# Numerical Modeling of Vegetated Flow by Considering Physical Vegetation Characteristics


Eun-kyung Jang[(1)], Myeonghui Ahn[(2)], Un Ji[(3)] & Inhyeok Bae[(4)]

(1) Korea Institute of Civil Engineering and Building Technology, Goyang-Si, Korea, e-mail jang@kict.re.kr
(2) Korea Institute of Civil Engineering and Building Technology, Goyang-Si, Korea, e-mail myeonghuiahn@kict.re.kr
(3) Korea Institute of Civil Engineering and Building Technology & Korea University of Science and Technology, Goyang-Si, Korea, e-mail jiun@kict.re.kr
(4) University of Science Technology, Goang-Si, Korea, email inhyeokbae@kict.re.kr



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## INTRODUCTION

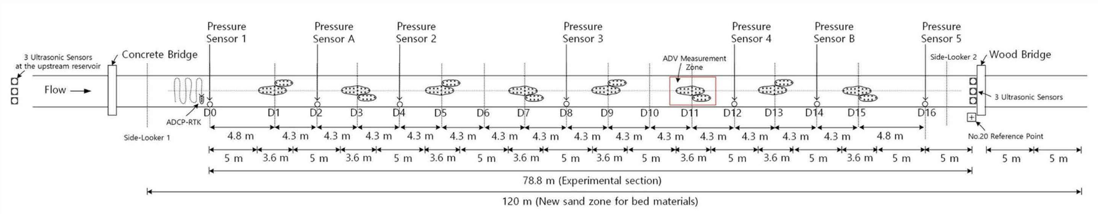
- Vegetation is an important factor in flow resistance and water level determination.
- Further, it plays a critical role in the physical, chemical, and biological processes of river systems (Aberle and Järvelä, 2013).
- Flow–vegetation interactions are known to affect sediment and solute transport, river topography, and ecology (Gurnel, 2014).
- Vegetation is generally used to artificially stabilize riversides, support the diversity of vegetation species, and serve as a buffer for riverbanks (Bunting et al., 2013).
- However, across the world, recent years have seen frequent and unpredictable flooding owing to global climate change.
- The excessive inflow of vegetation into river systems causes flood levels to rise abruptly and inflict damage.
- Therefore, there is an increasing need for accurately estimating vegetation-induced flow resistance (Jang et al., 2019).
- Therefore, this study analyzed the effectiveness of existing flow resistance formulas that consider the vegetation by comparing their results to the measured flow velocity in the stream-scale channel.
- This result can be used to obtain more accurate flow resistance values in numerical modeling.
- The results are applied to a two-dimensional numerical model for flow analysis that can estimate vegetation-induced flow resistance.

## METHODS

### Experiment

- Investigations on vegetated flows were performed at the Korea Institute of Civil Engineering and Building Technology–River Experiment Center (KICT-REC) in Andong, Korea.
- The REC can conduct real-scale tests with its three prototype channels (length: ~600 m, width: 11 m) and a large capacity pump facility (maximum flow rate: 10 m³/s)

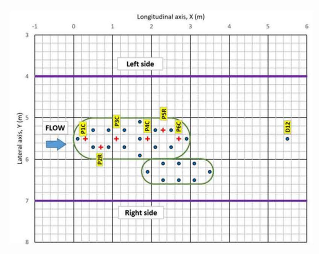

Large-scale outdoor flumes at KICT-REC (Lee et al., 2018)



Sketch of Vegetation Patches and Measurement Points (Ji et al., 2018)

- The channel section used was 120 m long with a trapezoidal cross section of 8-m width; the bank slope was 1:1.5 (V:H) and the bed slope was 1/1,000.
- Additionally, the artificial vegetation stem was 75 cm long and 2.3 cm in diameter.
- It had four small branches around the vegetation stem, and the number of leaves distributed among the stem and branches was 485.
- The leaves had an average length of 7.96 cm, a width of 1.88 cm, and an area of 15.04cm².
- For the flow velocity measurement, the MicroADV developed by SonTek was used with a sampling rate of 50 Hz and measuring time of 150s.

