J. Int. Environmental Application & Science, Vol. 11(2): 198-206 (2016)

Calibration of Hydraulic Model for Buna River

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Received April 02, 2016; Accepted June 02, 2016

Abstract: River flooding is one of the most frequent natural hazards in Albania. The area which is more vulnerable from river flooding is the area located in the county of Shkodra, in the northern part. This area has been significantly affected from flooding of Buna River in the recent years. Buna River, with a total length of around 44 km, collects the water from an important water system in Albania, composed of Shkodra Lake and Drini River, for which a flood model has been set-up using the HEC-RAS hydraulic software, based on the digital terrain model in WGS-84 coordinate system developed from the topographic survey made from both countries Albania and Montenegro. The hydraulic model built for Buna River have been calibrated using the trial and error method, reducing the difference between computed and observed water levels, by manually changing hydraulic roughness coefficients, Manning's "*n*" values for the main channel and the overbank area. Model performance during the calibration phase it is evaluated through both qualitative and quantitative measures, including both graphical comparisons of calculated and measured water levels and statistical tests. For the Buna River, the water levels modelled by HEC-RAS are in fairly good agreement with the observed data from online station. The values of the model error chosen to evaluate the performance of the hydraulic model after calibration process for low-flow and high-flow are quite satisfactory.

Keywords: *HEC-RAS, Buna River, mathematical model, model calibration, statistical analyses*

Introduction

Shkodra Lake, Buna and Drini River water system accumulates all the water in a general surface of 19580 km^2, when only Drini River with its branches Kiri and Gjadri has 14400 km^2, and Shkodra Lake with Moraça stream inflows has 5180 km^2. The general surface of the basin of this water system is expanded in Albanian, Montenegro, Kosovo, and Macedonia territories. The Water system of Shkodra Lake, Drini and Buna, has a watershed with significant amounts of annual precipitation ranging from 1600 mm to 4000 mm (IHM, 1984).

The length of Buna River from the upstream near Shkodra Lake until Adriatic Sea where it discharges is around 44km. After 1.5 km away from Shkodra Lake this river has a junction with Drini River. Buna River bed has a longitudinal mean slope of 1.2m/km and a lot of meanders and through its river bed the waters of Shkodra Lake, and Drini River are discharged into Adriatic Sea.

Drini River, that is the biggest river of east Adriatic and Ionian seacoast, has an annual mean discharge of 352m^3/sec at Bahçellëk station. Drini River has also a high hydro energetic potential, which is used by constructing three hydropower plants: Fierza, Koman, and Vau Dejes. The water flow regime of the Drini River is strongly influenced by the cascade of three reservoirs of Fierza, Koman and Vau Dejes. The Figure 1 shows the location of the study area.

Shkodra Lake, Buna and Drini River water system is one of the most complicated hydrological complexes in Albania (Stratobërdha *et al.,* 2002) due to different factors such as: the existence of a very big water basin, a considerable amount of rainfall in the period October-April, and concentration of water downstream the junction of Buna River with Drini River. This water system, in terms of hydraulic regime, is a complicated hydrographic system where the risk of periodical flooding of agricultural lands and residential areas influence the development of this area.

To study the water regime of Shkodra Lake, Drini and Buna River water system a mathematical model it is built, using HEC-RAS hydraulic software (USACE, 2010). An important step in the process of numerical modelling is the calibration of the model, which ensures having a reliable model that gives accurate predictions of different hydraulic parameters.

