# Riparian forests and riverine vegetation - risk factors in case of flooding?

HANS HELMUT BERNHART[1], HUBERT WEIGER[2], SANDRA SCHNEIDER[3]

*Keywords: Riparian forests, riverine vegetation, flood risks, mathematical modelling, roughness values*

## 1 Introduction

One of the objectives of the EU Water Framework Directive (WFD) is to achieve a good ecological status of surface water bodies. Ecological status refers to the quality of the structure and functioning of the aquatic ecosystems. In this context the development of riverine vegetation and riparian forests is the most important factor for the ecological improvement of regulated and modified rivers. It is obvious that an uncontrolled development of vegetation might result in higher local water levels in case of flooding and tighten the flood risks there, however, the positive retention effect on flooding further downstream should also be evaluated.

The influence of vegetation on the rising of the water levels during flood events depends, however, predominantly on the local velocity distribution within the cross-section. Cutting down of riparian trees and bushes has often little or no effect on the resulting water levels. Therefore, an adequate consideration of the vegetative flow resistance in a two-dimensional hydro-dynamical model (2D-model) is indispensable for the protection and implementation of new sustainable riverine vegetation.

Only an appropriate analysis of the given boundary conditions enables the proper finding of the balance between flood control and ecological needs. Flow resistance caused by bushes and trees is, at present, in many cases not adequately considered in the commonly used models. Based on the lack of knowledge concerning the realistic flow resistances of vegetation normally constant roughness values are used for the calculation of different discharge events. This might lead to a misinterpretation of the influences of the vegetation resistance on the water level with the result that vegetation and forest stocks are removed although this would not have been necessary.

These questions are discussed with reference to a case study on the River Danube in Bavaria and a research project on the River Elbe. Based on the results of laboratory experiments carried out in the "Theodor-Rehbock-Laboratory" of the Karlsruhe Institute of Technology (KIT) vegetative resistance values for different riparian forest stocks are presented.

## 2 Motivation: Analysis of the flood event 2002 on the River Danube in Bavaria

During the flood event in August 2002 the water level on the River Danube downstream of the river barrage Straubing (Danube-km 2320) rose to higher levels than expected for the given discharge. The analysis with a 2D-model presumes that the reason for this unexpected rise of the water level was the influence of the riverine vegetation and of maize fields in the flood plains; see photos in Figure 1.

1 KIT Karlsruhe Institute of Technology, Berghausener Straße 38, D-76229 Karlsruhe, Germany. e-mail: hhbernhart@web.de
2 Bund Naturschutz in Bayern e.V., Bauernfeindstraße 23, D-90471 Nürnberg, Germany. e-mail: hubert.weiger@bund-naturschutz.de
3 KIT Karlsruhe Institute of Technology, Kaiserstraße 12, D-76128 Karlsruhe, Germany. e-mail: sandra.schneider@kit.edu

***Figure 1.*** *Danube at Bogen (Danube-km 2311) with maize fields in summer 2003 and during the flood event in August 2002 with a water level reaching the top of the maize fields (RMD 2006)*

By establishing a 2D-model, which delivers resilient results concerning the influence of vegetation onto the water level, the following questions have to be considered:

- Which vegetative resistance values should be taken to describe the flow resistance caused by riparian forest and especially of such dense vegetation as maize fields taking into consideration emergent or submerged flow conditions?
- Which grid size should be chosen for wetlands to detect the influence of riparian vegetation?

# 3 Resistance values caused by maize fields and riverine vegetation

Frequently the Strickler-formula is chosen to describe the vegetative resistance since many experienced data are available for determining adequate $k_{St}$-values. Hartlieb (2006) carried out laboratory experiments to provide $k_{St}$-values for emergent and submerged maize fields. The flow resistance values for different flow approach directions are given in Figure 2. Hartlieb identified $k_{St}$-values from one to two as long as the maize fields are emergent. The $k_{St}$-values rise up to five for submerged flow conditions. Therefore, calculations in a 2D-model with a constant $k_{St}$-value will not lead to adequate results concerning the rising of the water level. Those low $k_{St}$-values indicate a very high flow resistance, which is due to the high density of maize fields. It can be observed in situ that maize fields block the flow nearly completely.

Compared to the modelling of such compact structures with little or no flow through the vegetation the modelling of the flow resistances of riverine vegetation is much more sophisticated since flow around the trees and branches occurs even in case of a dense vegetation.

Schneider (2010) carried out laboratory experiments in a 60 m long, 2.0 m wide and 0.7 m high re-circulating glass-walled flume to determine riparian softwood forest resistance values. The vegetation is simulated by using willows with and without leaves as well as hedges. The vegetation arrangement varied during the laboratory experiment between sparse up to dense softwood forest stocks. Recorded data for every setup were: water depth along the flume, flow velocity and pictures of the vegetation density. The chosen discharges created flow conditions with emergent vegetation to submerged vegetation.

