Floodplain modelling for real-time use based on an interlinked numerical 1D/2D model

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Abstract

During real-time flood management detailed knowledge of the hydraulic situation is essential, e.g. for early identification of possible failure locations or vulnerable supply roads. Climate-based changes in flood statistics make this even more important. Anticipatory hazard analysis often cannot be employed because of the multiplicity of possible events. Therefore, numerical models are required to enable the user to recognize current regional as well as local hazards and evaluate possible options for action.
This article describes several possibilities for flood simulations in hydraulically complex flow areas with emphasis on real-time use (minimal computational effort, user-based changes in hydrologic and topographic boundary conditions, stable calculations).
For this study a section of the Elbe River was examined using different types of models. The quality of the implemented interlinked 1D-2D-model (1D river channel, 2D floodplain simulations) was analysed by comparison of calculated results, in which a noticeable decrease in computational time without a significant loss of accuracy was attained.

1 Motivation and purpose

Sustainable flood management includes strategic plans for real-time management such as short-term initiatives as well as coordination of possible protective measures during or immediately before a flood. Depending on the size of the research area, anticipatory hazard analysis often cannot be employed because of natural limits in analysing possible events. Particularly in the case of extreme flooding in which design events are exceeded, models enabling the user to identify hazards within a few hours or even minutes are needed.
Currently, the more common models are not able to fulfil these demands. A possible solution is to link different types of numerical models such as:

- One-dimensional models for areas with distinct dominant flow for all discharges (e.g. river or flood channels)
- Two-dimensional models of areas with definitive multidimensional flow (e.g. floodplains, conjunctions, protected areas behind dykes)

2 Study area: Elbe River

A 55 km section of the Middle Elbe River was selected as the project area, involving a region of 140 km². It is affected by complex hydraulic conditions with a meandering river course, wide outstretched floodplains and backwater effects at the mouth of the tributary Mulde River, requiring high modelling standards. The studied river course extends from the gauge at Lutherstadt Wittenberg (Elbe-km 270) downstream to the city of Dessau-Rosslau (Fig. 1).

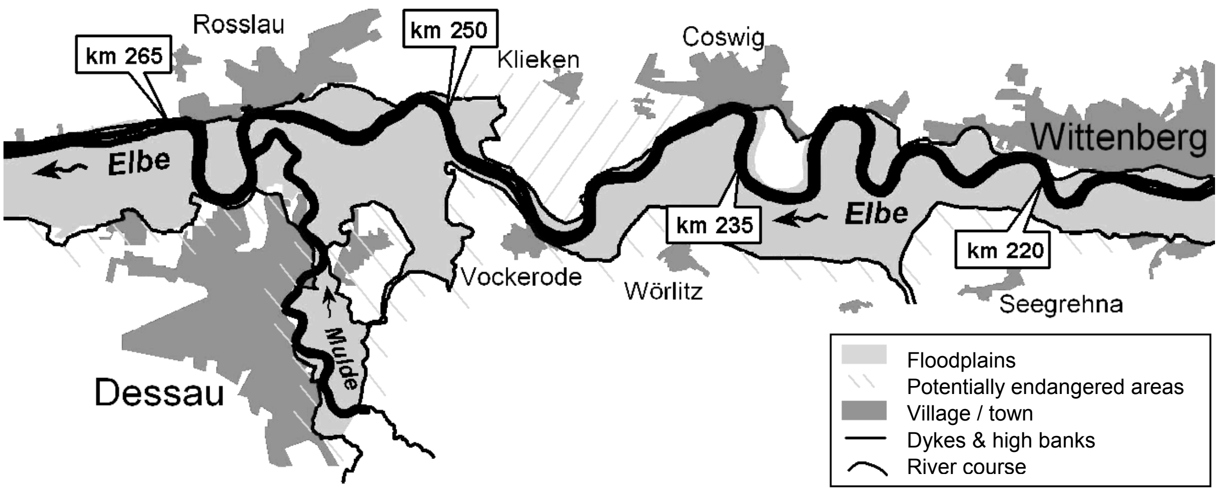

Figure 1: General map of the embanked Elbe River between Wittenberg and Dessau-Rosslau and the confluence of the tributary Mulde River.

