# Flow Exchange In Vegetated Environments
## Integrating Experimental Insights Into Practical Engineering

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# FLOW EXCHANGE IN VEGETATED ENVIRONMENTS: INTEGRATING EXPERIMENTAL INSIGHTS INTO PRACTICAL ENGINEERING

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## 1 INTRODUCTION

Vegetation provides practical protective tools for estuarine and coastal regions. The roots, stems, and canopy systems of mangroves can divert and retard the flow field within and surrounding vegetation regions (Truong et al., 2019) and also absorb external forces from waves (Phan et al., 2015). The area within the vegetation is usually calmer compared to the unprotected region outside. Consequently, sediment tends to be deposited inside the vegetation region (Vargas Luna et al., 2015). The sediment deposited then may have feedback on the wave and flow field and the growth conditions of the vegetation (Truong et al., 2017). These mutual interactions between ecological area (vegetation), hydrodynamic conditsions (wave and flow field), and morphological conditions (sediment transport) are the crux of any proposed nature-based solutions (NbS). From a hydraulic engineering perspective, these dynamic interactions can translate into the momentum and mass exchange processes between vegetation and nearby areas. By observing the evolution of mangrove forests and associated with the rate of erosion/accretion of the shoreline, Phan, 2015 and Truong., 2017 proposed a hypothesis of "squeezed mangrove forest", in which "the mangrove width" is considered a crucial length-scales that is related to the sustainable development of the mangroves. This length scale was physically interpreted and connected to the penetration of the mixing layer into the vegetation region (Truong., 2017; Truong et al., 2019). It is noted that whereas the characteristic of the incoming waves mainly controls the penetration of the mixing layer into the coastal mangroves, that of the estuarine mangroves is mainly governed by the characteristic of lateral flow. The latter is the primary focus of this study. Large vortex structures caused by the Kelvin-Helmholtz instability at the vegetation's edge play an essential role in the transverse exchange of mass and momentum (White & Nepf, 2007; Truong et al., 2019). These structures are usually large compared to the water depths and are termed large horizontal coherent structures (LHCSs). The Reynolds Shear stresses (RSs) induced by LHCSs contribute more than 90% to the total turbulent shear stress at the edge of the floodplain vegetated region (Truong & Uijttewaal 2019).

Nevertheless, our understanding of this topic often stems from small-scale laboratory experiments. Whether the presence and characteristic of vortex structures at the interface of the low flow and fast flow region obtained from small-scale physical models remain true for estuaries and coasts has not yet been determined. In order to obtain more insight into the physics of the exchange processes occurring at the vegetation interface at different scales, two unique physical models of vegetated channels have been conducted. One small-scale and another large-scale experiment, both with and without vegetation, were conducted at TU Delft Water Lab and the Korea Institute of Civil Engineering and Building Technology - River Experiment Center (KICT-REC), respectively. Two digital twin models of this flume were subsequently constructed using Delft3D, which were calibrated and validated using the collected datasets. In this study, recent findings pertaining to these experiments are presented.

## 2 EXPERIMENTAL SETUP

The small-scale flume in TU Delft Water Lab is 20 m long and 3 m wide, and the maximum water depth is 0.2 m. The transition slope between the floodplain and the open channel region is 1:10. The maximum discharge during the small-scale experiment is approximately 0.08 $m^3s^{-1}$. The large-scale experimental section in KICT is 150 m long and 11 m wide. The transition slope between the floodplain and the open channel region is 1:2. The width of the floodplain and the open channel are 4.3 m and 2.6 m, respectively. The maximum water depth was about 1.2 m in the main channel. The minimum water depth considered in the flume is approximately 0.15 m in the floodplain region. All pumps were open during the experiment, and the maximum discharge was about 2.4 $m^3s^{-1}$. The overview of these experiments is illustrated in Figure 1. The primary data set is the time series of the streamwise velocity and lateral velocity at a cross-section, collected using Acoustic Doppler Velocity (ADV) at a sampling rate of 25 Hz. Velocity measurements were taken over a time interval of 10 minutes to achieve representative statistical data.

## 3 RESULTS & CONCLUSIONS

The experimental results revealed well-organized large-scale vortex structures formed and moving along the edge of the vegetation region. Different associated flow events can be observed, including the flow toward the floodplain region (sweeps), the flow toward the open channel region (ejections), and the stagnant and reverse flows driven by the increased local pressure. The length of the LHCSs is approximately 1.2 m in small-scale flume and up to 15 m in large-scale. The period of these structures is about 10 seconds and 45 seconds for small-scale and large-scale, respectively. The penetration of these structures into the vegetation regions is approximately 10 cm and 2m at small-scale and large scale, respectively.

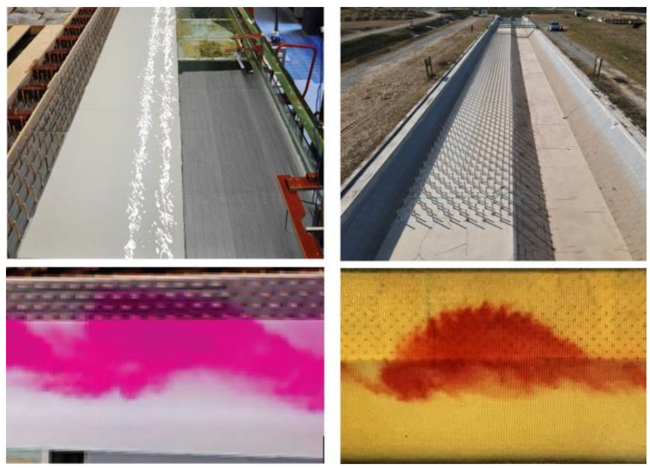

**Figure 1. Small-scale experiment setup in TU Delft Water Lab (left panel) and Large-scale experiment set up in KICT (right panel) in the scenario with vegetation on the floodplain region and the presence of LHCSs in the flumes.**

With the demonstrated presence of LHCSs in vegetated floodplain channels, the forthcoming research will center around validating the proposed hybrid eddy viscosity. This validation will involve utilizing both small-scale and large-scale experimental datasets. The hybrid eddy viscosity is intended to function as a turbulent model within the Reynolds-Averaged Navier-Stokes (RANS) framework, capturing the influence of LHCSs at the vegetation boundary.

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