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UNIVERSITY OF ARCHITECTURE CIVIL ENGINEERING AND GEODESY

Winter School at UACEG

Topic: Investments in Irrigation Infrastructure

Task for Students #1:

Estimation of Water Losses and Efficiency of an Irrigation System.

Determining of the Potential Water Savings Due to Investments in Irrigation Infrastructure

Explanations and Example

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TASK # 1

ESTIMATION OF WATER LOSSES AND EFFICIENCY OF AN IRRIGATION SYSTEM.

DETERMINING OF THE POTENTIAL WATER SAVINGS DUE TO INVESTMENTS IN IRRIGATION INFRASTRUCTURE

1. Initial data

A simplified scheme of the investigated Irrigation System (IS) is presented on Fig. 1.

The IS consists of 7 Irrigation Fields (IFs). The delivery network of IS has a Main Canal with two sections and two Distributary Canals. The volumes of water measured at specific locations at Main and Secondary Canal, as well as at turnouts to Irrigation Fields (IFs) are given in *Terms of Reference (TOR)*. The measured volumes of water are also shown on Fig. 1.

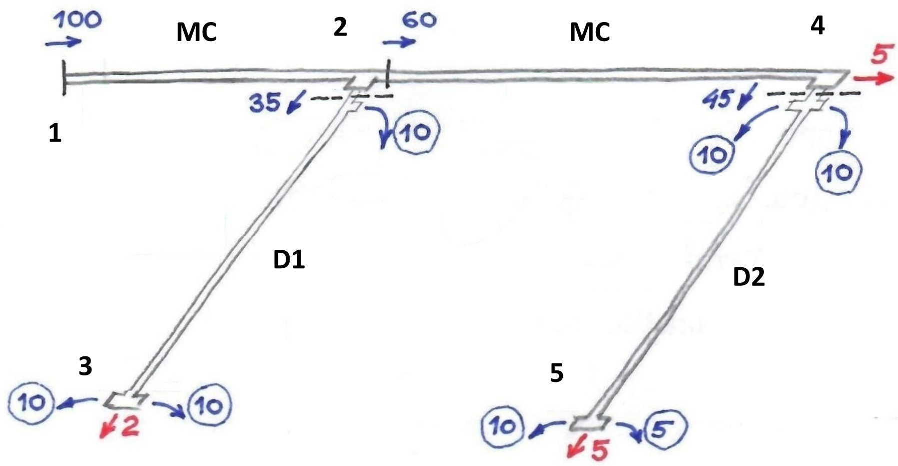

Fig. 1. Schematic View of the Delivery Network of the IS and Measured Volumes of Water at Specific Locations

2. Estimation of Water Losses and Efficiency of the IS

The water losses in the IS delivery network can be classified as *technical* and *operational*.

The technical losses ΔV are due to the technical status of the canals and structures in the delivery network. They are estimated as:

$$\Delta V = V_{dir} - V_{del} - \Sigma U, \text{ m}^3, \quad (1)$$

where V_{dir} is the directed volume of water at the inlet of the canal section, m^3;
V_{del} – the delivered volume of water at the outlet of the canal section, m^3;
ΣU is the sum of volumes supplied to clients in the canal section (volumes measured at turnouts of the IFs).

The operational losses ΔOp depend on the distribution method used in the delivery network of the IS. Usually, these losses are represented by the volumes of water, which are spilled unused during the process of water delivery to clients. In this case the operational losses ΔOp are equal to spilled volumes of water S, measured at the end of canals or at the division boxes of Main and Distributary canals. The operational losses are estimated as:

$$\Delta Op = S = V_{del} - V_{av}, \text{ m}^3, \quad (2)$$

where V_{av} is the available for further delivery volume of water, m^3.

The following approach is used for the current task.

Considering the eq. (1) and (2), as a result of measurements in the current IS, the available volumes of water are equal to the sum of volumes directed at the inlets of the downstream canals (see Fig. 2):

$$V_{av} = \Sigma V_{av,i}, \text{ m}^3. \quad (3)$$

The delivered volumes of water are not measured, but they can be estimated on the basis of the water balance of the canal section (Fig. 2), taking into account the eq. (2) and (3):

$$V_{del} = \Sigma V_{av} + S, \text{ m}^3. \quad (4)$$

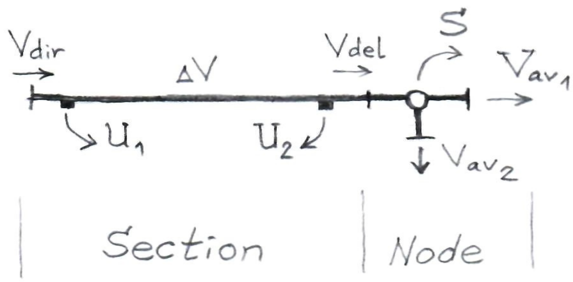

Fig. 2. Water Balance of the Canal Section

Considering eq. (1) and (4), the technical losses ΔV can be estimated as:

