SELECTION OF APPROPRIATE TRANSPORT FORMULAS FOR ESTIMATION OF TRANSPORT AND DEPOSITION RATES AT BABREKA 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 available bed load and permissible velocity formulas and the significant differences between obtained results enforce selection of appropriate sediment transport formulas in each particular case. In this study discharge and velocity approaches are used for estimation of sediment transport and deposition rates at Babreka Canal, Malka Vitska Irrigation Project in Bulgaria. Seven equations for prediction total bed load transport rates and five equations for minimum permissible velocity are compared. The results show substantial differences in performance. Two formulas for total bed load and two formulas for minimum permissible velocity are selected as appropriate for the studied canal.

Keywords: Sediment transport, Irrigation canal, Malka Vitska Irrigation Project, Bulgaria.

Introduction
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. Irrigation canal silting is important problem in achieving effective 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 the selection of appropriate sediment transport formulas in each particular case.
In this study discharge and velocity approaches were used for estimation of sediment transport and deposition rates at an existing irrigation canal -"Babreka", Malka Vitska Irrigation Project in Bulgaria. Seven equations for prediction total bed load transport rates and five equations for minimum permissible velocity are compared.

Material and methods
Determination of bed load rate is important to understand irrigation canal behavior including carrying capacity, sediment deposition, growth of vegetation. Basically irrigation canals are designed on the requirement that all sediment which enters the canal should be transported without sedimentation. Three methods for design stable canals are used: regime method, tractive force method and rational theory (HR Wallingford 1992). 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 includes the method of permissible velocity and the method of critical shear stress. The tractive force methods are used 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 transport rate equations can be found in the literature and the verification of the accuracy of this formulas is mainly based on laboratory and limited field data (Yang et al., 2009).

Among published, seven well-known equations for bed load transport rate determination were selected and compared in this study.

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

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

where q_s is 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):

$$q_s = \sqrt{(s-1)gd^3}\frac{K_{exp}\left(-\frac{0.391}{Fr^*}\right)}{0.465}, Fr^* < 0.182$$

$$q_s = 40\sqrt{(s-1)gd^3}KFr^{*3}, Fr^* \geq 0.182 s = \frac{\rho_w}{\rho_s}; K = \sqrt{\frac{2}{3}+\frac{36\upsilon}{d^3(s-1)}} - \sqrt{\frac{36\upsilon^2}{d^3(s-1)}}, \qquad (2)$$

where s is relative density; Fr* - dimensionless shear stress or Shields stress; υ - kinematic viscosity [m^2/s]; g - acceleration of gravity [m/s^2].

Selim Yalin equation (Hug, 1975):

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

$$r = \frac{Fr^*}{Fr^*_{crit}} - 1; \sigma = 2.45\frac{\sqrt{Fr^*_{crit}}}{s^{0.4}}, \qquad (3)$$

where Fr_{crit}* is critical Shields stress.

Gomez equation (Gomez, 2006):

$$q_s = \frac{0.0725\gamma QJ}{bd_{50}^{0.51}}, \qquad (4)$$

where Q is water discharge [m3/s]; J – energy gradient; b – canal length [m].

Van Rijn equation (Van Rijn, 1984):

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

where q* is dimensionless bed load transport rate; d* - dimensionless particle diameter.

Nagakawa - Tsujimoto equation (Van Rijn, 1984):

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

Nielsen equation (Nielsen, 1992):

$$q^* = 12(Fr^* - Fr^*_{crit})\sqrt{Fr^*}, \qquad (7)$$

The minimum permissible velocity or non-silting velocity is the lowest velocity that will not initiate sedimentation and will not allow a 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 ranged of 0.75-0.9 m/s. Non-silting velocity depends on the sediment diameter. Five well-known equations for determination of minimum permissible velocity are chosen for comparison – Zamarin, Grishkan, Roer, Poslavskii and Kennedy equations:

- Zamarin equation:

$$v_{min} = a\sqrt{R} \qquad (8)$$

where R is hydraulic radius; a – coefficient depend on particle size (Tab. 2).

Tab.2. Coefficient a in Zamarin equation

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:

$$v_{min} = kQ^{0.2} \quad (9)$$

where k is coefficient depend on *fall* velocity ω.
If fall velocity ω<1.5 mm/s, k=0.33; if value of ω is between 1.5 and 3.5 mm/s k=0.44 and if ω>3.5 mm/s k=0.55.

- Roer equation:

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

where A is coefficient equal to 39.3; m - width-to-depth ratio.

