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EVALUATION OF WATER DELIVERY EFFICIENCY IN IRRIGATION CANAL UNDER EXISTING MANAGEMENT STRATEGY USING HYDRAULIC MODEL

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Abstract
Managing water distribution in irrigation canals aims timely and in needed quantity implementation of supplies of water to irrigated area without excessive spillage i.e. at reduced conveyance loss and adequate water use for irrigation of the crops. This article analyzed existing management practice of water distribution in irrigation canal in view of efficiency. The study was carried out for an existing main irrigation canal. The operational water loss was evaluated by indirect quantitative approach. Hydraulic simulation model of the irrigation canal was created using hydraulic software HEC-RAS. Changes in hydraulic conditions due to existing structures along the canal course were taken into account in the model. The water operational loss was determined by simulation with HEC-RAS model in steady state conditions. The model was used to study the influence of the operating conditions on the size of loss. Results obtained show the influence of the management practice of the water distribution and operation conditions and maintenance of the canal on the magnitude of operational loss.

Keywords: water distribution, conveyance loss, steady state, simulation, HEC-RAS.

Introduction
Water distribution is the main technological process in the irrigation system and represents the transport of water from the water source to the irrigation area where the water volumes are distributed among the users in quantity and time. Managing water distribution in irrigation canals aims timely and in needed quantity implementation of supplies of water to irrigated area without excessive spillage or excess energy i.e. at reduced conveyance loss and adequate water use for irrigation of the crops. In many irrigation systems with manually operated open canals the existing practice of water allocation is the so-called planned water use, where pre-contracting between the water supplier and the water user is introduced for the time of delivery of the water volumes for irrigation. The water is delivered according to a weekly/decade water allocation plan, based on water requirements of the users within the limits of the seasonal contracts. The water allocation plan for the irrigation canal is based on the water balance for each canal section, taking into account the limited flow of the water source and the capacity of the canal itself. (Trifonov and Patamanska, 2006). Even when the water delivery schedule for the irrigation canal is properly drawn up and precise executed, there are large operational water loss in planned water use, the main reasons for which are:

- Delayed start of water supply in a remote section from the beginning of the irrigation canal. Because of water wave's propagation observed in the canals during changing discharges, one has to wait a long period of time, sometimes many hours, to arrive the needed water discharge and then to start water supply. By this reason, a certain volume of water is accumulated in the canal which, after the irrigation is stopped, escapes unused thus generating significant non-productive operational water loss (Ankum, 1993).
- Daily irrigation. Since it is watered only during a certain period of the day, and the flow in the main canal is continuous, much of the water supplied expires unused after the end of the irrigation.

The highest water loss is in the main irrigation canal, since there the largest water volumes are being allocated. The water loss should be reduced and thus loss management is needed. The aim of this study is to analyze and evaluate the behavior of the main irrigation canal in steady state flow conditions, to evaluate the operational loss in existing management practice of water allocation and to study the influence of the operation conditions and the canal maintenance on the extent of operational water loss.

Material and methods

Description of the study canal

The study canal is a part of an existing irrigation canal - the main canal M-1 of „Sredna Tundja“ irrigation scheme from a distribution shaft in the region of village Gavrailovo to Sotirya inverted siphon 18.5 km in length (fig. 1.) The canal has trapezoidal cross-section with 2.5 m bottom width, a side slope of 1.5, the average bottom slope of the 0.00006. The canal is designed for a discharge of 20.5 m^3/s and is separated into four canal sections with by gated cross-structures, situated in the transitional sections with a rectangular cross section. The canal is lined with concrete. Along the canal course there are three laterals, located in the end of the each of the first three canal reaches: an open canal and a pipeline designed for a discharge of 1.5 m^3/s and another open canal designed for a discharge of 2 m^3/s.

Figure 1. Map of Sliven region showing main canal of „Sredna Tundja“ irrigation scheme
Source: www.topomaps.info

Operational water loss in main irrigation canal can be quantified by:

- Direct measurements of the water discharges entering and exiting from the canal sections. In this case periodic simultaneous measurements of two water discharges are required, which is difficult to obtain in-situ conditions.
- Indirect method for estimating operational water loss using a model. Operational water loss is determined after conducting analysis of the steady state flow as a difference between the water volume in the canal under operating mode of feeding a water user and this one after switching it off.