$$\Delta V = V_{dir} - \Sigma V_{av} + \Sigma U + S, \text{ m}^3, \quad (5)$$

Considering the types of losses, the following types of efficiencies are defined:

a) Technical efficiency η_T:

$$\eta_T = \frac{V_{del}}{V_{dir}} = \frac{V_{dir} - \Delta V}{V_{dir}} \quad (6)$$

b) Operational efficiency η_{op}:

$$\eta_{op} = \frac{V_{av}}{V_{del}} = \frac{V_{dir} - \Delta V - S}{V_{dir} - \Delta V} \quad (7)$$

c) Overall efficiency η_0:

$$\eta_0 = \frac{V_{av}}{V_{dir}} = \frac{V_{dir} - \Delta V - S}{V_{dir}} \quad (8)$$

According to eq. (6), (7) and (8), the following relation can be drawn:

$$\eta_0 = \eta_T \eta_{op}. \quad (9)$$

Also, for any of the efficiency of the IS (technical, operational or overall), the following formula is valid:

$$\eta_D = \overline{\eta}_{MC} . \overline{\eta}_{DC} , \quad (10)$$

where η_D is the efficiency of the delivery network of the IS;

$\overline{\eta}_{MC}$ - the average efficiency of the Main Canal;

$\overline{\eta}_{DC}$ - the average efficiency of the Distributary Canals.

The estimations are performed in Table 1.

Table 1. Estimation of Water Losses and Efficiencies of the Delivery Network (Volumes in million m³)

Canal	Section from node to node	Measured values				Estimated			
		V_{dir}	ΣV_{av}	ΣU	S	ΔV	η_T	η_{op}	η_0
1	2	3	4	5	6	7	8	9	10
M	1 – 2	100	95	0	0	5	0,95	1,0	0,95
M	2 – 4	60	45	0	5	10	0,833	0,9	0,75
	Sum/Average*	100**	-	-	5	15	**0,850**	**0,941**	**0,800**
D1	2 – 3	35	0	30	2	3	0,914	0,938	0,857
D2	4 – 5	45	0	35	5	5	0,889	0,875	0,778
	Sum/Average*	80	-	65	7	8	**0,900**	**0,903**	**0,813**
	IS Sum/Average*	100**	-	65	12	23	**0,770**	**0,844**	**0,65**

*Notes: * When considering volumes – it is a sum of the values above, when considering efficiencies – it is an average.*
*** For Main Canal and for IS, the total directed volume V_{dir} is the one, measured at the head of the first section, not sum of all directed volumes in different sections. This is due to the fact that the different sections of Main Canal are linked in series, not in parallel.*

The losses can be estimated also by directly solving on the scheme the balance equation of different nodes in the network (Fig. 3).

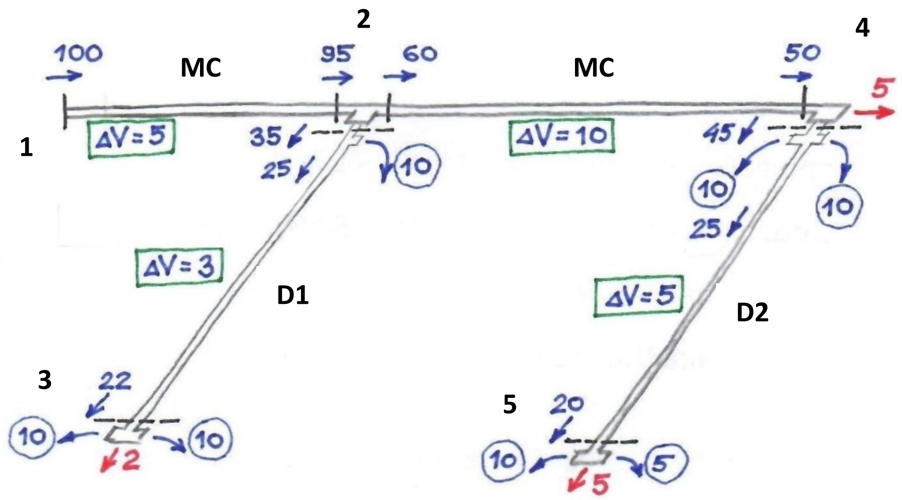

Fig. 3. Estimated Technical (ΔV) and Operational (S) Losses for the IS

To check the calculations, use eq. (10) for technical, operational and overall efficiencies.