The recalculation of the $k_{St}$-values for the hedges and willows varied from 4 up to 25 in dependence of the vegetation type, emergent or submerged vegetation as well as the stock density. Figure 3 presents the summary of the $k_{St}$-values for different riparian forest stocks and illustrates the great spectrum that has to be considered. Concerning riverine wetland areas on a macro-scale natural riparian forest stocks are characterised by a huge variety of different vegetation types. Therefore, the results are presented in a decision-making matrix, which enables an easy determination of the appropriate $k_{St}$-value especially for mixed riparian forest stocks in dependence of the stock density as well as the vegetation type. The figure sorts the $k_{St}$-values in such a way that the dense, stiff hedges stock is shown at the top left corner and the flexible, sparse stock of softwood-forest vegetation is shown at the bottom right corner.

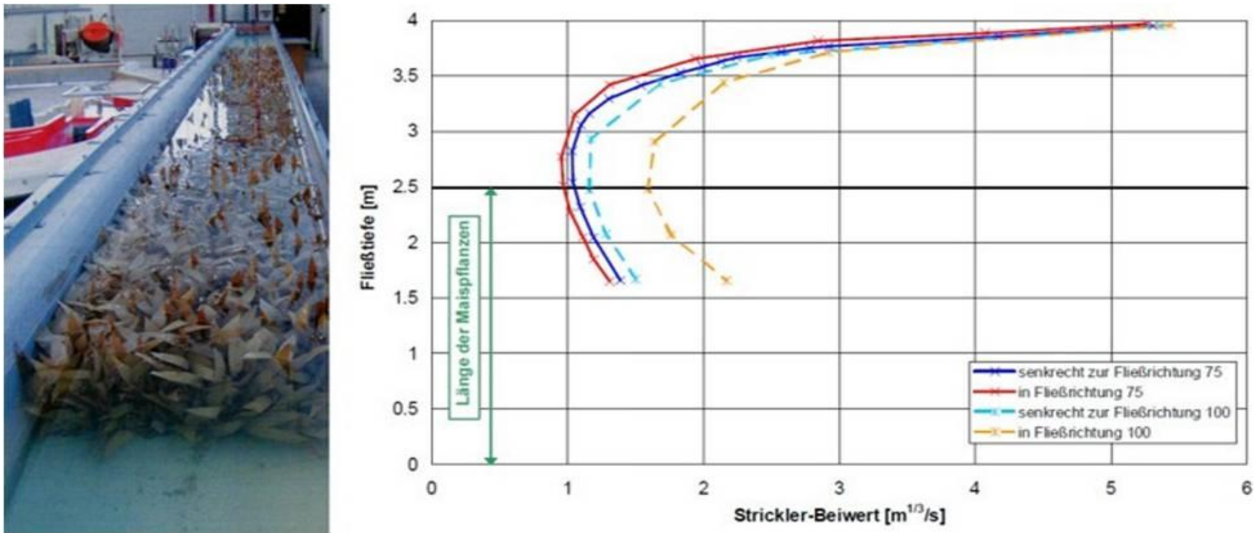


***Figure 2.*** *Strickler-values for maize fields as a function of the water depth in the flood plain; results of hydraulic modelling in the laboratory of the TU München; Fließtiefe = water depth, Strickler-Beiwert = $k_{St}$-values (Hartlieb 2006).*

| | | hedges, shrubs $k_{st}$ [$m^{1/3}/s$] | softwoodforest (summer, leafy) $k_{st}$ [$m^{1/3}/s$] | softwoodforest (winter, unleafy) $k_{st}$ [$m^{1/3}/s$] |
|---|---|---|---|---|
| dense | emergent | 4-7 | 7-10 | 13-15 |
| dense | submerged | 8 + | 11 + | 16 + |
| transition | emergent | 8-10 | 11-13 | 16-19 |
| transition | submerged | 11 + | 14 + | 20 + |
| sparse | emergent | 10-13 | 14-16 | 20-25 |
| sparse | submerged | 14 + | 16 + | 26 + |

***Figure 3.*** *Strickler-values for different riparian forest stocks as a decision-making matrix (Schneider 2010)*

# 4 Flow Velocity for emergent and submerged willow stocks

A typical result of the velocity measurements is shown in Figure 4. The picture on the left displays the velocity distribution for the reference conditions without any vegetation in the flume and on the right the velocity distribution for dense submerged willow stocks is shown; the white contours are due to the model vegetation and husks which serve as mounting and bottom roughness. The photos in Figure 5 visualize the great difference between the flow conditions for emergent willows and submerged willows with a rather high flow velocity in the overtopping layer (compare Figure 4).