- Poslavskii equation (Korpachev, 2009):

$$v_{min} = 0.34\sqrt{NR^{1/3}} \quad (11)$$

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

- Kennedy equation (Das, 2012):

$$v_{min} = 0.84h^{0.64} \quad (12)$$

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 water sources for the irrigation scheme.
Babreka canal is a main concrete lined canal with trapezoidal cross-section. Bottom width of the canal is 2 m, side slope 1:1 and for water discharge Q=0.728 m^3/s the water depth is h=1.08 m with energy gradient J=0.149‰ (Gadjev, 1989).
In 2009 during the inspection of the Danube Basin Directorate, vegetation and sediment deposition has been found in front of intake sluice gate of the Malka Vitska Irrigation Project. Sediment deposition and vegetation has been found 200 meters upstream from intake from the Vit River. (http://dariknews.bg/print_article.php?article_id=423682). Instruction for sediment removing has been given by the Danube River Basin Directorate, but there is no information whether it has been implemented.
At present, a poorly maintained Malka Vitska Irrigation Project is not fully used. The potentially irrigated area on the territory of the Dolni Dabnik Municipality is 9960.2 ha. From them, 1944 ha are not properly irrigated due to amortized hydraulic structures. The real irrigated area is less than 800 ha. Only some vegetables and tobacco are irrigated. There are no water users associations.

Results and discussion

The bed load transport rate for Babreka Canal is determined and compared in the range from 0.1 mm to 3 mm by seven well-known equations - Meyer-Peter and Muller (1), Einstein – Brown (2), Selim – Yalin (3), Gomez (4), Van Rijn (5), Nagakawa – Tsujimoto (6) and Nielsen equation (7). The bed load transport rate is determined for water discharge Q=0.728 m3/s, water depth h=1.08 m, energy gradient J=0.149‰ and Manning`s roughness n=0.0163. The transport capacity of all sediment for Babreka canal is guaranteed when the value of energy dissipation equal to 0.48 Watt/m^3 does not decrease in downstream direction

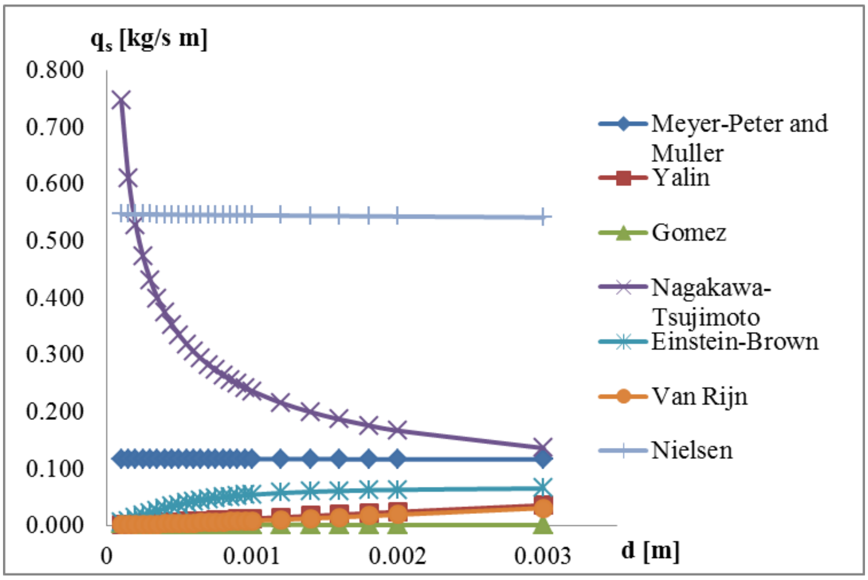

Fig. 1. Bed load transport rate results for Babreka Canal

The results graphically represent in Fig. 1 show that the Nielsen equation (7) and Mayer-Peter Muller equation (1) are more appropriate for diameter particle bigger than 3 mm. It is supposed that the range of smaller diameter particles will incoming into the canal. The results for bed load transport rate, calculated after Nagakawa-Tsujimoto formula (6) have downward trend with particle diameter increasing and this formula was assessed as not appropriate for this case. Gomez equation (4) is low predictor. The similar results were obtained using Van Rijn equation (5) and Yalin equation (3).

