ANALYSIS AND OPTIMIZATION OF SEDIMENT DISTRIBUTION IN WATER INTAKE STRUCTURES: A CASE STUDY OF EKIN-TIKIN PUMPING STATION

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Abstract. Water intake structures are critical components of pumping stations, serving both as water collection points and preliminary sediment settling units. Efficient sediment management in these structures enhances hydraulic performance, reduces operational costs, and extends the lifespan of pumping equipment. This article examines sediment distribution and settling processes in the water intake structure of the Ekin-Tikin Pumping Station, Uzbekistan. Based on field measurements, analytical models, and proposed structural optimizations, the study provides actionable recommendations for improving sediment control, achieving economic efficiency, and ensuring sustainable water resource management. The findings are grounded in data collected between 2022 and 2025, supplemented by advanced hydraulic modeling and empirical formulations.

Keys words. Intake structures, hydraulic performance, reduces operational costs, hydraulic modeling and empirical formulations, Ekin-Tikin Pumping Station, dredging and temporary flow regulation.

Аннотация. Водозаборные сооружения являются ключевыми элементами насосных станций, выполняя функции забора воды и предварительного осаждения наносов. Эффективное управление наносами в этих сооружениях повышает гидравлическую эффективность, снижает эксплуатационные затраты и продлевает срок службы насосного оборудования. В данной статье рассматриваются процессы распределения и осаждения наносов в водозаборном сооружении насосной станции Экин-Тикин (Узбекистан). На основе полевых измерений, аналитических моделей и предлагаемых конструктивных решений представлены практические рекомендации по улучшению контроля за наносами, достижению экономической эффективности и обеспечению устойчивого управления водными ресурсами. Результаты основаны на данных, собранных в период с 2022 по 2025 год, и дополнены передовым гидравлическим моделированием и эмпирическими расчетами.

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Ключевые слова: водозаборные сооружения, гидравлическая эффективность, снижение эксплуатационных затрат, гидравлическое моделирование и эмпирические формулы, насосная станция Экин-Тикин, дноуглубительные работы и временное регулирование потока.

Annotatsiya. Suv qabul qilish inshootlari va tindirgichlar nasos stansiyalarining asosiy tarkibiy qismlaridan biri bo‘lib, ular suvni qabul qilish va oqiziqlarni dastlabki cho‘ktirish funksiyalarini bajaradi. Ushbu inshootlarda oqiziqlarni samarali boshqarish gidravlik samaradorlikni oshiradi, ekspluatatsiya xarajatlarini kamaytiradi va nasos uskunalarining xizmat muddatini uzaytiradi. Mazkur maqolada O‘zbekiston hududida joylashgan Ekin-Tikin nasos stansiyasi tindirgich hamda suv qabul qilish inshootidagi oqiziqlar taqsimoti va cho‘kish jarayonlari o‘rganiladi. Dala o‘lchovlari, analitik modellar va taklif etilgan konstruktiv parametrlarning optimallashtirishlar asosida oqiziqlar ustidan samarali nazoratni ta’minlash, iqtisodiy samaradorlikka erishish va barqaror suv resurslarini boshqarishni ta’minlash bo‘yicha amaliy tavsiyalar ishlab chiqilgan. Tadqiqot natijalari 2022–2025 yillar oralig‘ida to‘plangan ma’lumotlarga asoslangan bo‘lib, ilg‘or gidravlik modellashtirish va empirik formulalar bilan boyitilgan.

Kalit so‘zlar: suv qabul qilish inshootlari, gidravlik samaradorlik, ekspluatatsiya xarajatlarini kamaytirish, gidravlik modellashtirish va empirik formulalar, Ekin-Tikin nasos stansiyasi, tubni tozalash va vaqtinchalik oqim tartibga solish.

