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Effective resistance of submerged vegetation: a first order approach

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The past decade has witnessed rapid developments in remote sensing methods that now permit an unprecedented description of the spatial variations in water levels (H_w), canopy height (h_c), and leaf area density distribution (a) at large spatial scales. These developments are now renewing interest in effective resistance formulations for water flow within and above vegetated surfaces so that they can be incorporated into large-scale codes modelling interactions between river flow, morphology and riparian vegetation. Such formulations must preserve the strong non-linearities in the functional relationship between the resistance value, canopy attributes (e.g. a and h_c), and H_w. Using a simplified scaling analysis on the depth-integrated mean momentum balance and a two-layer model for the bulk velocity, the Darcy-Weisbach friction factor (f) was shown to vary with three canonical length scales that can be either measured or possibly inferred from remote sensing products - H_w, h_c, and the adjustment length scale $L_c = (C_d a)^{-1}, where \mathrm{C}_d$ is the drag coefficient (of order unity). The scaling analysis proposed here reveals that these length scales can be combined in two dimensionless groups - H_w/h_c and L_c/h_c. The dependence of f on these two functional groups was then explored using a combination of first-order closure modeling and 130 experimental runs derived from a large number of flume experiments carried out for rigid and flexible vegetation. The proposed first order closure model was shown to reproduce the bulk velocity measured in the experiments to within 10 for rigid canopies. The first-order closure model was then used to explore the relationship between f and the two dimensionless groups across a wide range of H_w/h_c

and L_c/h_c. The model was able to reproduce all the main features of the non-linear decrease in f with increasing H_w/h_c at a given L_c/h_c and the non-linear increase in f with decreasing L_c/h_c. Furthermore, the model results did not exhibit any dependence on the bulk Reynolds number assuming C_d does not vary appreciably with the Reynolds number (i.e. the within single experiment variation in $C_d$are much smaller than across experiment variations in C_d). Implications of these findings to retardation curves now routinely used in the design of wetland construction (or restoration) and grassed swales for best management practices in water quality controls within urban environments are briefly discussed.