

CURRENT PROBLEMS IN 2D NUMERICAL MODELLING OF WATER FLOW IN THE RIVER CHANNELS

Eliška Grmelová*¹, Jiří Skokan¹, Jan Juriga¹, Veronika Chrástová¹, Šimon Pospíšilík¹

*Eliska.Grmelova@vutbr.cz

¹Institute of Water Structures, Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95, 602 00 Brno

Abstract

Currently, the use of two-dimensional numerical models in modelling water flow in river channels and floodplains is quite common. The quality of hydraulic calculation results is influenced by the number of input parameters. However, crucial in this context is primarily the availability of calibration data. Commonly used data from historical flood records are often burdened with significant uncertainties and, in many cases, are completely lacking. One option to ensure suitable calibration data is to measure flow rates and velocity fields in selected calibration profiles, e.g., using the ADCP method (Acoustic Doppler Current Profiler). The presented article showcases the authors' experiences with the calibration of a 2D numerical model applied to a real location, specifically using the mentioned method. The focus of the calibration lies mainly in the values of Manning's roughness coefficients and parameters of turbulent models. The conclusion of the article includes a discussion of the results and recommendations for further research directions in the field, which appear promising for practical applications.

Keywords

2D model, flood, calibration, floodplain, river channel, ADCP

1 INTRODUCTION

A precise digital terrain model, appropriate sizes and shapes of grid mesh cells, and a computational model setup, along with corresponding data for calibration, are needed for a high-quality 2D (two-dimensional) numerical model [1].

One of the important elements for the calculation is the choice of the type of calibration data. Calibration is possible using reliable measured data such as flow discharge, rating curve, water surface elevation, water depth, velocity field and flood extent. The following methods are used to measure these data in open channels:

- Station rating curve – on important rivers, perennially installed water-stage gauges stations are used. Water levels can be monitored online. On smaller rivers, disposable measurements were made. The accuracy of the measurement is 10–15% [2], [3], [4].
- Velocity field method – the point velocity or vertical velocity integration can be obtained using the hydrometric propellers, EMI (Electromagnetic Inductive Meters), ADV (Acoustic Doppler Velocimeter) or AECV (Acoustic Echo Correlation Velocimeter). ADCP (Acoustic Doppler Current Profiler) can also be used for partial or full integration of velocity field with measurement. The measurement accuracy is within the range of 3–10% [5].

The calibration for the model involved applying the rating curve and vertical velocity field (obtained by the ADCP method) in selected cross-sectional profiles. In common practice, calibration for velocity field measurements by the ADCP or hydrometric propeller method is not performed in our conditions. Globally, these methods for calibrating or verifying 2D hydrodynamic model results are more frequently used [6].

To achieve the desired accuracy of the results, adjustments the model involve editing Manning roughness coefficients or turbulent model parameters. Estimating the value of Manning roughness coefficients is dependent on factors such as channel shape, condition of vegetation cover, engineer's professional estimate and others. New methods are still being developed for easier and more accurate determination of these coefficients [1], [7].

The used software, HEC-RAS, has ability to perform 2D unsteady-flow modelling. The software can use either the model SWE (Shallow Water equations) or the DWE (Diffusion Wave equations). The used model SWE also has options for modelling turbulence and Coriolis effects. By changing these settings, the model can be calibrated as well [8].

In this paper, will describe the process of developing the DEM surface, setting up the 2D model and its calibration using ADCP data.

2 METHODOLOGY

This chapter will introduce:

- Description of the area of interest.
- DTM (digital terrain model).
- Description of the 2D hydrodynamic model.
- Model calibration.

Description of the area of interest

The area of interest is within the extent of the floodplain in the towns of Hranice na Moravě and Teplice nad Bečvou in the Czech Republic. The river under consideration in the Bečva River, as shown in Fig. 1.

