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Research Article

Evaluation of the Effect of Vegetation on Free Surface Flow Behavior

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Keywords

Numerical modeling,
Flow 3D,
Channel with vegetation,
Flood,
Free Surface Flow Behavior.

Abstract

The presentation of appropriate patterns and standards for vegetative cover planting for the management and efficient use of aqueducts, streams, and rivers in order to reduce the risk of flooding, undesired soil erosion and optimal utilization of water resources, so as to respond to current and future needs, is of high importance. In this research, the effects of vegetative cover on the flow regime were studied through modeling using FLOW 3D software. 18 models were generated with different plant densities and inflow velocities in the modeling software and the results of the modeling were compared after plotting the velocity profiles, average velocity, and channel height. The results showed that the impact of vegetative cover on performance will be different depending on the type of inflow velocity.

1. Introduction

One of the essential conditions for protecting waterways and rivers is to clean up the vegetation because vegetation coverage has a significant impact on the flow of channels and rivers. Vegetation coverage has many benefits, including sedimentation control and increased resistance to soil erosion in riverbeds, preventing soil erosion and reducing the flow rate and energy of the flow [1].

The presence of vegetation can have a significant impact on the severity and frequency of floods. Trees, bushes, and other vegetation help to absorb water, reducing the amount of runoff that can lead to flooding. This can be especially important in urban areas, where large amounts of impervious surfaces such as roads and parking lots can increase the risk of flooding. In addition to providing flood control benefits, vegetation can also help to reduce erosion and improve water quality, making it an important consideration in transportation and infrastructure planning.

For this purpose, planting vegetation and forests on the outskirts of cities is used to reduce the energy of floods and reduce damage. In recent decades, the impact of vegetation coverage on waterways and rivers and the hands have received special attention in managing floods and surface and river flows. The most significant factors are the Manning coefficient, and vegetation coverage is considered one of the most significant parameters for determining the Manning coefficient. As a result, the Manning coefficient changes based on changes in vegetation coverage in different parts of the year.

Vegetation on the margins and wide plates of rivers slows down the flow and aggravates flood conditions. The effect of different conditions and characteristics of vegetation in rivers on flow resistance is a subject that has been mentioned in numerous articles and researches. In recent years, due to floods, especially in Europe, river and waterway reconstruction projects have become very important. The reconstruction of the river and earthen canals is related to the investigation of the effect of vegetation, bushes and trees on the hydraulic performance of the waterway. In natural

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channels, vegetation causes energy loss by creating disturbance around plant stems and leaves and creates resistance to water movement. In general, the success of the use of vegetation depends on the conditions of the river and the severity of the degradability of the walls, the triple position of the wall surface, the type of plant, the variety and composition of the vegetation, the method of planting and biological stabilization, and the maintenance management of the vegetation [2, 3].

One of the most important issues in the management and protection of rivers, waterways and canals is to predict their hydraulic behavior with different planting patterns and to know the most effective and economical pattern of planting plants to reduce the destructive effects of sedimentation and water washing. Various researches have been carried out regarding the hydraulic conditions of the flow under the influence of the bed conditions. The first research to determine the relationships between the hydraulic roughness of the flow with the depth and speed of the flow, as well as the type and height of the vegetation, was started in the laboratory of the Soil Conservation Organization of the State of South Carolina located in the city of Spartag, USA [4].

Järvelä [5] studied the flow resistance caused by different combinations of natural covers of grass, lily bushes and willow trees in submerged and non-submerged conditions in a laboratory flume. The obtained results showed a great difference in friction coefficient with flow depth, velocity, Reynolds number and vegetation density. The leaves on the willow tree increase the friction coefficient two or three times compared to the leafless state. In a research, Ruei Ke, et al. [6] investigated the effect of bank vegetation on changes in the river bed, flow characteristics and changes in the river bed when water passes through the bank vegetation and came to the conclusion that when the flow passes through the vegetation The inflow is slower in the vegetation area along the channel wall and accelerates in the main channel part. The flow velocity decreases downstream of the vegetated area. Also, in the downstream of the vegetation area, the level of sedimentation and sedimentation decreased with the increase in vegetation density, and near the vegetation, the sink hole increased with the increase in vegetation density.

