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ASSESMENT OF SEDIMENT TRANSPORT RATE AND NON-SILTING VELOCITY IN IRRIGATION CANAL

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Abstract: Siltation is a significant factor, affecting the efficient operation and maintenance of the irrigation canals which influence the hydraulic behavior of the canals and economic benefits of irrigation. In last 25 years a tendency of silting up at the irrigation canals in Bulgaria is observed due to the following reasons: decreased area under irrigation, fluctuation in supply, non-regime section, "berming" of the canal, economic, crime and safety situation. The large number of bed load and permissible velocity formulas available and the significant differences between obtained results enforce selection of appropriate sediment transport formulas in each particular case. Discharge and velocity approach are used in this study for estimation of sediment transport and deposition rates at Babreka Canal, Malka Vitska Irrigation Project in Bulgaria. In this study seven equations for prediction total bed load transport rates and five equations for minimum permissible velocity are compared. Two formulas for total bed load and two formulas for minimum permissible velocity are selected as appropriate for study canal.
Keywords: Sediment transport, Irrigation canal, Malka Vitska Irrigation Project, Bulgaria

1. INTRODUCTION

Siltation is a significant factor, affecting the efficient operation and maintenance of the irrigation canals which influence the hydraulic behaviour of the canals and economic benefits of irrigation. Irrigation canals have been designed to ensure a transport capacity equal to or greater than the amount of incoming sediment. In last 25 years a tendency of silting up at the irrigation canals in Bulgaria is observed due to the following reasons: decreased area under irrigation, fluctuation in supply, non-regime section, "berming" of the canal, economic, crime and safety situation. An irrigation canal silting is important problem in their operation and maintenance and is capable of exerting direct and indirect effects on the hydraulic characteristics and economic benefits of irrigation.

The large number of bed load and permissible velocity formulas available and the significant differences between obtained results enforce selection of appropriate sediment transport formulas in each particular case.

2. MATERIAL AND METHOD

Determination of bed load rate is important to irrigation canal behavior understanding including the carrying capacity, sediment deposition, growth of vegetation. In generally irrigation canals are designed on the requirement that all sediment which enters the canal should be transported through without sedimentation. According HR Wallingford (1992) three methods for design stable canals are used: regime method, tractive force method, and rational theory. The regime design methods are sets of empirical equations derived from observations of canals and natural rivers. Tractive force method is based on a consideration of the balance of forces which act on sediment particle and include the method of permissible velocity and the method of critical shear stress. The tractive force methods are in use for shear stress and sediment transport determination. The rational theory includes the semi-empirical methods and it is based on the conveying the sediment load through the canal system based on energy dissipation considerations. At least 100 published transport rate equations can be found in the literature and verification of the accuracies of this formulas is mainly based on laboratory and limited field data (Yang et al., 2009).

Seven well-known equations for bed load transport rate determination are chosen for comparison in this paper.

Meyer-Peter and Muller equation (Quesnel, 1974):

$$q_s = \frac{8}{\sqrt{\rho_w}}\left(\tau_b - 0.047\left(\gamma_s - \gamma_w\right)d_{50}\right)^{3/2} \qquad (1)$$

where: q_s represents volumetric transport rate of bed load per unit width [kg/s m]; ρ_w - density of water [kg/m^3]; τ_b – bed shear stress;

γ_w – specific weight of water [kN/m^3]; γ_s - specific weight of sediment [kN/m^3]; d_{50} – median size of particle size distribution.

Einstein - Brown equation (Hug, 1975):

$$q_s = \sqrt{(s-1)gd^3}\,\frac{K\exp\left(-0.391/Fr^*\right)}{0.465}, Fr^* < 0.182 \quad q_s = 40\sqrt{(s-1)gd^3}KFr^{*3}, Fr^* \geq 0.182 \qquad (2)$$

where: s represents relative density $s = \frac{\rho_w}{\rho_s}$; Fr* - dimensionless shear stress or Shields stress; Fr_{crit}* - critical Shields stress; g - acceleration of gravity [m/s^2]; K- coefficient

$$K=\sqrt{\frac{2}{3}+\frac{36\nu^2}{d^3(s-1)}}-\sqrt{\frac{36\nu^2}{d^3(s-1)}}.$$

Selim Yalin equation (Hug, 1975):

$$q_s=0.635\sqrt{(s-1)gd^3}\,r\sqrt{Fr^*}\left[1-\frac{1}{\sigma r}\ln(1+\sigma r)\right] \tag{3}$$

where:

$$r=\frac{Fr^*}{Fr^*_{crit}}-1,\sigma_1=2.45\frac{\sqrt{Fr^*_{crit}}}{s^{0.4}}.$$

