METHOD FOR CALCULATIING IRRIGATION SETTLING BASINIS

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***Abstract** : In Azerbaijan, agricultural and industrial water demands are primarily met through surface water sources. Planned and sustainable water withdrawal from rivers can be achieved by effectively addressing sedimentation challenges. In certain cases, the use of lake-type or expanding settling basins is considered appropriate to enhance flow clarification and accelerate sediment deposition. The processes of sediment transport and settlement in basins of various configurations—both during water clarification and flushing-represent complex physical phenomena associated with channel dynamics. Effectively resolving these issues requires further improvement in the design and hydraulic calculation methods of hydraulic structures. The Republic of Azerbaijan plans to construct numerous river water intake facilities equipped with settlement basins, as well as in-channel and off-channel reservoirs and water supply systems.*

Key words: chamber, suspended sediments, flushing valve, middle wall, flushing channel.

Introduction. In Azerbaijan, water consumption for agriculture and industrial production is primarily provided by surface water sources. The intensive development of agriculture places ever-increasing demands on the quality and volume of water consumed. Therefore, significant work is currently underway to reconstruct existing and design new large hydraulic structures. To successfully address these issues, further improvements to the design and hydraulic calculation methods of water intake structures are required. The construction of numerous river water intake structures with settling basins, in-channel and out-of-channel reservoirs, and large canals is envisaged.

It should be noted that planned and sustainable water intake from rivers can be ensured by addressing sediment control issues. In some cases, the use of lake-type and expanding settling basins is considered appropriate to improve flow clarification and accelerate sediment deposition. Irrigation system settling basins are typically located at the head of the main canal or within the water intake structure. The nature of sediment movement and deposition in settling basins of various designs, both during water clarification and during flushing, is a complex physical phenomenon related to channel processes.

To calculate the dynamics of sedimentation in settling basins of various types, numerous methods have been proposed, the essence of which is given in the works of A. N. Gostunsky, Y.A. Ibadzade, Ch.G. Nuriyev, I.I. Levi, D.Ya. Sokolov, P.V. Mikheev, A.S. Obrazovsky, F.S. Salahov, Kh.Sh. Shapiro, F.B. Bashirov, F.Sh. Muhammedzhanov, K. I. Baimanov, N. T. Kaveshnikov and others.

The principles of calculating sediment deposition in settling basins, which form the basis of each method, are described in [1–11]. A comparison of the results of calculations using these methods, carried out by I. M. Volkov [3], I. E. Mikhailov [4],

V. S. Lapshenkov [8], and Yu. A. Ibad-zade [11], with the data of field studies of a number of settling basins built on the irrigation systems of lowland rivers, showed a significant discrepancy between the calculated and field values of 35–65 % on average.

For the calculation of irrigation settling basins, E. A. Zamarin [1] proposes the following formulas:

Length of the chamber,

$$L = (H_{avg} / W_o) (V_1 – V_{avg})/Ln(V_1 / V_{avg}) \quad (1)$$

Sediment fallout rate,

$$U_x = W_0 \quad (2)$$

where V_1 is average speed at the beginning of the settling basin;

V_{avg} , H_{avg} are respectively, the average speed and depth of the flow in the chamber;

W_o - is average hydraulic size at the beginning of the settling basin.

Arved J. Raudkivi [13] suggests the following formulas for determining the length of a settling basin:

Length of the settling basin

$$L = (H_{avg} / (W_o + u)) (V_1 – V_2)/Ln(V_1 /V_2) \quad (3)$$

Sediment fallout rate,

$$U_x = W_0 + u \quad (4)$$

where: V_1 is average speed at the beginning of the settling basin;

V_2 is average speed at the end of the settling basin;

H_{avg} is average depth of flow in the settling basin;

W_o is average hydraulic size at the beginning of the settling basin.

u is additional sediment settling velocity due to the design of the settling basin chamber u = Q/(2 BL); (*Q is water flow rate in the chamber, m^3/s, B is chamber width, m; L is length of the settling chamber, m*).