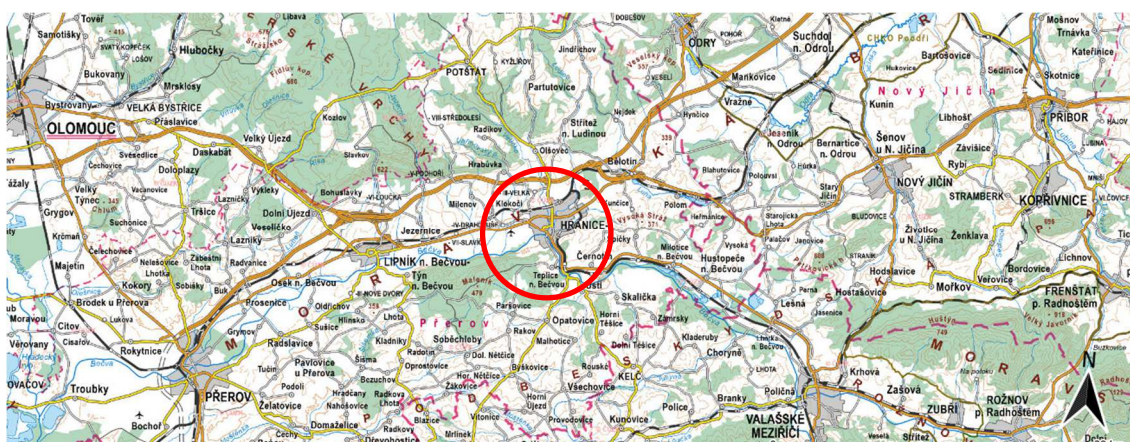


Fig. 1 Area of interest.

Digital terrain model

A high-quality DTM of the channel and the floodplain is a prerequisite for creating geometric data for the 2D hydrodynamic water flow model.

When generating a DTM, it is recommended to ensure that the geodetic data is up-to-date, with particular attention to verifying that the surveyed data aligns with the present state of the terrain. In this case, over 413,000 geodetic points were utilized. The final terrain completion involves interconnecting individual geodetic surveys, often requiring estimation and adjustment of the input data. Subsequently, the final DTM was assembled from the individual parts, and any missing sections were supplemented with less accurate Open data.



Fig. 2 Completed digital terrain model.

Open data services are available for the Czech Republic, provided by ČUZK (State Administration of Land Surveying and Cadastre). One of the datasets is the 5th generation DTM. Missing parts in the digital terrain model for calculation were filled in with more than 1.3 million points from Open data.

Each survey had different input quality, acquisition dates, and methods. The point data were combined and composed into a continuous underlying terrain for calculation (Fig. 2).

The terrain model was completed as a TIN dataset and, for computation purposes, exported to a raster format with a resolution of $0.25 \times 0.25 \text{ m}^2$.

2D hydrodynamic model

Based on the current flood inundation boundaries, the perimeter of the 2D computational mesh was established, and boundary conditions were subsequently applied. For the upstream boundary condition (BC), a volume flow rate was specified, while for the downstream BC, a water surface elevation from previous hydraulic models was used. Both upstream and downstream BCs were positioned away from the main area to prevent any interference with the results, as illustrated in Fig. 3.

