COMPARING VALIDATION RESULTS OF 1D VERSUS 2D MATHEMATICAL MODEL FOR BUNA RIVER

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ABSTRACT

Mathematical models are a valuable tool to study different water-related problems. 1Dimensional and 2Dimensional mathematical models are widely used in river engineering studies. 1D and 2D mathematical models are set up for Buna River using SOBEK software developed from Deltares Institute, the Netherlands. Buna River is part of the water system of Shkodra Lake, Drini and Buna River. This water system is the largest in Albania, and receives significant amounts of annual precipitation ranging from 1600 mm to 4000 mm. This water system discharges all its waters into the Adriatic Sea through Buna River bed, which has a total length of around 44 km. Around 1.5 km from flowing out of Shkodra Lake, Buna River joins Drini River, and then meanders in a low land area before discharging into the sea.

Validation is a very important step in the process of building a mathematical model for a water system. Validation of 1D and 2D mathematical models for Buna River is done by using the hourly water level data from on-line stations for an event. The results of both models are evaluated based on graphical comparison and statistical tests such as: Root Mean Square Error, Mean Absolute Error, and Correlation Coefficient. The 1D mathematical model shows a better performance for the flow inside the river banks (bankfull discharge) due to a more accurate representation of the river bathymetry.

Keywords: *Buna River, 1D and 2D mathematical models, validation, water level*

INTRODUCTION

The water system of Shkodra Lake, Drini and Buna River, which is the largest in Albania, collects the waters from a total surface of 19580 km^2. The drainage area of this water system is extended in different countries such as: Albania, Montenegro, Kosovo, and North Macedonia. Drini River with its branches Kiri and Gjadri has a total drainage area of 14400 km^2. Shkodra Lake has a total drainage area of 5180 km^2 [1]. All the waters of this water system are discharged into the Adriatic Sea through Buna River bed. Total length of Buna River is 44 km. After 1.5 km away from its source out of Shkodra Lake, Buna River has a junction with Drini River. Figure 1 shows the location of the study area, which is situated in the northwestern part of Albania.

River engineering studies are carried out by 1Dimensional and 2Dimensional mathematical models. 1D models consider that the hydraulic variables (velocity and depth) change mainly in the direction of the flow. 2D models consider the horizontal velocity components in two dimensions (V_x and V_y). Other types of models are coupled 1D/2D models, where river flow is modeled in 1D and floodplain flow is modeled in 2D. This modeling technique is very effective, because gives accurate results while reducing the calculation time.

Figure. 1: Location of the study area (Source: Google Physical)

An important step in the process of building a mathematical model is validation. After the mathematical model is calibrated, should be validated in order to be reliable to be used in the future for various scenarios.

MATERIAL AND METHODS

The water system of Shkodra Lake, Drini and Buna River it is modeled using the SOBEK software. This software is provided in the framework of IPA Cross Border Albania-Montenegro project. SOBEK software is developed by the Deltares Institute in Delft, the Netherlands. SOBEK is an integrated software package for river, urban and rural management [2]. This software is designed to perform one-dimensional hydraulic calculations for a full network of natural or constructed channels, and also 2Dimensional hydraulic calculations on two-dimensional (2D) horizontal grids [2]. This software offers the opportunity of using the coupling 1D/2D modeling technique. The philosophy of 1D/2D coupling in SOBEK is based on the fact that the width of the river channel is small compared to the size of the

2D grid cell [3]. This can be applicable for relatively small rivers with a large floodplain. Buna River is a wide river, with cross sections which varies from 300 m to 600 m. For this reason, the coupling 1D/2D modeling technique is not appropriate. The water system of Shkodra Lake, Drini and Buna River it is modeled in 1D and fully 2D using the SOBEK software.

