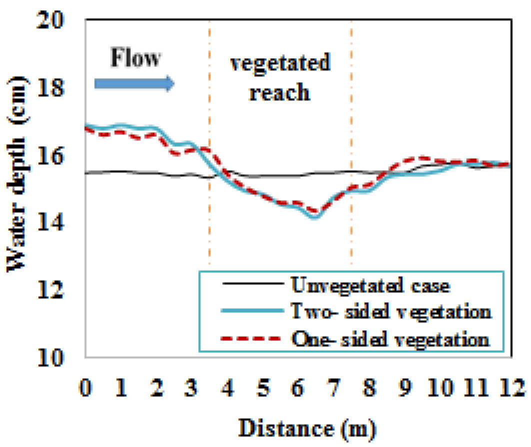


Fig 3. Definition sketch of the dimensional parameter.

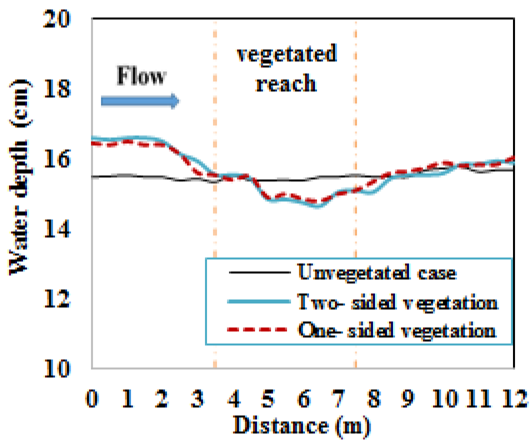
4.RESULT AND ANALYSIS

4.1 Effect of bank vegetation on water surface profile

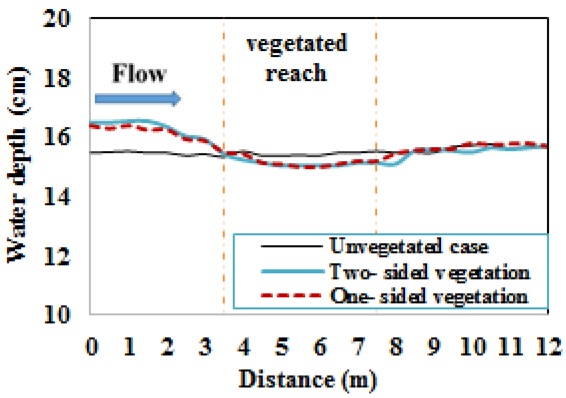
The water surface profile along the centerline of the flume was surveyed by an ultrasonic level meter. Figure 4 shows a comparison between water surface profiles for both one- and two-side rigid vegetation at different vegetation densities.



(High density)



(Medium density)



(Low density)

Fig 4. Water surface profile through sided vegetating channel at the same discharge (Q= 40 l/s) $Fr_o = 0.30$, with different densities.

Figure 4 shows that for both one- and two-sided rigid vegetation the water profile takes the same attitude. Where it raised upstream the vegetated reach then it lowered within it and gradually backed to the normal depth downstream the vegetated reach. This observation agreed with the previous studies [10-15]. From this result, it can say that sided vegetation acts as an obstacle to the flow, causing an increase in the flow resistance upstream it, thus the water depth increased. Following losses in energy, the water depth lowered within the vegetated reach.

Also, it is observed that vegetation density is a significant factor in changing the water depths. This result is agreeing with [2] but disagrees with [13] the reason may be back to the effect of the vegetation stiffness. Where [13] used flexible vegetation and this result is based on rigid vegetation simulation.

From the previous results, it can be concluded that the existence of bank vegetation gives un-accurate indicators for the water levels, which affect negatively the decisions of the water management process in the irrigation open channels

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4.2 Effect of Froude number on the water heading up (h_u %)