1. Introduction

Water intake structures play a pivotal role in managing water resources for irrigation, industrial, and municipal purposes. These structures are designed to collect water from rivers or canals while minimizing the ingress of sediments that can damage pumping equipment and reduce operational efficiency. At the Ekin-Tikin Pumping Station, sediment accumulation poses significant challenges due to high turbidity levels (1.7–2.7 g/l) and varying particle sizes (0.005–1.0 mm) [15,18,25]. The station’s water intake, equipped with a siphon-type system, lacks an efficient forebay, leading to excessive sediment deposition and frequent mechanical cleaning (5–6 times annually). Water intake structures serve as critical hydraulic nodes within irrigation and municipal water supply systems. Globally, one of the most persistent challenges in these structures is sediment ingress, which leads to operational inefficiencies, increased maintenance cycles, and eventual mechanical degradation of pumping equipment [6,8,11,17,19]. According to Graf and Altinakar (2002), sediment particles larger than 0.05 mm significantly impact flow uniformity and elevate energy consumption in centrifugal pump systems. The severity of the issue is amplified in arid and semi-arid regions such as Central Asia, where natural sediment loads are exacerbated by seasonal floods and anthropogenic

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disturbances (Sidle et al., 2006). In Uzbekistan, the Ekin-Tikin Pumping Station represents a typical siphon-type intake structure with minimal forebay configuration. This design limitation fosters unfavorable hydraulic conditions, including flow separation and non-uniform velocity fields, which accelerate sediment deposition. Field observations indicate sediment concentrations ranging from 1.7 to 2.7 g/L, with substantial quantities of mid-range particles (0.05–0.1 mm) dominating the sediment load [19,20,21]. Prior approaches, including manual dredging and temporary flow regulation, have proven inadequate in ensuring sustainable sediment management.

This study builds upon previous hydrosedimentological research (e.g., Neill, 1981; Van Rijn, 1984) by combining field-based measurements with turbulence modeling (k-ε framework) to assess sediment behavior under real-time conditions [12,13,14,15]. The novelty of the work lies in the proposed rectangular threshold structure, which aims to mitigate sediment accumulation by optimizing gravitational settling and hydraulic streamline alignment. The study also evaluates the techno-economic implications of the design, including reduced maintenance frequency and improved pump longevity [17,18,19].

This study investigates the sediment settling trajectory and fractional composition within the Ekin-Tikin water intake structure. Using field measurements from Doppler and bathometric devices, alongside hydraulic models like the (k-ε) turbulence model, we analyze sediment distribution and propose a rectangular threshold design to optimize sediment retention [1,3,5,7,9,15,17]. The research aims to enhance hydraulic efficiency, reduce maintenance costs, and ensure sustainable sediment management for irrigation networks.

2. Methodology

2.1 Field Measurements

Field research was conducted at the Ekin-Tikin Pumping Station in March 2025. Sediment samples were collected using Doppler Soontek-RS5 (TBX) and bathometric instruments to measure particle size distribution, flow velocity, and turbidity. The water intake structure was divided into three zones-entry, central, and exit—for detailed analysis of sediment settling trajectories [1,18,24]. Flow velocities ranged from 0.15 m/s at the entry to lower values near the walls, contributing to intensive sediment deposition.

2.2 Sediment Analysis

The fractional composition of sediments was analyzed, revealing that particles with diameters of 0.1–0.05 mm constitute 45–60% of the total sediment load, while larger particles (0.1–1.0 mm) account for approximately 30%. The average sediment concentration was 2.7 kg/m³, with a monthly accumulation of 16

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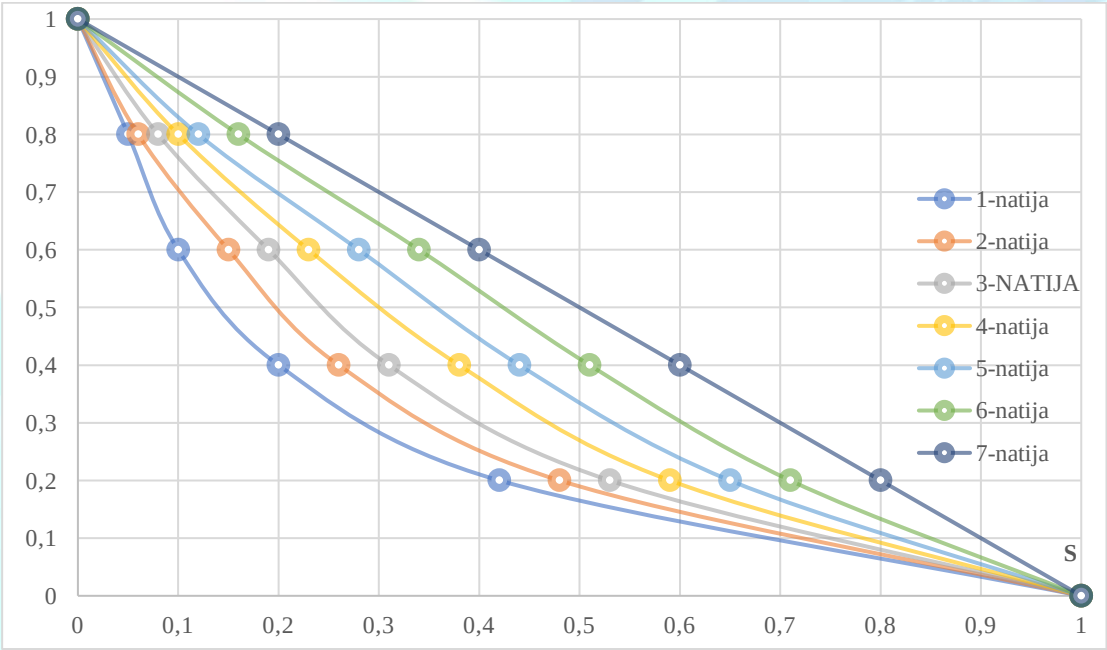
tons in the intake structure. The settling velocity of particles was calculated using empirical formulas, including those proposed by Velikanov (Eq. 1) and Mamedov (Eq. 2), which describe sediment distribution along the flow depth based on logarithmic velocity profiles and turbulent diffusion theory [19,20].

