



Evaluation and Modification of a Sediment Excluder for Cohesive Sediment in Irrigation Areas in Indonesia: Field Evidence, Numerical Modeling, and Physical Model Validation

*Herryan Kendra Kaharudin¹, Agustinus Purna Irawan², Wati A. Pranoto³

^{1,3}Doctoral Program in Civil Engineering, Faculty of Engineering, Universitas Tarumanagara,
Jakarta, Indonesia

²School Of STEM, Universitas Prasetiya Mulya, Jakarta, Indonesia

*)Correspondence writer (herryan.328232005@stu.untar.ac.id)

Received : 27 September 2026 Revised : 19 Oktober 2026 Accepted : 28 Oktober 2026

Abstract

KP-02 and KP-04 provide sand traps and sediment excluders primarily intended for non-cohesive sediment, whereas many irrigation systems carry predominantly silt and clay. This study evaluates existing structures and develops a modified Silt Settler concept for cohesive sediment using field evidence, numerical modeling, and physical model validation. Samples downstream of the Warujayeng sediment excluder contained 74.6–75.0% silt and 21.0–21.8% clay. At Tami Weir, cohesive fractions in bed sediment reached 77–100%, with TSS concentrations of 130–270 mg/L. HEC-RAS 2D modeling showed that sediment concentration in the existing sand trap decreased from 380–427 mg/L to approximately 150 mg/L, but fine sediment continued to enter the main canal. Two four-channel Silt Settler alternatives were simulated using FLOW-3D Hydro and evaluated against Krone deposition and Partheniades erosion thresholds. At a settling discharge of 5.0 m³/s, the deposition-opportunity index was 0.48% for Alternative 2A and 0.02% for Alternative 2B. The inlet baffle in Alternative 2A increased the projected index to 56.4–58.0%. Validation using a 1:5 physical model produced MAPE values of 6.43% for water level and 12.50% for velocity. The results support Alternative 2A with an inlet baffle and measurable cohesive-sediment criteria for updating KP-04.

Keywords: cohesive sediment; sediment excluder; Silt Settler; irrigation design criteria; FLOW-3D.

© Diterbitkan oleh Jurnal Teknik Sipil Cendekia 2026. This article is distributed under a Creative Commons Attribution-ShareAlike 4.0 International License.

INTRODUCTION

Sedimentation in irrigation canals reduces conveyance capacity, increases operation and maintenance costs, and affects the reliability of water distribution. In Indonesia, the main sediment-control structures upstream of main canals are designed according to the Irrigation Planning Criteria, namely the sediment trap specified in KP-02 and the sediment excluder specified in KP-04. The KP-02 sediment trap is

designed to settle fine sand with a lower grain-size limit of approximately 0.088 mm, whereas the KP-04 sediment excluder is not intended for silt and clay because these particles remain suspended throughout the flow depth as a result of turbulence. This condition is important because many rivers supplying irrigation schemes carry substantial fine-sediment loads.

The vulnerability of irrigation sediment traps to sedimentation in volcanic watersheds has been

mapped, while HEC-RAS-based sediment-trap management has been applied in the Pengasih irrigation system [1], [2], [3]. However, studies of cohesive-sediment behaviour within settling structures remain limited. Cohesive-sediment deposition is not governed by a single threshold [4], [5], [6]. Deposition requires the bed shear stress to remain below the deposition threshold, τ_d , whereas deposited material is eroded when the bed shear stress exceeds the higher erosion threshold, τ_e . In addition, classical settling criteria based on surface loading require very large structure areas for micrometre-sized particles [7], [8], [9], [10]. These conditions indicate that planning approaches primarily intended for non-cohesive sediment need to be evaluated when applied to irrigation systems dominated by silt and clay.

This study address was analyzed using the two-dimensional sediment-transport module of HEC-RAS 6.6 [11]. the problem through a sequential chain of field evidence, numerical modelling, and physical model validation. The sequence includes demonstrating the sediment condition passing through KP-02 and KP-04 structures, assessing the performance of the existing Tami Weir sediment trap using a two-dimensional model, developing and evaluating a Silt Settler concept using a three-dimensional model with cohesive-sediment threshold analysis, and validating the numerical model using a physical model. The resulting evidence is integrated to formulate measurable criteria as a basis for updating KP-04. Thus, the study not only evaluates existing structures but also links sediment characteristics, hydrodynamic conditions, deposition opportunity, flushing, and model verification in the formulation of planning criteria.

The objectives of this study are to: (i) demonstrate from field data that KP-02 and KP-04 structures do not adequately retain cohesive sediment; (ii) assess the performance of the existing Tami Weir sediment trap using a two-dimensional model; (iii) develop and evaluate a Silt Settler concept using a three-dimensional model with cohesive-sediment

threshold analysis; (iv) validate the numerical model using a physical model; and (v) formulate measurable criteria as a basis for updating KP-04. Detailed three-dimensional analysis, flushing, and validation are presented in companion manuscripts [12], [13], while this article integrates the complete chain of evidence and emphasizes its implications for planning.

METHOD

A. Research Framework and Study Locations

The study was organized into six stages, as shown in Figure 1. The first stage consisted of collecting field evidence through sediment sampling in the Warujayeng and Koya Tami irrigation schemes. The second stage evaluated the performance of the existing Tami Weir sediment trap using a two-dimensional HEC-RAS model. The third stage developed two alternative Silt Settler concepts, while the fourth stage evaluated the alternatives using FLOW-3D Hydro simulations. The fifth stage validated the numerical model using a 1:5 physical model. The final stage synthesized the results into a configuration and measurable criteria for cohesive sediment as a basis for updating KP-04.

