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HYDRAULIC MODELING FOR BETTER OPERATIONAL PERFORMANCE OF EXISTING IRRIGATION CANAL

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Abstract: Mathematical simulation model is a suitable tool for understanding the hydraulic behavior of an open irrigation canal and obtaining information on actual hydraulic parameters of water flow. In this paper, a simulation model of an open irrigation canal created using hydraulic software HEC-RAS is presented. The model was calibrated with observed flow data in steady state conditions and optimal roughness value and actual canal carrying capacity were determined. Computer simulations for different values of roughness and operating discharge were carried out in order to diagnose the condition of the lining and defining the limits of the hydraulic parameters of the studied canal.

Keywords: irrigation canal, simulation model, hydraulic modeling, diagnostics, analysis

INTRODUCTION

In irrigation systems the flow parameters are measured in a limited number of points along the canal course, which does not provide sufficient information for effective management - supply of needed water for irrigation of the agricultural crops without deficiency or excess spillage.

Mathematical simulation model is a suitable tool for understanding the hydraulic behavior of the open irrigation canal and for obtaining information about the actual values of the flow parameters. As a result of the hydraulic analysis of the flow in the canal carried out with a model, complete information is obtained about the changes in water levels along the canal occurring after each change of water supply at the head of the canal and/ or change of the water discharge in the canal off takes (Baume et al,.1994). The roughness factor is an essential parameter of the mathematical models of the open canals as it participates in the calculations of the friction slope and influences the hydraulic parameter determination accuracy. Models should be calibrated by roughness parameter.

Computer analysis can be very useful in assessing the existing situation of an old irrigation system with open canals and in searching for possible solutions to improve water management. With the calibrated steady flow model, in terms of roughness hydraulic studies and assessing the influence of operating conditions can be carried out.

In this paper, a simulation model of an open irrigation canal created using hydraulic software HEC-RAS is presented. The model was calibrated with observed flow data in steady state conditions and optimal roughness value and actual canal carrying capacity was determined. Computer simulations for different values of roughness and operating discharge were carried out in order to diagnose the condition of the lining and defining the limits of the hydraulic parameters of the studied canal.

MATERIALS AND METHODS

— Description of software used

In this study, the freeware software HEC-RAS, Version 4.1 (Hydrologic Engineering Center - River Analysis System) developed by U.S. Army Corps of Engineers, is selected to create a simulation model of the study canal. Using this software, one-dimensional hydraulic calculations are performed in a branched network of natural and / or artificial channels. The software system includes a user interface, steady flow model, unsteady flow model and modules that provide graphical and tabular presentation of the results. It can simulate steady and unsteady flows in open channel. For the steady state conditions, water surface profile can be simulated in critical, supercritical and mixed flow regimes (US Army Corps of Engineers, 2010).

For conducting hydraulic modeling and simulation of the water surface profile in irrigation canal data are required for its geometry, the boundary conditions, the water discharge, the canal roughness, geometric description of the hydraulic structures along the canal course, such as gates, culverts, weirs. Introducing the geometry of the canal includes defining the profile of the canal bed of the study reach by setting series of cross-sections that longitudinally define its shape.

For the calculation of the longitudinal water surface profile at steady flow, the one-dimensional equation of energy (Bernoulli equation) is integrated by the standard step method. In order to be able to start the calculation, a discharge upstream of the canal and a stage downstream are set as boundary conditions. For the interior points the stage is estimated keeping the water discharge constant.

As results of canal flow simulation the following hydraulic parameters: depth/ water surface elevation, energy grade line elevation, friction slope, flow velocity, critical depth/critical depths line elevation, water volume in the canal and others can be determined.

The roughness coefficient cannot be measured directly and therefore it is necessary to determine it by other methods. One of the methods used to assess the roughness is by simulation with a mathematical model. The classic approach for evaluation and calibration of the parameter roughness is associated with modeling of the steady flow in the canal (Malaterre et al, 2010).

