

A process-based hydraulic resistance coefficient for flow over vegetation

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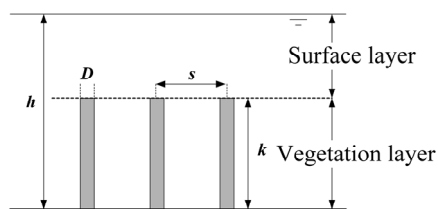
Hydraulic resistance of vegetation

The hydraulic resistance of vegetation can play a major role in the hydrodynamics of rivers with extensive natural floodplains. Contrary to commonly used wall roughness methods, vegetation penetrates the flow field and thereby causes drag and, subsequently, additional energy losses.

Here, a description for the hydraulic resistance is proposed, that is based on measurable plant characteristics.

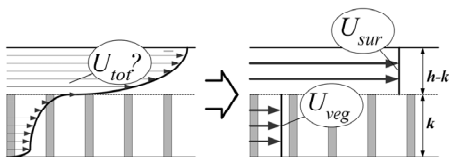
Two-layer model

Flow in presence of submerged vegetation is described by defining two separate flow layers: the **surface layer** and the **vegetation layer**.



The vegetation is characterised by a separation distance s , a stem diameter D and a cylinder height k . The depth of flow is given by h .

Based on scaling considerations of the forces involved, depth-averaged flow velocities are estimated in both flow layers. Taken together, the average flow velocity for the entire flow depth can be calculated.



In order to arrive at an average velocity U_{tot} , the average velocity in the surface and the vegetation layer are estimated separately (U_{sur} and U_{veg} respectively).

Further reading:

Huthoff, F. (2007). *Modeling hydraulic resistance of floodplain vegetation*. PhD Thesis, University of Twente, Enschede, Netherlands.

Meijer, D.G. and E.H. Van Velzen (1999). *Prototype scale flume experiments on hydraulic roughness of submerged vegetation*. Proceedings of the 28th International IAHR Conference, Graz, Austria.

Process-based description

Combining the velocity scaling expressions for the surface and the vegetation layer (see **Two-layer model**) yields an expression for the total depth-averaged flow velocity:

$$\frac{U_{tot}}{u_k} = \left(\frac{k}{h}\right)^{1/2} + \frac{h-k}{h} \left(\frac{h-k}{s}\right)^{2/3}$$

Where the flow velocity for non-submerged vegetation is described by:

$$u_k = s \sqrt{\frac{2gi}{DC_D}}$$

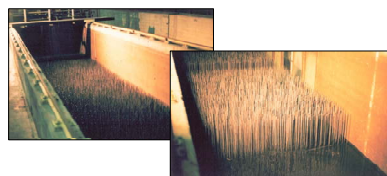
Comparison to laboratory measurements yield good results (see **HKV experiments**).

Next, resistance coefficients are calculated as:

$$\text{Chézy} \quad C = \frac{U_{tot}}{\sqrt{hi}}$$

$$\text{Manning} \quad n = \frac{h^{2/3}}{U_{tot}} \sqrt{i}$$

HKV Experiments (1997)

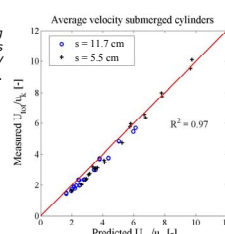


In 1997 flume experiments were conducted by HKV CONSULTANTS at the WL Delft Hydraulics facility 'De Voorst'. Several configurations of water levels, cylinder heights and cylinder surface densities were used.



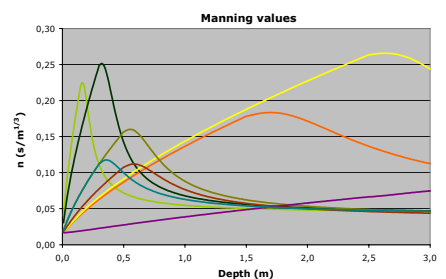
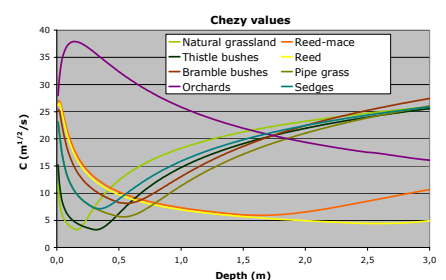
In the experiments vegetation was replaced by rigid cylinders. Also, measurements with natural reed were carried out.

The proposed velocity scaling expression for the total depth as compared to results of the HKV flume experiments.



Hydraulic resistance coefficients

Below, the process-based hydraulic resistance description is applied to a selection of common vegetation types.



As can be seen, the hydraulic resistance coefficient (Chézy or Manning) varies significantly with flow depth.

Estimated geometrical parameters for a selection of vegetation types. For calculating hydraulic resistance a drag coefficient $C_D = 1$ was used.

Vegetation type	D (cm)	k (cm)	s (cm)
Natural grassland	0.3	15	1.3
Sedges	0.6	30	6.5
Thistle bushes	0.3	30	1.9
Bramble bushes	0.5	50	8.9
Pipe grass	0.4	50	5.4
Reed-mace	1.8	150	20.6
Reed	0.5	250	10.7
Orchards	15	250	235

Conclusions

- Based on a two-layer model of flow over vegetation, a process-based hydraulic resistance coefficient is calculated.
- Vegetation characteristics are explicitly included in the resistance coefficient.
- The hydraulic resistance coefficient for vegetation can change significantly depending on flow stage.

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