The first study location was the Warujayeng irrigation scheme in Nganjuk Regency, East Java, with a cultivated irrigation area of 12,491 ha. The scheme receives water from the Brantas River through the left intake of the Mrican Movable Weir and has a sediment excluder representing an application of KP-04. The second location was Tami Weir in Muara Tami District, Jayapura City, Papua, which supplies the approximately 5,000-ha Koya Tami irrigation scheme. Tami Weir is a fixed weir with a seven-tooth sawtooth spillway, an intake capacity of 7.5 m³/s, and two sediment traps. Because flushing of the sediment trap was ineffective, the operator added a second drain gate downstream of the sediment trap; however, deposited sediment still required mechanical excavation.

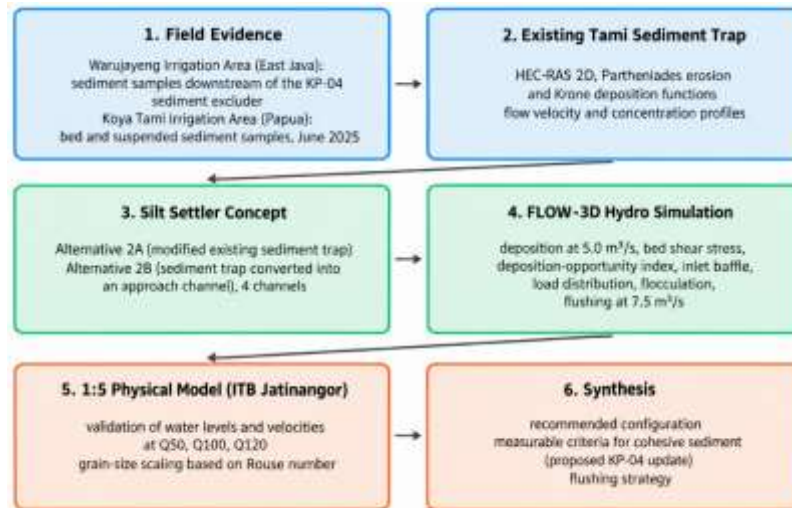


Figure 1. Research framework from field evidence to synthesis of planning criteria.

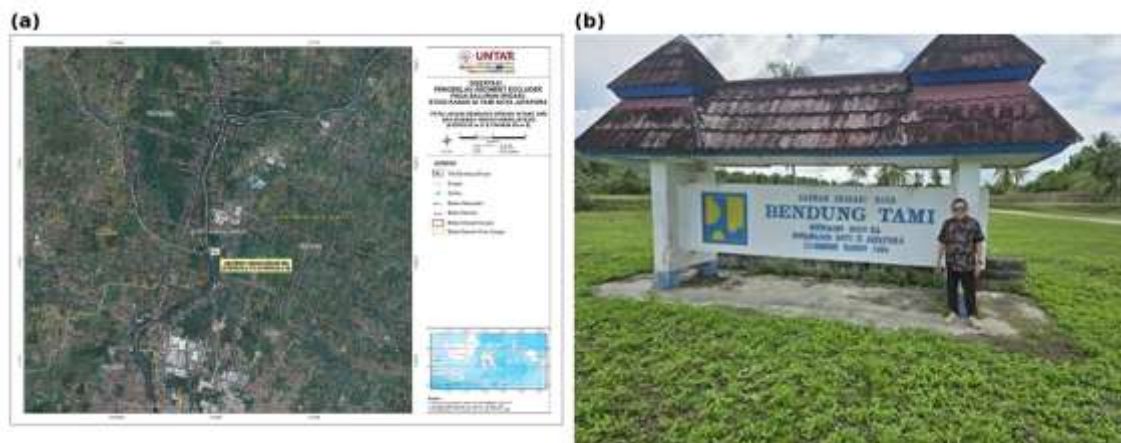


Figure 2. Research locations. (a) Location map of the Mrican Barrage, left-bank intake, and Warujayeng Irrigation Area (DI Warujayeng), Nganjuk Regency; (b) Tami Barrage, Koya Tami Irrigation Area (DI Koya Tami), Jayapura City.

B. Sediment Sampling and Analysis

In the Warujayeng irrigation scheme, two sediment samples were collected from the main canal downstream of the sediment excluder in June 2025. The sediment excluder was not visible in the field because it was located at the canal bottom, and according to the operator, flushing was conducted routinely every month. At Tami Weir, bed and suspended sediment samples were collected in June 2025 at three locations: the Tami River channel near the intake (L1), the sediment trap (L2), and the irrigation canal downstream of the sediment trap (L3), with two samples collected at each location. Grain-size grading was determined using sieve and hydrometer analyses, while

total suspended solids (TSS) were measured in water samples.

C. Two-Dimensional HEC-RAS Model of the Existing Sediment Trap

The performance of the existing Tami Weir sediment trap was analyzed using the two-dimensional sediment-transport module of HEC-RAS 6.6. The model domain was constructed using an irregular mesh with a size of 0.4 m in the main channel and 0.2 m near the walls. Manning coefficients ranged from 0.025 to 0.030. Cohesive-sediment erosion was calculated using the Partheniades function and deposition using the Krone method [5], [6], with a median diameter of 12 μm and a critical

erosion shear stress of 0.20 N/m². The initial bed-layer thickness was 1.5 m, while the

hydraulic and sediment time steps were 10 s and the simulation duration was 30 days. Hydraulic conditions were analyzed at discharges of 7.5 m³/s and 9.0 m³/s. The velocity and sediment-concentration distributions presented in Figure 4 use a discharge of 9.0 m³/s as the capacity test. Field TSS data at L1, the river near the intake, had an average value of 269.5 mg/L and were used as the main data for sediment-transport modeling. The sediment concentration specifically prescribed as the upstream boundary condition is not explicitly stated in the source data and is therefore not separately specified in the methodological description.

D. Silt Settler Concept and FLOW-3D Hydro Model

Two four-channel Silt Settler alternatives were developed, as shown in Figure 5. Alternative 2A modifies the existing sediment trap and main canal using a curved-to-straight flow path with a total length of 331.96 m. Alternative 2B converts the existing sediment trap into a conveyance channel and constructs a new straight Silt Settler with a length of 408–423 m. The central third channel was made deeper to provide deposition space, while a new flushing structure was placed downstream.