Gomez equation (Gomez, 2006):

$$q_s=\frac{0.0725\gamma QJ}{bd_{50}^{0.51}} \tag{4}$$

where: Q represents water discharge [m^3/s]; J – energy gradient; b – canal length [m].
Van Rijn equation (Van Rijn, 1984):

$$q^*=\frac{0.053}{d^{*0.3}}\left(\frac{Fr^*}{Fr^*_{crit}}-1\right)^{2.1} \tag{5}$$

where: q* - represents dimensionless bed load transport rate; d* - dimensionless particle diameter.
Nagakawa-Tsujimoto equation (Van Rijn, 1984):

$$q_s=0.02\rho_s Fr_*\sqrt{(s-1)gd_{50}}\left[1-\frac{0.035}{Fr_*}\right]^3 \tag{6}$$

where: ρ_s represents density of the sediment [kg/m^3].
Nielsen equation (Nielsen, 1992):

$$q^*=12\left(Fr^*-Fr^*_{crit}\right)\sqrt{Fr^*} \tag{7}$$

The minimum permissible velocity or non-silting velocity is the lowest velocity that will not initiate sedimentation and will not allow the growth of vegetation. According Chow (Chow, 1973) the average velocity from 0.6 to 0.9 m/s would prevent sediment deposition and higher velocity than 0.75 m/s would ensure vegetation-free canal. Therefore, the minimum permissible velocity should be in the range of 0.75-0.9 m/s. Non-silting velocity depends on the sediment diameter. Five well-known equations for minimum permissible velocity determination are chosen for comparison – Zamarin, Grishkan, Roer, Poslavskii (Korpachev, 2009) and Kennedy equations (Das, 2012).
Zamarin equation:

$$\mathrm{v_{min}}=\mathrm{a}\sqrt{\mathrm{R}} \tag{8}$$

where: R represents hydraulic radius; a – coefficient depend on particle size (table 1).

Table 1. Values of coefficient a

d [mm]	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	3.0
a	0.2	0.45	0.67	0.82	0.9	0.95	1.0	1.02	1.05	1.07	1.1	1.11

Grishkan equation:

$$\mathrm{v_{min}}=\mathrm{kQ^{0.2}} \tag{9}$$

where: k represents a coefficient depend on fall velocity ω;

if fall velocity ω<1.5 mm/s - k=0.33;
if ω is between 1.5 and 3.5 mm/s - k=0.44;
if ω>3.5 mm/s - k=0.55.

Roer equation:

$$\mathrm{v}=\mathrm{A}\left[\frac{\mathrm{m}+2}{2}(\rho_\mathrm{p}-1)\omega\right]^{0.326}\mathrm{R^{0.473}} \tag{10}$$

where: A represents coefficient equal to 39.3; m - width-to-depth ratio.
Poslavskii equation:

$$\mathrm{v_{min}}=0.34\sqrt{\mathrm{NR^{1/3}}} \tag{11}$$

where: N represents capacity refers to the maximum amount of sediment of a given size that a stream can transport in traction as bedload.
Kennedy equation:

$$\mathrm{v_{min}}=0.84\mathrm{h^{0.64}} \tag{12}$$

3. RESULTS

Malka Vitska Irrigation Project is located in Dolni Dabnik Municipality, south Bulgaria and it is owned and managed from Irrigation System SOJSC, Pleven Branch. The Vit River, Krushovits-3 Reservoir, Dolni Dabnik Reservoir and Valchovets Reservoir are the source of water for the scheme. Babreka canal is a main canal with trapezoidal cross-section. Bottom width of the canal is b=2 m, side slope – m=1 and for water discharge Q=0.728 m3/s water depth h=1.08 m and energy gradient J=0.149‰ (Gadjev, 1989).

During the inspection of the Danube Basin Directorate, in 2009 vegetation and sediment deposition has been found in front of intake sluice gate the Malka Vitska Irrigation Project. Sediment deposition and vegetation has been found 200 meters upstream from intake in the Vit River (http://dariknews.bg/). The Danube River Basin Directorate has been given instructions for sediment removing, but there is no press release on whether it has been implemented.

Currently, a poorly maintained irrigation system is not fully used. Only vegetables and tobacco are irrigated in Dolni Dabnik Municipality. There are no water users associations. The potentially irrigated area on the territory of the Municipality is 99 602 000 square meters. From them 19 440 000 square meters are not properly irrigated due to amortized hydraulic structures. The real irrigated area is less than 8 000 000 square meters.

The bed load transport rate for Babreka Canal is determined in the range from 0.1 mm to 3 mm by equations (1), (2), (3), (4), (5), (6) and (7). The results shown in Figure 1 indicate that the Nielsen formula (7) and Mayer-Peter Muller formula (1) is more appropriate for diameter particle bigger than 3 mm. Nagakawa-Tsujimoto formula (6) have downward trend with particle diameter increasing and (6) is not appropriate for this case. Gomez formula (4) is low predictor. Van Rijn formula (5) and Yalin (3) formula have the similar results.

