CALIBRATION AND VERIFICATION OF A 1-D FLOW MODEL FOR A LOOPED RIVER NETWORK

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Summary: *This paper presents the calibration and verification of a looped river network model. The model was calibrated by altering the Strickler's coefficient using three different approaches, by simply assigning a constant value of the Strickler's coefficient in a cross section, defining the Strickler's coefficient as a function of the discharge, and finally by associating the Strickler's coefficient to the local depth .The verification is conducted by comparing the computed results, for all of the considered methods with measurements on the Danube River for the time interval from January 1st to December 31st of the year 2006. Careful examination of the results allowed the selection of the most suitable calibration method for future reference.*

Keywords: *Numerical model, looped river network, calibration, verification*

1. INTRODUCTION

The aim of this paper is to advance the calibration of a one-dimensional flow model for a looped river network, paying special attention to the selection and implementation of the most suitable calibration approach. Despite the fact that 1-D models are widespread (modeling flood prone river systems, channel network modeling, laboratory experiments, etc.) Ref. [1, 2, 3], their proper calibration still presents a major challenge. Castellarin et al. discussed useful guidelines for identification of the geometric description of natural rivers [4]. K. W. Chau wrote a paper proposing a system that would help researchers in the calibration process, and Vidal et al. provided the bases of a framework for the calibration practice in 1-D river hydraulics [5].
The applied numerical model supports water flow modeling in looped river network [6] with a dam as an internal boundary condition. The calibration is done by varying the Strickler's coefficient along the domain using three approaches, finally evaluated through the verification process.

2. MODEL APPLICATION

The 1-D open channel flow model is tested on a river network that consists of the Danube (from the Iron Gate I Hydroelectric Power Station at *rkm 943* to Novi Sad at

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rkm 1254.15 with 292 computational points), Tisa (Titel at *rkm 0* to Senta at *rkm 123* with 40 computational points, including the dam in Novi Becej at *rkm 62.35*) and Sava (from Belgrade at *rkm 0* to Sabac at *rkm 102.85* with 35 computational points). The downstream boundary condition is the known water-level on the Iron Gate I. Upstream boundary conditions are needed at all tributaries, hence the known discharge through time was used at each one. The analyzed area on the Tisa river includes the dam at Novi Becej. The simulation time is one year and 15 days, using the first 15 days as the stabilization period. The computational time step was 15 minutes, while the distance between computational points was approximately *1km* on the Danube and *3km* on the Sava and Tisa rivers. These distances generally satisfy the optimal cross-sectional spacing requirement in one-dimensional models [4].

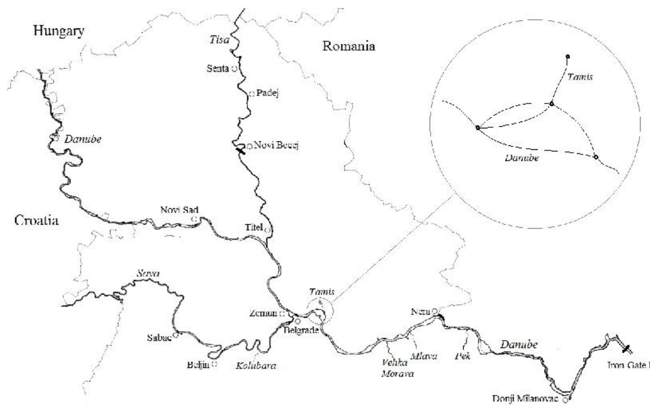

Figure 1. The modeled river network (river names marked with italic)

3. THE CALIBRATION APPROACH

Common 1-D open channel flow models behave poorly in terms of flow distribution across a section in a natural meandering channel with vegetated flood plains [7]. Therefore, model calibration remains a critical step in numerical modeling [5]. The model used in this paper enables multiple calibrating options. The considered approaches are calibration with a constant Strickler's coefficient, variable coefficient set as a function of the discharge, and coefficient as a function of the depth. Each approach was implemented on the examined domain and used for the model calibration and verification. The criteria to evaluate the considered methods is the requirement of the calibration process, the physical justification of the considered approach as well as the results deviation from the measurements.

