

HEC-RAS MODELING OF SEASONAL IRRIGATION WATER SUPPLY RELIABILITY UNDER CANAL BLOCKING MANAGEMENT

Robi Sabhar¹, *Dinar Dwi Anugerah Putranto², Rosidawani³, Agus Lestari Yuono⁴, Riani Muharomah⁵

¹Doctoral Degree Program, Faculty of Engineering, Sriwijaya University, Indonesia
^{2,3,4,5}Department of Civil Engineering and Planning, Faculty of Engineering, Sriwijaya University

*Corresponding Author, Received: 17 July 2025, Revised: 22 Mar. 2026, Accepted: 26 Mar. 2026

ABSTRACT: The agricultural productivity of tidal swamp land in the Air Saleh Swamp Irrigation Area (DIR), Banyuasin Regency, South Sumatra Province, Indonesia is still sub-optimal. One of the causes is the lack of irrigation water supply in the 2nd and 3rd planting season. A significant effort to overcome this problem includes the construction of canal blocking that functions to maintain water level during high tide in channel and soil moisture on land used for rice growth. The construction of canal blocking is designed to maintain water level in channel and groundwater on agricultural land covering an area of 144 ha. Therefore, this research aimed to fulfill the availability of irrigation water using a combination of rainfall systems and canal blocking to improve agricultural land productivity. Canal blocking construction was made of coconut tree trunks, which were packed with sacks full of local soil to enhance structural solidity and reduce decomposition. On the outside, sacks were installed containing a mixture of sand and cement which functioned to withstand erosion by water flow. The construction of canal bulkhead was installed with 10-inch PVC pipes draining water into channel to regulate flow level during excessive rainfall. These trunks were used as the main construction material because of local availability, resistance to submersion in water, durability against shear and overturning forces. Furthermore, simulation and optimization of water management system were carried out by modeling using the HEC-RAS program. This allowed for analysis of water level during irrigation with sediment transport and accumulation when flushing and functioning as drainage.

Keywords: Canal blocking, Productivity, Water surface elevation, Sedimentation, HEC-RAS

1. INTRODUCTION

The Air Saleh Swamp Irrigation Area (DIR) in Banyuasin Regency, South Sumatra Province, Indonesia, is categorized as suboptimal land, facing limitations or constraints in terms of productivity. This land is classified as type C hydrotopography, which has not been flooded by high tide. The groundwater level is less than 50 cm and is dependent on rainwater as a source of irrigation water [1]. Generally, the rainy season occurs from October to April, while the dry season spans from May to September. In this context, the planting pattern that has been implemented at DIR is Rice-Rice rotation, with planting seasons carried out 2 times. Planting Season I (one) is carried out from October to January with agricultural productivity of 5 to 6 tons/ha. Meanwhile, Planting Season II (two) spans from March to June, and agricultural productivity of 2 to 3 tonnes/ha (Survey results, 2025), which is still sub-optimal. To address this limitation, the use of canal blocking has been proven effective. Horton [2] conducted an experiment for chili cultivation in Central Kalimantan Province, and produced 14-15 tonnes/ha, compared to when there was no construction. High production from water supply method through canal blocking has increased chili cultivation by expanding cultivated land through the conversion of oil palm land into food

crops or horticultural cultivation land, which is more productive [3].

The strategy to increase rice production on sub-optimal land should be a government priority in providing and socializing the appropriate technology during cultivation. The government also needs to maintain the availability of New Superior Variety (VUB) seeds, fertilizers, and agricultural machinery (in Indonesia the same as Alsintan, Beginning, 2023). As a new strategy, construction of canal blocking has a good effect on maintaining groundwater level and keeping the land in wet or humid conditions. When water level is raised to 0.6 m, the wet effect can extend to 200 m perpendicular to canal [4].

Several canal blocking structure technologies have been built in various areas that have sub-optimal land conditions. However, many experienced construction failures due to the use of less suitable materials. Stability of canal bulkhead structure with a span of 5 meters and construction materials that are resistant to safe shear and overturning forces are required. This is because seepage in the downstream part of canal bulkhead will still occur, causing an increase in water level at upstream part and flow time [5]. A previous research had shown that a greater speed of water flow in channel with increasing time correlated with a higher value of erosion depth [6]. Therefore, the use of local fill soil with a permeability value of <0.125

cm/hour was recommended as an embankment body [7].

In an experiment conducted by Ade et al [8], using a hydraulic simulation process with the HEC-RAS model showed that the average water level was able to exceed the land elevation. However, it was not optimal, as the average height of the inundation was only 0.001 m or 1 mm [9]. From previous research, the results of hydraulic simulations showed that operational losses contributed a significant volume compared to seepage losses in physical infrastructure and management using operator-based and non-automatic control structures [10]. In most of the operating scenarios, the maximum seepage losses was 10%, and the remaining 90% was related to operations. This showed that fluctuation in inflow to canal caused an increase or decrease in operational losses, serving as a determining factor in affecting the total losses.