Mathematical model equations

To model the flow SOBEK software solves the full Saint-Venant equations. These equations are derived from the principle of conservation of mass (equation 1) and the principle of conservation of momentum in X and Y direction (equations 2 and 3). The Saint-Venant equations solved in SOBEK software [2] are given as follow:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = 0 \quad (1)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial \zeta}{\partial x} + g\frac{u|\vec{u}|}{C^2 h} = 0 \quad (2)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial \zeta}{\partial x} + g\frac{u|\vec{u}|}{C^2 h} = 0 \quad (3)$$

where: ζ water level above plane of reference [m]

h total water depth $h = \zeta + d$ [m]

d depth below plane of reference [m]

C Chézy Coefficient [$\sqrt{m}/s$]

u, v velocity in x and y - direction [m/s]

$|\vec{u}|$ velocity magnitude $|\vec{u}| = \sqrt{u^2 + v^2}$ [m/s]

The Saint-Venant equations are solved in SOBEK software by the Delft numeric scheme. This numerical scheme developed by Stelling, is a finite difference numerical technique based on the rectangular staggered grid [4]. In 1D modeling technique, the equation of conservation of mass and momentum in x direction (along the river channel) are solved. In 2D modeling technique, the equation of conservation of mass and momentum in x and y direction are solved.

Setting up the 1Dimensional mathematical model for the study area

The 1D mathematical model using SOBEK software was set up based on the digital terrain model developed from the topographic survey made in the study area during the period 2005-2006, from the Albanian Academy of Sciences and the Academy of Sciences and Arts of Montenegro [5]. The topographic survey was carried out for a large number of cross sections in Buna River and lower part of Drini River. The mathematical model built in SOBEK software for the water system of Shkodra Lake, Drini and Buna River is presented in figure 2. An important step in the process of setting up a 1D mathematical model is entering the cross section data. For this reason, it is very important to have a large number of cross sections to describe the geometry of the river system. The quality of the mathematical model depends on the accuracy of the terrain data. For the study area were used around

400 cross sections in total. Cross sections were measured at intervals of around 100 m from each–other, which gives a good representation of river bathymetry. Some of the cross sections are used to describe the bathymetry of Buna River mouth in Montenegro and Albania, and some cross sections in the downstream part of Drini River (1 km before joining Buna River). Another important element, which describes the river cross sections, is the roughness coefficient. For the river cross sections in SOBEK, which are Y-Z profiles, are used different roughness coefficients for main channel and overbank area. Figure 3 represents Manning's roughness coefficient *n* for a given cross section in the 1D mathematical model in SOBEK software.