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

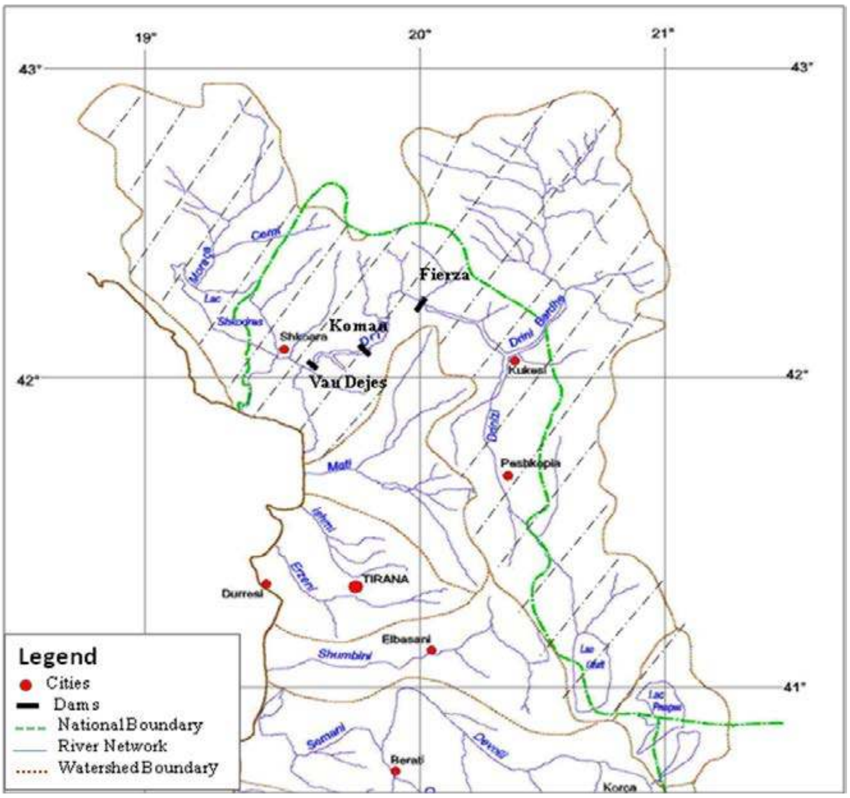

Figure 2. Shkodra Lake, Buna and Drini River water system (*Source: Jean Pierre Debuiche, 2000*)

Materials and Methods

To study the hydraulic regime of Shkodra Lake, Drini and Buna River water system, which is shown in Figure 2, was used HEC-RAS hydraulic software, created by the Hydrological Engineering Center in USA, which was also applied in (Hoxha *et al.* 2005). This software it is designed to perform one-dimensional hydraulic calculations for a full network of natural or constructed channels.

The mathematical model built in HEC-RAS is based on the digital terrain model in a single coordinate system (WGS84, UTM-34) (Pandazi, *et al.* 2011), realized from the topographic survey carried out in the study area during the period 2005-2006, from the Albanian Academy of Sciences and Academy of Sciences and Arts of Montenegro (ASA & MASA, 2006).

Hydraulic Model in HEC-RAS

An important element in the process of setting –up a hydraulic model in HEC-RAS software (Abazi, 2016) for Buna River is to enter the necessary geometric data, which consist of defining the River System Schematic, river cross section data, downstream reach lengths, resistance coefficient, energy losses, river confluences and bifurcation data, etc,.

River System Schematic

The river system schematic characterizes how different branches of the river are connected with each other. The connection of branches with each other is very important for the model in order to understand how the calculations should be continued from one branch to another. In the case of the Lake Shkodra, Drin and Buna River water system, in addition to Buna River cross sections, are taken into consideration some cross sections in the downstream part of Drini River.