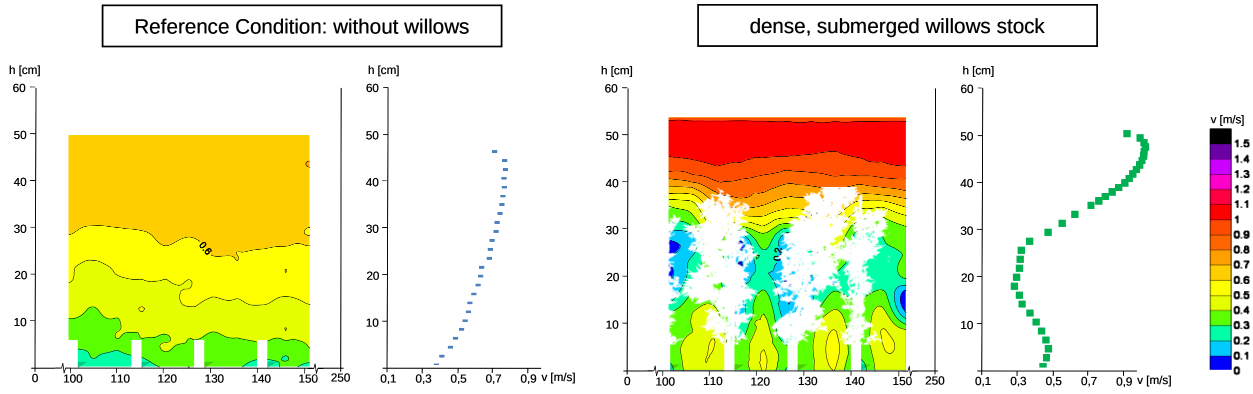


***Figure 4.*** *Velocity distribution with and without vegetation (Schneider 2010)*

***Figure 5.*** *Flow through the model vegetation and flow conditions with overtopping (Schneider 2010)*

# 5 Grid size for modelling floodplain areas

Concerning the grid size of floodplain areas in a 2D-model it is obvious that rather small elements are necessary for an adequate calculation of the influence of riverine vegetation. Whereas the effect of maize fields might be calculated with a grid size of 20 m x 20 m or even larger this would be absolutely inappropriate for riverine vegetation. With such rough-textured grids it is not possible to identify the influence of small groups of bushes and trees on the rising of the water levels.

# 6 Study case River Danube

The evaluation of the results given in Figures 2 and 3 illustrates the great variations which could be found and give a good hint which resistance values should be chosen according to the flow conditions for emergent or submerged vegetation. It is obvious that a constant $k_{St}$-value will not represent the real flow resistance neither for maize fields nor for riparian forest and riverine vegetation. The Strickler-values in the columns on the left and in the middle in Figure 3 are of special interest in comparison to the value of $k_{St}$ = 5 for the riparian vegetation and $k_{st}$ = 10 for riparian forest chosen for the calculation on the River Danube. If additionally the riverine vegetation covers a part of the grid size only, it might be more than questionable that calculations with such model parameters can deliver appropriate results. The cut down activities deduced from those results are shown in the photos in Figure 6. It can be stated that the effect on the water level that is expected due to these measures will not occur.

***Figure 6.*** *Situation before (left) and after cutting of trees (Landschaft + Plan, Passau, 2006)*

# 7 Study case River Elbe

Possibilities of implementing new riparian forest areas in the floodplain were investigated on the River Elbe. For the calculation of the additional flow resistances to be expected from the vegetation a 2D-model with a grid-size of a few square meters was used. Almost 50 ha of riparian vegetation areas could be identified along a river stretch of 15 km. The implementation of all new riparian stock areas would result in a water level increase of 0.06 m (Schneider 2010).

# 8 Conclusion

The influence of riverine vegetation on the resulting water level depends on the appropriate consideration of the flow resistance values. A realistic evaluation of the flow conditions can only be verified with 2D-models based on small grid sizes. The choice of constant values for emergent or submerged flow conditions and sparse or dense vegetation is not suitable for calculations. If the influence of vegetation is not adequate the resulting effect might be overestimated.

# Acknowledgements

The research work at the Karlsruhe Institute of Technology ("Theodor-Rehbock-Laboratory") was supported by the Deutsche Bundesstiftung Umwelt (DBU).

# References

RMD Wasserstraßen GmbH (2006): Projektgebiet Bayerische Donau von Straubing bis Pfelling, Bericht über die Grundlagenermittlung, Ist-Zustands-Analyse und Szenarienuntersuchungen am 2-dimensionalen HN-Modell. München, 23.05.2006, pp. 32 and 33

Hartlieb, A. (2006): Modellversuche zur Rauheit durch- bzw. überströmter Maisfelder. In Wasserwirtschaft Nr. 3/2006, pp. 38-41

Schneider, S. (2010): Widerstandsverhalten von holziger Auenvegetation. Dissertation, Karlsruhe Institute of Technology (http://digbib.ubka.uni-karlsruhe.de/volltexte/1000016530)