Numerical modeling of hyporheic exchange induced by submerged rigid vegetation

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Flow-vegetation interaction affects fluid flow hydraulics and associated material transport in river corridors. Concomitant changes in pressure within the flow field due to the presence of vegetation may act as a driver for the formation of hyporheic flow across the sediment-water interface. This potentially important process, however, has yet to be studied. In order to investigate vegetation-induced hyporheic exchange, a series of numerical models of interlinked surface-subsurface flow modified by plant stems was conducted.  Periodically staggered plant stem arrays on a flat sediment bed were considered within a coupled multiphysics computational fluid dynamics approach. Plants were idealized as rigid cylinders and arranged in different streamwise and spanwise spacing distances. Each vegetation array was then subjected to a broad range of flow Reynolds Numbers (Re). The results showed that hyporheic flow occurs in all conditions with the presence of vegetation. The vegetation-induced hyporheic flux is found to be a function of Re via a power law. The flux increases with inter-stem space until the space reaches the distance that rigid stems no longer affect the flow structures in the vicinity of each other. Larger inter-vegetation distances lead to a larger hyporheic zone. A direct comparison with bedform-induced hyporheic flow showed that vegetation can induce higher hyporheic flux through relatively shallower exchange zones. The results of all the simulations were synthesized into predictive models for hyporheic flux, bulk residence time and exchange depth based on drag coefficient, vegetation density and Reynolds Number.