The computational procedure is iterative and simulations with the irrigation canal model are carried out for a series of roughness values. For the determination of the roughness coefficient, the values of the hydraulic parameters in the observation points along the irrigation canal course and the numerical results of the computer experiments are compared according to a certain criterion. Nguyen and Fenton investigate the application of three main types of target function and show that least squares minimization gives the best results (Nguyen and Fenton D., 2004). The best match between the observed and calculated values for the hydraulic parameter, according to the selected criterion, determines the optimal roughness value.

— Description of the studied canal

The studied canal is a first part of an existing irrigation canal - the main canal M1-1 of „Sredna Tundja" irrigation system, in length 7.586 km, which starts from an attachment facility from the Binkus bent on the Tundzha river from an elevation of 185 m to a distribution shaft in the region of village Gavrailovo 7.586 km in length (fig. 1.) The canal is designed up to discharge 41 m^3/s.

The canal has trapezoidal cross-section and consists of 3 sections, two of them lined with concrete 2.642 km and 3.403 km in length with 2 m bottom width, a side slope of 1.5, the average bottom.

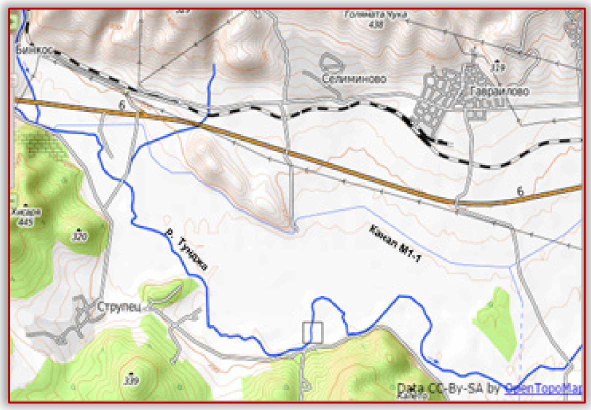

Figure 1 - Map of main canal M-1-1 of „Sredna Tundja" irrigation system and vicinity area (www.topomaps.info)

RESULTS

Hydraulic simulation model of the studied canal was created using hydraulic software HEC-RAS. It was built on the basis of the design parameters of main irrigation canal M 1-1. When creating the simulation model a realistic representation of the existing situation was sought. To reproduce the real geometry of the canal, three cross sections are set - at the canal inlet, at the head of rocky canal section and at the head of lined canal section in the canal end. The irrigation canal has a simplified geometry and the cross sections can be introduced with four points and a value of the coefficient of roughness. Since two of the canal sections are not completely lined, they were introduced with six points and changes in the lining are recorded by entering two values of the roughness coefficient for the lined and unlined part of the bank (Figure 2a). As boundary conditions rating curve at the head of the canal and critical depth at the end were set.

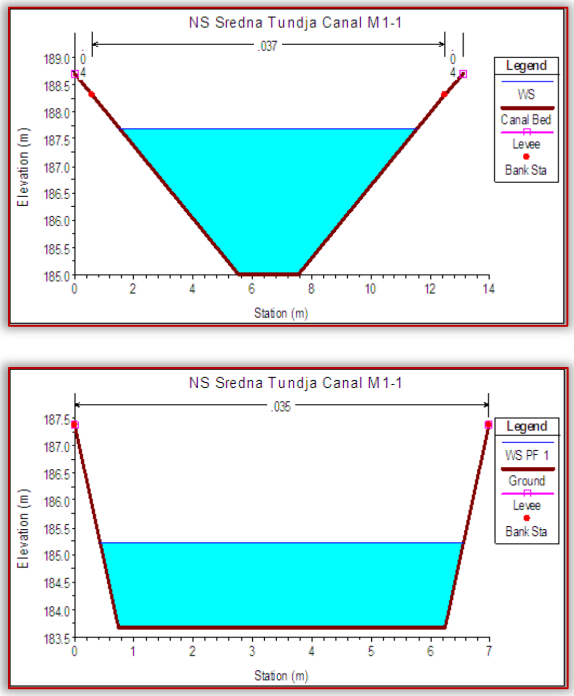

Figure 2 - Canal cross sections

Calibration of HEC-RAS model of the M1-1 canal for roughness coefficient n.