Nehal, et al. [7] investigated the effect of non-submerged vegetation on flow resistance using Calmus Acorus plant. This research was conducted in a rectangular laboratory flume with a length of 22 meters, a height of 0.7 meters and a width of 7.1 meters and a floor slope of 7%. To roughen the floor of the flume, a thick layer of 52 meters long and two centimeters thick was used. The results of the research indicate that the relationship between flow depth and discharge is significantly dependent on the vegetation density, so that the vegetation creates a great resistance to the flow and thus has a great effect on the water level. Manning's roughness coefficient varies with flow depth and depends on vegetation density. The average speed decreases with the flow and then the growth roughness increases with the decrease in speed.

In areas where the flow passes through vegetation, the characteristics of the flow are largely determined by the type and density of the vegetation, as well as the depth and speed of the flow. The investigated issues related to flow resistance are classified into two groups: flow on short and submerged plants and flow on tall and non-submerged plants [8].

In the relationship presented by Freeman, et al. [9], it was shown that Manning's roughness coefficient is directly proportional to the area occupied by the plant, and in the presence of plant leaves, this area increases, and as a result, Manning's roughness coefficient increases. Vegetation in rivers can be submerged or semi-submerged. Submerged vegetation is usually planted at a low height such as grass or bushes. The effect of depth on flow resistance is different in submerged and non-submerged plant conditions. Freeman, et al. [6] concluded during the experiments that in the presence of flow, the plant bends and the depth of absorption reaches 80% of the plant height. Nikora, et al. [10] showed by comparing the parameters of aquatic plants that the ratio of the average height of the plant to the average depth of the stream and also the ratio of the length of the part covered by channel plants to the average depth of the stream are the best descriptors of roughness.

The method of conducting this research is in the form of research description and modeling, and it is aimed at reaching a practical answer based on the research done by Feizbahr, et al. [8]. The most important goal of this research is to investigate the effect of density and height of the vegetation, as well as the speed of the flow and the rate of the downstream flow, as well as the changes in the free surface of the flow.

2. Methodology

Flow-3D is one of the most important software in the field of water engineering and hydraulic structures. Flow-3D is a good alternative to physical models in solving problems of fluid mechanics and hydrodynamics. One of the capabilities of this program in the field of hydraulic analysis is its ability to use the Volume of Fluid (VOF) method in modeling free surface flows. Compared to other models in the field of computational fluid dynamics, the Flow-3D model has a wide range of applications and capabilities, and in addition, it is user-friendly and has a very strong graphical interface [11, 12].

In this modeling, a three-dimensional network with a real scale was used for the entire overflow and rapids. The number of cells used in this simulation is equal to 1955888 cells. The inlet boundary was introduced to the model as constant speed and depth. Due to the presence of supercritical flow, no parameters for the flow have been considered at the exit boundary. Absolute roughness for the floor and walls was introduced to the model. In this case, the flow was assumed to be non-viscous, and the entry of air into the flow was not considered. After 7.7×10^{-4} seconds, this model reached the convergence accuracy of 2.39×10^{-5}.

Due to the inability to model the vegetation in FLOW 3D software, in this research, the vegetation of the bushes has been simulated with rods with a diameter suitable for the conditions of the plant. In this model, the effect of plant height is also considered, and modeling can provide relatively acceptable results in these conditions.

18 models with inlet velocities proportional to the height of the regular semi-hexagonal channel were considered to create supercritical conditions, Manning's coefficients were

applied based on Chow's studies [13] and it was studied considering the concrete channel bed. Velocity profiles were drawn and analyzed.

Because the flow is critical after passing through the plant bed, for the best possible convergence of the results, the initial conditions are used to fulfill the above conditions. For the initial conditions, it is assumed that there is an inflow velocity and depth from the beginning of the calculation range to the plant bed, and the rest of the areas are considered dry. Flow boundary conditions apply only to the flow boundary. At the upstream boundary, velocity and water level are applied to the model. Due to the supercritical flow at the outlet boundary of rapid, no boundary conditions are applied to the model in this part and the flow parameters in this part are calculated by the software. The input flow is generated by applying the flow rate using the Volume Flow Rate (VFR) option, and the output flow is considered the Outflow, and the Symmetry option is considered for the other boundaries.