As shows in Figure 2 after selection (2) and (5) for bed load transport rate is appropriated for study canal. The minimum permissible velocity determination for Babreka Canal is determined in the range from 0.1 mm to 3 mm by equations (8), (9), (10), (11) and (12). The results shown in Figure 3 indicate that the Poslavskii formula (11) have downward trend with particle diameter increasing and (11) is not appropriate for this case. Kennedy formula (12) and Grishkan formula (9) is more appropriate for diameter particle bigger than 3 mm.

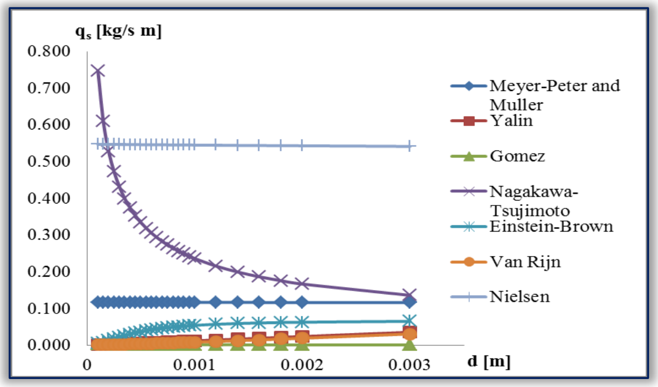

Figure 1 - Bed load transport rate results for Babreka Canal

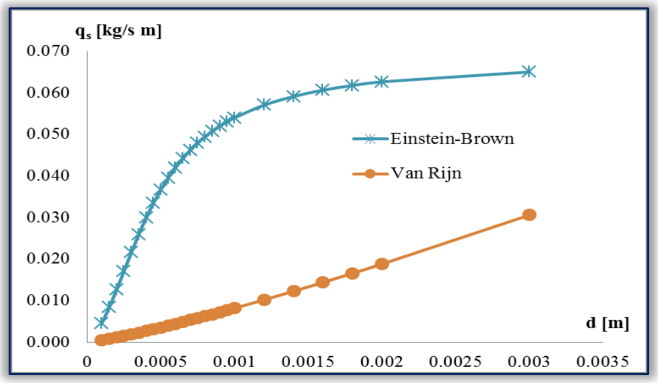

Figure 2 - Bed load transport rate results appropriate for Babreka Canal

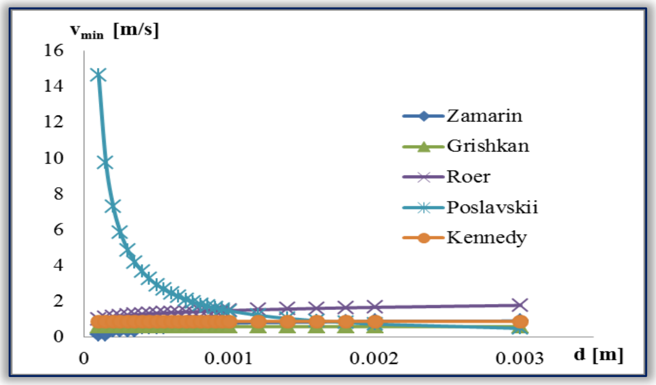

Figure 3 - Minimum permissible velocity results for Babreka Canal

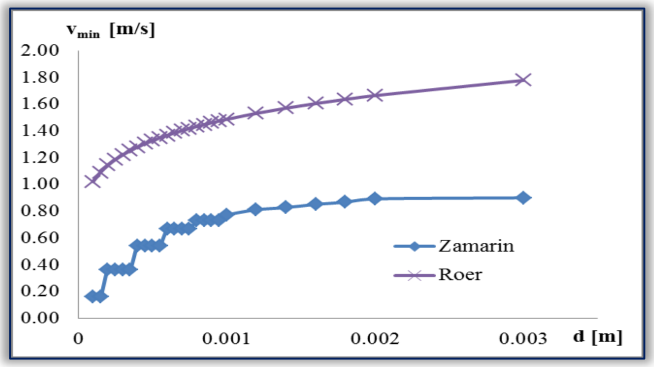

Figure 4 - Minimum permissible velocity results appropriate for Babreka Canal

4. CONCLUSIONS

The results show substantial differences in performance of the different formulas. Einstein - Brown formula (2) and Van Rijn formula (5) for bed load transport rate and Zamarin formula (8) and Roer formula (10) for minimum permissible velocity are selected as appropriate for study canal.

Note:
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