Vegetation Sample



Location of the Velocity Profile Measurement

### Delft3D and Flow Resistance

- This study used the Delft3D model for flow analysis by considering the vegetation effects.
- The bulk roughness coefficient for the section between D2 and D14 was measured using Chezy's equation.
- The most representative of existing relationships that consider the vegetation are those proposed by Baptist et al. (2007), Västilä and Järvelä (2014), and Luhar and Nepf (2013).

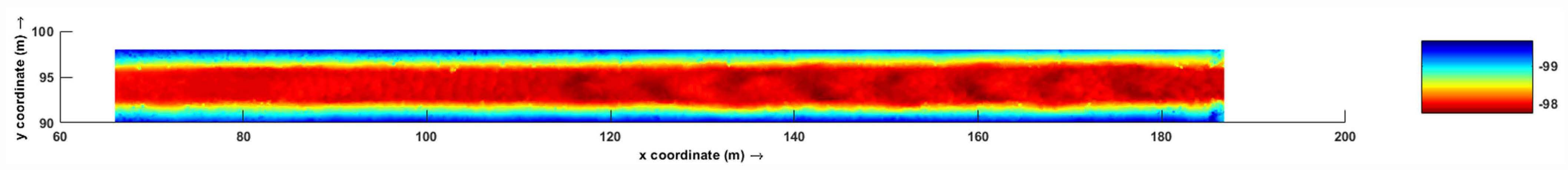
| Formula | Baptist et al. (2007) | Västilä and Järvelä (2014) | Luhar and Nepf (2013) |
|---|---|---|---|
| Conditions | Submerged condition (H>h): $C_r = \sqrt{\frac{1}{1/C_b^2 + C_D mDh/(2g)}} + \frac{\sqrt{g}}{\kappa}\ln\left(\frac{H}{h}\right)$ | Friction factor of foliage: $f_F'' = 4\frac{A_L}{A_B}C_{D\chi,F}\left(\frac{u_m}{u_{\chi,F}}\right)^{\chi F}$ | Overflow velocity: $U_o = \left(\frac{2gS(WH - wh)}{C_f L_b + C_v L_v}\right)^{\frac{1}{2}}$ |
| | Emergent condition ($H < h$): $C_r = \sqrt{\frac{1}{1/C_b^2 + C_D mDh/(2g)}}$ | Friction factor of stem: $f_S'' = 4\frac{A_S}{A_B}C_{D\chi,S}\left(\frac{u_m}{u_{\chi,S}}\right)^{\chi S}$ | In-patch velocity: $U_v = \left(\frac{2gSwh + C_v L_v U_o^2}{C_D awh}\right)^{\frac{1}{2}}$ |
| | If the flow resistance due to bed can be neglected: $C_r = \sqrt{\frac{2g}{C_D mDh}}$ | Friction factor of foliated vegetation: $f_{tot}'' = \frac{4}{A_B}\left[A_L C_{D\chi,F}\left(\frac{U}{U_{\chi,F}}\right)^{\chi F} + A_S C_{D\chi,S}\left(\frac{U}{U_{\chi,S}}\right)^{\chi S}\right]$ | Depth-averaged velocity: $U = U_o(1 - B_X) + U_v B_X$ |

Estimation Formulas for Vegetation Roughness

## MODELING RESULTS

### Modeling Conditions

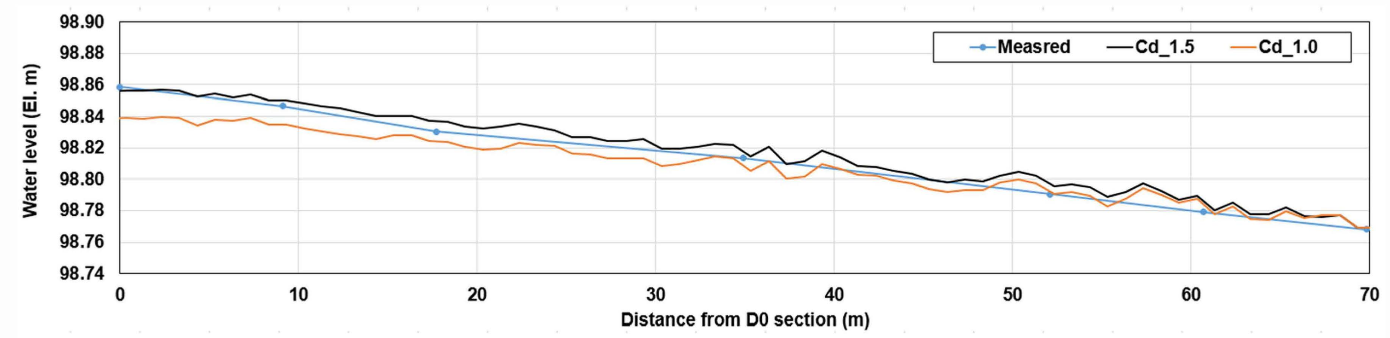
- The experimental channel section consisted of seven vegetation patches of artificial willow saplings placed in an alternate bar arrangement .
- A flow discharge of 2.805 m³/s was calculated with the measured velocity and cross-sectional area in the approach channel section.
- A downstream water level of 98.76 m and Chezy's flow resistance of 48.17 was set as the boundary conditions.