Table 1. Studied models.

Studied models	**Models name**	**Channel depth (m)**	**G**	**Hydraulic depth**	**Inlet velocity**	**Froude number**	**Vegetation height (cm)**	**Vegetation density %**	**Manning coefficient based on chow's study**
2 cm - 5%	Model 1	0.2	9.8	0.16	0.5	0.36	2	5	0.03
2 cm - 10%	Model 2	0.2	9.8	0.16	0.5	0.36	2	10	0.03
2 cm - 15%	Model 3	0.2	9.8	0.16	0.5	0.36	2	15	0.035
4 cm - 5%	Model 4	0.2	9.8	0.16	0.5	0.36	4	5	0.02
4 cm - 10%	Model 5	0.2	9.8	0.16	0.5	0.36	4	10	0.03
4 cm - 15%	Model 6	0.2	9.8	0.16	0.5	0.36	4	15	0.035
6 cm - 5%	Model 7	0.2	9.8	0.16	0.5	0.36	6	5	0.03
6 cm - 10%	Model 8	0.2	9.8	0.16	0.5	0.36	6	10	0.04
6 cm - 15%	Model 9	0.2	9.8	0.16	0.5	0.36	6	15	0.05
2 cm - 5%	Model 10	0.2	9.8	0.16	1	0.71	2	5	0.03
2 cm - 10%	Model 11	0.2	9.8	0.16	1	0.71	2	10	0.035
2 cm - 15%	Model 12	0.2	9.8	0.16	1	0.71	2	15	0.05
4 cm - 5%	Model 13	0.2	9.8	0.16	1	0.71	4	5	0.03
4 cm - 10%	Model 14	0.2	9.8	0.16	1	0.71	4	10	0.05
4 cm - 15%	Model 15	0.2	9.8	0.16	1	0.71	4	15	0.07
6 cm - 5%	Model 16	0.2	9.8	0.16	1	0.71	6	5	0.05
6 cm - 10%	Model 17	0.2	9.8	0.16	1	0.71	6	10	0.11
6 cm - 15%	Model 18	0.2	9.8	0.16	1	0.71	6	15	0.15

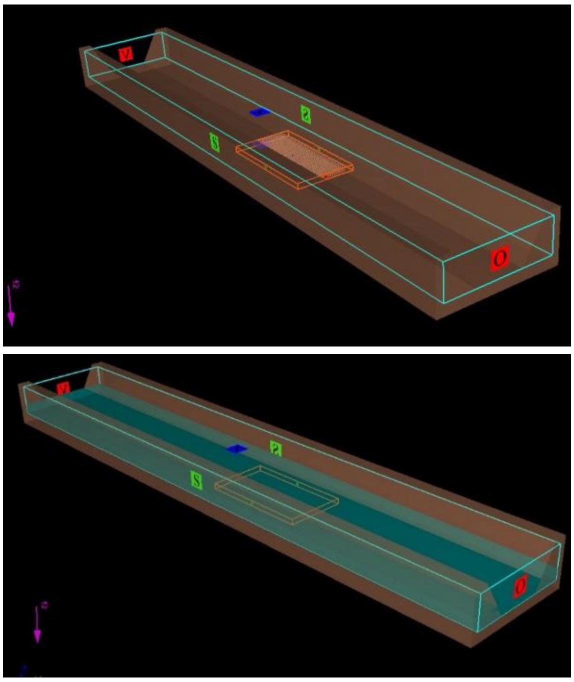

Figure 1. Modeling of channel and applying boundary conditions

3. Results and Discussion

After conducting experiments on the physical model and plants, the results were shown in the form of graphs. The total number of experiments in this research was 18, due to the limitations in modeling. To investigate the effects of vegetation, the trend of flow velocity changes at a constant depth and with 3 models of vegetation density and height at 2 different velocities has been obtained.