3 Model fundamentals

The interlinked model is based on the 2D-module FLUMEN (fluvial.ch, Schwyz) with which the 2D shallow water equations are solved using a finite volume method with explicit time discretisation based on an unstructured triangulated mesh. The program calculates detailed information on the distribution of depth-averaged flow velocities, water levels and bed shear stresses within the computational area. The model was linked to the 1D-module FLUSH which is based on the 1D Saint Venant equations. The parameterization of flow resistance is done using the Manning-Strickler equation. A consistent geocoding of the 1D and 2D models is established using a polygon of the river course.
The flow over a imaginary weir is taken as an interface between the two models. The height of the weir is either defined by the height of the dyke included in the 1D-crossection or by the topography of the 2D-calculation mesh. The amount of water exchanged by the two models is estimated using a Poleni-type formula with respect to backwater effects [Beffa, 2006].

4 Model comparison

In order to quantify the model performance of the coupled 1D/2D technique, an additional full 2D model was set up as a reference so that the results of the two model types can be compared. Within the 1D/2D model 715 river cross-sections were used to represent the river channels of the Elbe and Mulde, the floodplain discretisation was chosen comparable to the 2D-reference model. The interlinked model was calibrated using the same resistance parameters in the floodplains as in the reference model.

Particularly important for the interlinked models' computational quality is the correct representation of overflow from the 1D into the 2D area and vice versa. Figure 2 shows an exemplary view of the flow across a meander loop near Coswig during the flood of August 2002 ($Q_{Elbe} = 3880\ m^3/s$) illustrated by velocity vectors calculated by both models. There is good agreement between the models for the general flow directions. There is also a slight underestimate of the velocities on the floodplains by the interlinked model, however the quality of prediction for real-time use during a flood is not significantly affected.

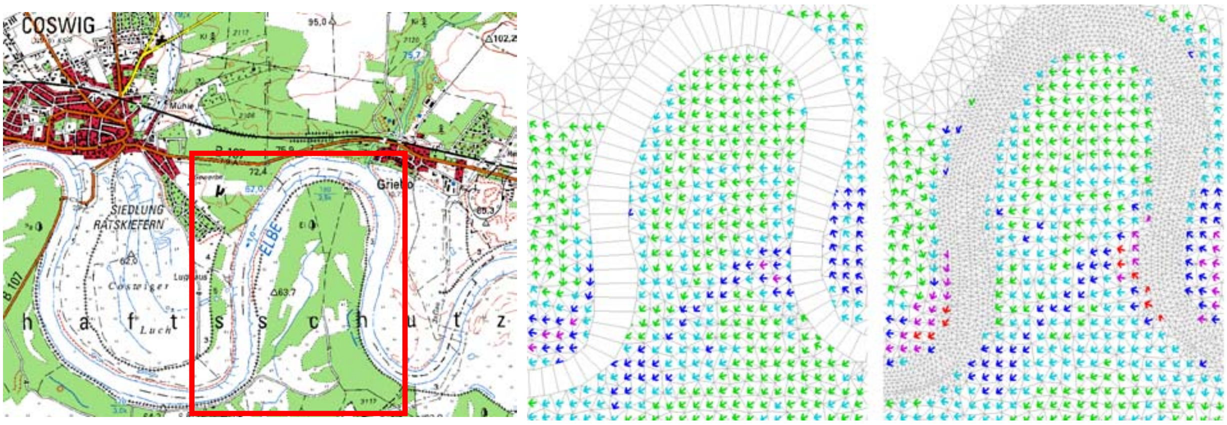

Figure 2: Comparison of calculated overflow near Coswig using a regular 2D model and the interlinked 1D/2D model.