Initial Bed Elevation (m)

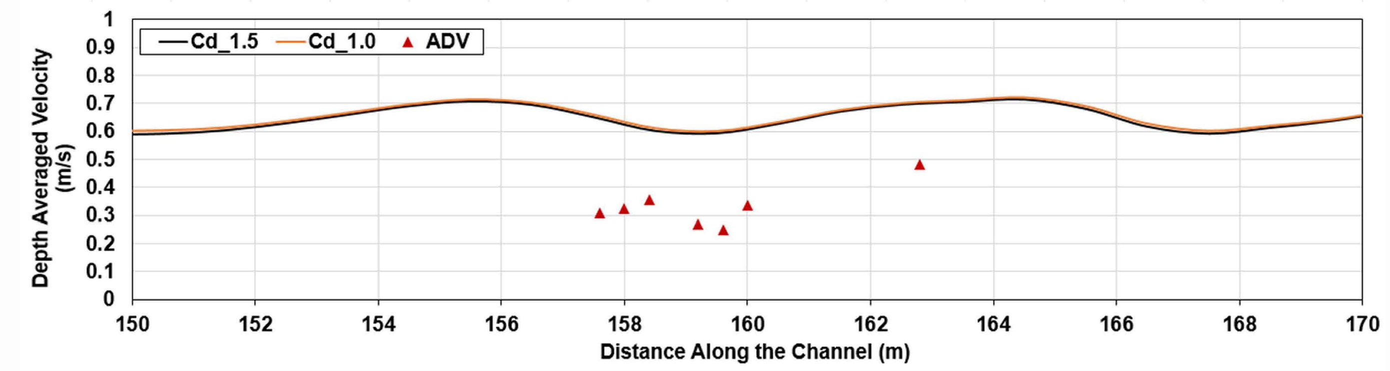
### Simulation Results

- According to the measurement, the water level at sensor 1, which was the patch start point, was 98.86 m. Additionally, a value of 98.856 m was measured for a Cd of 1.5 and 98.839 m for a Cd of 1.0.
- In the downstream, the measured water level was 98.77 m then, 98.769 m for both Cd1.5 and Cd1 were simulated.
- Therefore, Cd1.5 with a difference of 0.004 m in the upstream and 0.001 m in the downstream was more suitable.




Comparison of Delft3D Results and Measurement of the Velocity (m/s)

- When comparing the velocities in the same vegetation patch section, the simulated depth-averaged velocity was higher than the measured velocity using ADV.
- The vegetation patch had a difference of approximately 0.35 m/s from the measured velocity, although the pattern of the decrease in flow rate due to vegetation was consistent in the passage.
- It is possible that the simulated result was a depth-averaged velocity and the measured velocity was within the vegetation patch, thus making it relatively small.




Comparison of Delft3D Results and Measurement of the Velocity (m/s)

## CONCLUSIONS

- The flow velocity was calculated for all sections using the flow resistance coefficient applied to Chezy's formula that incorporates the Cd Value.
- When comparing the water level obtained by applying Cd1 and Cd1.5, it was found that Cd1.5 was better matched with the measured water level.
- Velocity that is slightly higher than the measured flow velocity was derived, and it will therefore have to be considered by referring to some existing formulas that take into account the effects of vegetation.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