To calculate irrigation sedimentation basins, Yu. A. Ibadzade and Ch. G. Nuriyev [11] propose the following formulas:

Length of the settling basin

$$L = (\rho_o - \rho_{out})/(\rho_{out} - \rho_{cr})*(V_{avg} H_{avg} / W_o) \quad (5)$$

Change in turbidity along the length of the settling basin

$$\rho_{out} = \rho_{cr} + (\rho_o - \rho_{cr})/(V_{avg} H_{avg} / W_o + L_x)* (V_{avg} H_{avg} / W_o) \quad (6)$$

The rate of sediment deposition along the settling chamber

$$U_x = (\rho_x W_0)/(\rho_o - \rho_{cr.}) \quad (7)$$

where ρ_o , ρ_{out} is turbidity of the flow at the beginning and end of the settling basin, respectively;

ρ_x is variable value of turbidity of the flow along the settling chamber;

ρ_{cr} is critical turbidity of the flow in the settling basin;

V_{avg} , H_{avg} are respectively, the average speed and depth of the flow in the settling basin;

W_o is average hydraulic size of turbidity at the beginning of the settling basin.

K. I. Baimanov [10] proposes the following formulas for determining the length and turbidity of the settling basin flow in the following form:
Length of the settling basin

$$L = \alpha VH/ W_0 \quad (8)$$

Change in turbidity along the length of the settling basin

$$\rho_{out} = \rho_{cr} + (\rho_o - \rho_{cr}) \exp(- W_0 L_x (\rho_o - \rho_{cr})/ HV \rho_o) \quad (9)$$

The rate of sediment deposition along the settling chamber

$$U_x = (\rho_0 - \rho_{cr}) W_0 / \rho_o \quad (10)$$

where: α is intensity factor in fractions of dynamic speed;

ρ_o is turbidity of the flow at the beginning of the settling basin;

ρ_{cr} is critical turbidity of the flow in the settling basin;

V , H are respectively, the average speed and depth of the flow in the settling basin;

W_o is the average hydraulic size of sediments in the calculated interval.

Analysis of existing formulas for settling basin calculations. As can be seen, many formulas have been developed for settling basins calculations. Analysis of these formulas shows that the length of the settling basins is directly related to the sediment settling rate within the chamber. Even with identical geometric and hydraulic parameters of the settling basins, the sediment settling rate varies significantly along the chamber. Our field studies on existing settling basin have shown that the sediment settling rate can be expressed as follows:

$$U_x = \rho_x W_0 / (\rho_0 - \rho_{out}) \quad (11)$$

From formula (11) it is clear that, when $\rho_x = \rho_o$ and $\rho_{out} = 0$ which corresponds to the beginning of the settling basin, $U_x = W_0$; at $\rho_x = \rho_{out}$ which corresponds to the end of the settling basins $U_x = \rho_{out} W_0 / \rho_0$. To calculate the dynamics of sediment deposition in an arbitrary channel, where ρ_{out} unknown in formula (11) is taken $\rho_{out} = \rho_{tr}$. To calculate ρ_{tr} in a settling basin, one can use the formula of F. S. Salakhov [11]**:**

$$\rho_{tr} = 0.0135\ V^3 /(H_{avg}\ W_o) \qquad (12)$$

Some researchers associate the sediment deposition rate during settling in a settling basin with critical turbidity [4, 5, 9]. Many formulas have been proposed to determine critical turbidity in a settling basin, which depend on various factors. It should be noted that the calculation results using these formulas differ significantly from each other [5, 9]. Some researchers associate critical turbidity with suspended velocities, which complicates hydraulic calculations. The flow in a settling basins chamber is very complex, and determining critical turbidity values using known formulas is very difficult; these values can be assessed as "conditional". Therefore, we believe that critical turbidity should be ignored in the formula for determining the sediment deposition rate in a settling basin. Considering the complexities and significantly different coefficients, existing formulas for calculating critical turbidity can be replaced with formulas for transporting capacity. The formula for the transporting capacity of suspended flows has been analyzed and compared with numerous field data [12]. Using transport capacity in hydraulic calculations yields results closer to field data. Given these advantages, we used flow transport capacity instead of critical turbidity in our settling basin calculations. A numerical analysis of the above formulas was conducted. The calculations were performed using the following initial data, using the Kul-Aryk settling basins as an example. **[11]:** H_{av} = 2.5 m, V_{av} = 0.3 m/s, ρ_o = 6.0 kg/m^3 , W_o = 0.00122 m/s, ρ_{cr} = 0.37 kg/m^3 , V_1 = 0.5 m/s, V_2 = 0.1 m/s, L = 800. The results obtained are presented in Table 1.