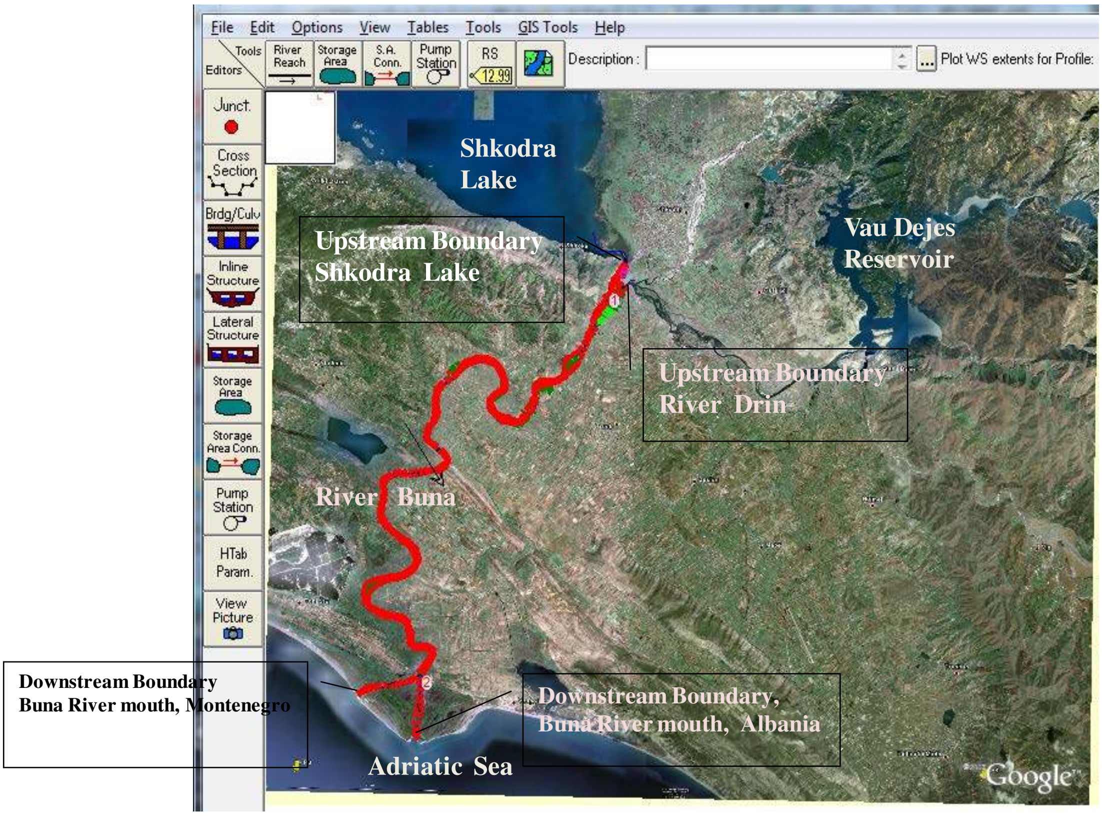

Figure 3. View of the hydraulic model built in HEC-RAS software (*Source: Google Satellite*)

River cross sections

River cross sections are an essential part of river schematization. It is very important to have a sufficient number of cross sections to accurately describe the main channel and overbank geometry, because this can be a great source of errors during the calibration process. For the Water System of Lake Shkodra, Drin and Buna River were used 395 river cross sections of whom 15 cross sections in the Shkodra Lake, 9 cross sections in the Drin River before joining the River Buna, 14 cross sections describing the mouth of Buna River in Montenegro, and 12 cross sections describing the Buna River mouth in Albania. The hydraulic model built in HEC-RAS appears in the following Figure 3, where can be distinguished the cross sections that are taken in the Shkodra Lake as well as cross sections that were taken in River Drin at about 1 km in length, which make possible the consideration of flows entering into Buna River from the Drini River, which is a tributary with a great influence in the Buna River flow.

Resistance coefficient

An important element in describing the river cross sections is the bed flow resistance coefficient, in our case it was used the Manning's n values. For the river cross sections, which are Y-Z profiles it is possible to define different friction values per cross-section lying on a reach for the main channel (n_1) and for the overbanks (n_2), Figure 4. The more precise values for the Manning's *n* roughness coefficient are defined in the calibration process.