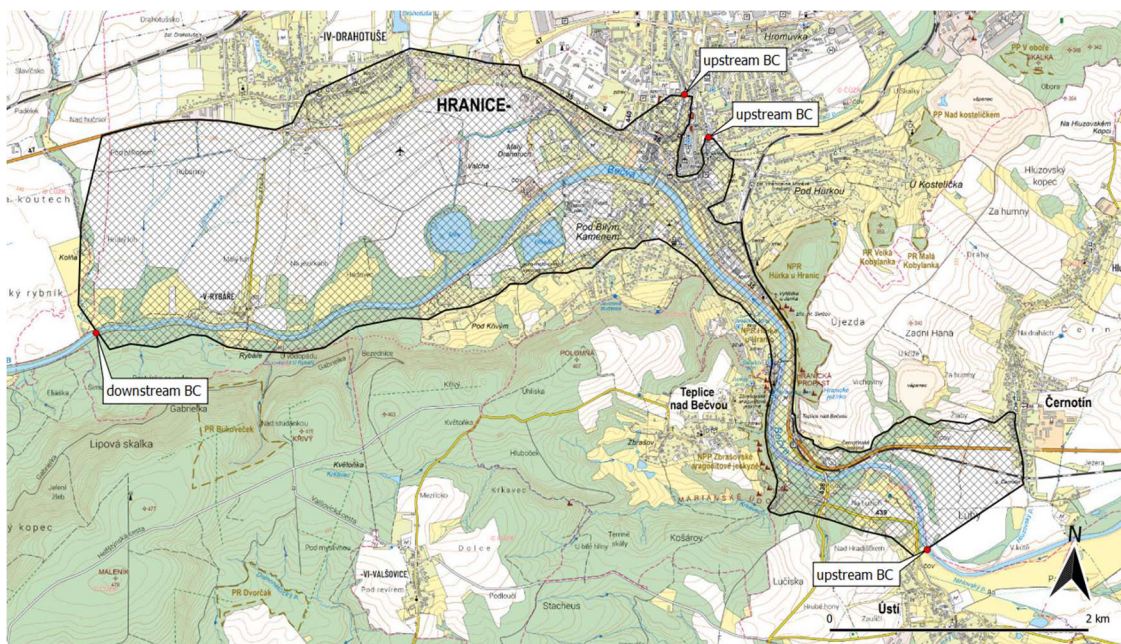


Fig. 3 Perimeter of 2D computational mesh.

Based on the channel width and the requirements of the turbulent model, appropriate elements sizes and shapes were selected (Fig. 4), along with Manning roughness coefficients and other numerical and flow parameters. The dimensions of area elements ranged from 5 to 20 m for the inundation area and 2 to 5 m for the channel. In total, 73,000 elements constituted the computational mesh.

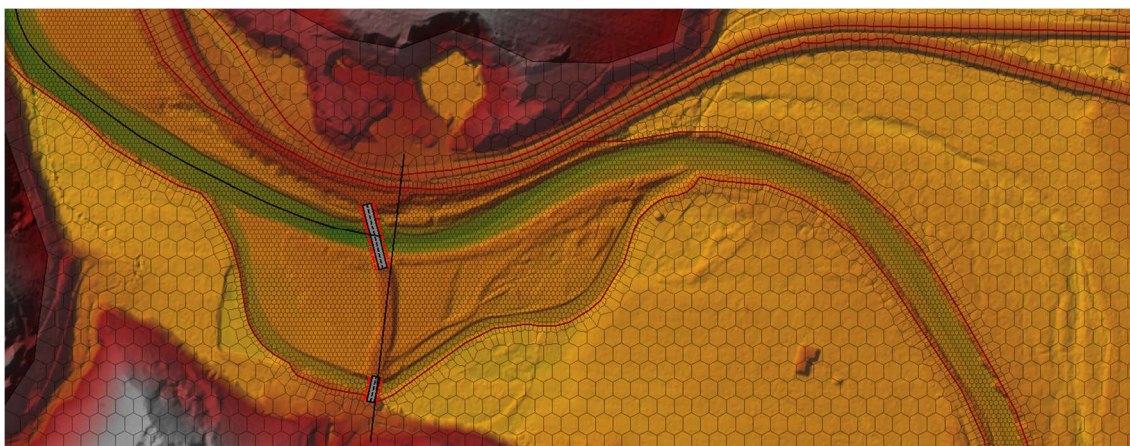


Fig. 4 Mesh elements.

Model calibration

The model was created to determine the flooded area during flood discharges. Calibration is performed for lower values of flows to prevent them from leaving the channel. In the out-of-channel spill area, a number of uncertainties increase; therefore, it is not appropriate to calibrate for high flows.

From the provided hydrological data, calibration was carried out in specific cross-sections. The cross-section of the limnographic station in Teplice nad Bečvou was utilized during calibration, employing the rating curve. For verification, the cross-section downstream, where the velocity field was measured, was selected. The position of the calibration cross-section is shown in Fig. 5. Both sets of flow data were obtained from the ADCP measuring instrument.

During the model fitting process, a combination of calibration to the gauge curve and verification to the velocity field, and vice versa, was tested. The rating curve was selected as the reference for calibration.

The variation in the reference calibration was chosen based on the rating curve and was conducted for two flow rates.