The HEC-RAS model of the M1-1 canal was calibrated using data for observed inlet water discharge and one depth at the end of the canal before the distribution shaft in the area of the village of Gavrailovo. Calibration data was selected from the daily operational information for canal depth measurements during the period from 14th of May to 29th of July 2012 under steady state of canal conditions.

The model has been used to simulate the steady flow in the canal M1-1 for increasing values of the roughness coefficient of the lined part of the canal cross sections in the range of 0.014 to 0.04 and the roughness coefficient equal to 0.035 for the unlined part and the rocky section in the steady state conditions. The initial value of the roughness for concrete lined canal and grassed surface of unlined part of the banks were selected in tables published in (Chow, 1959). A total of 20 experiments were conducted.

The simulated and measured values of the depth in the end of the canal for different values of the roughness coefficient are presented in Table 1. The simulated depth hydrographs were compared with observed depth hydrograph using linear regression. No significant deviation between the measured and estimated values is available and high correlation (R^2>0.9) between the observed and simulation depths was achieved for the respective water discharges. An optimum value of the roughness n = 0.037 is determined for which the correlation coefficient is the highest (Figure 3).

Table 1. Measured and simulated depth hydrographs for different values of the roughness coefficient
Q_{in} - inlet discharge, h_o - measured depth in canal end, h_s - simulated depth in canal end, n- roughness coefficient

Q_{in}, m^3/s	h_o, m	h_s, m n=0.014	n=0.025	n=0.035	n=0.037
3.5	0.83	0.69	0.76	0.81	0.82
9.5	1.39	1.15	1.24	1.31	1.33
12.5	1.61	1.33	1.42	1.49	1.51
15.68	1.66	1.48	1.58	1.65	1.67
18.44	1.78	1.59	1.69	1.77	1.78

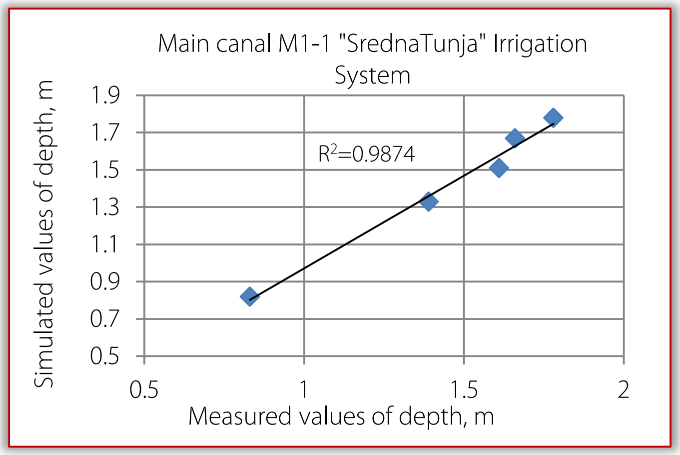

Figure 3 - Comparison of measured values of depth in the tail of canal versus simulated values for roughness coefficient n =0.037 using linear regression

By simulations of steady flow in the canal for estimated optimum value of the roughness n = 0.037 and increasing values of the inlet water discharge the current canal carrying capacity of 20 m^3/s is determined, as water discharge for which the depth in the lined canal section reaches the maximum 3.3 m, determined by the height of the lining. A 50% reduction in capacity shows a significant worsening of the operational performance of the canal.

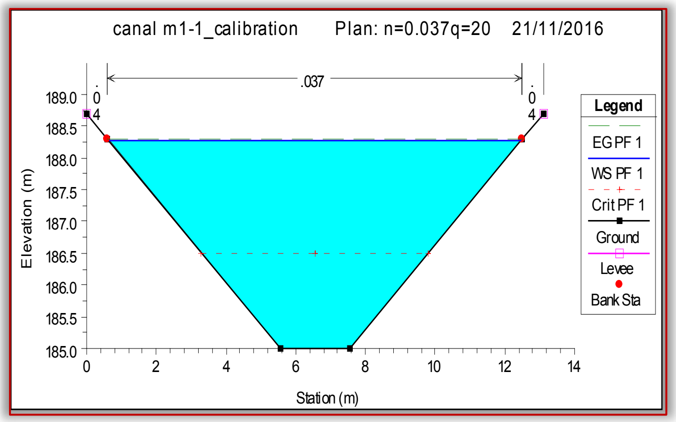

Figure 4 - Canal cross section plot for roughness coefficient n =0.037and inlet discharge Q_{in} =20 m^3/s.