3.1. *Speed Counters*

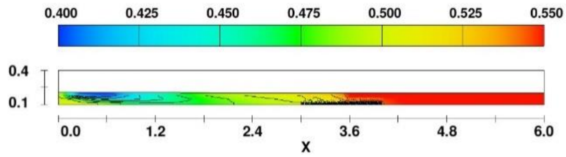

Figure 2. Velocity contour for Model 1

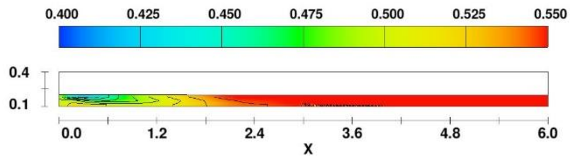

Figure 3. Velocity contour for Model 2

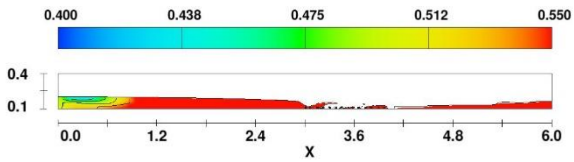

Figure 4. Velocity contour for Model 3

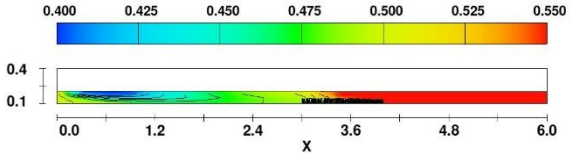

Figure 5. Velocity contour for for Model 4

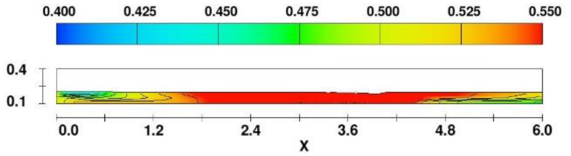

Figure 6. Velocity contour for Model 5

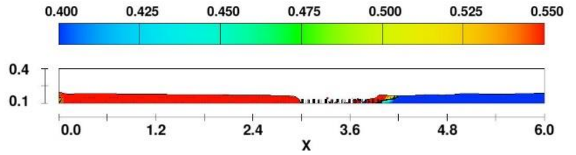

Figure 7. Velocity contour for Model 6

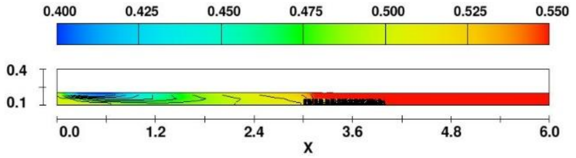

Figure 8. Velocity contour for for Model 7

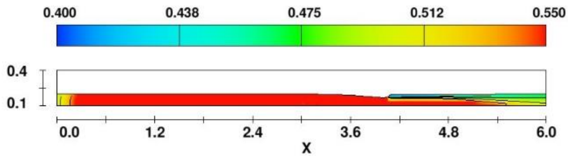

Figure 9. Velocity contour for Model 8

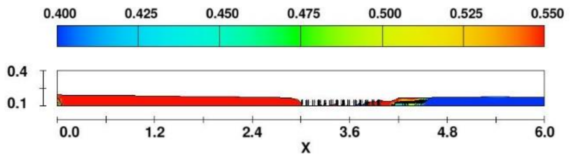

Figure 10. Velocity contour for for Model 9

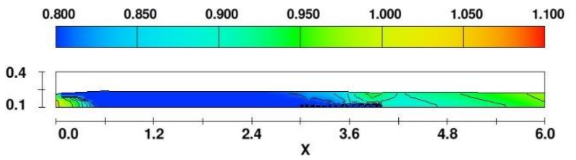

Figure 11. Velocity contour for Model 10

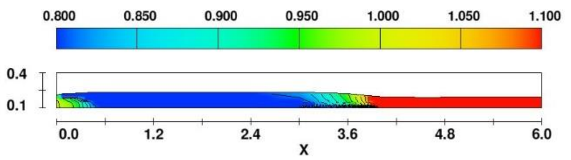

Figure 12. Velocity contour for for Model 11

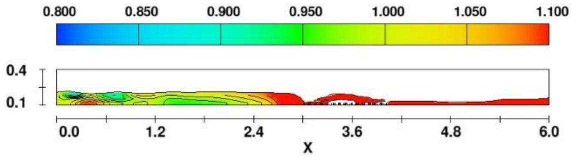

Figure 13. Velocity contour for Model 12

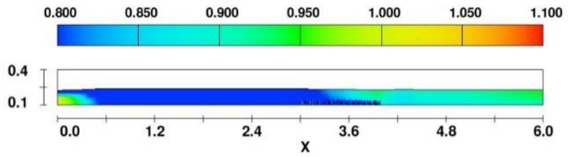

Figure 14. Velocity contour for for Model 13

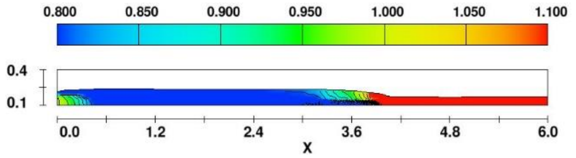

Figure 15. Velocity contour for for Model 14

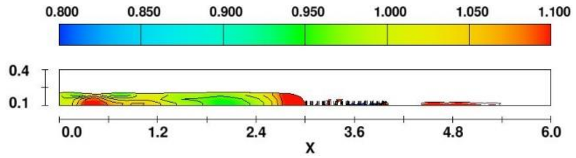

Figure 16. Velocity contour for Model 15

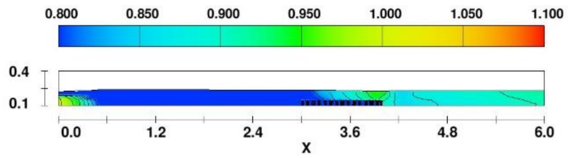

Figure 17. Velocity contour for Model 16

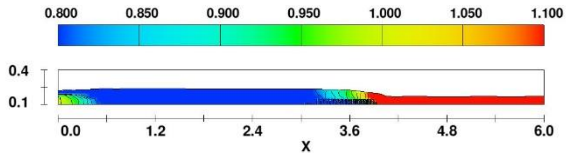

Figure 18. Velocity contour for Model 17

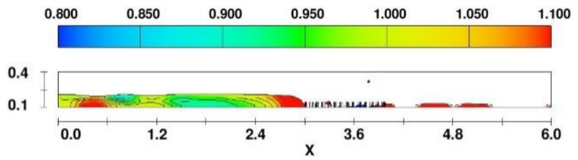

Figure 19. Velocity contour for Model 18

According to the above observations, it can be seen that in the vegetation with a density of 15%, with the increase of the water input speed, the water speed after the bed increases with the plant density. Of course, increasing the upgrade other than model 18 affects the speed rate. In model 18, the increase in height and density of 15% can be considered as an obstacle in the flow path, which causes a sharp increase in the speed downstream.