The irrigation canals are divided into sections with gated cross-structures, which causing the back water profiles in the canal. Accurate assessment of the water volume accumulated in the canal when changing from one steady state of flow to another can be obtained by hydraulic simulation model capable of modeling the hydraulic structures along its course.

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 long 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.

Results and discussion

Hydraulic simulation model of the study canal was created using hydraulic software HEC-RAS (Figure 2). It was built on the basis of the design parameters of main irrigation canal M-1-2. When creating the simulation model, a realistic representation of the existing situation was sought. To reproduce the real geometry of the canal, five cross sections are set - at the canal inlet and out let and at the end of each canal reach (Figure 3).

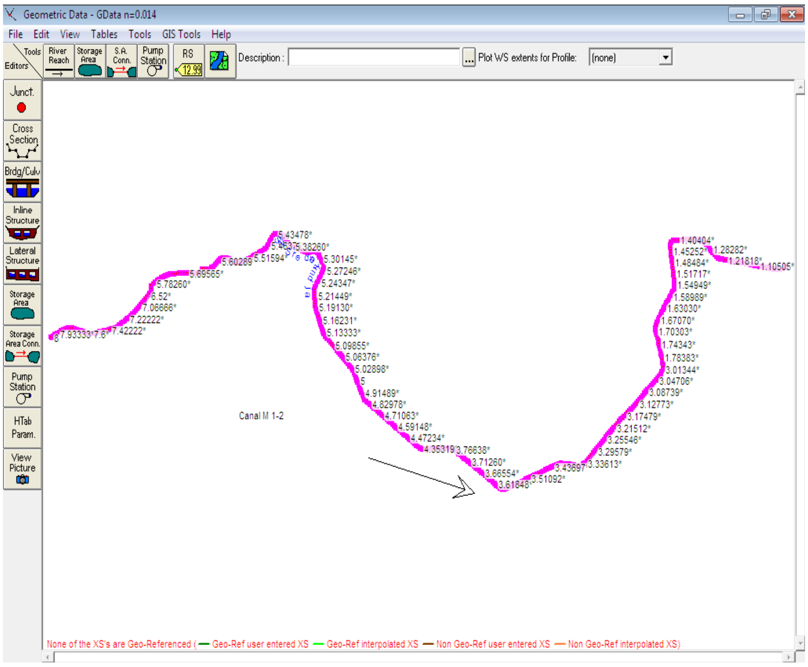

Figure 2. Lay-out of study canal

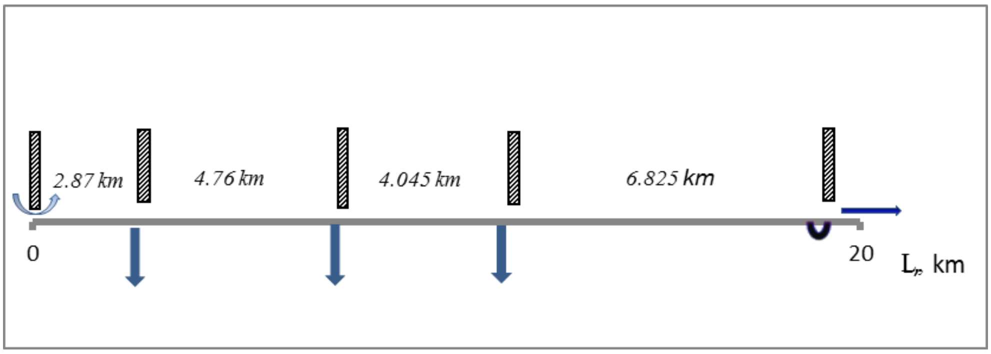

Figure 3. Calculation model

Changes in hydraulic conditions due to existing structures along the canal course were also taken into account in the model. Geometric descriptions of three gated hydraulic structures situated along the canal course (Figure 4b) and cross sections with water users were introduced. Since the canal is not completely lined, changes in the lining are recorded by entering two values of the roughness coefficient for the lined and unlined part of the bank (Figure 4a).