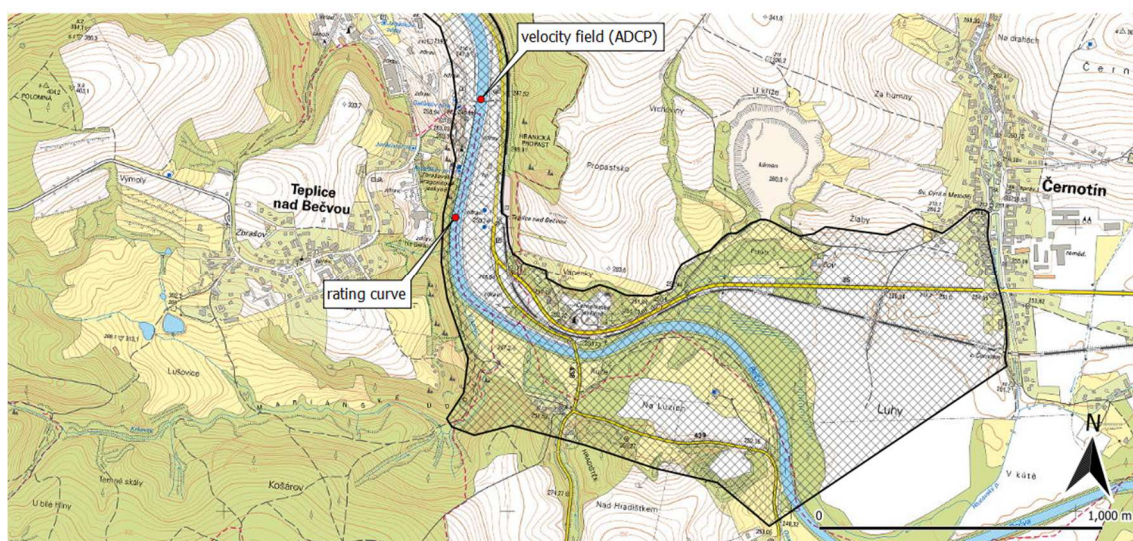


Fig. 5 Calibration profiles.

Calibration is achieved by adjusting the Manning roughness and configuring parameters of the turbulent model. Tab. 1 presents different calculation variants with various combinations of model settings.

The SWE-ELM (shallow water equations Eulerian-Lagrangian method) was utilized for all variants. DL and DT represent mixing coefficients in the longitudinal (L) and traverse (T) directions, while CS denotes the Smagorinsky coefficient [8].

The Manning’s roughness coefficient for the riverbed was determined based on the channel type and the cover of the inundation area, derived from local surveys and orthophoto maps. The setup of the SWE-ELM model coefficient is grounded in the research team’s experience. Variations were designed to be comparable to each other.

Tab. 1 Used model parameters.

Var.	n _{bed}	Equation set	Turbulence model	D _L	D _T	C _s
1	0.025	SWE-ELM	None	-	-	-
2	0.025	SWE-ELM	Conservative	0.3	0.1	0.05
3	0.025	SWE-ELM	Conservative	1	0.3	0.05
4	0.02	SWE-ELM	Conservative	0.3	0.1	0.05
5	0.02	SWE-ELM	None	-	-	-
6	0.02	SWE-ELM	Conservative	1	0.3	0.05
7	0.02	SWE-ELM	Conservative	0.3	0.1	0.2

3 RESULTS AND DISCUSSION

In the transverse profiles selected for calibration, the steady-state level was extracted from the 2D hydrodynamic model. Both cross-sections are located in a relatively straight section; thus, the surface is not significantly affected by deformation, allowing us to read the horizontal mean water level.

Fig. 6 and 7 depict water levels from cross-section used during the calibration process with a rating curve. Fig. 6 shows water levels from cross-section, that was used for calibration using a rating curve. Variation 1, 2 and 3 share the same Manning roughness coefficient (0.025) but have different settings for the turbulent model. Water levels from 2D hydrodynamic models, specifically variation 4, 5, 6, and 7, are closer to the measured real water level in the channel. Their Manning roughness coefficient value is lower (0.02) than in variations 1, 2, and 3. The lowest step is variations 4 and 5. Although the setup of the turbulent model is different, these two variants achieve very close results.