Simulation of steady flow in the canal for different value of roughness coefficient n.

With the model of canal M1-1 simulations were conducted for different values of roughness in order to diagnose the condition of the lining and study the parameters of flow in canal and determining their limits. For several values of the roughness coefficient of the lined part of the cross section: n=0.017, 00.025, 0.035, 0.037 and inlet water discharge 18.5 m^3/s, a steady flow in the canal was simulated.

The analysis of the modeling results shows the influence of the roughness on the flow parameters in the irrigation canal. Figure 5 shows a longitudinal profile along the canal axis and water surface profiles for the different values of roughness coefficient. Increasing the roughness in the canal leads to an increase in canal depths. With further increases in roughness, the depths in the canal will reach the maximum of 3.3 m, set at design with the height of the lining. Therefore, in the poor condition of the irrigation canal lining the operating discharge should be reduced.

The simulated water surface profiles obtained can be used as reference for estimating the roughness in the presence of updated data for observed depths at characteristic points along the canal course.

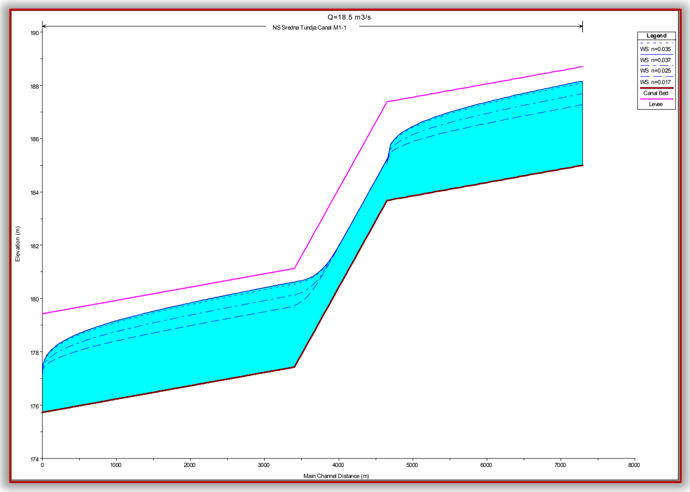

Figure 5 - Water surface profiles for different values of roughness coefficient n= 0.017, 0.025, 0.035, 0.037 and water discharge Q = 18.5 m^3/s

CONCLUSIONS

Using the HEC-RAS hydraulic software, a simulation model of the M-1-1 canal of „Sredna Tundja" irrigation system was established, which was calibrated under steady-state conditions with available operating data for observed depths. The results obtained in the hydraulic model studies have shown:

For roughness coefficient equal to 0.037 there is a good match to the simulated with the measured values of the depth at the end of the canal at a high degree of correlation (R^2= 0.987).

By determining the estimated value of the canal roughness, an actual value of the canal carrying capacity 20 m^3/s can be determined. A 50% reduction in capacity shows a significant worsening of the operational performance of the canal.

With the increase of the coefficient of roughness, which simulates the deterioration of the lining, the depth in the canal increases and it can reach the maximum determined during design.

The results of computer analysis can be used in the redesign and rehabilitation of existing canals and to select the appropriate procedure for the operational management.

Note

This paper is based on the paper presented at ISB-INMA TEH' 2017 International Symposium (Agricultural and Mechanical Engineering), organized by University "POLITEHNICA" of Bucharest – Faculty of Biotechnical Systems Engineering, National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest, Scientific Research and Technological Development in Plant Protection Institute (ICDPP), National Institute for Research and Development for Industrial Ecology – INCD ECOIND, Research and Development Institute for Processing and Marketing of the Horticultural Products "HORTING" and Hydraulics, Pneumatics Research Institute INOE 2000 IHP, University of Agronomic Sciences and Veterinary Medicine of Bucharest (UASVMB) – Faculty of Horticulture and Romanian Society of Horticulture (SRH), in Bucharest, ROMANIA, between 26 – 28 October, 2017.

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