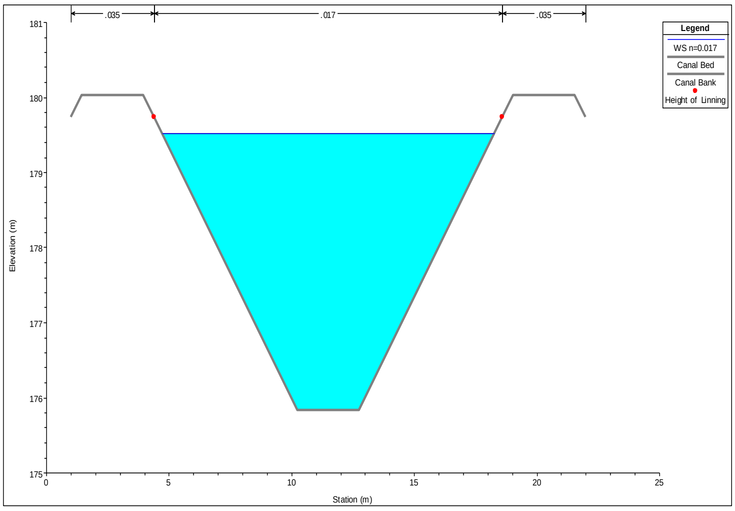

Figure 4a. Canal cross section plot

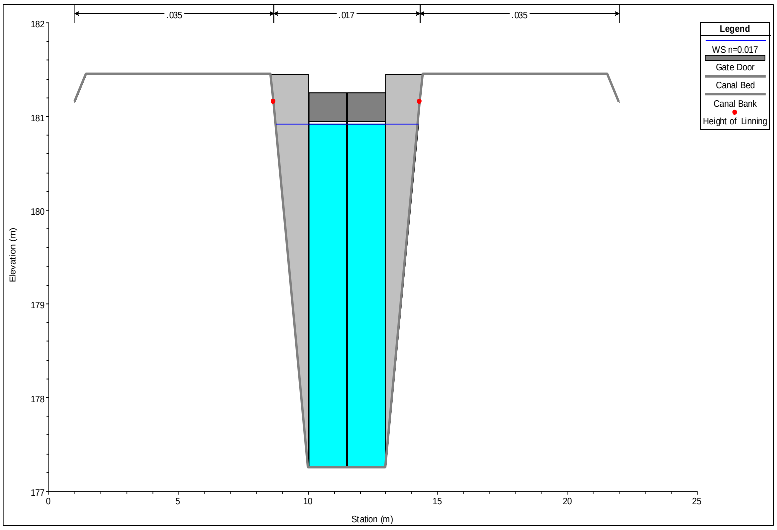

Figure 4b. Canal cross section plot

The water operational loss in existing management practice of planned water use was determined by simulation with HEC-RAS model of the study canal in steady state conditions. Steady flow simulations in the canal were performed in the following two cases:

- The canal gates are fully open and the canal flows at the maximum water discharge of 20.5 m^3/s supplying water to only one of lateral canals.
- The canal flows at decreased discharge after stopping water supply to a corresponding lateral canal. The case of simultaneously stopping the water to the lateral canal and correspondingly decreasing the water discharge at the study canal inlet was considered.

To investigate the influence of canal maintenance on the magnitude of operational water loss, the numerical experiments were conducted for several values of the roughness coefficient of the lined part of the canal cross section: 0.014, 0.017, 0.020, 0.025 and the roughness coefficient equal to 0.035 for the unlined part. The values of the roughness for concrete lined canal and grassed surface of unlined part of the banks were selected in tables published in (Chow, 1959). An exception is the maximum value of the coefficient of roughness of 0.025, the choice of which aims at simulating a severe deterioration of the operational condition of the canal. A total of 12 experiments were conducted.