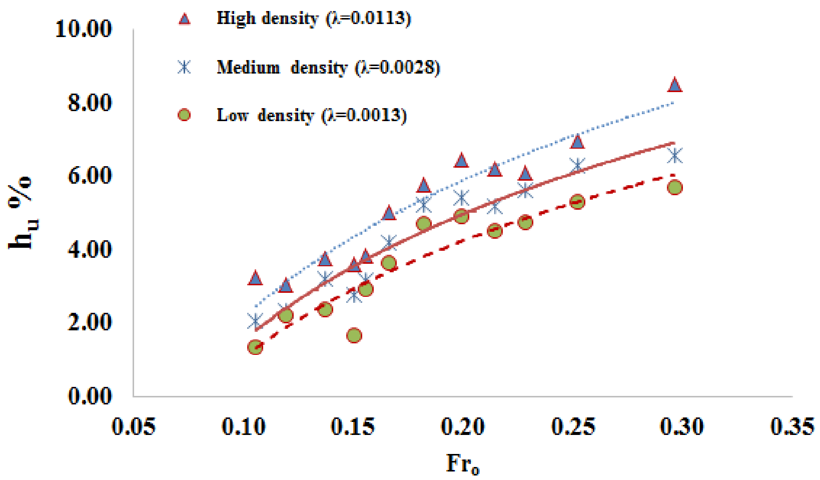
The upstream heading up percentage represents the percentage of the increase of water depth at the upstream cross section due to side vegetation, (h_u % =100x (Y_u – Y_o)/Y_o). The effect of Froude number (Fr_o) on h_u% is examined for different vegetation densities (Fig.5).

Figure 5 concluded that, heading up increased with increasing vegetation density and the Froude number. Also, it is noted that for two-sided high vegetation density the h_u % is higher than the medium density by about 27% and 44% compared to the low density. While for the One-sided vegetation the percentages are 20% and 40% compared to medium and low density respectively.

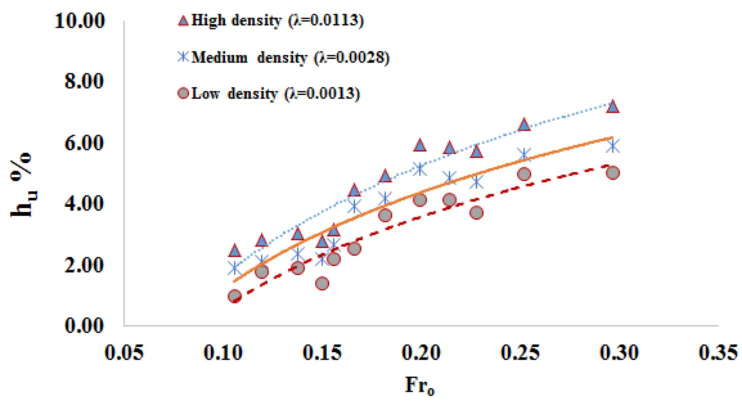
By calculations, it is observed that the effect of the Two- sided vegetation on the heading up is more than one- sided vegetation. But to ensure that there is a significant variance between Two-sided and one-sided vegetation, a paired t-Test with confidence level 95% was done using Microsoft excel for more verification (see Table 3).

The paired t-Test aims to compare the mean of the heading up results due to both the two-and – the one sided vegetation, where the test hypotheses;

- The null hypothesis = All groups have the same mean ($H_{0:}\ \mu_1=\mu_2$).
- The alternative hypothesis $=H_l=$ The two groups means are significantly different from each other, ($H_{1:}\ \mu_1 \# \mu_2$).



(Two-sided vegetation)



(One-sided vegetation)

Fig 5. Relation between upstream heading up and Froude number.

Table 3. The significant variance of the effect of the different vegetation distribution on h_u%.

Vegetation	**Vegetation distribution**	**t Stat**	**t Critical**	**p-Value**	***Variance***
High (λ=0.0113)	Two-sided vegetation	7.21	1.80	0.00	*Significant*
	One-sided vegetation				
Medium (λ=0.0028)	Two-sided vegetation	6.23	1.80	0.00	*Significant*
	One-sided vegetation				
Low (λ=0.0013)	Two-sided vegetation	6.12	1.80	0.00	*Significant*
	One-sided vegetation				

Table 3 shows that; for all densities (p-Value) <0.05 and t (stat) > t critical. This means that, the alternative hypothesis achieved and there is a large significant difference between the effect of the two-sided and the one-sided vegetation on the upstream heading up

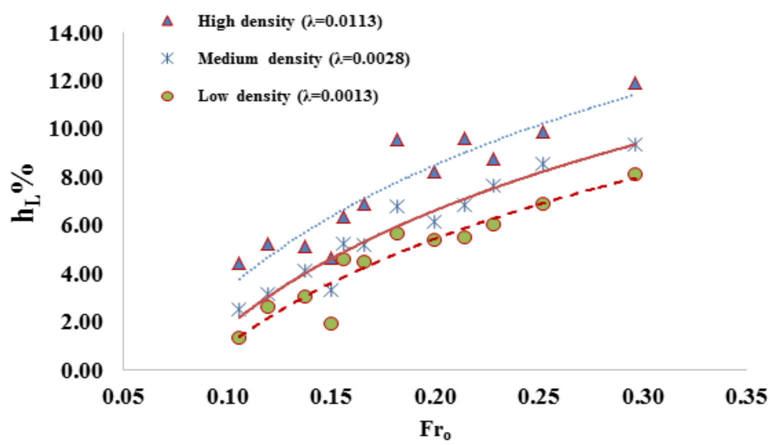
4.1 Effect of Froude number on the water head losses (h_L %)