Sediment deposition rates according to different formulas (Table 1)

Distance, m	0.00	200	400	600	800
ρ_X	6.0	4.52	3.65	3.15	2.75
Formulas	The value of U_x according to different formulas				
(2)	0.00122	0.00122	0.00122	0.00122	0.00122
(4)	0.00169	0.00169	0.00169	0.00169	0.00169
(7)	0.00122	0.00098	0.00079	0.00068	0.00059
(10)	0.00114	0.00114	0.00114	0.00114	0.00114
(11)	0.00122	0.00092	0.000742	0.00064	0.00056

Theoretical study. To derive the equation for sediment settling dynamics, we consider the nature of suspended particle motion in the settling zone of a horizontal sedimentation basins. We consider a plane problem. The flow motion is assumed to be uniform and turbulent. We assume a suspended sediment distribution diagram in a rectangular initial section. We consider the nature of the change in excess turbidity along a flow length dx in a rectangular channel of depth , width b , with a water flow velocity V. (Fig. 1) .

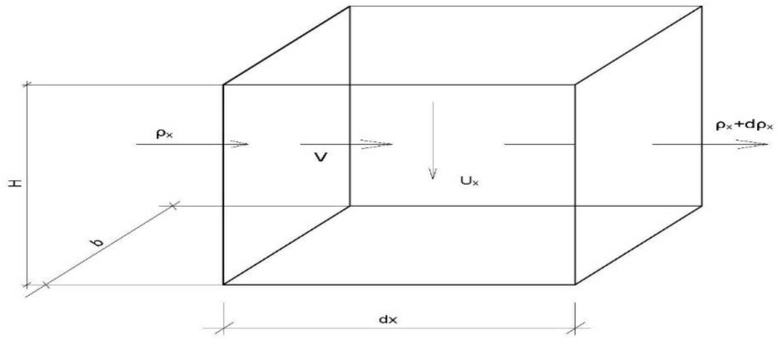

Fig. 1. Calculation scheme for changes in turbidity along the length of the settling basins.

Let's formulate a sediment balance equation for an elementary section dx. The sediment flow rate in the initial section will be VHb ρ_x , and at the end it will be VHb($\rho_x + d\,\rho_x$). The sediment flow rate deposited per area " bdx " will be equal to " U_x bdx ρ_x " . Taking these dependencies into account, the sediment balance equation will be:

$$VHb\,\rho_x - VHb(\rho_x + d\,\rho_x) = U_x\,bd\,\rho_x \qquad (13)$$

Taking into account (11), we obtain a differential equation in the following form:

$$dx = -(VH/W_0)(\rho_0 - \rho_{out})\,d\rho_x/\rho_x^{\,2} \qquad (14)$$

After integration we will have:

$$x = (VH/W_0)(\rho_0 - \rho_{out})/\rho_X + C \qquad (15)$$

The value of C is determined from the initial conditions (at x=0 ; $\rho_x = \rho_o$):

$$C = -(VH/W_0)(\rho_0 - \rho_{out})/\rho_o \qquad (16)$$

Taking into account (16), we obtain the following equation:

$$x = (VH/W_0)(\rho_0 - \rho_{out})/\rho_X - (VH/W_0)(\rho_0 - \rho_{out})/\rho_o \qquad (17)$$

At $x = L$ and $\rho_x = \rho_{out}$ from equation (17) we obtain an expression for determining the length of the settling basins (for the desired turbidity at the outlet of the settling basins) in the following form:

$$L = (VH/W_0)(\rho_0 - \rho_{out})(1/\rho_{out} - 1/\rho_o) \qquad (18)$$

Thus, with a known value of the turbidity leaving the settling basins

ρ_{out} can be determined using formula (18) to determine the length of the settling basins. From equation (17), an expression for the change in turbidity along the length of the settling basin can be obtained in the following form:

$$\rho_x = (VH/W_0)(\rho_0 - \rho_{out}) / (x + (VH/W_0)(\rho_0 - \rho_{out}) / \rho_o) \qquad (19)$$

If the output turbidity is unknown, then in formula (18) we take $\rho_{out} = \rho_{tr}$;

$$\rho_x = (VH/W_0)(\rho_0 - \rho_{tr}) / (x + (VH/W_0)(\rho_0 - \rho_{tr}) / \rho_o) \qquad (20)$$

Formula (20) was verified with the measured data of the Bagramtapa settling basins [5]. The multi-chamber settling basin with hydraulic flushing of the Bagramtapa hydroelectric complex is located on the right bank of the Araz River immediately behind the water intake. The settling basin has 9 chambers with a length of 120 m and an average depth of 2.7 m. The chamber width is 12 m and is divided by a wall into two sections of 6 m each. The bottom of the settling basins chambers has a reverse longitudinal slope of = 0.005. The normal flow rate of the settling basins is 85.7 m³/sec, the flush flow rate of the chamber is 15.0 m³/sec. A comparison of the calculated and measured data is given in Table 2. As can be seen from these data, the calculated turbidity at the outlet of the settling basins quite closely matches that measured in kind. The deviation for individual observations ranges from -27.02% to +24.44% and averages 3.76%.