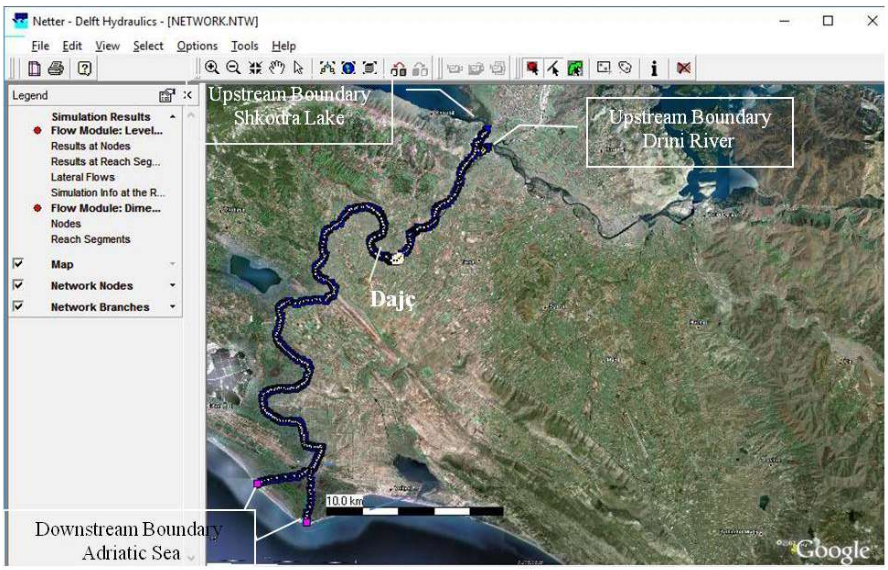

__Figure 2.__ The 1D mathematical model built in SOBEK software for the study area

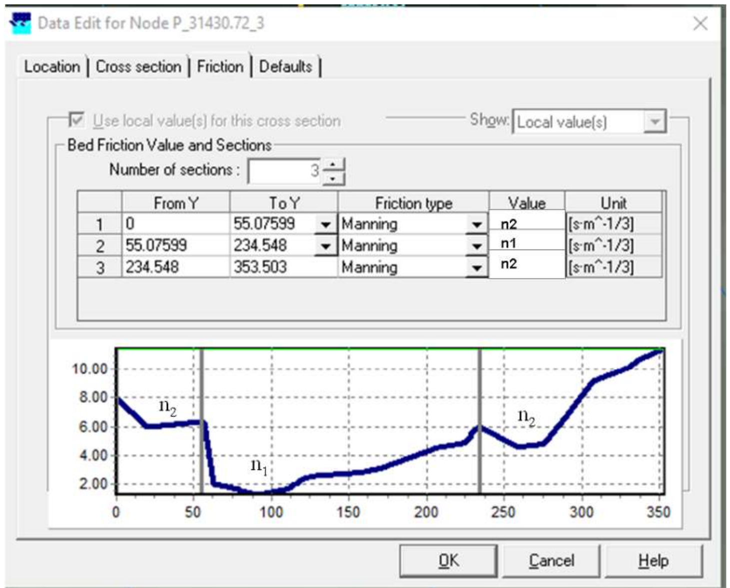

Figure 3. *Representation of roughness coefficient for the 1D model built in SOBEK*

Roughness coefficient values for the main channel (n_1) and for the overbank area (n_2) are given preliminary values based on tables and figures compiled by Ven Te Chow [6]. During the calibration process different values of Manning roughness coefficient n_1 and n_2 were tested. Manning roughness coefficient n_1 and n_2, which give the best match between the measured values and model outputs were accepted.

Setting up the 2Dimensional mathematical model for the study area

The digital terrain model (DTM) is an important component of the 2Dimensional mathematical model. The quality of the mathematical model depends on the accuracy of the DTM for the study area. The DTM includes the topography of the river bed and topography of the floodplain. The DTM of river bed and overbank area was generated based on topographic survey carried out in the study area in 2005-2006, in the framework of a joint project between Albania and Montenegro [5]. The DTM for the floodplain was generated based on the digitalization of about 43 topographic maps on scale 1:10 000 covering the study region [7]. The topography of the study area is represented in SOBEK software by a rectangular 2D grid with grid cell size $\Delta x=\Delta y$. To have a good representation of the topography of the main channel and overbank area, the grid cell size of $\Delta x=\Delta y=15$ m was chosen. The 2D mathematical model built in SOBEK software for the study area is presented in figure 4. Another important element of the 2D model for the study area is the 2D grid of roughness coefficient. This grid consists on the values of roughness coefficient for Buna River and lower part of Drini River, and values of roughness coefficient for the floodplain area. The roughness coefficient for the floodplain area was evaluated based on CORINE Land Cover 2012 database. Roughness coefficient values (Manning coefficient) for the cells in the main channel (n_1), and for the cells in the overbank area (n_2) were given preliminary values based on literature recommendation [6]. After the calibration process, the roughness coefficient values (n_1) and (n_2), which give the best match between the measured values and model outputs were accepted.