The head losses percentage represents the percentage of the difference between upstream and downstream water depth (h_L % =100x $(Y_u - Y_d)/Y_o$). The relationships between head losses percentage and Froude number (Fr_o) at different vegetation densities are represented in Fig.6 for both one- and Two-side rigid vegetation.

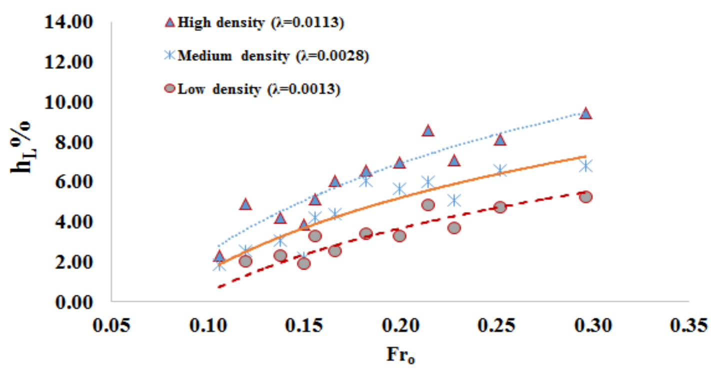
Figure 6 concluded that, the head losses increased with increasing vegetation density. It is observed that for Two-sided high vegetation density the h_L % is higher than the medium density by about 32 % and 50 % compared to the low density. While for the One-sided vegetation the percentages are 23 % and 48 % compared to medium and low density respectively.

A paired t-Test with confidence level 95% was done was done to verify if there is a significant variance between Two-sided and one-sided vegetation (see Table 4). The t- Test hypotheses;

- The null hypothesis = (H_0: $\mu_1=\mu_2$).
- The alternative hypothesis =(H_l= $\mu_1 \# \mu_2$).



(Two-sided vegetation)



(One-sided vegetation)

Table 4. The significant variance of the effect of the different vegetation configurations on h_L%.

Vegetation density	Vegetation distribution	t Stat	t Critical	p-Value	*Variance significant*
High (λ=0.0113)	Two-sided vegetation	6.60	2.20	0.00	*Significant*
	One-sided vegetation				
Medium (λ=0.0028)	Two-sided vegetation	5.64	2.20	0.00	*Significant*
	One-sided vegetation				
Low (λ=0.0013)	Two-sided vegetation	7.17	2.20	0.00	*Significant*
	One-sided vegetation				

Table 4 indicates that; for all densities (p-Value) <0.05 and t (stat) > t critical. This means that, the alternative hypothesis achieved and there is a large significant difference between the effect of two-sided and one-sided vegetation on the head losses.

4.2 Empirical Relationships

To establish an empirical equation between the dependent variables and more than one independent variable, a multiple regression analysis was done using Statistical software packages [Data fit 9 software]. The regression was performed using 95% as a confidence level. And the adjusted R^2 value was used as a measure of goodness of fit, where the Predicted R^2 indicates how well the model predicts responses for new observations.

4.2.1 The relation between side vegetation density (λ) and the water heading up ratio (h_u%)

An empirical equation was developed to assess understanding the impact of side vegetation density on increasing water depth upstream the vegetation reach (h_u%).

For Two-side vegetation

$$h_u\% = \left(\frac{(Y_u - Y_o)}{Y_o}\right) * 100 = 12.31 + 136.77(\lambda) + 4.97 \ln Fr_o \quad (6)$$

$R^2 = 0.90$

For one-side vegetation

$$h_u\% = \left(\frac{(Y_u - Y_o)}{Y_o}\right) * 100 = 11.29 + 134.23(\lambda) + 4.71 \ln Fr_o \quad (7)$$

$R^2 = 0.89$

All contributing factors were found to be significant predictive factors, where all factors had p-values <0.0001. Figure 7 shows the plot between predicted and measured heading up due to vegetation, which show that, there is a good fitting quality for the experimental data.

