THE INITIAL ANALYSIS OF THE RIVER IBAR TEMPERATURE DOWNSTREAM OF THE LAKE GAZIVODE

by

Dragan V. KALABA[a], Ivana B. IVANOVIĆ[*b], Dejan M. ČIKARA[a], and Gordana O. MILENTIJEVIĆ[a]

[a]Faculty of Mechanical Engineering, University of Pristina, Kosovska Mitrovica, Serbia
[b]Innovation Center of the Faculty of Mechanical Engineering, Belgrade, Serbia

Original scientific paper
DOI: 10.2298/TSCI121112175K

As a result of a very limited number of geometric and other input data, the temperature modeling of the river Ibar downstream of the lake Gazivode was started by analyzing one river reach between Pridvorica, secondary dam in the system Gazivode, and the city Kosovska Mitrovica. River reach was selected so that the numerical results can be compared with available measured temperature data. Water quality component of HEC-RAS one-dimensional hydraulic river model was used for temperature calculations.

Key words: h*ydraulic modeling, HEC-RAS, river flow; river temperature;*

Introduction

A watercourse of the river Ibar downstream of the artificial lake Gazivode is strongly influenced by the lake and dams which are located at its end. The surrounding area, in length of about 20 km downstream the river, is rural with about sixty villages distributed at both sides of the river. As the river passes mainly through alluvial plan, and the climate conditions are rather favorable, the land is predominantly agricultural.

The lake Gazivode has been a major undertaking in the late seventies, and the impact of the lake continues to provoke contradictory opinions. Despite the position, and large quantity of water that can be regulated from the dams, the water resources are very poorly utilized. There are no detailed studies of hydrodynamics of the river, and on the influence of the lake, climate, and soil composition on the water quality. For that reason, the setting of the hydraulic river model was initiated. Final result of the study should be a detailed analysis of the water temperature as one of the most important factors that affect the water quality. Temperature studies will also provide essential information about the impact of the lake and dams on the water quality of the downstream course of the river.

For the beginning, the HEC-RAS software is selected for numerical calculation. That software has long been used for one-dimensional river flow simulations [1, 2]. It is recently enriched with a component for the analysis of river water quality [3]. As professional software, and at the same time simple one-dimensional, the HEC-RAS should serve as a good tool for the hydraulic model setup and the initial parametric analysis of the temperature component of the water quality model.

[*] Corresponding author, e-mail: iivanovic@mas.bg.ac.rs

Hec-ras numerical modeling

The HEC-RAS is numerical software for hydrology calculations. It is widely used in one-dimensional water surface profile calculations in case of steady and unsteady river flow regimes. In addition, it contains components for one-dimensional sediment transport/movable boundary and river water quality numerical calculations. In this work, the steady flow component and the water quality component were used to perform initial temperature analysis of one short section of the river Ibar.

Steady flow calculations

The steady one-dimensional flow model can calculate subcritical, supercritical and mixed flow regime water surface profiles. Procedures are explained in details in reference [4]; only the basic elements will be highlighted here below.

To calculate water surface elevation and energy grade line of two adjacent cross sections the standard step method is applied to energy equation

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e$$

where Z_1 and Z_2 are elevations of the main channel inverts, V_1 and V_2 are average velocities, a_1 and a_2 are velocity weighting coefficients, g is gravitational acceleration, and h_e is energy head loss.

The energy head loss is calculated from the following formula

$$h_e = L\overline{S_f} + C\left|\frac{a_2 V_2^2}{2g} - \frac{a_1 V_1^2}{2g}\right|$$

where $\overline{S}_f$ is representative friction slope between two sections, C is expansion or contraction loss coefficient, and L is discharge weighted reach length given by the following formula

$$L = \frac{L_{LOB}\overline{Q_{LOB}} + L_{CH}\overline{Q_{LOB}} + L_{LOB}\overline{Q_{ROB}}}{\overline{Q_{LOB}} + \overline{Q_{CH}} + \overline{Q_{ROB}}}$$

where L_{LOB}, L_{CH} and L_{ROB} are input cross-section reach lengths, and $\overline{Q_{LOB}}$, $\overline{Q_{CH}}$, and $\overline{Q_{ROB}}$ are arithmetic average values of the flows between sections for left overbank, main channel and right overbank respectively.