The simulations were performed using FLOW-3D Hydro with a three-dimensional RANS approach, the Volume of Fluid (VOF) method, and the RNG k- ϵ turbulence model [14]. The settling discharge was set at 5.0 m³/s with a sediment class of 0.03–0.0625 mm. The FLOW-3D sediment model uses a non-cohesive sediment approach with a single Shields threshold; therefore, cohesive-sediment behaviour was evaluated through post-processing [6]. Bed shear stress was calculated using $\tau_b = 0.7198 U^2$ and compared with the deposition threshold $\tau_d = 0.06$ N/m² and erosion threshold $\tau_e = 0.20$ N/m².

The deposition-opportunity index was defined as the fraction of sediment-transport exposure, $\int_{CUH} dx$, occurring at locations where $\tau_b < \tau_d$. The model was also used to evaluate the effect of the inlet baffle in Alternative 2A, surface loading, flocculation effectiveness, and flushing at a discharge of 7.5 m³/s using one gate and full-gate opening. Detailed formulations of the three-dimensional and flushing analyses are presented in companion manuscripts.

E. 1:5 Physical Model

An undistorted 1:5 physical model was constructed at the Water Structure and Irrigation Laboratory, ITB Jatiningor Campus, using Froude similarity. Because the flume was only 60 m long, the model represented 300 m of the upstream structure. Water levels were measured at 23 locations, consisting of the inlet, five points in each channel, and the outlet, for Q50, Q100, and Q120 discharges representing 2.5, 5.0, and 6.0 m³/s at the prototype scale. A total of 69 water-level observations were therefore obtained. Velocity was also measured at 23 locations. Model agreement was assessed using MAPE, RMSE, and PBIAS. Sediment scaling for transport testing was established based on Rouse-number similarity.

RESULTS AND DISCUSSION

A. Field Evidence: Fine Sediment Passing Through KP-02 and KP-04 Structures

The sediment found downstream of both structures was dominated by cohesive fractions, as shown in Figure 3 and Table 1. In the Warujayeng irrigation scheme, samples from the main canal downstream of the sediment excluder contained 75.01% silt and 20.97% clay in sample 1, and 74.59% silt and 21.79% clay in sample 2. Sand accounted for only 4.02% in sample 1 and 3.62% in sample 2, indicating that the sediment passing into the main canal consisted almost entirely of silt and clay fractions. Because upstream samples were not collected simultaneously, the efficiency of the sediment excluder could not be quantified.

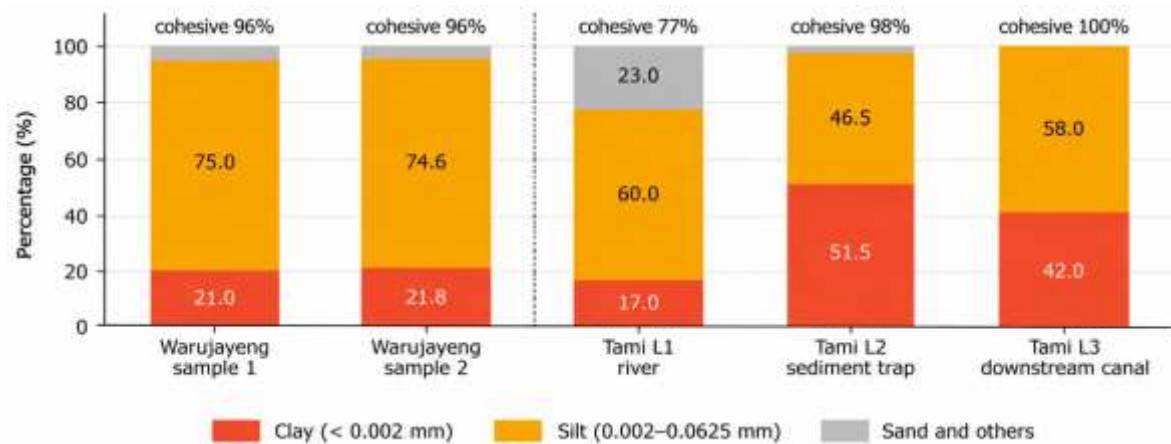


Figure 3. Sediment fraction composition downstream of the sediment excluder at the Warujayeng irrigation scheme and at three locations of Tami Weir.

At Tami Weir, cohesive fractions in bed sediment reached 77% in the river channel (L1), 98% in the sediment trap (L2), and 100% in the downstream canal (L3), with average TSS concentrations of 269.5, 130, and 133 mg/L, respectively. The increase in the cohesive fraction from the river toward the downstream canal indicates that the sediment

trap retained part of the sand but allowed silt and clay to pass downstream. A field inspection in April 2026 also found deposits extending to the second drain gate, with sediment management still relying on mechanical excavation.

Table 1. Sediment characteristics at the study locations

Location	Specific gravity (–)	Sand (%)	Silt (%)	Clay (%)	Cohesive fraction (%)	TSS (mg/L)
Warujayeng, sample 1	2.49	4.02	75.01	20.97	96.0	–
Warujayeng, sample 2	2.48	3.62	74.59	21.79	96.4	–
Tami L1, river channel near intake	2.462	23.0	60.0	17.0	77	269.5
Tami L2, sediment trap	2.346	2.0	46.5	51.5	98	130
Tami L3, downstream canal	2.430	0.0	58.0	42.0	100	133

This section contains the research results and their scientific analysis. The research findings presented must be scientific findings supported by adequate data. These findings are not simply a presentation of data, but rather a scientific explanation that includes: the findings obtained, the reasons for the phenomenon, and an explanation of the patterns or trends in the observed variables.