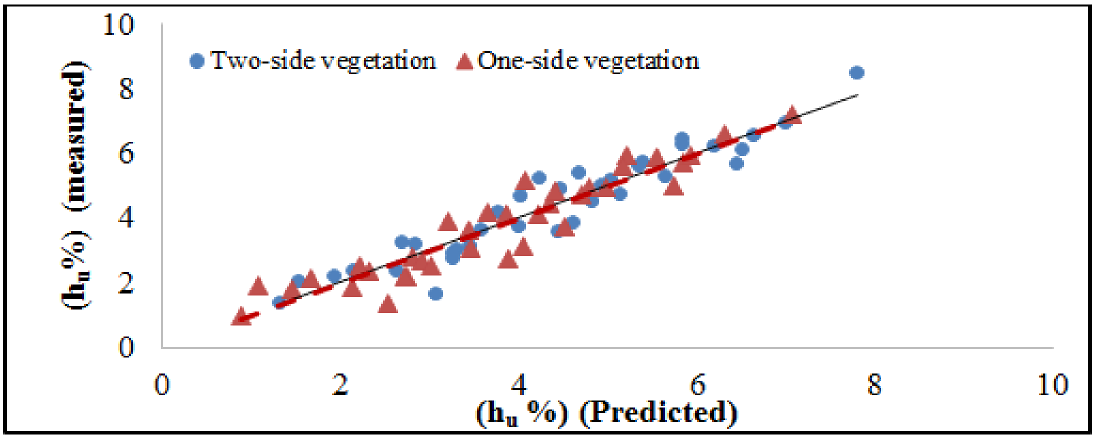


Fig 7. Comparison between measured and predicted heading up.

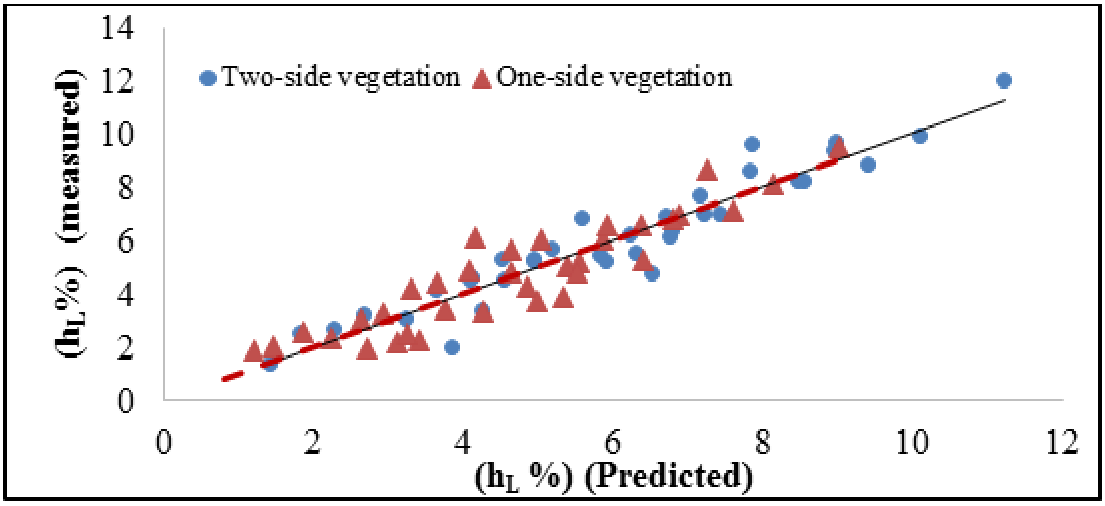


Fig 8. Comparison between measured and predicted head losses.

4.2.2 The relation between side vegetation density (λ) and the water head losses ratio (h_L%)

An empirical equation was developed to assess understanding the impact of side vegetation density on increasing water depth upstream the vegetation reach (h_u%).

For Two-side vegetation

$$h_L\% = \left(\frac{(Y_u - Y_d)}{Y_o}\right) * 100 = 16.65 + 266.16(\lambda) + 6.92 \ln Fr_o \quad (8)$$

$R^2 = 0.90$

For one-side vegetation

$$h_L\% = \left(\frac{(Y_u - Y_d)}{Y_o}\right) * 100 = 12.68 + 261.66(\lambda) + 5.43 \ln Fr_o \quad (9)$$

$R^2 = 0.85$

All contributing factors were found to be significant predictive factors, where all factors had p-values <0.0001. Fig.8 shows the plot between predicted and measured heading up due to vegetation, which show that, there is a good fitting quality foe the experimental data.