The friction slope is calculated from Manning's equation

$$Q = K\sqrt{S_f}$$

The conveyance is calculated from the following formula

$$K = 1/n \cdot AR^{(2/3)} \qquad \text{(for SI units)}$$

where n is Manning's roughness coefficient, A is cross-sectional area, and R is hydraulic radius.

When the flow is rapidly varying it passes from subcritical to supercritical flow regime or vice versa, water surface elevation, WS, is equal to critical water surface elevation (critical depth), Y_C, and the total energy head

$$H = WS + \frac{V^2}{2g}$$

passes through a minimum. In the case of the steady flow calculations, when the water surface passes through critical depth the energy equation cannot be used and within HEC-RAS it is replaced by the momentum equation.

Water quality calculations

The water quality module of HEC-RAS is based on the solution of one-dimensional transport equation (advection-dispersion equation, see references [5] and [3]). The ULTIMATE QUICKEST explicit upwind scheme is used for the numerical solution.
For the heat transport the source/sink term is given by the following formula

$$\text{heat}_{\text{source/sink}} = \frac{q_{net}}{\rho_w C_{pw}} \frac{A_s}{V}$$

where q_{net} is the net heat flux at the air water interface, φ_w is the density of water, C_{pw} is the specific heat of water, A_s is the surface area of water quality cell, and V is the volume of water quality cell.

The net heat flux is sum of the following heat flux components

$$q_{net} = q_{sw} + q_{atm} - q_b + q_h - q_l$$

The solar radiation q_{sw} is a function of the latitude ϕ, the declination δ, the local hour angle h, the solar constant Q_0, the radius vector r, the atmospheric attenuation a_t, the reflectivity of the water surface R, and the percent sky covered with clouds Cl:

$$q_{sw} = q_0 a_t \cdot (1 - R) \cdot \left(1 - 0.65 Cl^2\right) \cdot q_0 = \frac{Q_0}{r^2} \cdot (\sin\phi \sin\delta + \cos\phi \cos\delta \cos h)$$

The atmospheric long wave radiation q_{atm} and back long wave radiation q_b are functions of the emissivity of air ε_a or water ε_w, the Stefan Boltzman constant σ, and the air temperature T_{ak} or water temperature T_{wk}:

$$q_{atm} = \varepsilon_a \cdot \sigma \cdot T_{ak}^4 \cdot q_b = \varepsilon_w \cdot \sigma \cdot T_{wk}^4$$

The sensible heat q_h is a function of the diffusivity ratio K_h/K_w, the specific heat of air at constant pressure C_p, the density of water φ_w, the air temperature T_a, the water surface temperature T_w, and the wind function $f(U)$:

$$q_t = \frac{K_h}{K_w} \cdot C_p \rho_w \cdot (T_a - T_w) \cdot f(U)$$

The latent heat q_1 is a function of the atmospheric pressure P, the latent heat of vaporization L, the density of water φ_w, the saturated water pressure at water temperature e_s, the vapor pressure of overlying air e_a, and the wind function $f(U)$:

$$q_t = \frac{0.622}{P} \cdot L \rho_w \cdot (e_s - e_a) \cdot f(U)$$

Model description

As previously mentioned, the main objective at this initial stage of research is a preliminary analysis of the terrain and a creation of the model for the further in-depth temperature water quality analysis of the river Ibar between the artificial lake Gazivode and the city Kosovska Mitrovica.

The only major tributary of the Ibar in this area is the river Sitnica, and it flows into the Ibar beyond the observed section. In the studied section, the river Ibar flows mainly through the alluvial plain which is shortly interrupted after the village Varage, and nearby dam Trepča, in the length of approximately 2 km. The dam Trepca is the third in the series of dams which starts with the Gazivode, located at the end of the 24 km long artificial lake Gazivode, and the Pridvorica located around 2.3 km below the Gazivode. There is only one bridge, located between the Pridvorica and the village Zubin Potok, and it was not taken into account in this analysis.