B. Performance of the Existing Sediment Trap at Tami Weir

The HEC-RAS 2D simulation showed a substantial reduction in flow velocity within the existing sediment trap, as presented in Figure 4a. At a discharge of 9 m³/s, the flow

velocity of approximately 0.8–1.0 m/s at the inlet decreased to below 0.2 m/s in the main pool and below 0.1 m/s at distances of 40–100 m. Relatively high velocities occurred mainly at the bend on the left side of the inlet. The simulation also showed that the water-surface elevation remained below the 44 m bank elevation, indicating that the flow remained within the structure cross-section.

Despite the reduction in flow velocity, the sediment concentration still indicated that fine sediment was transported toward the downstream section. The concentration in the upstream section ranged from 380–427 mg/L, decreasing to approximately 200–250 mg/L in the middle section and about 150 mg/L

downstream. The largest reduction occurred within the 40–100 m zone, which represented the main deposition zone. However, the remaining downstream concentration indicated that a portion of the fine sediment continued to pass into the main canal.

Sediment particles with a diameter of approximately 12 μm have a settling velocity of about 0.13 mm/s according to Stokes' law. This low settling velocity allows a substantial

portion of the fine particles to remain suspended while passing through the sediment trap. The modelling results are consistent with the field observations at Tami, where the cohesive fraction of bed sediment reached 77–100% and TSS concentrations ranged from 130–270 mg/L. Thus, although the existing sediment trap reduced sediment concentration, it did not prevent silt and clay fractions from entering the main canal.

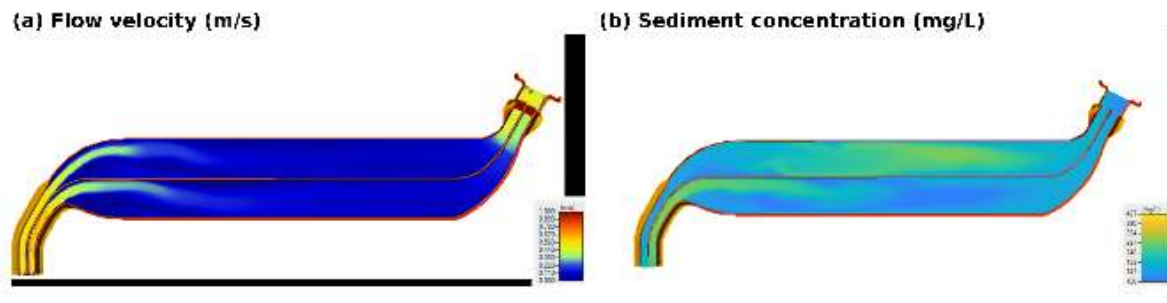


Figure 4. HEC-RAS 2D simulation results for the existing sediment trap at Tami Weir at a discharge of 9.0 m³/s: (a) flow velocity (m/s); (b) sediment concentration (mg/L).

C. Performance of the Silt Settler Concept Based on FLOW-3D

Two four-channel Silt Settler alternatives were developed to address the limitations of the existing sediment trap, as shown in Figure 5. Alternative 2A modifies the existing sediment trap with a curved flow path followed by a

straight section, whereas Alternative 2B converts the existing sediment trap into an approach channel and provides a new Silt Settler with a straight flow path. Both alternatives were analysed using FLOW-3D Hydro at a settling discharge of 5.0 m³/s, with deposition opportunity evaluated when the bed shear stress was below the cohesive-sediment deposition threshold of 0.06 N/m².

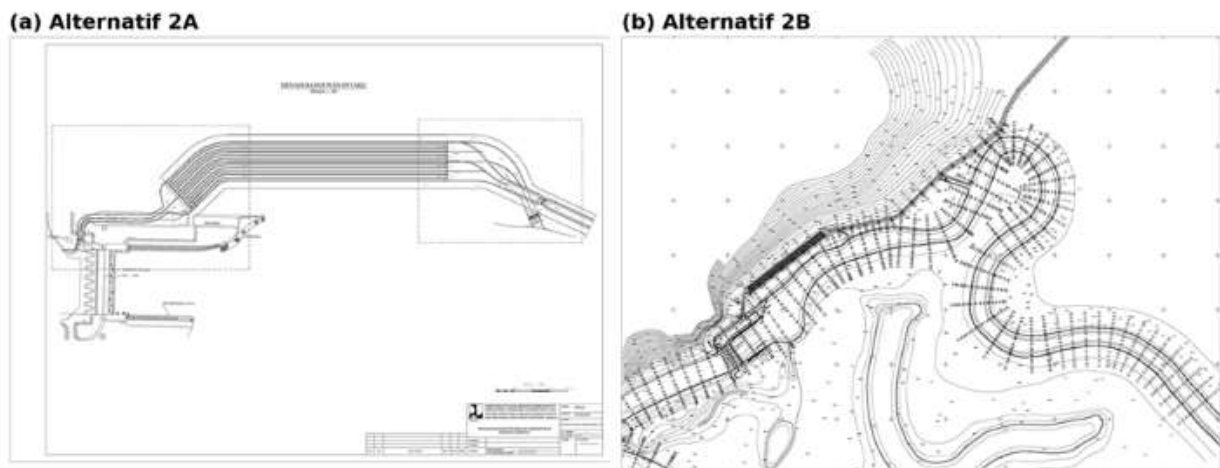


Figure 5. Silt Settler design concept at Tami Weir: (a) plan of Alternative 2A (modification of the existing sediment trap); (b) layout of Alternative 2B (existing sediment trap converted into an approach channel).

The simulation results showed that both alternatives, as originally designed, provided

very limited deposition opportunity, with deposition-opportunity indices of 0.48% for Alternative 2A and 0.02% for Alternative 2B. In Alternative 2A, Channels 1 and 4 exhibited the most favourable hydraulic conditions for deposition, with velocities of approximately 0.17–0.19 m/s and deposition-opportunity indices of 90.27% and 84.24%, respectively. However, these two channels received only about 0.6% of the sediment load because the incoming flow was concentrated in the central channels. This resulted in a theoretical performance ceiling of 87.26%. In contrast, Alternative 2B provided a more uniform load distribution, with a coefficient of variation of 0.211, but the shallower and faster flow conditions caused the bed shear stress in all four channels to remain above the deposition threshold, resulting in a performance ceiling of only 0.08%.

