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Longitudinal Dispersion from Cylinders to Realistic Plant Forms

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Abstract

Many studies on the hydrodynamics and mixing processes due to vegetation have significantly simplified the physical characteristics of plants by representing the stem distribution, e.g. for reeds, as an array of cylinders. These studies often use single diameter cylinders, placed in regular arrays, producing unrealistic preferential flow paths. New solute tracing studies (Machibya 2024) were performed using realistic plant forms, with leaves, stems and branches. Experiments were conducted in a 12.5 m long, 300 mm wide flume and longitudinal dispersion coefficients (D_x) were determined over a range of discharges. The results confirm the linear relationship between D_x and the mean velocity, *u* observed in cylinder arrays. The longitudinal dispersion coefficients for the realistic plant forms were found to be an order of magnitude greater than those from studies conducted using cylinders. This illustrates and quantifies the effect of plant structure on solute mixing processes.

1. BACKGROUND

Sonnenwald *et al*. (2017) summarised longitudinal dispersion coefficient (D_x) values for real vegetation at low velocities, whilst Sonnenwald *et al*. (2019) provided estimates for D_x based on parameterisation of vegetation and flow. Corredor-Garcia *et al*. (2022, 2025) investigated the mixing processes and flow hydrodynamics within a cylinder distribution containing a range of diameters in a random spatial distribution. This new study determines the longitudinal dispersion coefficient in open channel flows containing realistic vegetation.

2. METHOD

The study was performed using realistic plastic plant forms, with leaves, stems and branches. Initial tests were conducted without vegetation, to determine the basic channel characteristics. These were followed by the installation of dense vegetation, Fig. 1, with a solid volume fraction of 0.008, over the complete channel length, Fig. 2. Uniform flow conditions were created, with a fixed flow depth of 105 mm (i.e. emergent plants), across a range of discharges up to 12 l/s.

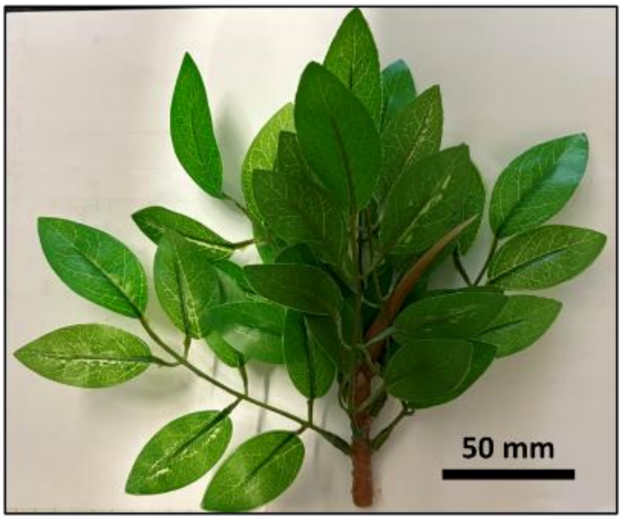

Fig. 1. Realistic “plant”.

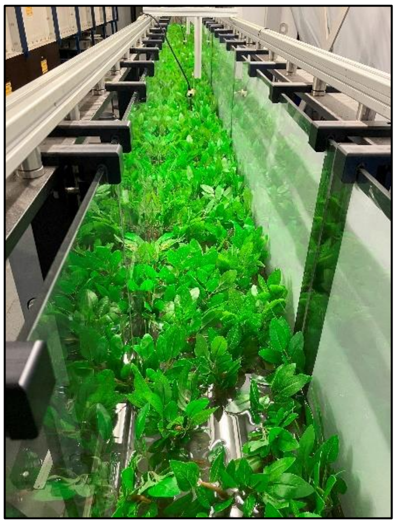

Fig. 2. Flume installation of realsitic plants.

Four Turner C7 Cyclops were evenly spaced at 3 m intervals along the flume, measuring fluorescence concentrations at the mid-width and mid-depth point. Five repeat instantaneous injections of a small volume of Rhodamine WT were made, providing data to estimate 15 values of the mean flow velocity, u (m/s) and the longitudinal dispersion coefficient, D_x (m^2/s) for each flow condition. An example of the recorded raw data is shown in Fig. 3.