5.CONCLUSIONS

The research was carried out to study the effect of rigid sided vegetation on water depth in terms of heading up and head losses, under sub-critical flow at different discharges, and vegetation density in trapezoid open channel. Which concluded the following: -

- The rigid sided vegetation obstructs the flow, causing a change in the behavior of the water surface profile. Where the flow resistance increased upstream the vegetated reach, thus the water depth increased. Following energy losses, the water depth lowered through the vegetated reach.
- The Heading up and head losses are a function in the vegetation density and Froude number and they have a direct relationship with them.
- Observationally and statically, the effect of the two-sided vegetation has the more significant influence on increasing the upstream heading up and the head losses than one-sided vegetation.
- For the two-sided vegetation, the heading up caused by the high density is higher than the medium density by about 27% and 44% for the low density. While for the one-sided vegetation the percentages are 20% and 40% compared to medium and low density respectively.
- For the two-sided vegetation, the head losses caused by the high density is higher than the medium density by about 32% and 50% for the low density. While for the one-sided vegetation the percentages are 23% and 48% compared to medium and low density respectively.
- Multiple regression analysis and empirical equations were presented to assess understanding of the impact of the sided vegetation density on the heading up and the head losses (Equations (6- 9)).
- According to the estimated heading up and head losses, a maintenance program should be done to the sided vegetation to keep water levels within requirements.

6. RECOMMENDATIONS FOR MANAGEMENT THE VEGETATED CHANNEL

- the existence of sided vegetation gives un-real indicators for the water levels, which affect negatively the decisions of the water management process in the irrigation open channels. Where water level is the main tool in water management in irrigation channels, so any change in it will affect directly water distribution to branches, opening gate calibration, free flowing of drainage collectors, else.
- The research represented four equations (Equations (6-9)) asses to estimate the change in the water level as a function in the Froude number and the vegetation density.
- Consequently, to the previous point, management of the vegetation density should be done to keep the water level at a level where it doesn't cause any hydraulic problem and economic damage.

7. ACKNOWLEDGMENTS

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REFERENCES

[1] X. Liu, L. Tang, Y. U. Han, J. Chen, and S. Yang, “Experimental Study on Flow Resistance Over Rigid Vegetated Channel,” *IEEE Access*, 2019, vol. 7, pp. 93974–93985, doi: 10.1109/ACCESS.2019.2927691.

[2] A. Hamimed, L. Nehal, M. M. Benslimane, and A. Khaldi, “Contribution To The Study Of The Flow Resistance In A Flume With Artificial Emergent Vegetation,” *Larhyss Journal*, 2013, ISSN 1112-3680, pp. 55–63.

[3] M. A. M. Abdeen, “Predicting the impact of vegetations in open channels with different distributaries’ operations on water surface profile using artificial neural networks,” *J. Mech. Sci. Technol.*, 2008, vol. 22, no. 9, pp. 1830–1842, doi: 10.1007/s12206-008-0510-x.

[4] G. Abdel-aal, A. Habib, A. Ali, and M. Shaheen, “Effect of Submerged Weeds on Water Flow in Open Channels,” *Egypt. J. Eng. Sci. Technol.*, 2014, vol. 17, no. 1, pp. 195–213, doi: 10.21608/eijest.2014.97009.

[5] H. Afzalimehr and S. Dey, “Influence of bank vegetation and gravel bed on velocity and Reynolds stress distributions,” *Int. J. Sediment Res.*, Jun. 2009, vol. 24, no. 2, pp. 236–246, doi: 10.1016/S1001-6279(09)60030-5.

[6] P. M. Hirschowitz and C. S. James, “Conveyance estimation in channels with emergent bank vegetation,” *Water SA*, 2009, vol. 35, no. 5, [Online]. Available: http://www.wrc.org.za.

[7] H. Afzalimehr, E. Fazel Najfabadi, and V. P. Singh, “Effect of Vegetation on Banks on Distributions of Velocity and Reynolds Stress under Accelerating Flow,” *J. Hydrol. Eng. © ASCE*, 2010, doi: 10.1061/ASCEHE.1943-5584.0000229.

[8] N. M. Czarnomski, D. D. Tullos, R. E. Thomas, and A. Simon, “Effects of Vegetation Canopy Density and Bank Angle on Near-Bank Patterns of Turbulence and Reynolds Stresses,” *J. Hydraul. Eng.*, Nov. 2012, vol. 138, no. 11, pp. 974–978, doi: 10.1061/(asce)hy.1943-7900.0000628.