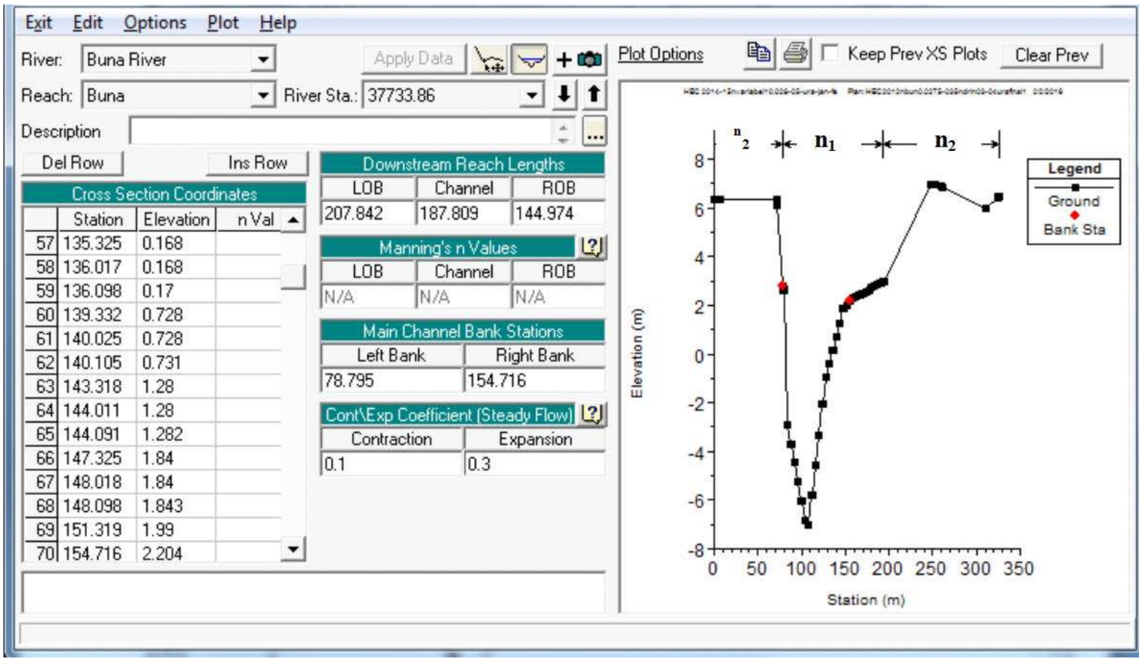

Figure 4. Manning's *n* roughness coefficient representation for a selected river cross sections

Results and Discussions

Model calibration, defined as the procedure assessing model setup, is a necessary stage in the modelling process (Vidal, *et al.* 2005). According to the definition of "model calibration" (Refsgaard *et al.* 2004) it is: "the procedure of adjustment of parameter values of a model to reproduce the response of reality within the range of accuracy specified in the performance criteria". After many years of computational hydraulic practice, model calibration still remains a critical and time-consuming task in the commonly defined modelling process.

The calibration of the hydraulic model built in HEC-RAS it is performed following the traditional method of trial-and-error (Vidal *et al.* 2007), which is based on the visual comparison of computed and observed values of water levels, and the manual adjustment of Manning's *n* parameter values. For the estimation of Manning's *n* values, the tables and figures compiled by (Chow, 1959) were used, which relate a description of the channel, considering its nature and its characteristics, to a range of values for Manning's "*n*". In order to reduce model errors, flow resistance coefficient "*n*" values estimates are then refined by comparing outputs from the model runs with measured data of recorded water levels.

The hydraulic model built in HEC-RAS software has been calibrated for time series of water level measurements at Dajç (River Buna), Buna Bridge (River Buna), and Bahçellëk Bridge (River Drin) automatic stations. These on-line automatic stations are installed lately from the financing of different projects (Hoxhaj *et al.* 2015; GIZ, 2014) and World Bank, 2014). The location of automatic stations is shown in Figure 5. At these locations hourly data were available, which provides a good opportunity for a detailed calibration of the model. The water level data used in the calibration had different time resolution, for the Dajç station were 15 minutes time interval data, whereas Buna Bridge, and Bahçellëk Bridge were hourly data. All these data were analyzed for missing data and then hourly water level data were used for the calibration process.

Figure 5. Location of automatic stations used for the calibration of the hydraulic model (*Source: Google Streets*)

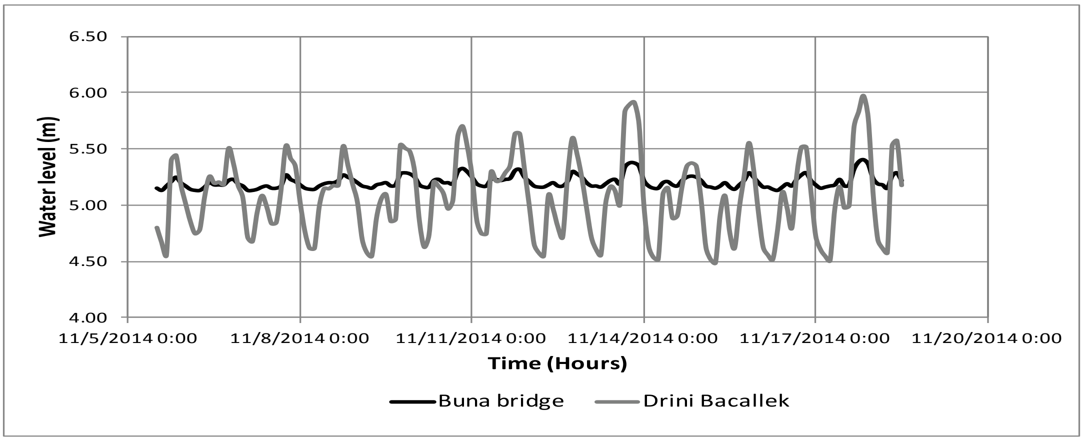

Figure 6. Water level measurement from the automatic station in Buna and Drini Rivers for the low-flow period

The time series of water levels used for calibration process include periods of low-flow and high-flow data. To calibrate the model for low-flow regime the inflow hydrographs from the automatic stations of Buna Bridge (River Buna), and Bahçellëk Bridge (River Drin) were used as upstream boundary condition for the period of time 6-18 November 2014. As downstream boundary condition constant water level of Adriatic Sea was used. Figure 6 shows the water level measurements from the automatic stations in River Buna and Drin for the period of low- flow.