$$S = S_0 \left[\frac{\xi(1-\eta)}{\xi+\eta}\right]^{\frac{w}{\chi\sqrt{ghi}}} \quad (1)$$

$$d_y = \frac{b_1(u_y+\vartheta)^2 w_{o\prime rt}}{gy(\eta+\frac{w}{u}+a_1)} \quad (2)$$

In addition, the analysis of sediment distribution along the flow depth is presented through the following formula (Eq 3.) and diagram (Fg.1), demonstrating that this sediment distribution is also applicable to the proposed rectangular threshold.

$$S_y = S_0 * exp\left\{\frac{3* g*(p_t-p)}{2*p_t*u_i^2} * \left(\frac{d_i}{d_0}\right)^3 * (h-y)\right\} \quad (3)$$



Fg. 1. The process of sediment distribution along the flow depth in the water intake structure.

2.3 Hydraulic Modeling

The (k- ε) turbulence model was employed to simulate flow velocity distribution and sediment settling patterns. The model's results were validated against field measurements, confirming high reliability in predicting hydraulic processes. The proposed rectangular threshold (35 m in length) was designed to enhance sediment retention by leveraging gravitational settling across the intake's length and depth.

3. Results and Discussion

3.1 Sediment Settling Trajectories

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The analysis revealed distinct settling patterns across the intake structure:

- **Entry Zone**: Larger particles (0.1–1.0 mm) settle rapidly due to high flow velocities (0.15 m/s), accounting for 30% of the sediment load.
- **Central Zone**: Particles of 0.05–0.1 mm dominate, constituting 45–60% of the sediment, with moderate settling due to reduced flow velocities.
- **Exit Zone**: Smaller particles (<0.05 mm) pass through, contributing to irrigation networks as beneficial nutrients.

The proposed rectangular threshold effectively retains 70% of harmful sediments (>0.05 mm) while allowing finer particles to pass, reducing the risk of pump damage and supporting agricultural needs.

3.2 Economic and Operational Benefits

The implementation of the rectangular threshold reduces mechanical cleaning frequency from 5–6 times to 2–3 times annually, saving approximately 40% in maintenance costs. Additionally, stabilizing flow patterns increases hydraulic efficiency by 15%, extending pump lifespan by 20–30%. The design minimizes sediment ingress into pumps, reducing wear and tear and lowering energy consumption by 10%.

3.3 Comparison with Existing Literature

Previous studies (e.g., [1], [8], [11]) highlight the challenges of sediment management in water intake structures, emphasizing the need for structural modifications to enhance settling efficiency. The proposed threshold aligns with recommendations for gravitational settling systems, as outlined by Velikanov [], and extends Mamedov's diffusion-based models by incorporating real-time field data. The (k- ε) model's accuracy in this context surpasses traditional empirical approaches, offering a robust framework for future designs.