[9] M. Masouminia, “The Simulation of the Effect of Rigid Bank Vegetation on the Main Channel Flow,” *MSc Thesis*, Eastern Mediterranean University, Gazimağusa, North Cyprus, 2015.

[10] N. Mohammadzade, H. Afzalimehr, V. P. Singh, and N. M. Miyab, “Experimental Investigation of Influence of Vegetation on Flow Turbulence,” *Int. J. Hydraul. Eng.*, 2015, vol.no. 3, pp. 54–69, 2016, doi: 10.13140/RG.2.1.5017.5441.

[11] D. Liu, M. Valyrakis, and R. Williams, “Flow Hydrodynamics across Open Channel Flows with Riparian Zones: Implications for Riverbank Stability,” *Water*, Sep. 2017, vol. 9, no. 9, p. 720, doi: 10.3390/w9090720.

[12] O. M. Eraky, M. A. R. Eltoukhy, M. S. Abdelmoaty, and E. Farouk, “Effect of rigid, bank vegetation on velocity distribution and water surface profile in open channel,” *Water Pract. Technol.*, 2022, vol. 17, no. 7, pp. 1445–1457, doi: 10.2166/wpt.2022.068.

[13] T. A. El-Samman, “Flow characteristics of vegetated channels,” *P.H.D. Thesis, Ain Shams Univ. Cairo, Egypt*, 1995.

[14] H. Zhang, “Determination of Emergent Vegetation Effects on Manning ’ s Coefficient of Gradually Varied Flow,” *IEEE Access*, 2019, vol. 7, pp. 146778–146790, doi: 10.1109/ACCESS.2019.2946917.

[15] Y. Wu, H. Jing, C. Li, and Y. Song, “Flow characteristics in open channels with aquatic rigid vegetation,” *Journal of Hydrodynamics*, 2020, vol. 32, no. 6, pp. 1100–1108, 2020.

[16] B. M. Stone and H. T. Shen, “Hydraulic Resistance of Flow in Channels with Cylindrical Roughness,” *J. Hydraul. Eng.*, 2002, vol. 128, no. 5, pp. 500–506, doi: 10.1061/(asce)0733-9429(2002)128:5(500).

[17] C. S. James, A. L. Birkhead, A. A. Jordanova and J. J. O’Sullivan, “Flow resistance of emergent vegetation,” *J. Hydraul. Res., 2004, 42 390-398*.

[18] M. Ben Meftah, F. De Serio, D. Malcangio, A. F. Perrillo, and M. Mossa, “Experimental study of flexible and rigid vegetation in an open channel,” *Proc. Int. Conf. Fluv. Hydraul. - River Flow 2006*, vol. 1, pp. 603–611, doi: 10.1201/9781439833865.ch62.

[19] U. C. Kothyari, K. Hayashi, and H. Hashimoto, “Drag coefficient of unsubmerged rigid vegetation stems in open channel flows,” *J. Hydraul. Res.*, 2009, vol. 47, no. 6, pp. 691–699, doi: 10.3826/jhr.2009.3283.

[20] N.-S. Cheng and H. T. Nguyen, “Hydraulic Radius for Evaluating Resistance Induced by Simulated Emergent Vegetation in Open-Channel Flows,” *J. Hydraul. Eng.*, 2011, vol. 137, no. 9, pp. 995–1004, doi: 10.1061/(asce)hy.1943-7900.0000377.

[21] K. Panigrahi, “Experimental Study of Flow Through Rigid Vegetation in Open Channel,” *MSc Thesis, National Institute of Technology, Rourkela, Odisha, India*, 2015.

[22] M. Ahmed and A. Hady, “Evaluation of Emergent Vegetation Resistance and Comparative Study Between Last Descriptors,” *Control Sci. Eng.* , 2017, vol. 1, no. 1, pp. 1–7, doi: 10.11648/j.cse.20170101.11.

[23] P. Chakraborty and A. Sarkar, “Study of flow characteristics within randomly distributed submerged rigid vegetation,” *J. Hydrodyn.*, 2018, vol. 31, no. 2, pp. 358–367, doi: 10.1007/s42241-018-0132-4.

[24] X. Tong *et al.*, “Hydraulic features of flow through local non- submerged rigid vegetation in the Y-shaped confluence channel,” *Water (Switzerland)*, 2019, vol. 11, no. 1, doi: 10.3390/w11010146.