The water flow regime of Drini River is strongly influenced from the management of the cascade composed of three hydropower reservoirs at Fierza, Koman and Vau Dejes. Flow data, at the downstream part of Drin River before the confluence with Buna River, are influenced from the operation of the Vau Dejes hydropower.

Drini River is a tributary with a great influence in the Buna River flow. Fluctuations of Drini River flow due to the operation of the Vau Dejes hydropower are reflected in discharges and water levels of Buna River downstream from the junction with Drini River. The effect of Drini River flow fluctuations is also noticed in the Buna River flow upstream the junction, but in a smaller scale as can be seen from the following figures.

To calibrate the model for high-flow regime the inflow hydrographs from the automatic stations of Buna Bridge (Buna River), and Bahçellëk Bridge (Drini River) were used as upstream boundary conditions for the period of time 25 January -24 February 2015. As downstream boundary condition was used constant water level of Adriatic Sea. Figure 7 shows the water level measurements from the automatic stations for the period of high-flow.

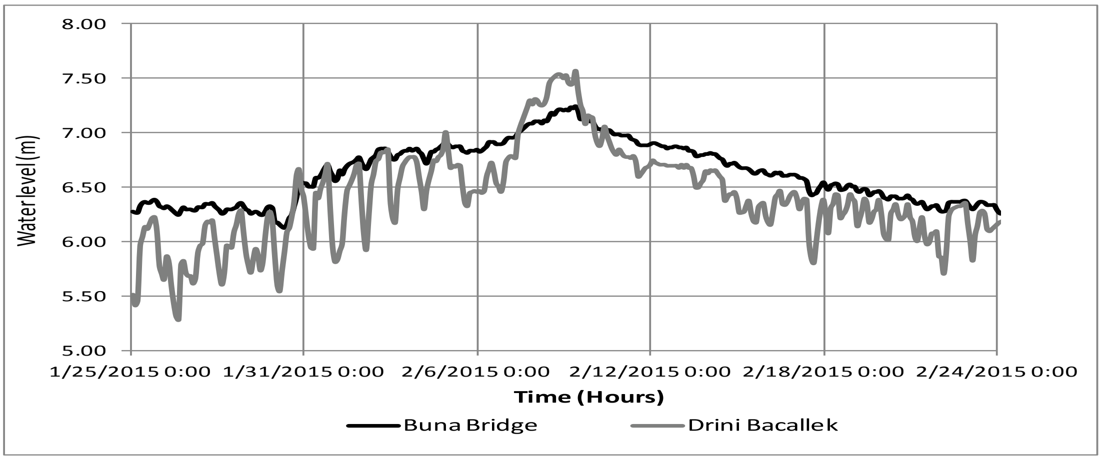

Figure 7. Water level measurement from the automatic station in Buna and Drini Rivers for the high-flow period

Model performance analyses

To analyze the performance of the model in the calibration phase both qualitative and quantitative measures are used, involving both graphical comparisons and statistical tests (Duda *et al.* 2012). Graphical comparison includes the time series plots of observed versus simulated water levels. Time series plots are generally evaluated *visually* based on the agreement between the simulated and observed values of water levels. For the statistical tests, three methods of error analysis were considered. The first is the Root Mean Square Error (RMSE), the second is the Mean Absolute Error (MAE), and the third is the Correlation Coefficient (R) (Solomatine, 2003). These methods are described in the table below.

Statistic tests used for the evaluation of the model performance was used following equation.

Root Mean Squared Error (RMSE): $$\sqrt{\frac{(p_1-a_1)^2+...(p_n-a_n)^2}{n}}$$

Mean Absolute Error (MAE): $$\frac{|p_1-a_1|+....+|p_n-a_n|}{n}$$

Correlation Coefficient **R:** $$\frac{\sum_{i=1}^{n}(p_i-\bar{p})(a_i-\bar{a})}{\sqrt{\sum_{i=1}^{n}(p_i-\bar{p})^2}\sqrt{\sum_{i=1}^{n}(a_i-\bar{a})^2}}$$

where:

RMSE= Root Mean Square Error
MAE = Mean Absolute Error

a = actual measured data set
p= predicted modeled data set
n = number of entries in the data set

The water level measurement at Dajçi stations were selected to be included in the error analysis because this stations is the most reliable and consistent available. Particular emphasis was given during the calibration process to ensure a good fit to these data sets. Measured data at Dajçi station were recorded at hourly intervals, and at each instance of measurement, results were extracted from the HEC-RAS model and compared with these measured data.