The three-dimensional results show that the differences in deposition opportunity between the two alternatives were associated with distinct flow and sediment-load distribution patterns. In Alternative 2A, the concentration of incoming flow in the central channels limited the sediment load reaching the outer channels, despite their favourable local hydraulic conditions. In Alternative 2B, the sediment load was distributed more uniformly; however, the flow conditions across the four channels remained unfavourable for deposition because bed shear stress exceeded the deposition threshold. Thus, the comparison indicates that a more uniform sediment-load distribution alone does not ensure effective deposition. The overall performance also depends on whether the flow conditions within

the settling channels allow cohesive particles to settle.

The main limitation of Alternative 2A was therefore the load distribution at the structure entrance, rather than the hydraulic condition within the channels. The addition of an inlet baffle reduced the coefficient of variation of load distribution from 1.474 to 0.297–0.331. Based on this load redistribution, the projected deposition-opportunity index increased to 56.4–58.0%. These values represent an upper-bound estimate, because the load shares under baffled conditions were obtained from the flushing simulation rather than from a baffled settling simulation at the 5.0 m³/s settling discharge.

Both alternatives still operated at surface loadings of 2.2–8.1 m/h, which exceeded the guideline range of 0.5–1.5 m/h. The minimum settling velocity required under these conditions ranged from 0.61–2.26 mm/s, whereas field sediment with a D₅₀ of approximately 12 µm had a settling velocity of only about 0.13 mm/s. This indicates that improving deposition opportunity cannot be achieved through flow redistribution alone and also requires a reduction in surface loading through a longer settling path or a lower unit discharge.

Flocculation also could not be relied upon to improve deposition under field conditions. The sediment concentrations required for effective flocculation were 599–1,530 mg/L for Alternative 2A and 660–4,800 mg/L for Alternative 2B, which were above the field sediment concentrations. Therefore, the Silt Settler design needs to rely on hydraulic conditions that support deposition, particularly lower bed shear stress, more uniform load distribution, and sufficient settling length.

Table 2. Summary of Silt Settler performance based on FLOW-3D Hydro at a settling discharge of 5.0 m³/s

Parameter	Alternative 2A	Alternative 2B	Baffled Alternative 2A
Settling path length (m)	331.96	408–423	331.96
Mean channel velocity (m/s)	0.17–0.59	0.32–0.51	–
Deposition-opportunity index, $\tau_d = 0.06$ N/m ² (%)	0.48	0.02	56.4–58.0*
Performance ceiling (%)	87.26	0.08	–

Load-distribution coefficient of variation (–)	1.474	0.211	0.297–0.331
Surface loading (m/h)	2.38–8.14	2.19–3.59	–
Concentration required for effective flocculation (mg/L)	599–1,530	660–4,800	–

D. Flushing

A flushing simulation of baffled Alternative 2A was conducted at a discharge of 7.5 m³/s to evaluate the ability of the structure to remove accumulated sediment. Two scenarios were compared: flushing using one gate and full-gate opening. Full-gate opening produced an outlet velocity of approximately 2–4 m/s, whereas the one-gate scenario produced 0.5–2 m/s. Despite the difference in outlet velocity, the flushed sediment masses were nearly identical, amounting to 246.2 tonnes for the one-gate scenario and 248.4 tonnes for full-gate opening, with the same maximum bed lowering of 0.117 m.

These results indicate that outlet velocity was not the primary limiting factor governing the amount of sediment removed under this configuration. The difference in flushed mass was only approximately 0.9%. The main advantage of full-gate opening was water-use efficiency [15], [16], [17]. Water consumption was 0.0505 m³/kg of sediment for full-gate opening compared with 0.0539 m³/kg for the one-gate scenario, corresponding to approximately 6.3% lower water use during the simulation period.

The sediment-transport pattern exhibited a characteristic depletion behaviour. Under the one-gate scenario, sediment transport began at 71 s and reached a peak rate of 2,012 kg/s at 96 s. Under full-gate opening, transport began at 110 s and reached a peak rate of 1,343 kg/s at 178 s. Half of the total flushed mass (T50) was reached at 178 s for the one-gate scenario and 234 s for full-gate opening, whereas 90% of the mass (T90) was reached at 342 s and 428 s, respectively. Thus, approximately seven minutes of flushing was sufficient to remove about 90% of the sediment mass that could be mobilized under both scenarios.

The four simulated sediment fractions were transported in relatively similar proportions, approximately 22.6–27.2% per fraction. This indicates that, within the simulated grain-size range, the flushing process did not produce measurable grain-size sorting at the outlet. Therefore, the flushing results primarily demonstrate the ability of the structure to deplete the stored sediment, while the difference in gate configuration mainly affected water consumption rather than the total mass of sediment removed.

Table 3. Summary of flushing mass balance for baffled Alternative 2A at a discharge of 7.5 m³/s

Parameter	One gate	Full-gate opening
Flushed mass (tonnes)	246.2	248.4
Water use (m ³ /kg sediment)	0.0539	0.0505
Transport onset / peak time (s)	71 / 96	110 / 178
Peak transport rate (kg/s)	2,012	1,343
T50 / T90 (s)	178 / 342	234 / 428
Maximum bed lowering (m)	0.117	0.117

E. Model Validation and Sediment Scaling

The FLOW-3D model was validated against a 1:5 physical model to evaluate the ability of the numerical model to reproduce the hydraulic conditions of the structure. Validation was conducted at 69 water-level measurement

points and 23 flow-velocity measurement points under Q50%, Q100%, and Q120% discharges of 2.5, 5.0, and 6.0 m³/s at prototype scale, respectively. The water-level results produced a MAPE of 6.43%, RMSE of 0.024 m, and PBIAS of –4.73%, whereas the flow-velocity results produced a MAPE of 12.50%,

RMSE of 0.044 m/s, and PBIAS of +8.59% based on magnitude.