According to the above results, it can be concluded that with increasing speed, the effect of vegetation in reducing the speed of the stream becomes more noticeable. In general, it can be seen that with the increase in speed, the slope of the speed increase of the profiles increases from the channel bed to its surface, which is completely justified considering that in the software, the plant bed is entered only at the bottom of the channel. Of course, it can be mentioned that according to the modeling of vegetation with similar rods, this modeling can show acceptable results for these types of grasses on the bottom of the channel.

4. Conclusion

In this research, the effects of vegetation density and stream entry speed on the flow speed and free surface were modeled with FLOW 3D software, and the following conclusions were reached:

- The increase in the density of vegetation has different effects on the flow process due to the elevation and speed.
- The presence of an obstacle in the way of the flow causes the flow to change from a uniform state to a gradual or rapid variable flow.
- Fast variable currents are formed in a short part of the channel and have a small cross-section. Head drops in fast variable RVF flows are localized and occur due to severe turbulence.
- After meeting the bed with vegetation with a high rise and higher density, the flow becomes turbulent and rises at a speed of 05m/s, and the return of the flow increases the water level upstream.
- At high speed, the current passes through the vegetation, and despite the strong turbulence, the speed downstream increases noticeably. And as the density increases, this increase in speed is more noticeable.
- With the increase in speed, the effect of vegetation in increasing the speed of the flow becomes more noticeable.

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