In this comparison, it becomes evident that the Manning roughness coefficient exerts the greatest influence. In this case, the turbulent model setting does not hold higher significance in the calibration profiles, but this does not mean that its change cannot be reflected elsewhere in locations with stronger turbulent effects.

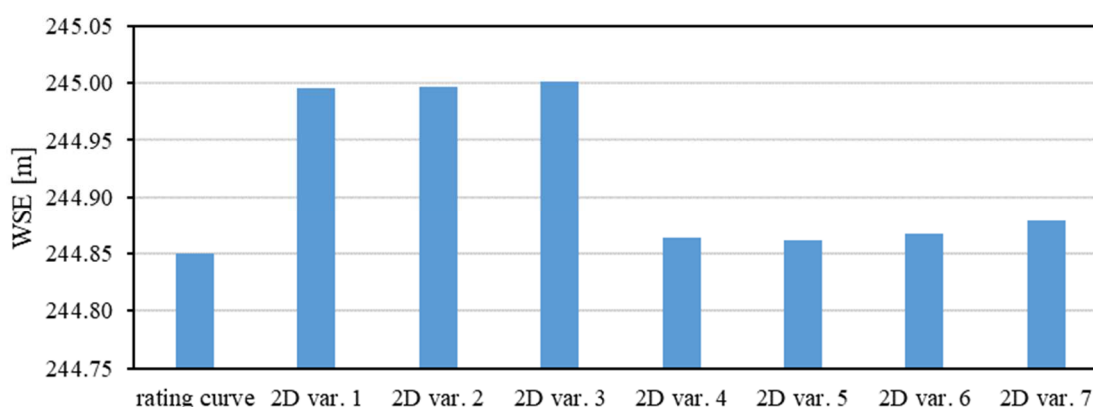


Fig. 6 Water surface elevations for $Q = 82 \text{ m}^3/\text{s}$.

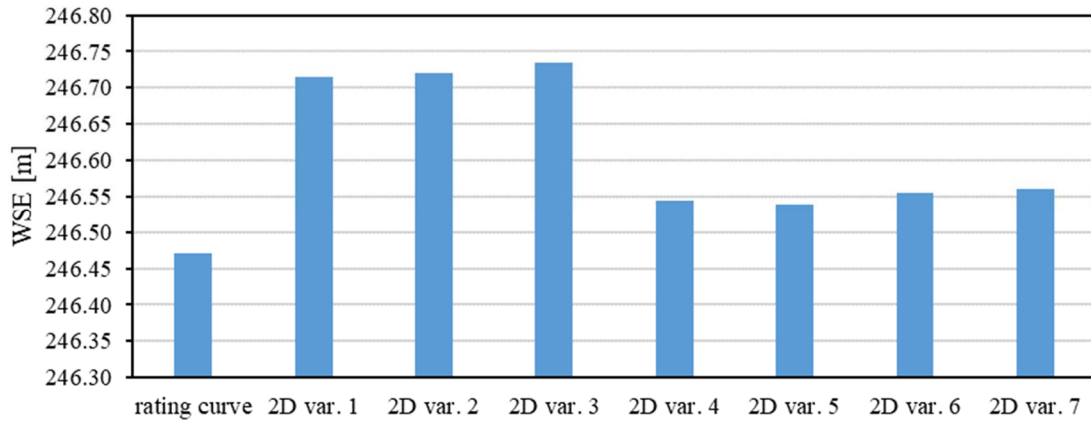


Fig. 7 Water surface elevations for $Q = 273 \text{ m}^3/\text{s}$.