These results indicate agreement between the numerical and physical models for the tested hydraulic parameters. In addition to the statistical measures, the recirculation patterns in the two edge channels were also reproduced by the numerical model. The simulation showed that half of the deposition occurred within the first 27–34 m, while 90% occurred within the first 82–109 m. With a 60 m physical model representing approximately 300 m of the prototype, the main working zone of the structure was therefore included within the tested model.

For the sediment experiment, the initially adopted sediment-diameter scaling relationship, $(n_d = n_L^{1/3})$, resulted in a model particle diameter of approximately 0.0067 mm and a model-to-prototype Rouse-number ratio of 0.018. Under this condition, the model produced almost no sediment deposition. In contrast, using the prototype

sediment diameter of 0.075 mm without scaling produced a Rouse-number ratio of 2.24 and tended to overestimate deposition. Based on Rouse-number similarity, a particle diameter of 0.050 mm with a relative density of 2.65 produced a ratio of approximately 1.00 and was therefore selected for the physical sediment test.

This scaling approach should be interpreted within the limitations of the physical model. The model can represent sediment fractions from coarse silt to very fine sand in the sediment-transport experiment. However, the field cohesive sediment with a D50 of approximately 12 μm is not directly represented by the physical model and is instead evaluated through deposition and erosion threshold analysis. Therefore, the current validation primarily supports the reliability of the hydraulic-field representation, while validation of cohesive-sediment transport in the physical model remains to be completed through further testing.

Table 4. Summary of FLOW-3D validation against the 1:5 physical model

Parameter	Number of data	MAPE (%)	RMSE	PBIAS (%)	Category
Water level	69	6.43	0.024 m	−4.73	Very good
Flow velocity	23	12.50	0.044 m/s	+8.59*	Good

To synthesize the evidence obtained from the different methods, Table 5 compares the key findings, interpretations, and limitations of laboratory sediment testing, HEC-RAS 2D

modelling, FLOW-3D Hydro simulations, and hydraulic validation using the 1:5 physical model.

Table 5. Comparative Matrix of Laboratory Testing, Numerical Modelling, and Physical Model Validation

Method	Key results	Main interpretation	Limitation
Laboratory sediment testing	Warujayeng samples contained 74.59–75.01% silt and 20.97–21.79% clay. At Tami, cohesive fractions reached 77–100%, while TSS concentrations were approximately 130–269.5 mg/L.	Fine and cohesive sediment is present downstream of the existing sediment-control structures.	The efficiency of the Warujayeng sediment excluder could not be quantified because simultaneous upstream samples were unavailable.
HEC-RAS 2D modelling	At a discharge of 9.0 m ³ /s, simulated sediment concentration decreased from 380–427 mg/L upstream to approximately 150 mg/L downstream.	The existing sediment trap reduces the simulated sediment concentration, but fine sediment continues to enter the main canal.	The results represent the existing structure and do not directly compare the proposed three-dimensional alternatives.

FLOW-3D Hydro 3D modelling	The deposition-opportunity indices were 0.48% for Alternative 2A and 0.02% for Alternative 2B. An inlet baffle produced a projected index of 56.4–58.0%.	The original alternatives provide limited deposition opportunity. Improving sediment-load distribution may substantially improve the potential for deposition.	The baffled result is an upper-bound projection and requires verification through a settling simulation at 5.0 m ³ /s.
Hydraulic validation using a 1:5 physical model	Water level: 69 measurement points, MAPE 6.43%, RMSE 0.024 m, and PBIAS –4.73%. Velocity: 23 measurement points, MAPE 12.50%, RMSE 0.044 m/s, and PBIAS +8.59%.	The numerical model shows agreement with the physical model for the tested hydraulic parameters.	Validation supports hydraulic representation; physical validation of cohesive-sediment transport remains incomplete.

F. Planning Implications: Proposed Criteria for Cohesive Sediment

The combined field evidence, numerical modelling, and physical-model validation indicate that the limitations of existing sediment-control structures are not solely a maintenance issue but are also related to planning criteria developed primarily for non-cohesive sediment. The FLOW-3D results show that geometric modification alone is insufficient to increase the deposition opportunity of cohesive sediment. Structures intended for cohesive sediment need to simultaneously provide sufficiently calm flow, uniform sediment-load distribution at the structure entrance, adequate settling length, and an efficient flushing pattern. Based on these findings, several measurable criteria are proposed as supplementary criteria for KP-04, as summarized in Table 5.

First, sediment characterization should form part of the planning basis. Grain-size analysis of bed and suspended sediment in the river, structure, and downstream canal should be conducted using sieve and hydrometer analyses, together with TSS measurements. The present study found cohesive fractions of 77–100% at Tami Weir and approximately 96% at the Warujayeng irrigation scheme. These findings indicate that identifying silt and clay fractions is necessary before determining the type and dimensions of sediment-control structures.

Second, surface loading needs to be controlled. The simulations showed that Alternatives 2A and 2B operated at surface loadings of 2.2–8.1

m/h, whereas the guideline for fine-sediment settling traps is 0.5–1.5 m/h. Field sediment with a D₅₀ of approximately 12 µm has a settling velocity of about 0.13 mm/s, which is substantially lower than the minimum settling velocity required under the simulated structural conditions, approximately 0.61–2.26 mm/s. Therefore, a longer settling path or a lower unit discharge is required to reduce surface loading.