Geometric data

The path of river reach is taken from topographic map loaded into the HEC-RAS geometric data editor. The reach starts few meters downstream of the dam Pridvorica, at the elevation of 578 m, and ends few meters upstream of the dam Trepca, at the elevation 553 m. Since the reach length is 6.67 km, sixty eight initial cross-sections, labeled 0 to 67, were positioned at every 100 m.

The distances between cross-sections were adjusted, first in order to achieve proper length, and afterwards in order to achieve appropriate position of individual cross-section. Before the interpolation to a maximum distance of 20m additional cross-sections were added to all positions where it was necessary due to sudden change in flow geometry. The geometry of cross-sections used in calculations was based on extremely rough measurements and do not represent exact cross-sections of the river channel. More precise measurements remain to be carried out in the future.

Temperature field measurements

The one day measurements presented in **Table 1** are from July 2012 when the air temperature was rather high for this period of the year. The turbine discharge from the hydroelectric power plant Gazivode was $30 m^3 s^{-1}$ at 7:30 h. The measurements were performed with precise thermometer with probe PCE-T317, and water flow meter P-770-M with probe Mini Water 6050-1008.

The average velocity between the turbine discharge at Gazivode and the village Suvi Do is $1.12 ms^{-1}$.

Results and discussion

The steady hydraulic model was used for experimenting with the water quality analysis. The flow was simulated for one profile. The flow rate was set to $28 m^3/s$. As the stream is much steeper in the first part, it was experimented with different boundary conditions, but a normal depth of 0.0035 was finally chosen as downstream condition. The Manning's value was set to 0.045 since the surfaces of the main channel and overbanks are diverse, with rough sections and stones, and with sections covered by vegetation and agricultural land [2].

Table 1.Water temperature data between the lake Gazivode and the village Suvi Do

Position	Distance from turbine discharge [km]	Time [h]	The river flow [m³/s]	Air temperature [°C]	Water temperature [°C]
Lake Gazivode	-0.5	10:45	2	36.6 / 26.2	8.7
Turbine discharge	0	11:00	32	36.7 / 26.2	5.6
Dam Pridvorica	+1.75	11:15	28	37.1 / 26.5	7.3
Dam Trepca	+9.25	11:30	27	38.2 / 32.5	9.3
Suvi Do	+16.75	12:00	27	39.6 / 30.8	14.2

The mean velocity value obtained from above simulation is 1.147 ms^{-1}, and the measured mean velocity value, mentioned in the previous section, is 1.12 ms^{-1}.

In the water quality model the minimum cell length was set to 20 m. With this condition imposed, the final cell lengths were between 20 and 33.5 m. For dispersion coefficient the computed values option was selected. By choosing this option it is ensured that dispersion coefficients will be calculated at each face using variables obtained in hydraulic model (see reference [5]).Throughout all calculations, the constant values were selected for following meteorology parameters: atmospheric pressure 1000 mb, relative humidity 78% (which is the mean value of humidity for this area), cloudiness 0.3 (the values are between 0.1 and 0.5 for scattered clouds), dust coefficient 0.06 (the values are between 0 for rural areas and 0.2 for urban areas, 0.06 is a default value in HEC-RAS),and wind speed of 1 ms^{-1}.

The first calculation was executed with constant water temperature boundary condition of 7.3 ºC in the cross-section 67, the initial water temperature of 7.3 ºC in all cross-sections, the constant short wave radiation was set to 100Wm^{-2}, and the constant air temperature was set to 16 ºC.

The results are illustrated in fig. 1. As expected, temperature increases for a while until it reaches constant value. The maximal value of temperature, reached at cross-section 0, is 7.47 ºC. In the absence of data for the initial temperature distribution, the results from above calculation were used as initial condition in other calculations. In the next simulation the short wave radiation parameter was changed.

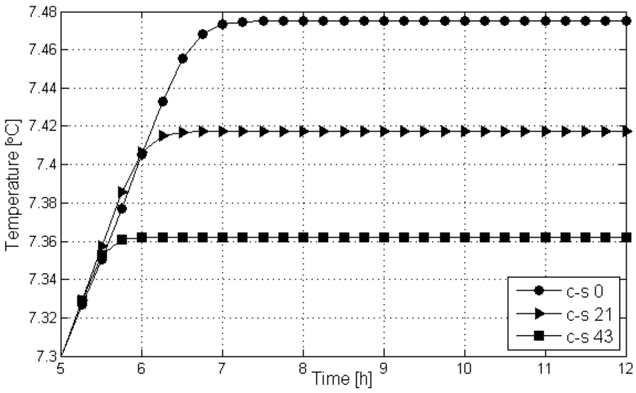

Figure 1.Temperature as function of time for constant meteorology parameters and uniform initial conditions presented for different cross-sections

The simulation was executed with short wave radiation parameter generated by HEC-RAS for the month of July and from latitude and longitude values of the area (43 N, 21 E).