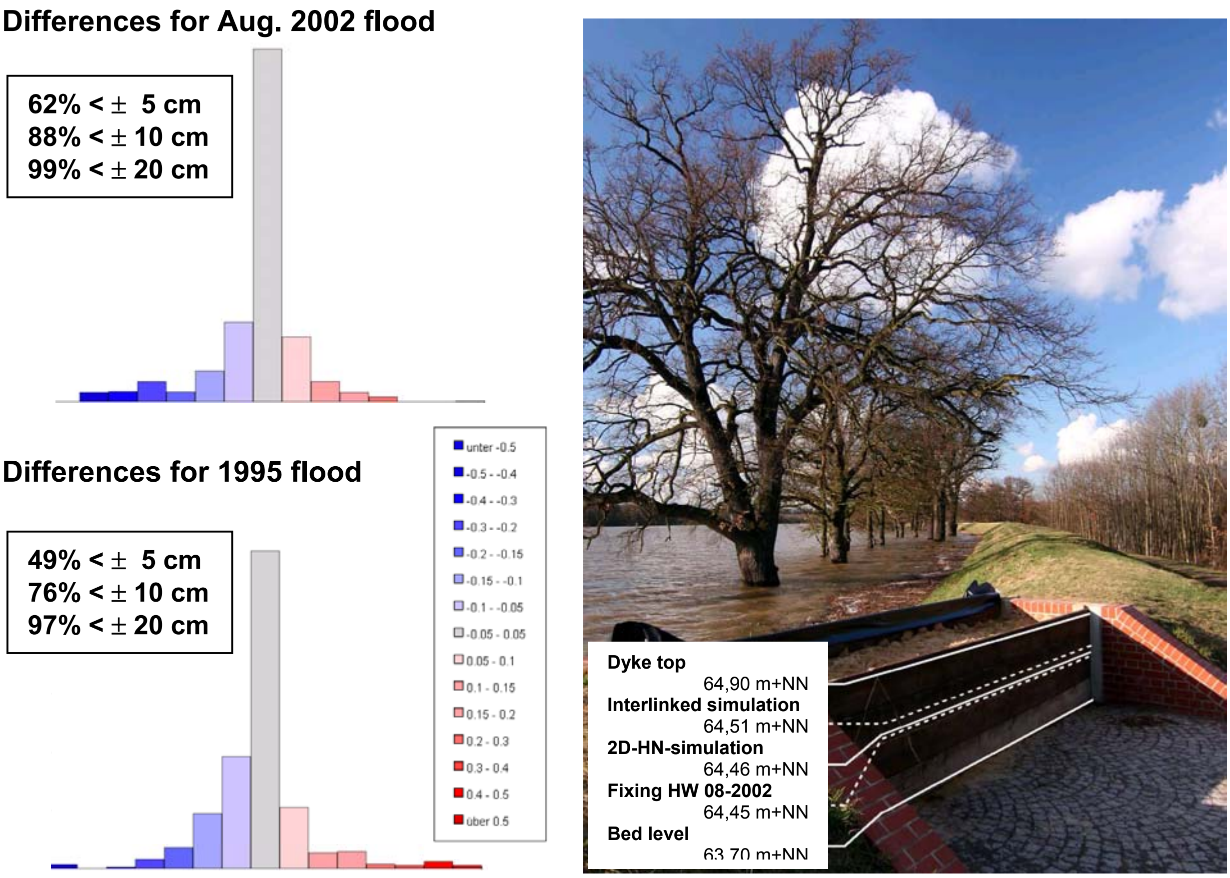

Figure 3: Differences in calculated water levels using the 2D reference model and the interlinked model as well as exemplary analysis of a dyke opening near Wörlitz for the August 2002 flood.

Furthermore, the differences in plane water levels between the two models are important. Figure 3 shows the differences in calculated water levels using the 2D reference model and the interlinked model as well as exemplary analysis of a dyke opening near Wörlitz for the flood of August 2002. 80% of the differences are within the ±10 cm interval and almost all differences lie within ±20 cm. Larger variations shown for the calculation of the 1995 flood (Q_{Elbe} = 1140 m³/s) resulted from dyke sections being only slightly overflowed. In such regions only a few centimetres difference in water level at the river can cause a significant difference in the flood depth of adjacent deep floodplains. However, in the realm of a planned real-time system, the achieved accuracy is adequate making the interlinked model a very practical option for early-warning flood prediction.

5 Summary

The pilot study showed that the use of common 2D-models is not suitable for real-time use during a flood, especially in areas with complex flow conditions such as the investigated section of the Elbe River. In contrast, the results offered by an interlinked 1D/2D model are quite promising and seem to offer a good balance between computational effort and accuracy.

During this research the implementation of a 1D module on larger sections of the Elbe and Mulde rivers made a reduction of 60% of the mesh triangles possible. Another factor is that the elimination of the smallest 2D mesh triangles, mostly situated within the river channel, allowed larger time steps to be used due to the explicit time discretisation. Overall a 70 - 85% reduction in computational time compared to a regular 2D model could be achieved.

In future the interlinked model will be integrated into a Geographical Information System (GIS) with special adaption to emergency management and more user-friendly accessibility for practical operations. The investigation took place within the hydraulic subproject of the research project "Operationelles Hochwassermanagement in großräumigen Extremsituationen am Beispiel der Mittleren Elbe" funded by the RIMAX-initiative of the German Federal Ministry of Education and Research and the HGF/CEDIM junior research group "Floods".

References

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