Processing data in Table 1
Column {1} – Canal sections (described, starting from the head of the Main Canal);
Column {2} – Sections, described with starting and ending node;
Column {3} – Volumes directed at the canal/section inlet, in million m^3;
Column {4} – Sum of the volumes at the inlets of canals, which start from the ending node of the canal section;
Column {5} – The total volumes delivered to the clients in the canal section (sum of volumes, measured at the turnouts of the canal section), in million m^3;
Column {6}- The spilled volumes, measured at the ending node of the canal section, in million m^3;
Column {7}- The technical losses volumes, estimated by eq. (5);
Column {8}- The technical efficiency, estimated by eq. (6);
Column {9}- The operational efficiency, estimated by eq. (7);
Column {10}- The overall efficiency, estimated by eq. (8);

Rows in grey color: The values for volumes are sum of the values from the rows in white above. The values for efficiencies are average and they are calculated using the same formulae, as for the rows in white above.

2. Estimation of Potential Water Savings

According to the *TOR*, the investments for improvement (rehabilitation) of irrigation infrastructure will be done for the canal section which has the biggest technical losses of water and the lowest technical efficiency η_T. The investments will be for rehabilitation of the worst subsection of the canal.

According to data in Table 1, for the current IS,

***The section subject to rehabilitation is*: Main Canal (between nodes 2 and 4).**

For that section ΔV = 10 units and η_T = 0,833.

According to the *TOR* the canal section has 3 subsections – I, II and III. More detailed measurement has established that the total losses in the section ΔV are distributed in the 3 subsections as follows: Section I – 20%ΔV; Section II – 60%ΔV; Section III – 20%ΔV (See Fig. 3).

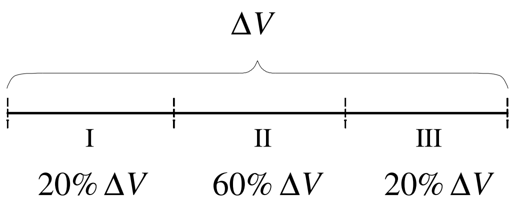

Fig. 3. Losses in the Canal Subsections as percent of Total Losses in the Section

On the basis of the data on Fig. 1 and 2 and the data in Table 1, the losses in three subsections are estimated (Fig. 4). The efficiencies of the 3 subsections are also estimated and shown of Fig. 4.

According to the *TOR* the canal subsection II will be rehabilitated, because it has the biggest technical losses, thus, it is in the worst technical status.

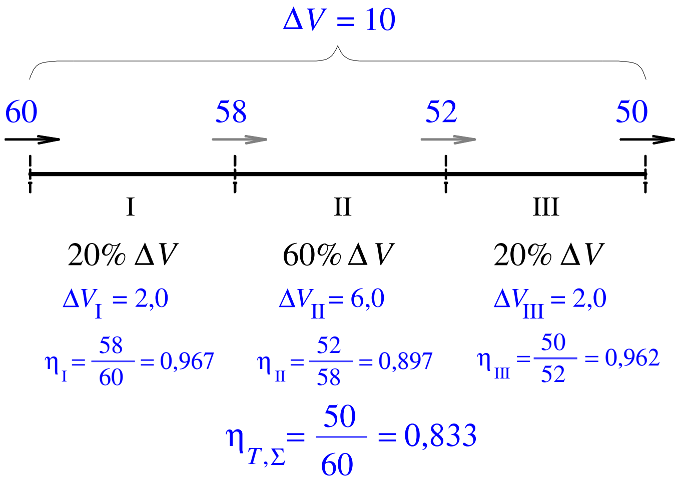

Fig. 4. Losses and Technical Efficiencies of the Canal Subsections before Rehabilitation

According to the *TOR*, after the rehabilitation the losses in the worst canal subsection will be decreased to **25% of the losses** before the rehabilitation.

For the canal subsection II, the new losses will be:

$$\Delta V_{II}^{new} = 25\%\Delta V_{II}^{old} = 0,25.6 = 1,5\,.$$

Since no other investments in IS infrastructure is made, we can assume that for the next periods of time the demand (supplied volumes of water U to Irrigation Fields) downstream of the rehabilitated canal will be the same as before the investments. We can assume that the technical losses, as well as the operational losses in the downstream canal sections will remain the same.

Under these assumptions, at the outlet of canal section, the delivered volume has to be the same as before the investments – $V_{del} = 50$ (See Fig. 5).