Appointing a *constant Strickler's coefficient* for each computational point is a widely accepted calibration method. The final goal of this calibration approach is selecting only one Strickler's coefficient at each cross section that will produce the best results. With this in mind, all the modeled reaches are calibrated for the time interval of six days, for each of these cases separately, resulting in six series of Strickler's coefficient for the complete model. The final value of the coefficient for a cross section is obtained by averaging the previously selected series.

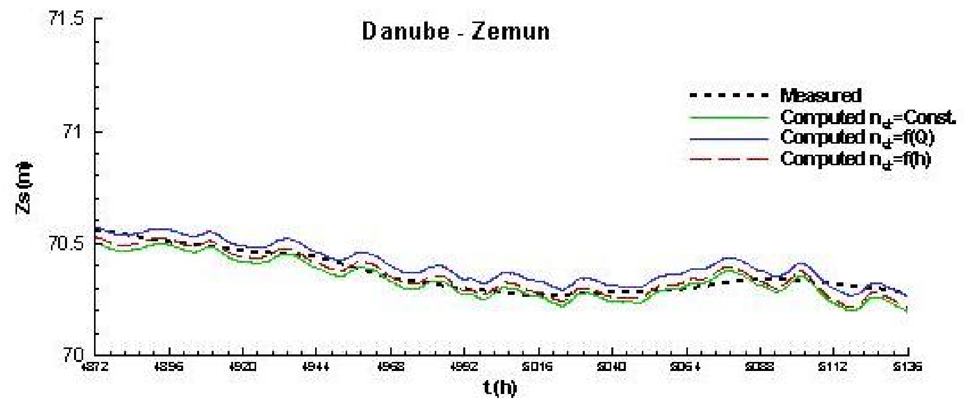

Figure 2. Comparison of results and measurements at Zemun

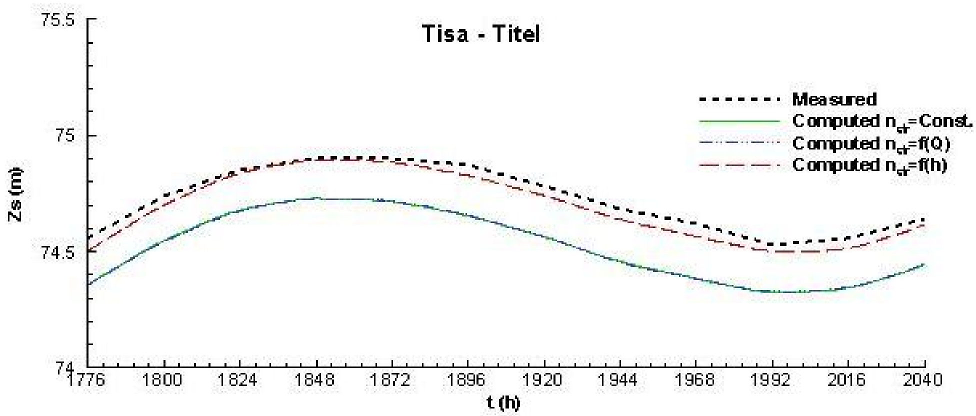

Figure 3. Comparison of results and measurements at Titel

Although this approach can produce good results in the calibration process, using constant Strickler's coefficient n_{str} for long term simulations proved to be inefficient, since these values are valid in a certain interval of discharges located around the values used for calibration Fig. 2. Varying the discharges in a broader range increases the deviation between measurements and computed values as confirmed by the simulation results on Fig. 3. These results indicate that instead of using constant n_{str} through the simulation, a relationship enabling the variation of n_{str} throughout the computation should be implemented. An additional issue of the constant coefficient n_{str} approach is the excessive work it requires during the calibration, since its accuracy depends upon the attention paid to selecting the characteristic discharges and their separate calibration.