Data on the hydraulic elements of the Bagramtapinsky sedimentation basin (Tab. 2)

Average speed in the chamber -V, m/sec	**Average depth - H, m**	**Chamber length - L, m**	**Average hydraulic size at the inlet -W, m/sec**	**Initial turbidity ρ, kg/m3**	**Measured turbidity at outlet, kg/m3**	**Estimated turbidity at outlet, kg/m3**	**Deviation, %**
0.192	2.42	120	0.000180683	0.554	0.539	0.529	-1.80
0.168	2.77	120	0.000351682	1,352	1,166	1,240	6.31
0.166	2.55	120	0.000474843	5.45	4,820	4,803	-0.34
0.14	2.31	120	0.00061407	2,934	2,251	2,390	6.15
0.18	1.95	120	0.000725652	2,046	1,610	1,639	1.82
0.16	1.89	120	0.000534455	1,686	1,342	1,391	3.65
0.195	1.75	120	0.001118238	2,204	1,810	1,582	-12.60
0.17	1.7	120	0.0005888	2,817	2,245	2,264	0.83
0.14	2.25	120	0.000894109	4,134	2,758	3,084	11.81
0.194	1.87	120	0.001280805	2,694	1,831	1,892	3.35
0.151	1.86	120	0.000592281	2,084	1,522	1,663	9.27
0.125	2.07	120	0.001028772	3,135	1,932	2,122	9.85
0.21	1.8	120	0.000870864	2.95	2,297	2,311	0.61
0.17	1.96	120	0.000782265	1.7	1,071	1,326	23.84
0.13	1.88	120	0.00035928	0.893	0.610	0.759	24.44
0.11	1.94	120	0.001184942	0.608	0.500	0.365	-27.02

In the work [5, 11] an example of calculation of the Kul-Aryk settling basins is given using the formulas of A. N. Gostunsky, P. V. Mikheev and Yu. A. Ibadzade. Calculations according to formulas (9) and (19) are given and added to the results of this example [11]. The calculation results are presented in Table 3 and Fig. 2.

Turbidity calculated using different formulas (Table 3)

Distance from the beginning, m	**A.N. Gostunsky**	**P.V. Mikheeva**	**Yu.A. Ibadzade**	**According to formula (9)**	**According to formula (19)**
200	4.42	4.58	4.62	4.52	4.51
400	3.28	3.69	3.78	3.43	3.61
600	2.48	3.08	3.22	2.62	3.01
800	1.89	2.65	2.82	2.03	2.58
1000	1.48	2.32	2.52	1.59	2.26
1300	1.06	1.92	2.18	1.14	1.93
1600	0.78	1.68	1.94	0.86	1.64
2000	0.58	1.42	1.7	0.64	1.39
2500	0.46	1.28	1.48	0.49	1.17