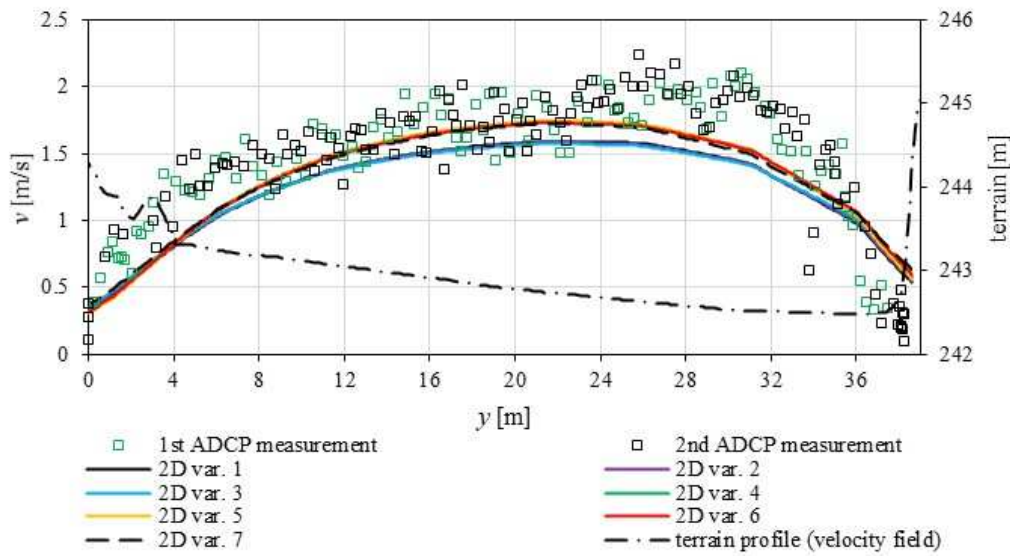


Fig. 8 Vertical velocity fields for $Q = 82 \text{ m}^3/\text{s}$.

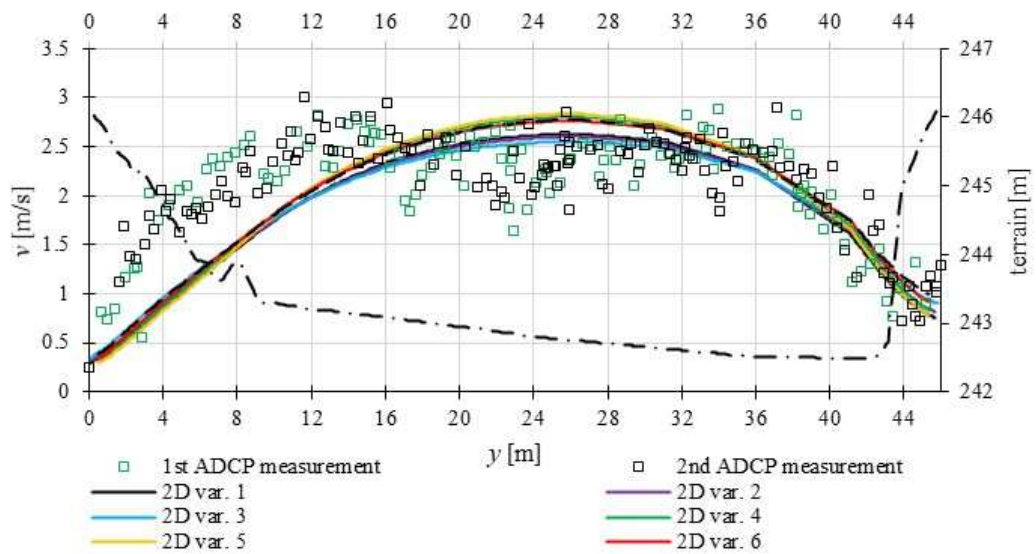


Fig. 9 Vertical velocity fields for $Q = 273 \text{ m}^3/\text{s}$.

The vertical velocities obtained through ADCP measurements are presented alongside the calculated velocities of the individual variants of the 2D hydrodynamic model in Fig. 8 and 9. When comparing vertical velocities, the results show similarity between variations 1, 2, 3 and then variations 4, 5, 6, 7. Once again, the value of the Manning roughness coefficient demonstrates the highest ability to influence the results of the 2D hydrodynamic model. The turbulent model setup has much less influence on the velocity waveform.