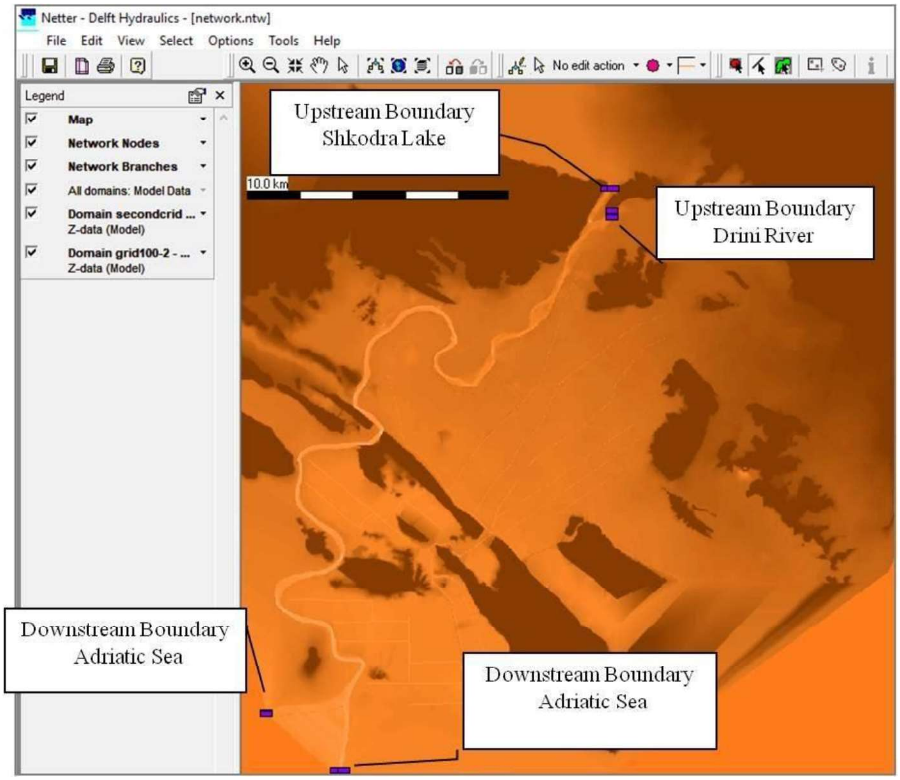

Figure. 4: *View of 2D mathematical model built in SOBEK software for the study area*

RESULTS AND DISCUSSION

Model validation is an important step in the process of modelling of a water system. According to ASME [8], validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model. During the validation process, the predictive capability of the mathematical model is evaluated. After the mathematical model is calibrated, it is then validated for a new set of measured data different from the ones used in the calibration process. The purpose of calibration process is to match the model results with field measurements by changing different model parameters, while the purpose of validation is to test the calibrated values of the model parameters.

The 1D and 2D mathematical models for the study area are validated based on hourly water level measurements from the online automatic stations of Dajç

(Buna River), Buna Bridge (Buna River), and Bahçellëk Bridge (Drini River) shown in figure 2. The inflow hydrograph at Buna Bridge takes into account the flow coming out of Shkodra Lake into the Buna River. Whereas the inflow hydrograph at Bahçellëk Bridge takes into account the flow coming into Buna River from Drini River. The inflow hydrographs at Buna Bridge and Bahçellëk Bridge are used as upstream boundary conditions, whereas as downstream boundary condition it is used the hydrograph of Adriatic Sea water level at Buna River mouth in Albanian and Montenegro. The discharge hydrographs at Buna Bridge and Bahçellëk Bridge station are calculated based on stage–discharge relationship created from discharge measurements done in these stations for the period 1992-2001, and 2010 [9].

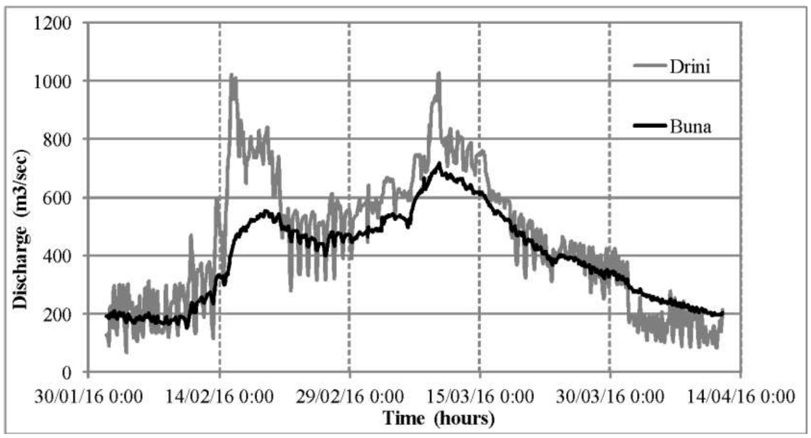

Figure. 5 *The inflow hydrographs at Buna and Drini River for the validation period*

Performance analyses of 1D versus 2D mathematical model

According to Silgram and Schoumans [10], the accuracy of the mathematical model is defined as the degree to which the predicted values of the model are close to the corresponding measured values. Mathematical model performance is evaluated based on graphical comparison of simulated values against measured data and statistical test. Statistical tests used to evaluate the performance of 1D and 2D mathematical models for the study area are: Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Correlation Coefficient (R). The validation period is from 01-02-2016 until 11-04-2016. This period is chosen because the river flow goes from low to high flow. Missing and inconsistent data from hourly water levels from the online stations are corrected. In figure 6 are presented hourly water level results from the 1D and 2D mathematical model versus measurements from the on-line station in Dajç for the period of validation.

