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Evaluation of an analytical model for hydraulic resistance of submerged vegetation

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The hydraulic resistance of vegetation can play a major role in the hydrodynamics of vegetated streams or rivers with extensive natural floodplains. Contrary to commonly used wall roughness methods, vegetation penetrates the flow field causing drag and, subsequently, additional energy losses. Klopstra et al. (1997) derived an analytical solution of the flow velocity profile over and through a field of homogeneously distributed rigid cylinders. This solution has been adopted as a standard method to determine vegetation roughness in the Netherlands as described in the handbook for hydraulic resistance of vegetation in floodplains (Van Velzen et al., 2003). Although the analytical solution gives a good description of the flow over submerged cylinders some assumptions oversimplify the problem. In this paper these assumptions are evaluated and suggestions for improvement are made.

In order to arrive at an analytical solution to the force balance that governs the flow specific turbulence characteristics of the flow between the vegetation are required. Above the vegetation layer standard boundary layer theory is applied. Consequently, the turbulence characteristics are treated inconsistently over depth. Comparison of the analytical solution with a physically more consistent numerical model revealed that the analytic velocity profile performs well when an unrealistic bottom boundary condition (complete slip) is used.

For the turbulent length scale α, that fixes the shape of the velocity profile, only empirical expressions are available that lack physical justification. By introducing a spacing hydraulic radius based on representative length scales a new empirical closure for this length scale was found. Besides the (slightly) improved predictive power of the newly found expression, other advantages as compared to the existing ones are that (i) it is dimensionally correct and (ii) it converges to the roughness height for relatively deep flow.

Furthermore, the analytical velocity profile is integrated over depth to obtain the average flow velocity. A few assumptions were used to simplify the final expression. In combination with the newly found relation for α, the method describes average flow velocities through the rigid cylinders accurately. Application to other data shows that in some cases the predicted flow velocities can deviate significantly, especially for sparse vegetation the expression does not seem appropriate.

References:

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