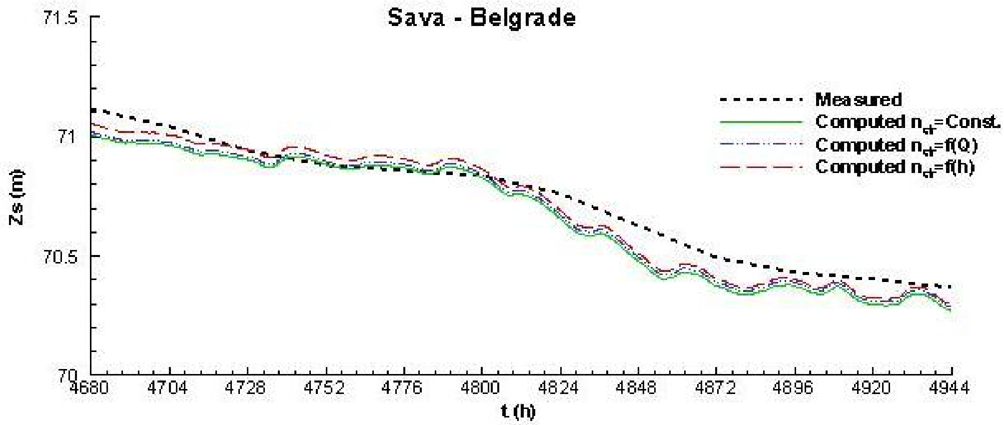

Figure 4. Comparison of results and measurements at Belgrade

Inspired by this, the developed model was extended in order to allow the *Strickler's coefficient to change with the discharge*. As a result, for an arbitrary cross section multiple pairs of n_{str} and corresponding discharges are assigned, enabling the variation of the roughness through the computation, thus producing better results in the verification procedure (Fig. 4). This method introduced a controversy as a result of the Iron Gate I dams influence. Ordinary, the increased discharge results in water level elevation, unless dams are used to keep the water level at a constant value, when the discharge is low, or dropping the water level in case of floods, when the discharge is high. This results in a physically unnatural relation between n_{str} and the discharge, which can introduce instabilities in the numerical solution. Another disadvantage of this method is that it has the same requirements in the calibration process as the method with the constant n_{str}.
The issues with this approach are the vague physical meaning and the amount of work needed to produce adequate results, that subsequently lead to the use of another approach and *connecting the Strickler's coefficient with the water depth*.
Using the logarithmic velocity distribution, the friction factor C_d can be presented as

$$C_d = \frac{\kappa^2}{\left[\ln\left(Z_1/k\right)\right]^2}, \tag{1}$$

where κ denotes the von Karman's constant, Z_1 is the distance from the bed at which the C_d is computed, defined as a fraction of the depth h, and k is the absolute roughness used as the calibration parameter. After computing C_d, using Eq. (2) we obtain n_{str},

$$\varphi = \sqrt{\frac{g}{C_d}} \cdot h^{-1/6}. \tag{2}$$

The k is used for calibration through Eq. (1), and afterwards, depending on the depth, the Strickler's coefficient is computed, thus allowing a more reasonable calibration. Since now the n_{str} depends on the local depth, the influence on the water level dictated by the dam does not introduce inconsistencies. Another advantage of this method is that it simplifies the calibration, since the impact of the discharge variations vanishes this way.

4. RESULT'S ANALYSIS AND VERIFICATION

Although the simulation period was from 1st of January to 31st of December 2006, in order to analyze the studied approaches the results are compared and presented on a shorter time interval (from 10 to 30 days). The results of the one year simulation are given for the selected approach solely. Figure 2 shows the influence of the Iron Gate I dam on the flow, displayed as frequent variations of the water level.

Due to the proximity of the downstream boundary condition, all of the considered calibration approaches gave similar and good results.

However, as the distance from downstream boundary increases, the differences between measured and computed results become more obvious. Considering the accuracy of the presented results, the physical interpretation and the amount of work required in the calibration process, it would be reasonable to model the Strickler's coefficient as a function of depth.