Third, bed shear stress along the settling path should remain below the deposition threshold. The analysis used the Krone deposition threshold of approximately 0.06 N/m² as the basis for calculating the deposition-opportunity index. Under the initial configurations, the index was only 0.48% for Alternative 2A and 0.02% for Alternative 2B. This indicates that providing a settling area geometrically does not by itself guarantee deposition when the bed-shear condition remains unfavourable.

Fourth, sediment load should be distributed more uniformly among the channels. In Alternative 2A, the load-distribution coefficient of variation was 1.474, indicating a non-uniform distribution. Adding an inlet baffle reduced this value to 0.297–0.331 and produced a projected deposition-opportunity index of 56.4–58.0%. However, these values remain an upper-bound projection, because the load distribution was obtained from the flushing simulation and has not yet been verified through a baffled settling simulation at the 5.0 m³/s settling discharge.

Fifth, flushing criteria should consider both flushing discharge and duration. The simulation indicates that a flushing discharge

of approximately 150% of the settling discharge can be used as a reference for the investigated configuration, while the duration can be determined from T90. For the structure analysed, T90 ranged from 342–428 s, or approximately seven minutes. Full-gate opening produced a similar flushed mass to the one-gate configuration while using 6.3% less water.

Sixth, design verification should be conducted progressively using numerical and physical models. A three-dimensional model can be used with post-processing based on cohesive-sediment thresholds, followed by a physical model using Rouse-number similarity. In this study, hydraulic validation produced MAPE values of 6.43% for water level and 12.50% for flow velocity, while a model sediment diameter of 0.050 mm was selected based on Rouse-number similarity.

Table 5. Proposed measurable criteria for a cohesive-sediment Silt Settler as a basis for updating KP-04

Aspect	Proposed criterion	Basis from this study
Sediment characterization	Sieve and hydrometer analysis of bed and suspended sediment in the river, structure, and downstream canal, accompanied by TSS measurement	Cohesive fractions of 77–100% (Tami) and approximately 96% (Warujayeng) require hydrometer analysis to distinguish silt and clay
Surface loading	$q = U_h/Lq = U_h/L$ not greater than 0.5–1.5 m/h	Alternatives 2A and 2B operated at 2.2–8.1 m/h
Bed shear stress	$\tau_b/\tau_{b,c}$ below the deposition threshold of approximately 0.06 N/m ² along the settling path	Deposition-opportunity indices of 0.48% (2A) and 0.02% (2B)
Load distribution	Sediment load distributed uniformly among channels, for example using an inlet baffle	CV decreased from 1.474 to 0.297–0.331; projected index 56.4–58.0%
Flushing	Flushing discharge approximately 150% of settling discharge; duration determined from T90	Flushed mass 246–248 tonnes; T90 342–428 s; full-gate opening used 6.3% less water
Design verification	3D model with cohesive-threshold post-processing, followed by physical modelling using Rouse-number similarity	MAPE 6.43% and 12.50%; model sediment diameter 0.050 mm

These criteria should be interpreted together with the limitations of the study. The baffled configuration index remains an upper-bound projection; sediment-transport testing in the physical model has not yet been completed; the efficiency of the Warujayeng sediment excluder could not be quantified because simultaneous upstream sampling was unavailable; and upstream sediment-reduction measures, such as river normalization, groundsills, and check dams, were not quantitatively analysed. Therefore, a baffled simulation at the settling discharge and sediment testing in the physical model are still required before the final configuration is established.

CONCLUSION

Based on field evidence, laboratory testing, HEC-RAS 2D modelling, three-

dimensional modelling using FLOW-3D Hydro, and hydraulic validation against a 1:5 physical model, the following conclusions were obtained:

1. The KP-02 and KP-04 criteria are not adequate for cohesive sediment. Sediment downstream of the sediment excluder in the Warujayeng irrigation scheme contained 74.59–75.01% silt and 20.97–21.79% clay, while bed sediment at Tami Weir contained 77–100% cohesive fractions. Because simultaneous upstream samples were not available at Warujayeng, the efficiency of the sediment excluder could not be quantified.
2. The existing sediment trap at Tami Weir still allows fine sediment to enter the main

canal. The HEC-RAS 2D simulation showed that sediment concentration decreased from 380–427 mg/L upstream to approximately 150 mg/L downstream. Although the concentration was reduced, part of the fine sediment continued to be transported into the main canal, consistent with the field results showing cohesive fractions of 77–100% and TSS concentrations of 130–270 mg/L.

3. The initial performance of Silt Settler Alternatives 2A and 2B was limited in their unbaffled configurations. At a settling discharge of 5.0 m³/s, the deposition-opportunity indices were only 0.48% and 0.02%, respectively. Adding an inlet baffle to Alternative 2A improved load distribution and produced a projected deposition-opportunity index of 56.4–58.0%. This value represents an upper-bound projection and still requires verification through a baffled simulation at the settling discharge.
4. Flushing of baffled Alternative 2A removed nearly similar sediment masses under the two gate-opening scenarios. At a discharge of 7.5 m³/s, the flushed masses were 246.2 tonnes with one gate and 248.4 tonnes with full-gate opening. Approximately 90% of the flushed mass was removed within 342–428 s, while full-gate opening used 6.3% less water than the one-gate scenario.
5. The FLOW-3D model showed hydraulic agreement with the 1:5 physical model and provided a basis for cohesive-sediment planning criteria. Validation produced MAPE values of 6.43% for water level and 12.50% for flow velocity. Sediment scaling based on Rouse-number similarity resulted in a model particle diameter of 0.050 mm for sediment-transport testing. Measurable criteria concerning sediment characterization, surface loading, bed shear stress, load distribution, flushing, and design verification are proposed as a basis for updating KP-04.

ACKNOWLEDGEMENT

The authors gratefully acknowledge Balai Wilayah Sungai Papua for access to Tami Weir and field data, the management of the Warujayeng Irrigation Scheme for permission to conduct sediment sampling, the Water

Structures and Irrigation Laboratory, ITB Jatinangor Campus, for providing physical-model facilities, and Dazztech Solutions Sdn Bhd for support in the use of FLOW-3D.