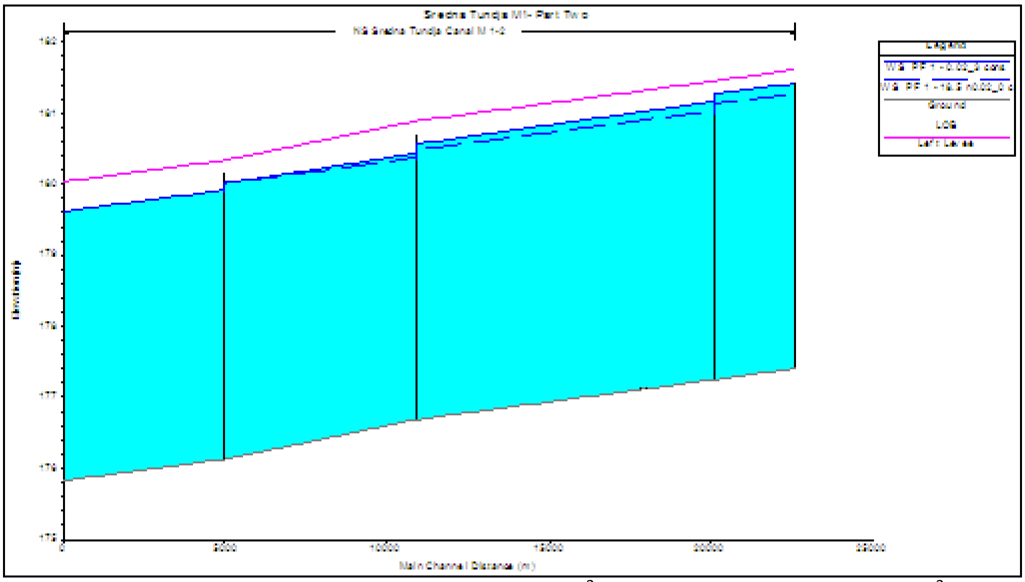

Figure 5. Water surface profiles at an inlet discharge of 20.5 m^3/s and a water discharge of 2 m^3/s supplied to a lateral canal and at an inlet discharge of 18.5 m3/s and n = 0.02 .

Fig. 5 shows the water surface profile obtained at an inlet discharge of 20.5 m^3/s and a discharge of 2 m^3/s supplied to the lateral canal at the end of the third canal reach and the water surface profile at an inlet discharge of 18.5 m^3/s and for roughness coefficient n = 0.02. The water surface profiles are backwater curves among which the accumulated water volume in the canal is located. This volume is determined as a difference of the results obtained for the canal volume under steady state flow conditions with maximum inlet discharge and working lateral canal and the canal volume after stopping the supply of water to it. The accumulated volume in the canal forms the operational water loss. The results for the accumulated water volume in the canal reaches for the different roughness coefficients are presented in Table. 1. and Fig. 6. It can be seen that if the user is located farther from the canal inlet, operating water loss is increased significantly. Poor operating conditions and canal maintenance also result in increased operational water loss.It is important to reduce operational water loss for increasing efficiency. Various principles and methods of canal management aimed at reducing water loss and increasing efficiency of water allocation were developed. Steady-state analysis of an irrigation canal flow using simulation model can be useful for choosing of an appropriate procedure for efficient canal management at any particular case.

Table 1. Accumulated water volume in the canal reaches

n	Canal reach lenght in *km*		
	2.87	7.63	11.675
	Wacc, m^3	Wacc, m^3	Wacc, m^3
0.014	160	4310	18780
0.017	200	4750	20330
0.02	230	5080	21730
0.025	380	6510	22760

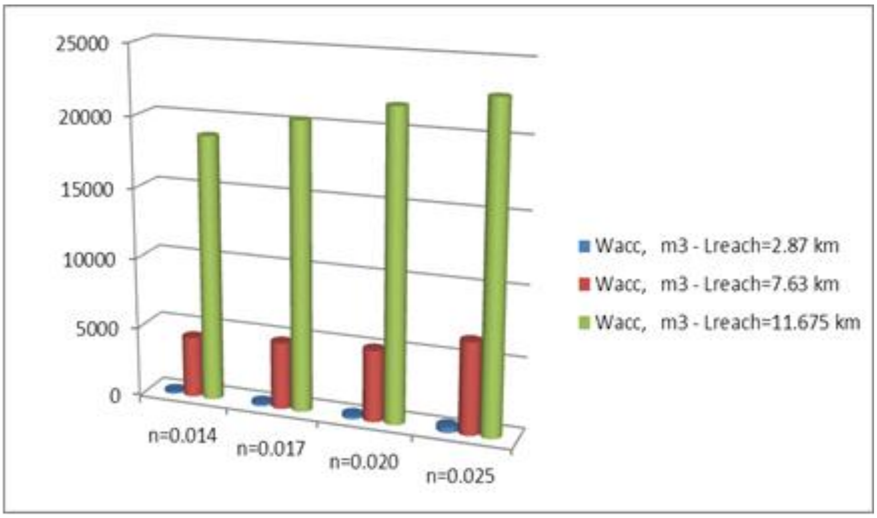

Figure 6. Accumulated water volume in the canal reaches

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