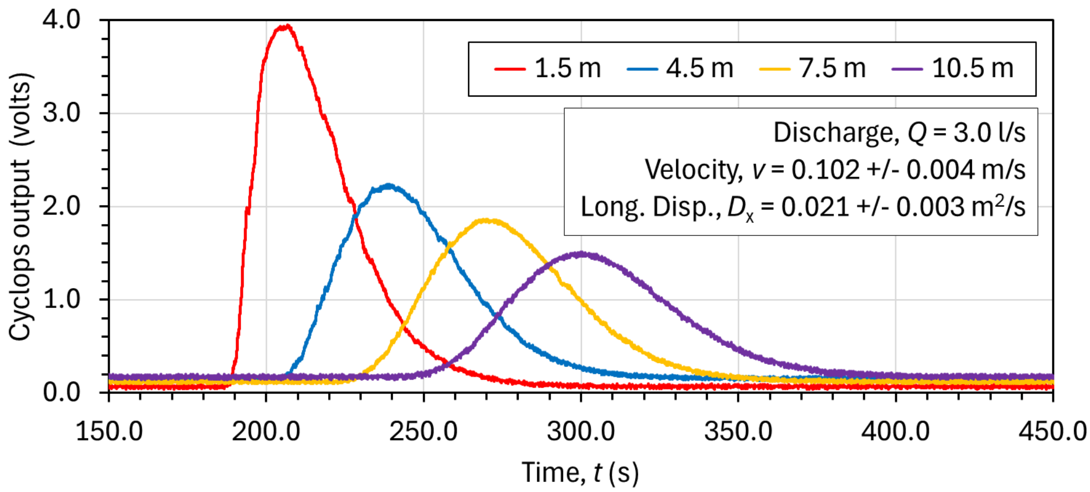

Fig. 3. Recorded temporal variation of Cyclops output.

3. RESULTS

The travel times and dispersion coefficient values were obtained by optimizing the solute routing equation using the TCPAT2 code (Sonnenwald and Guymer 2024). The results show a linear relationship between D_x and velocity, with the D_x values for the realistic plant forms an order of magnitude greater than those from previous similar studies that used cylinder arrays, Fig. 4. This emphasizes how plant structure influences mixing processes.

Normalizing D_x, using previously suggested length scales of stem diameter or stem spacing, did not agree well with previous non-dimensional values. However, normalizing D_x by a characteristic plant diameter, in this case 0.133 m, aligned these new results with earlier ones, for stem Reynolds numbers in excess of 300. This indicates that a “representative diameter” may serve as a more appropriate length scale for complex vegetation forms.

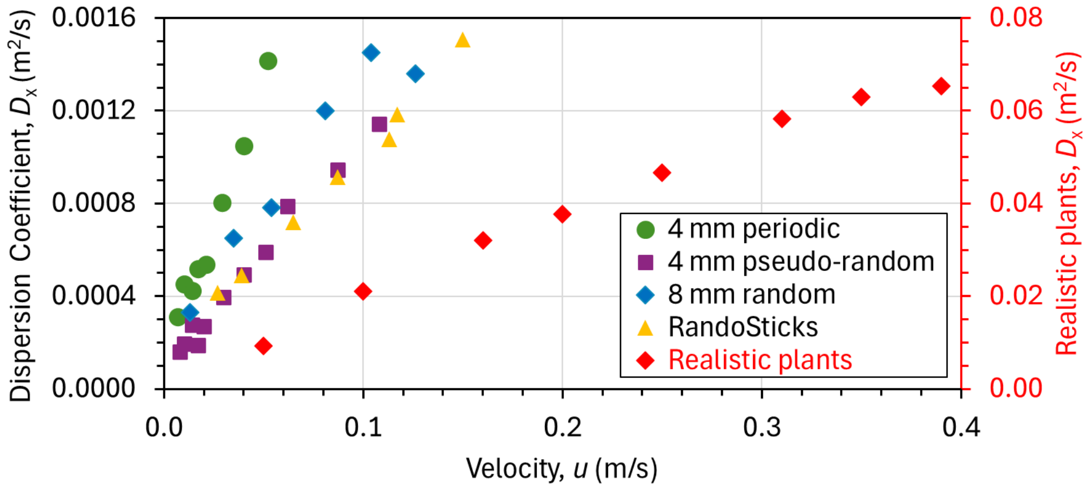

Fig. 4. Variation of Optimised Longitudinal Dispersion Coefficient, D_x with mean velocity, u, for cylindar arrays and a realistic plant form.

4. CONCLUSIONS

This study confirms that earlier simplified physical models using cylinder arrays do not accurately reflect the complex mixing processes seen in realistic vegetated flows.

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