The resulting radiation time series for few days at the end of July and beginning of August are illustrated in fig. 2.

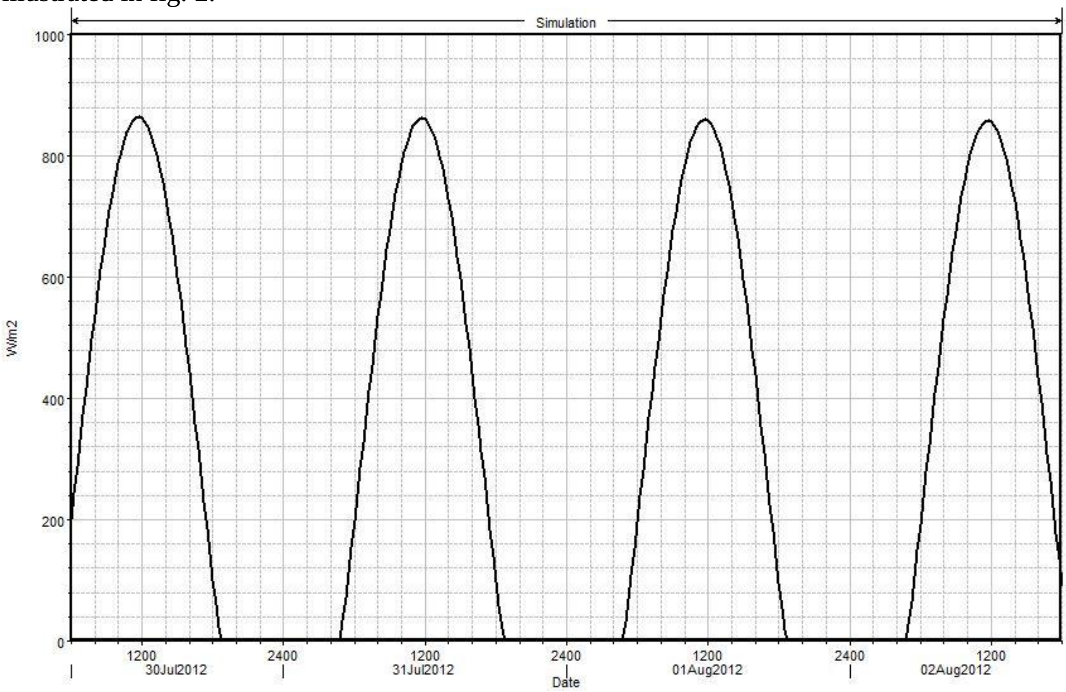

Figure 2.Short wave radiation time series calculated from latitude and longitude values of the area

The resulting water temperatures, for cross-sections already presented in Figure 1, are illustrated in fig. 3. First, it is obvious that the initial condition for water temperature has not been uniform. The temperature change is influenced by change in short wave radiation and the increase of temperature follows the increase of this meteorology parameter. The maximal value of water temperature obtained at most downstream cross-section is 8.76 ºC. This value is still lower than measured temperature of 9.3 ºC at the dam Trepča presented in tab. 1.