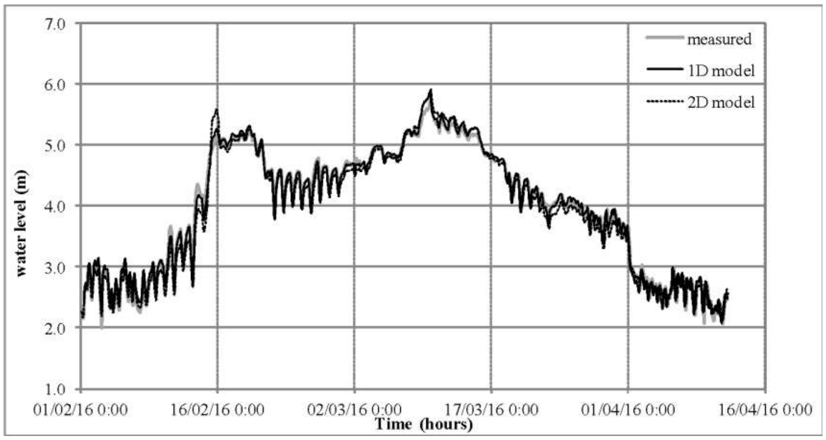

Figure. 6. *Measured versus simulated water levels from the 1D and 2D model for the validation period*

Based on graphical comparisons there is generally strong agreement between measured and simulated water levels at Dajç station from the 1D and 2D models. The discrepancies between the measured and simulated water levels from the 1D and 2D models generally are within ±15 cm, which is an acceptable value. The 1D and 2D model results appear to match the time of the peak, but slightly overestimate the peak flood levels (especially in the second peak). From the graphical comparison, the water level predicted from the 1D model are much closer to measured level in comparison with the water levels predicted from the 2D model.

The performance of the 1D and 2D mathematical model is analyses based also on statistical tests. For the 1D model the values of statistical tests are as follow: RMSE =11.6 cm, MAE=9.4 cm, R=0.95. For the 2D model the values of statistical tests are as follow: RMSE =13.1 cm, MAE=10.1 cm, R=0.94. The results of the statistical tests indicate that the 1D model performs better than the 2D model having smaller values of RMSE and MAE and a slightly higher Correlation Coefficient value than the 2D model.

As a final remark, the 1D model for the study area performs better than the 2D model for the validation period based on graphical comparison and statistical tests.

CONCLUSIONS

Buna River is part of the water system of Shkodra Lake, Drini and Buna River, which is the largest in Albania. This water system was studied through the 1D and fully 2D mathematical modeled built in SOBEK software. The 1D mathematical model represents the River Buna and lower part of Drini River bathymetry with around 400 cross sections spaced at a distance of 100 m from each other. The 2D model uses a rectangular grid, with cell size of 15 m. This value is chosen because it gives a good representation of the river bathymetry and the irregular floodplain area. Smaller grid cell sizes will make the 2D model more accurate, but will increase the total number of grid cells. This will lead to the increase of the computation time and will face software limitations for the total number of cells that can handle during the simulation.

Graphical comparison between measured water levels and computed from 1D and 2D model for the validation period shows an acceptable difference value. The timing of the two flow peaks are predicted well from both models, but the peak water levels are slightly higher than measured water levels, especially for the 2D model. Regarding the statistical tests, the 1D and 2D model have quite satisfactory errors values.

Validation results indicate that 1D model performs better than the 2D model based on graphical comparison and statistical tests. This fact makes the 1D model more suitable to model the flow up to bankfull discharge. The 1D model performs better than the 2D model saving also computational time, due to a more accurate representation of the river bathymetry with river cross sections. Rectangular 2D grids have problems in representing complex geometric river shapes. In contrary, 2D curvilinear grids follow the river channel and can capture well the river bathymetry. The curvilinear grid, which is currently been implemented from Deltares Institute will improve the flow representation in the fully 2D model.

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