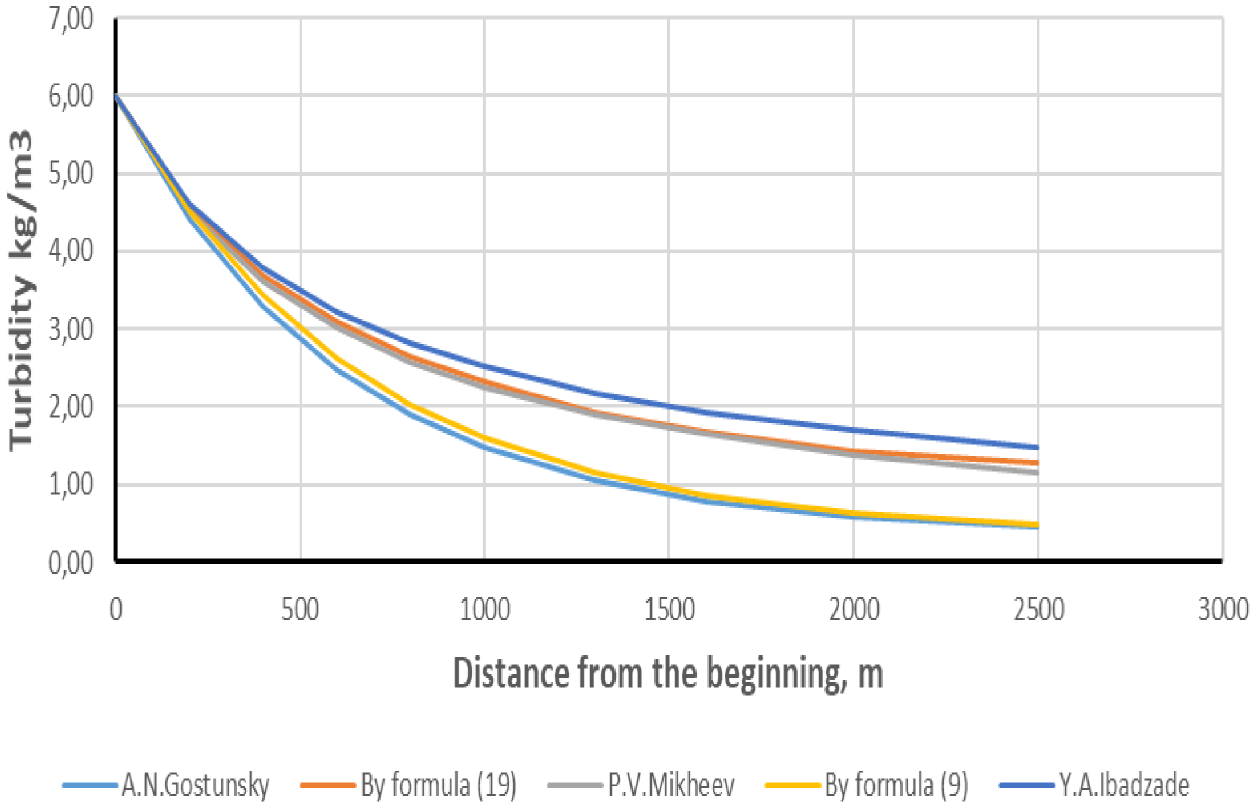

Fig. 2. Changes in turbidity along the length of the settling basins.

Key findings.

Irrigation settling basin play a vital role in improving water quality when using modern irrigation systems (sprinkler, drip, etc.). The following studies were conducted in this paper:

1. An analysis of sediment deposition dynamics in irrigation sedimentation basins was conducted using known methods (formulas). The errors in these methods were identified.
2. New formulas were developed for determining the length of the sedimentation basin and sediment settling dynamics. The calculation results using the new formula were compared with existing formulas.
3. The results of the analytical calculations were compared with field measurements at the Bahramtepe irrigation settling basin. The average deviation was 3.76%.

The obtained results can be used for the design of new sedimentation basin, as well as for the optimization of existing structures in order to increase the efficiency of sediment settling and improve the quality of the outlet water.

Bibliography

1. E.A. Zamarin. Hydraulic structures. Moscow, 1960.
2. I.M. Volkov, P.F. Kononenko, I.K.Fedichkin. Hydraulic structures. Moscow, 1968.
3. I.M. Volkov. Design of hydraulic structures. Moscow, 1977.
4. I.E. Mikhailov, Gravity horizontal settling basin for hydroelectric power plants and irrigation systems. Moscow, 2023.
5. A.G. Khachatryan, H.Sh. Shapiro, Z.I. Sharova. Siltation and flushing of irrigation sedimentation basin and reservoirs. Moscow, 1966.
6. Rozanov N. P. Hydraulic structures. Moscow. 1985.
7. Hydraulic Structures. Designer's Handbook. Moscow, 1983.
8. Coursework and diploma projects on hydraulic structures. Edited by V.S. Lapshenkov. Moscow: Agropromizdat, 1989.
9. N.T. Kaveshnikov, "Modern Methodological Approaches to Calculating Hydraulic Sedimentation Basin Parameters." Prirodoobustroystvo, No. 1, 2008.
10. K.I.Baimanov, K.K.Nazarbekov, R.K.Baimanov. Method for calculating sediment deposition in irrigation sedimentation basin. Problemy Mekhaniki. Uzbek Journal, No. 3, 2019, pp. 22-27.

11. Yu.A. Ibadzade, Ch.G. Nuriyev. Sedimentation basin of river water intakes. Moscow, 1979.
12. Yu.A. Ibadzade. Water Canals. Moscow, 1975.
13. Arved J.Raudkivi . Sedimentation Exclusion and Removal of Sediment from Diverted water. Rotterdam 1993.