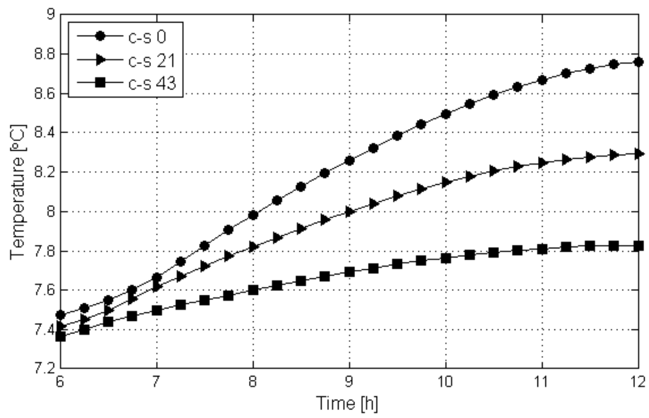

Figure 3. Temperature as function of time for non-uniform short wave radiation meteorology parameter and for non-uniform initial conditions

The linear changes in air temperature from 16 ºC to 30 ºC, and 16 ºC to 37 ºC, have been added in the following simulations. The maximal values of water temperature at cross-section 0 were 8.92 ºC and 9 ºC. The simulation with second linear air temperature distribution, with dust coefficient decreased from 0.06 to 0.01, the cloudiness decreased from 0.3 to 0.1 ms^{-1}, the wind speed decreased from $1ms^{-1}$ to $0.5ms^{-1}$, and the humidity from 78 % to 68 %, was resulted with water temperature decrease of 0.06 ºC.

When the first calculation with the linear change in air temperature from 16 ºC to 37 ºC is executed with the short wave radiation values calculated for August 31, and not for July 31, the maximal value of water temperature for the most downstream cross-section is 0.13 ºC lower. The difference in calculated water temperatures is illustrated in fig. 4.

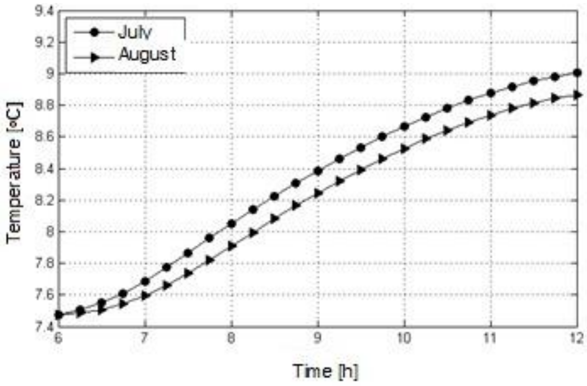

Figure 4 Difference between water temperatures in one cross-section calculated for the short wave radiation values at the end of July and at the end of August (all other parameters are the same)

Conclusions

The water temperature analysis of the river Ibar downstream of the lake Gazivode was initiated. The first geometric data were collected, the basic hydraulic model for the starting reach was constructed, and the elementary water temperature analysis is performed. Although previous collections of data necessary for this type of analysis were poor and incomplete, and quite superficial values were chosen for most of the parameters, the results obtained from simulations are in good agreement with the measured data. The emphasis is put on parametric analysis which should facilitate the future research.

Acknowledgments

This research was realized as a part of the project "Studying climate change and its influence on the environment: impacts, adaptation and mitigation" (43007) financed by the Ministry of Education and Science of the Republic of Serbia within the framework of integrated and interdisciplinary research for the period 2011-2014.

References

[1] M. S. Horritt and P. D. Bates, "Evalution of 1D and 2D numerical models for predicting river flood inundation," *Journal of Hydrology,* vol. 268, 2002, 1-4, pp. 87-99

[2] V. R. Thorndycraft, G. Benito, M. Rico, A. Sopena, Y. Sanchez-Moya and A. Casas, "A long-term flood discharge record derived from slackwater flood deposits of the Llobregat River, NE Spain," *Journal of Hydrology,* vol. 313, 2005, 1-2, pp. 16-31

[3] J. Drake, A. Bradford and D. Joy, Application of HEC-RAS 4.0 temperature model to estimate groundwater contributions to Swan Creek, Ontario, Canada, *Journal of Hydrology*, vol. 389, 2010, 3-4, pp. 390-398

[4] G. W. Brunner, HEC-RAS, River Analysis System Hydraulic Reference Manuel Version 4.1, 2010. [Online]. Available: www.hec.usace.army.mil/software/hec-ras/hecras-document.html.

[5] G. W. Brunner, River Analysis System User's Manuel Version 4.1, 2010. [Online]. Available: www.hec.usace.army.mil/software/hec-ras/hecras-document.html.

Paper submitted: November 12, 2012
Paper revised: April 5, 2013
Paper accepted: September 15, 2013