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A model for hydraulic resistance to assess the impact of vegetation on flood routing mechanics

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The past decade witnessed rapid developments in remote sensing methods that now permit an unprecedented description of the spatial variations in water levels (Hw), canopy height (hc), 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 simplified water routing models driven by such remote sensing products.

The appropriate specification of such a flow resistance factor for surfaces covered by vegetation remains uncertain and is the subject of active research. Here, an analytical model for the flow resistance factor is proposed for submerged vegetation, where the water depth is commensurate with the canopy height and the roughness Reynolds number is sufficiently large so as to ignore viscous effects. The analytical model predicted that the resistance factor will vary with three canonical length scales: the adjustment length scale that depends on the foliage drag and leaf area density, the canopy height, and the water level. These length scales can reasonably be inferred from a range of remote sensing products, making the proposed flow resistance model eminently suitable for operational flood routing. Despite the numerous simplifications invoked in the model, agreement between measured and modeled resistance factors and bulk velocities was reasonable across a wide range of experimental and field studies of flow through canopies. The proposed model asymptotically recovers the flow resistance formulation when the water depth greatly exceeds the canopy height. This analytical treatment provides a unifying framework that links the resistance factor to a number of concepts and length scales already in use to describe canopy turbulence. The implications of the non-linear coupling between the resistance factor and the water depth on solutions to the Saint-Venant equation in flood routing are explored via analytical and numerical case studies of flood routing through grass swales, which shows a reasonable match between empirical design standard for swales and theoretical predictions from the model.