Model performance analyses for the low-flow period

After a dozen of simulations different values of Manning's "*n*" for the main channel (n_1) and for the overbanks (n_2) are applied. The resulting water levels at Dajçi station for the low-flow period: 6-18 November 2014, which ensure the best fit to the measure water levels, are presented in figure 8.

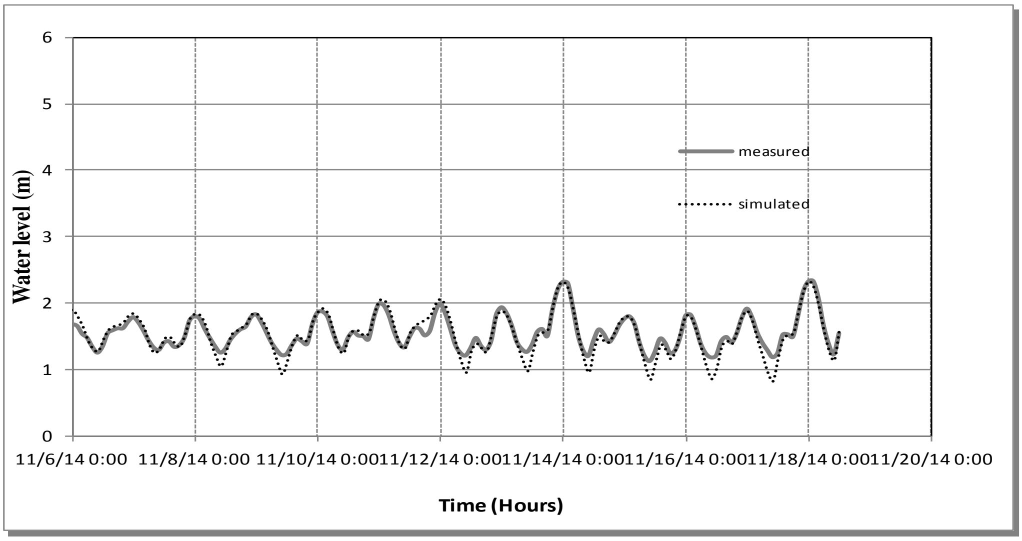

Figure 8. Comparison of measured and simulated water levels at Dajçi station (River Buna) for the low- flow period

As can be seen from the figure above, there is generally strong agreement between measured water levels at Dajçi station and simulated water levels from the model built in HEC-RAS. The discrepancies between measured and simulated water levels generally are within ±10 cm.

The error analysis was performed over the simulation period for low-flow based on the statistic tests. The values of the model errors after the calibration process for low- flow were RMSE =10.6 cm (Root Mean Squared Error), MAE=8.1 cm (Mean Absolute Error), and R=0.98 (Correlation Coefficient), which are acceptable errors values.

Model performance analyses for the high- flow period

After a dozen of simulations different values of Manning's "*n*" for the main channel (n_1) and for the overbanks (n_2) are applied. The resulting water levels at Dajçi station for the high-flow period: 25 January -24 February 2015, which ensure the best fit to the measure water levels, are presented in figure 9.

Based on graphical comparisons for the high-flow period in figure 9, there is generally strong agreement between measured and simulated water levels at Dajç station in Buna River. The discrepancies between the measured and simulated water levels generally are within ±15 cm, which is an acceptable value for flood models. For the Buna River, the water levels modeled by HEC-RAS for the selected flood event are in fairly good agreement with the observed data. The 1D model results appear to match the peak timing, although slightly overestimating the peak flood levels.