Starting from the outlet of the last canal subsection, the new volumes of water at the inlet of the rest of the subsections are estimated, by summing the new technical losses in these subsections (Fig. 5).

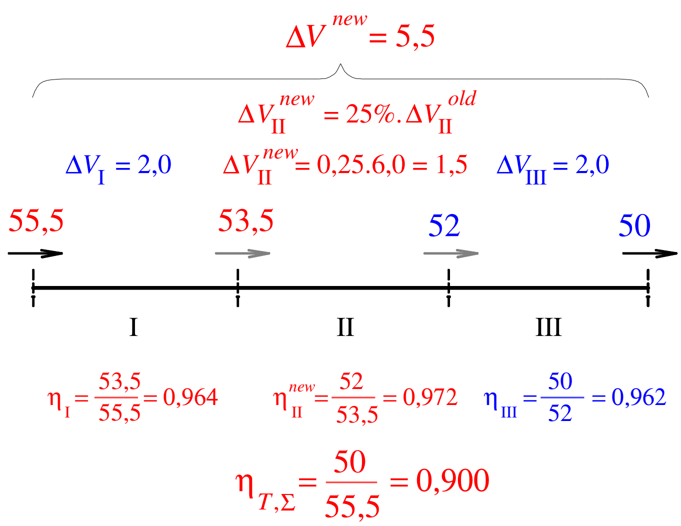

Fig. 5. Losses and Technical Efficiencies of the Canal Subsections after Rehabilitation

As a result of investments, the new directed volume at the inlet of the first canal subsection (the inlet of the Main Canal from node 2 to 4) has to be $V_{dir} = 55,5$ (See Fig. 5).

The Potential Water Savings (*PWS*) are estimated on the *level of the investment*. "The level of investment" means that part of the IS, which benefits from the investment. For the current case, the benefitting part of IS includes: (i) section of Main Canal from node 2 to node 4 and; (ii) the Distributary canal D2. The *PWS* in absolute terms for this part of the IS are:

$$PWS = V_{dir}^{old} - V_{dir}^{new} = 60 - 55,5 = 4,5\,.$$

In relative terms, the Relative Potential Water Savings (*RPWS*) are:

$$RPWS = \frac{V_{dir}^{old} - V_{dir}^{new}}{V_{dir}^{old}} = \frac{60 - 55,5}{60} = 0,075 = 7,5\%$$

According to the National Requirements, the investments are eligible if they assure RPWS between 5% and 25%. In the current case, RPWS = 7,5% > 5%, thus investments are eligible.

The formula for approximate estimation of *RPWS* by means of efficiencies is:

$$RPWS = \frac{\eta^{new} - \eta^{old}}{\eta^{old}}$$

where η_{new} is the overall efficiency of the distribution network of the IS after the rehabilitation (after the investments);
η_{old} is the overall efficiency of the distribution network of the IS before the rehabilitation (before the investments).

According to data in Table 1, the following values of overall efficiency of the benefiting part of IS are estimated:

$$\eta_{0,D}^{old} = \eta_{0,MC}^{old} . \eta_{0,D2}^{old} = 0,75 . 0,778 = 0,584\,.$$

The new overall efficiency of the MC for the section between nodes 2 and 4 is (see Table 1):

$$\eta_{0,MC}^{new} = \eta_{T,\Sigma,MC}^{new} . \eta_{op,MC}^{old} = 0,90 . 0,90 = 0,81\,.$$

Thus, the new overall efficiency of the benefiting part part of the IS will be:

$$\eta_{0,D}^{new} = \eta_{0,MC}^{new} . \eta_{0,D2}^{new} = 0,81 . 0,778 = 0,63$$

The *RPWS* estimated by means of new and old efficiencies will be:

$$RPWS = \frac{\eta^{new} - \eta^{old}}{\eta^{old}} = \frac{0,63 - 0,584}{0,584} = 0,079 = 7,9\%$$

The error between the exact value (7,5%) and the approximate value (7,9%) is +5,3%.

Note (not to be written in the explanatory note)

If the *PWS* have to be estimated on the level of the entire IS, the value of *RPWS* will be different. The *PWS* for the entire IS are *PWS* = 4,5. While calculating *RPWS*, we should take into account that the overall consumption of the entire IS decreases by 4,5 units, thus it becomes V_{dir}^{new} = 100 – 4,5 = 95,5. Thus:

$$RPWS = \frac{V_{dir}^{old} - V_{dir}^{new}}{V_{dir}^{old}} = \frac{100 - 95,5}{100} = 0,045 = 4,5\% < RPWS_{min} = 5\%.$$