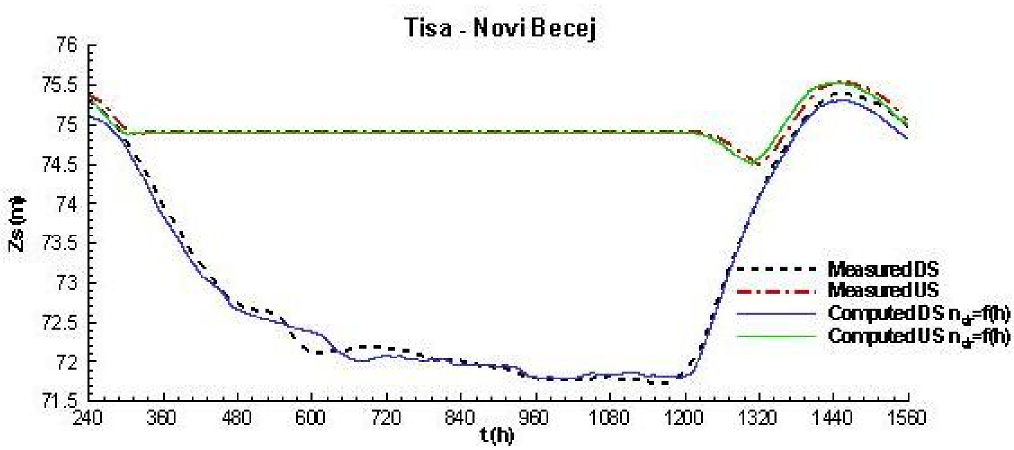

Figure 5. Comparison of results and measurements at Novi Becej

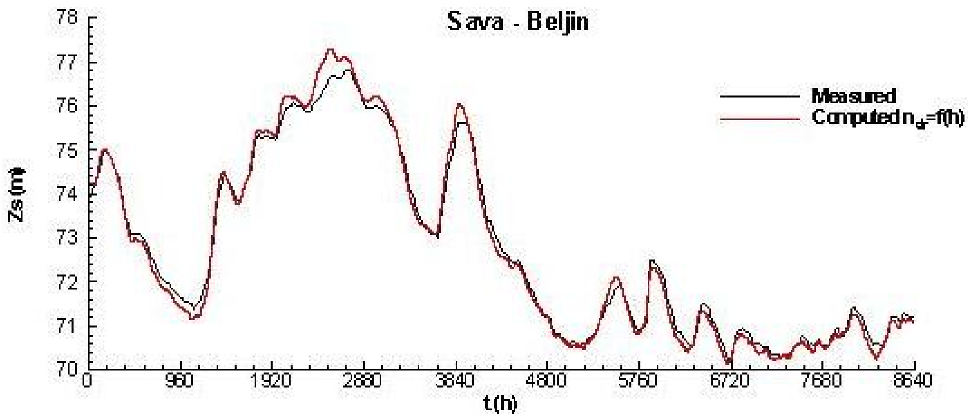

Figure 6. Comparison of long term (one year) results and measurements at Beljin

Accordingly, the most suitable approach for future references is using the depth-dependent model. In order to achieve clarity, the results are presented for a time interval of only 55 days. Figure 5 shows the results for water levels at upstream and downstream face of the dam in Novi Becej, and Fig. 6 presents results for Beljin. The agreement of the computed and measured water levels is satisfactory, especially regarding the broad range of water levels and discharges caused by the 2006 flood. Examining the results confirms the developed models accuracy.

5. CONCLUSION

The considered model was implemented on a looped river network that consists of the Danube River and all of its greater tributaries in Serbia. The calibration was done by changing the Strickler's coefficient, using three alternate approaches. The first approach used constant value for the Strickler coefficient for each cross section and produced poor results for discharges that alter from the ones used for calibration. To address the later, the Stricler's coefficient was assigned as a function of discharges at each cross section. This approach also proved to be inadequate since it was time consuming and physically unjustified. Thus, a third approach was introduced, that allowed the connection of the Strickler's coefficient to the local depth leading to better results, intelligible reliance between the roughness and local depth, and easier calibration. After determining the best calibration approach, the results of a long term (one year) simulation were presented endorsing the proposed calibration approach, as a simple, yet practical way of model calibration.

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КАЛИБРАЦИЈА И ВЕРИФИКАЦИЈА ЛИНИЈСКОГ МОДЕЛА ТЕЧЕЊА У МРЕЖИ ОТВОРЕНИХ ТОКОВА

Резиме: *Рад даје опис поступка калибрације и верификације развијеног модела мреже отворених токова. Модел је калибрисан мењањем Strickler-овог коефицијента користећи три различита приступа, задавањем константне вредности Strickler-овог коефицијента по попречном пресеку, дефинисањем коефицијента као функција од протицаја, и коначно, везивањем Strickler-овог коефицијента за локалну дубину у попречном пресеку. Верификација модела је урађена поређењем резултата, за све размотрене методе калибрисња, са мерењима спроведеним током периода од 01.01.2006. до 31.12.2006. Детаљна анализа резултата је омогућила избор најповољније методе за калибрацију модела.*

Кључне речи: *Нумерички модел, мрежа отворених токова, калибрација, верификација*