The calibration issue remains a subject for further solutions. When using the rating curve for calibration, the water level tends to be too high compared to the vertical velocity field data. On the other hand, calibration based on velocity data results in a water level lower than that indicated by the rating curve. Due to these differences, the rating curve calibration was chosen as the reference.

It is evident that the model is adequate when calibrated to the rating curve channel. However, attempts to calibrate the model using the velocity field revealed the need for modifications. Smaller computational mesh cells could introduce more variability into the velocity field and describe it more accurately. With such large cells, much of the information is smoothed out in the interpolation between the calculated values on the mesh cell.

The uncertainty is present not only in the measured data used for calibration but also in the accuracy of the DTM and the size of computational mesh cells.

4 CONCLUSIONS

This paper presents some of the uncertainties associated with the development and solution of a 2D hydrodynamic model of channel and floodplain flow. The calculations were performed using HEC-RAS 6.4.1 software.

The approach involved calibrating and verifying the model for two measured conditions, including the velocity profile in the channel. The results indicate that the 2D model built in this manner is unable to capture the variability of the measured values in the velocity field.

A refinement of the computational grid in the channel is under consideration to capture more details. However, in a practical solution to the floodplain delineation problem, such a detailed approach may not be appropriate, as it could lead to significant computation times for the solver. In this case, we settled for calibration to the water surface elevation obtained from the measured rating curve.

For the calibration of the velocity field, it might be advisable to truncate the model, take boundary conditions from the larger model, and employ a considerable refinement of the computational grid in the channel. Calibration of the channel roughness and turbulence parameters can be performed on the truncated model produced in this way. In this case, the uncertainty would manifest itself in the use of parameters from a truncated, more detailed model with a different computational element size compared to the larger full-length model that no longer includes such detail.

It was also discovered that the Manning coefficient, reflecting the condition of the cover, significantly influences the model results.

This serves as an introduction to the issue, and more detailed research will follow.

Acknowledgements

This article was elaborated with the support of project FAST-S-23-8233 “Sensitivity Analysis of Selected Input Parameters in Water Flow Numerical Modelling”.

References

- [1] DUCHAN, D., KOTAŠKA, S., POSPÍŠILÍK, Š., DRÁB, A. Citlivostní analýza vybraných vstupních parametrů numerického modelu HEC-RAS při hydraulických výpočtech proudění vody v korytech toků a záplavových území (Sensitivity analysis of selected input parameters of the numerical model HEC-RAS in and floodplain flow calculations). *Vodohospodářské technicko-ekonomické informace (VTEI)* [online]. 19. 4. 2021, vol. 63, no. 2, pp. 42–47. ISSN 0322-8916. DOI 10.46555/VTEI.2021.01.001
- [2] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO 748:2021. Hydrometry – measurement of liquid flow in open channels. 5. 2021
- [3] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO 18365:2013, Hydrometry – selection, establishment and operation of a gauging station. 1. 2013
- [4] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. ISO 18320:2020, Hydrometry – measurement of liquid flow in open channels. 1. 2020
- [5] DONGSU, KIM, MARIAN, MUSTE. Multi-dimensional representation of river hydrodynamics using ADCP data processing software. *Environmental Modelling & Software* [online]. 2012, v. 38, pp. 158–

166. ISSN 1364-8152. DOI 10.1016/j.envsoft.2012.05.011
- [6] MASAFU, Christopher, WILLIAMS, Richard, SHI, Xiaogang, YUAN Qiangqiang, and Mark TRIGG. Unpiloted aerial vehicle (UAV) image velocimetry for validation of two-dimensional model simulations. *Journal of Hydrology* [online] 2022, v. 612 part C, p. 128217. ISSN 0022-1694. DOI 10.1016/j.jhydrol.2022.128217
- [7] SALAH ABD EMOATY, Mohamed and T.A., El-samman. Manning roughness coefficient in vegetated open channels. *Water Science* [online], 34:1, 124–131. ISSN 2357-0008. DOI 10.1080/11104929.2020.1794706
- [8] HEC RAS 6.4.1 software documentation. CEIWR-HEC [online], 2023 [accessed 2023-11-1]. Available at: www.hec.usace.army.mil/software/hec-ras/