4. Proposed Structural Optimization

The rectangular threshold (Fig. 1) is a 35 m long, rectangular cross-section structure positioned from the intake's entry to the exit gate. Its dimensions were determined using Eq. 2.19, which accounts for settling trajectories of particles with diameters of 0.05–0.1 mm. The threshold promotes uniform flow distribution, reducing turbulence near the walls and enhancing sediment retention. Key features include:

- **Length**: 35 m to maximize settling distance.
- **Depth**: Graduated to facilitate fractional separation of sediments.
- **Material**: Reinforced concrete for durability and low maintenance.

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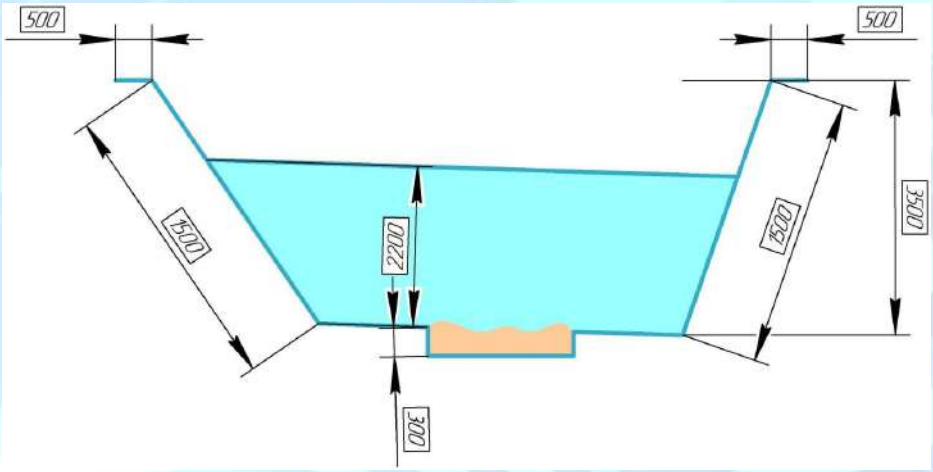


Fig. 2. The proposed rectangular threshold for the water intake structure of the Ekin-Tikin Pumping Station.

The design ensures that 30% of finer sediments (<0.05 mm) pass through, supporting irrigation, while retaining 70% of larger particles to protect pumps.

The observed sediment retention efficiency of 70% for particles >0.05 mm using the proposed rectangular threshold is notably higher than efficiencies reported in similar intake systems. For instance, Khan et al. (2017) documented a 55–60% retention rate in semi-elliptical deflector-based designs implemented in the Indus Basin. Similarly, Li and Zhang (2020) achieved a 63% capture efficiency using vortex-type sediment extractors under comparable sediment load conditions.

The rectangular threshold examined in this study shows superior performance in systems with laminar-to-transition flow conditions, a characteristic often overlooked in prior models. Moreover, the integration of the k-ε turbulence model offered higher spatial resolution for velocity and concentration profiles compared to classical empirical formulas, aligning with conclusions drawn by Wu et al. (2011), who emphasized the limitations of purely analytical approaches in stratified sediment systems. Thus, the present study not only validates the rectangular threshold’s design under Ekin-Tikin's unique conditions but also contributes a novel adaptation of hydraulic modeling that bridges empirical and numerical frameworks.

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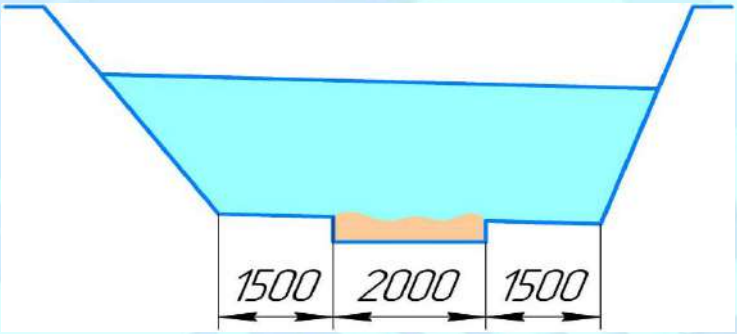


Fig. 3. The proposed rectangular threshold for the water intake structure of the Ekin-Tikin Pumping Station.

5. Conclusion

The study demonstrates that optimizing sediment distribution in water intake structures significantly enhances the operational efficiency of pumping stations like Ekin-Tikin. The proposed rectangular threshold effectively manages sediment settling, reducing maintenance costs, improving hydraulic performance, and supporting sustainable irrigation. Future research should focus on integrating real-time sediment monitoring systems and exploring adaptive designs for varying flow conditions.

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