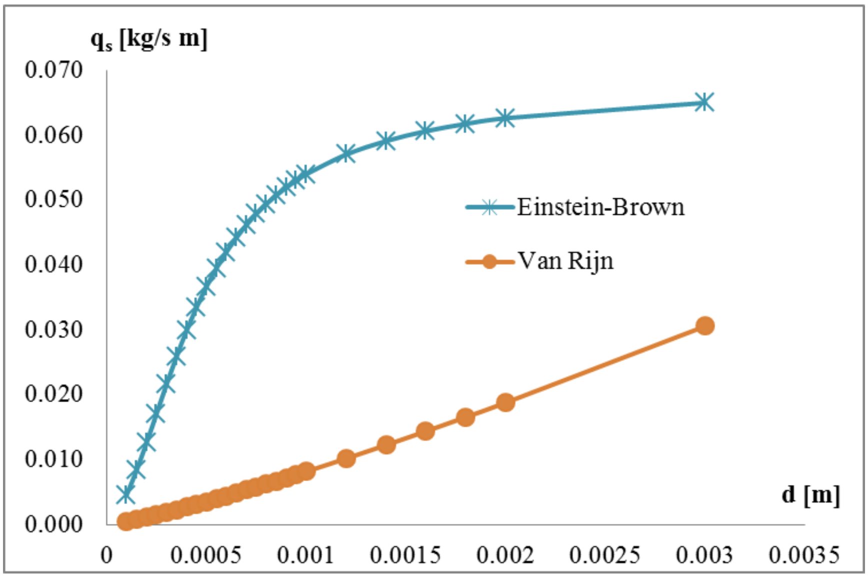

Fig. 2. Bed load transport rate results appropriate for Babreka Canal

In this study the application of Einstein – Brown equation (2) and Van Rijn equation (5) for calculation of bed load transport rate was assessed as appropriate for the studied canal (Fig.2).
The minimum permissible velocity for Babreka Canal was determined in the range from 0.1 mm to 3 mm for water discharge Q=0.728 m3/s, water depth h=1.08 m, energy gradient J=0.149‰ and Manning`s roughness n=0.0163 using five well-known equations Zamarin (8), Grishkan (9), Roer (10), Poslavskii (11) and Kennedy (12).
The results are shown in Fig. 3. The bed load transport rate results determined using Poslavskii formula (11) have downward trend with particle diameter increasing and equation (11) is not

appropriate for this case. Kennedy formula (12) and Grishkan formula (9) are more appropriate for diameter particle bigger than 3 mm. It is supposed that the range of smaller diameter particles will incoming into the canal.

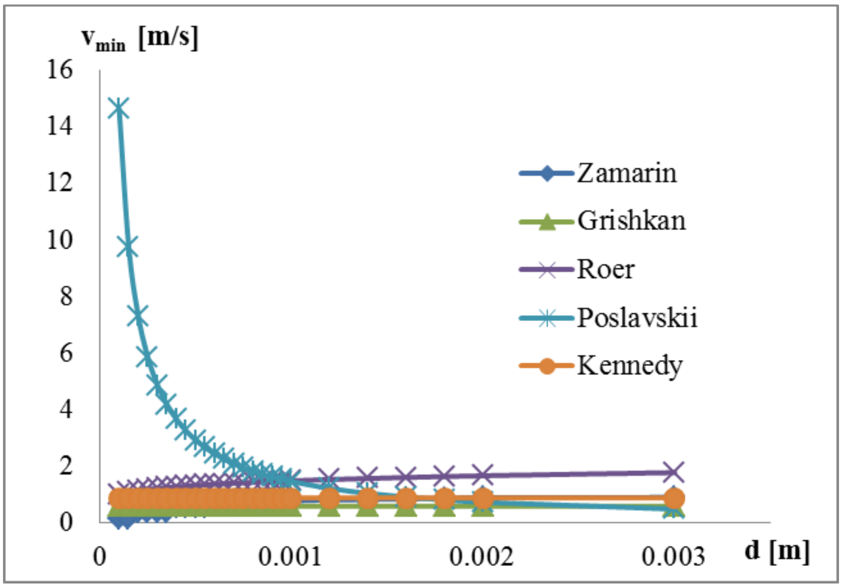

Fig. 3. Minimum permissible velocity results for Babreka Canal

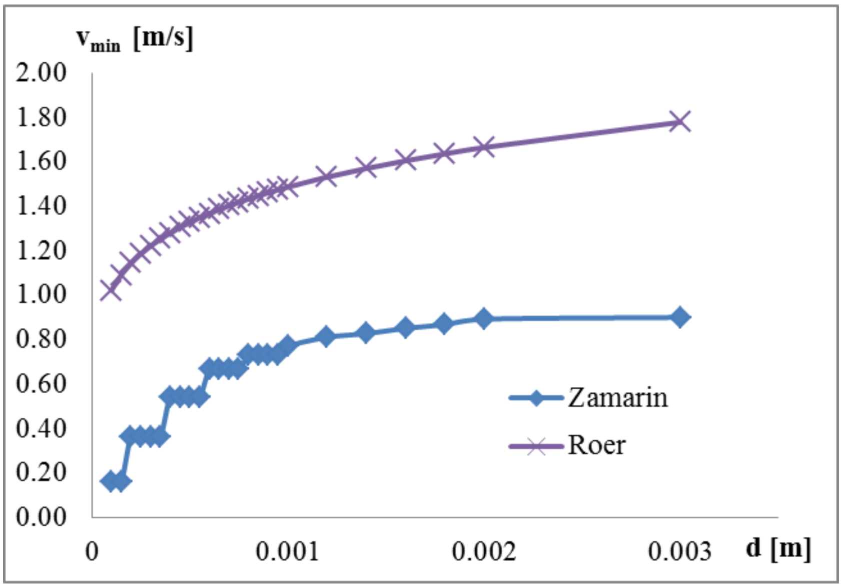

Fig. 4. Minimum permissible velocity results appropriate for Babreka Canal

The application of the Zamarin equation (8) and Roer equation (10) for calculation of minimum permissible velocity was assessed as appropriate for the studied canal (Fig.4).

Conclusions

The results obtained show substantial differences in the 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 the studied canal.

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