REFERENCES

- [1] A. G. Pradipta *et al.*, “Mathematical Modeling-Based Management of a Sand Trap throughout Operational and Maintenance Periods (Case Study: Pengasih Irrigation Network, Indonesia),” *Water (Switzerland)*, vol. 14, no. 19, 2022, doi: 10.3390/w14193081.
- [2] A. G. Pradipta *et al.*, “Mapping the vulnerability of irrigation sand traps in a tropical volcanic basin, Indonesia,” *Sci. Rep.*, vol. 13, no. 1, pp. 1–17, 2023, doi: 10.1038/s41598-023-45036-z.
- [3] A. G. Pradipta, H. H. Loc, S. Nurhady, N. Murtinigrum, and S. S. Arif, “Managing Irrigation Sediment Barriers in a Tropical Volcanic Basin through Mathematical Model,” *ACS EST Water*, vol. 4, no. 9, pp. 3798–3815, 2024, doi: 10.1021/acsestwater.4c00116.
- [4] U. K. Singh, M. Jamei, M. Karbasi, A. Malik, and M. Pandey, “Application of a modern multi-level ensemble approach for the estimation of critical shear stress in cohesive sediment mixture,” *J. Hydrol.*, vol. 607, p. 127549, 2022, doi: <https://doi.org/10.1016/j.jhydrol.2022.127549>.
- [5] M. Stone *et al.*, “Deposition and erosion behaviour of cohesive sediments in the upper River Taw observatory, southwest UK: Implications for management and modelling,” *J. Hydrol.*, vol. 598, p. 126145, 2021, doi: <https://doi.org/10.1016/j.jhydrol.2021.126145>.
- [6] R. Maltauro, M. Stone, A. L. Collins, and B. G. Krishnappan, “Advancing mechanistic understanding of cohesive sediment transport: Integrating flume experiments, field measurements, and modelling approaches in a gravel-bed river,” *Sci. Total Environ.*, vol. 956, no. October, p. 177301, 2024, doi: 10.1016/j.scitotenv.2024.177301.

- [7] S. Defontaine, I. Jalon-Rojas, A. Sottolichio, N. Gratiot, and C. Legout, "Settling dynamics of cohesive sediments in a highly turbid tidal river," *Mar. Geol.*, vol. 457, p. 106995, 2023, doi: <https://doi.org/10.1016/j.margeo.2023.106995>.
- [8] L. Ye, J. A. Penaloza-Giraldo, A. J. Manning, J. Holyoke, and T. J. Hsu, "Biophysical flocculation reduces variability of cohesive sediment settling velocity," *Commun. Earth Environ.*, vol. 4, no. 1, pp. 1–9, 2023, doi: [10.1038/s43247-023-00801-w](https://doi.org/10.1038/s43247-023-00801-w).
- [9] G. Liu, Y. Wu, and J. Zhu, "Settling velocity of fine sediment in quiescent water with varying sediment concentration and salinity," *Front. Mar. Sci.*, vol. 12, no. January, pp. 1–22, 2026, doi: [10.3389/fmars.2025.1730670](https://doi.org/10.3389/fmars.2025.1730670).
- [10] W. Ali, A. Kirichek, and C. Chassagne, "Collective effects on the settling of clay flocs," *Appl. Clay Sci.*, vol. 254, p. 107399, 2024, doi: [10.1016/j.clay.2024.107399](https://doi.org/10.1016/j.clay.2024.107399).
- [11] Z. A. Gurmu, H. Ritzema, C. de Fraiture, and M. Ayana, "Hydrodynamic modelling to develop design and operational options for sedimentation reduction in irrigation schemes, Ethiopia," *J. Hydrol. Reg. Stud.*, vol. 53, no. June 2022, p. 101816, 2024, doi: [10.1016/j.ejrh.2024.101816](https://doi.org/10.1016/j.ejrh.2024.101816).
- [12] H. K. Kaharudin, A. P. Irawan, and W. A. Pranoto, "Deposition Potential of Cohesive Sediment in Modified Sand Trap Designs: A FLOW-3D Assessment with Inlet Baffles at Tami Weir, Papua, Indonesia," 2026.
- [13] H. K. Kaharudin, A. P. Irawan, and W. A. Pranoto, "Flushing Performance of a Baffled Silt Settler: Mass-Balance Comparison of Single-Gate and Full-Gate Operation Using FLOW-3D," 2026.
- [14] M. Z. Qamar, M. K. Verma, and A. P. Meshram, "Physical and numerical modelling for settling efficiency of desilting chamber," *ISH J. Hydraul. Eng.*, vol. 30, no. 3, pp. 372–382, 2024, doi: [10.1080/09715010.2024.2345338](https://doi.org/10.1080/09715010.2024.2345338).
- [15] Y. G. Lai, J. Huang, and B. P. Greimann, "Hydraulic Flushing of Sediment in Reservoirs: Best Practices of Numerical Modeling," *Fluids*, vol. 9, no. 2, pp. 1–30, 2024, doi: [10.3390/fluids9020038](https://doi.org/10.3390/fluids9020038).
- [16] C. B. Goulart, T. Bleninger, H. de Oliveira Fagundes, and F. M. Fan, "Modeling uncertainties of reservoir flushing simulations," *Int. J. Sediment Res.*, vol. 38, no. 5, pp. 698–710, 2023, doi: <https://doi.org/10.1016/j.ijsrc.2023.04.005>.
- [17] V. Dermawan, E. N. Cahya, M. N. Hidayat, and N. Sholawatini, "Operation of Flushing Gate on Sediment Flushing Efficiency: A Case Study of Alale Weir," *Media Komun. Tek. Sipil*, vol. 30, no. 1, pp. 126–134, 2024, doi: [10.14710/mkts.v30i1.60651](https://doi.org/10.14710/mkts.v30i1.60651).