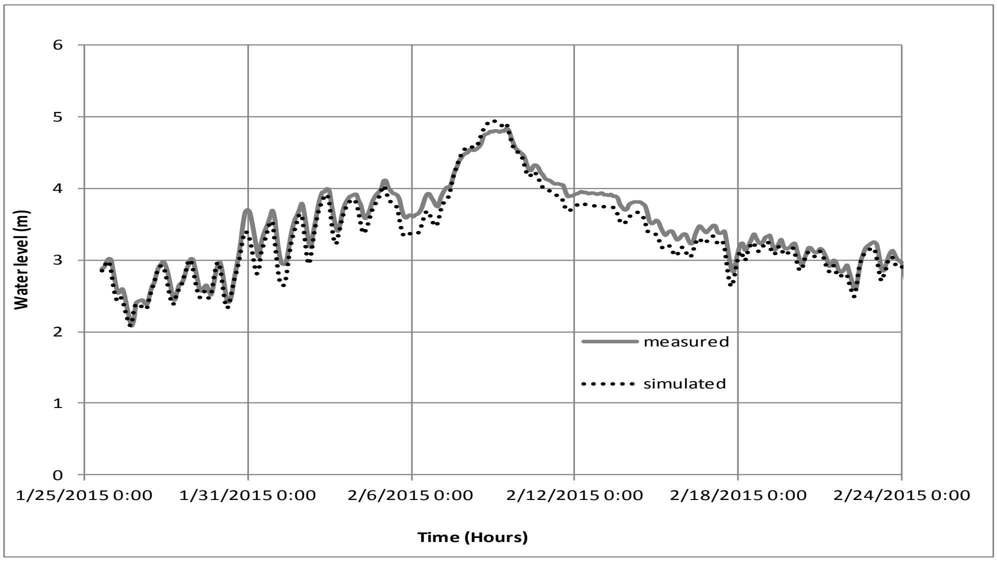

Figure 9. Comparison of measured and simulated water levels at Dajçi station (River Buna) for high-flow period

The values of the model errors after the calibration process for high- flow period were RMSE =15.6 cm (Root Mean Squared Error), MAE=13.7 cm (Mean Absolute Error), and R=0.95 (Correlation Coefficient). These error values show a good performance of the hydraulic model. The values of the model error chosen to evaluate the performance of the hydraulic model after calibration process for low- flow and high- flow are quite satisfactory.

Conclusions

Shkodra Lake, Buna and Drini River water system is one of the most complicated hydrographic complexes in Albania due to different factors such as: the existence of a very big water basin, a considerable amount of rainfall in the period of October-April, and concentration of water downstream the junction of Buna River with Drini River. To study the hydraulic regime of Shkodra Lake, Drini and Buna river water system, a mathematical model was built in HEC-RAS hydraulic software. This model was set- up based on the digital terrain model in WGS-84 coordinate system developed from the topographic survey made from both countries Albania and Montenegro in 2005-2006, which includes a considerable amount of cross sections starting from its outflow from Shkodra Lake until the discharge into Adriatic Sea, taking into consideration also the flow from the tributary, River Drin.

The calibration of the hydraulic model built in HEC-RAS it is performed following the traditional method of trial-and-error, which is based on the manual adjustment of Manning's "n" parameters in order to have a good match between observed and computed values of water levels. The hydraulic model built in HEC-RAS software has been calibrated for time series of water level measurements at Dajç (River Buna), Buna Bridge (River Buna), and Bahçellëk Bridge (River Drin) automatic stations for periods of low-flow and high-flow. The water level data from the automatic stations were hourly data, which give a good opportunity for a detailed calibration of the model.

Model performance during the calibration it is evaluated through both graphical comparisons of measured and simulated water levels, and statistical tests at Dajç station. After a lot of simulations using different Manning's "n" values for the main channel (n_1) and for the overbanks (n_2), the average difference between measured and computed maximum water levels for the low-flow and high-flow period generally are within ± (10÷15) cm. These values are acceptable values for flood models. The timing of the flow peaks is exact, but the peak floods water levels are only slightly higher than observed water levels.

To evaluate the performance of the hydraulic model built in HEC-RAS software are used the static tests such as RMSE (Root Mean Square Error), MAE (Mean Absolute Error), and R (Correlation Coefficient). The values of the model errors after calibration process for the low-flow period were RMSE=10.6 cm, MAE=8.1 cm, and R=0.98. The values of the model errors after calibration process for the high- flow period were RMSE=15.6 cm MAE=13.7 cm, and R=0.95. The values of the model errors for the low-flow period and the high-flow period were quite satisfactory, which shows a good performance of the hydraulic model for Buna River.

In order to have a more accurate hydraulic model for the Buna River, some other on-line monitoring stations are needed to be installed along Buna River flow. The water level data from these stations will improve the quality of the calibration process.

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