Controlling water level at the tertiary stage by farmers is essential for successful irrigation systems. To achieve this, a flap gate type is developed, operating predominantly as drainage during rice growth. The model also supplies water when plant enters the generative phase, achieving an average rice production of 7.5 t/ha. This condition shows that with proper water management, balanced fertilizer application, and adaptive rice varieties, cultivation in tidal lowland areas is successful and prevents land shifts [11]. To perform flushing, installing a pump in the middle intake can increase water circulation in canal with a one-way outflow during low tide. Although the inflow depends on the closing gate when in the same position, the volume of rainwater can be discharged for each rainy day [12].

Under existing conditions and network expansion with narrow intake channel, the duration of rainwater deficit tends to be shorter. Therefore, the leaching and drainage aspects require more water storage and wide intake channel. In comparison, flushing criteria require the use of pumps and gates [13]. To maintain the condition of water in each plot of land and tertiary channel, maximum operation of automatic water gate is required. Furthermore, to prevent oxidation of pyrite layer, water level must be above the base elevation [14].

2. RESEARCH SIGNIFICANCE

Effective flow management strategies are required to improve system efficiency and reduce operational losses by optimizing water level regulation and canal bulkhead operations. Adequate water storage infrastructure is essential to capture surplus supply during periods of low demand and retain it for use during shortages.. The developed model is designed to estimate water surpluses and deficits relative to demand, enabling strategic storage and redistribution during peak requirements.

Reliable storage is particularly important for farmers under dry or water-scarce conditions. Rainfed rice cultivation commonly faces water and nutrient limitations, highlighting the need for improved management technologies to support stable and sustainable agricultural productivity.

3. METHODOLOGY

3.1 Research Location

The research location was situated at coordinates Longitude 104° 54' 39" – 105° 00' 45" East longitude and between Latitude 2° 41' 42" – 2° 43' 11" South latitude (Fig.1). Specifically, the research was performed in Air Saleh Village, Telang District, Banyuasin Regency, South Sumatra Province, Indonesia. To reach the location, the river route is used through a speedboat from Kuto Besak Pier, Palembang City for approximately 2 hours.

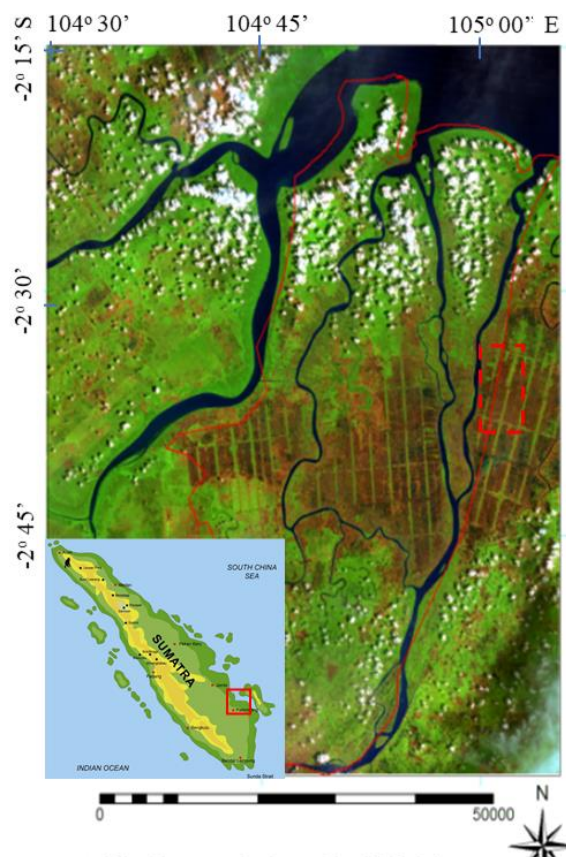


Fig.1 3-4-2 Band combination Landsat image, DIR Air Saleh research location

3.2 Data

3.2.1 Water Level Data (AWLR)

Water level observations were carried out using an AWLR (Automatic Water Level Recorder) device at 8 points. Measurement data were taken from 2 types of water level measured at the same

time. These include groundwater (TMAT), representing the height of water in the ground, and channel water level (TMAS) which is the height of water in channel.

3.2.2 Soil Investigation (Hand Drill and Sondir)

Soil investigation aims to evaluate the condition of soil layer at the research location and determine the depth of hard type. The analysis is carried out to obtain soil parameter data for calculations in planning of canal blocking structure. Sondir testing refers to SNI 2827: 2008 (Indonesian National Standard) to obtain parameters of soil layer penetration resistance in the field using a quasi-static penetration sondir tool. These parameters are cone resistance C_w (q_c), shear resistance T_w (f_s), shear ratio (R_f), and total soil shear (T_f), which are used for the interpretation of soil layers as part of the design of canal blocking structure foundation. Meanwhile, hand boring testing refers to SNI 4148-1: 2017 (standard for sampling fine-grained soil with thin-walled tubes for geotechnical purposes). The purpose of hand boring testing is to determine soil layer and take samples of disturbed and undisturbed soil for testing physical and engineering properties in the laboratory.

3.2.3 Rain Data

Rain data were taken from the website: POWER DAV: <https://power.larc.nasa.gov/data-access-viewer/> National Aeronautics and Space Administration (NASA), with a time interval of 20 years, namely between January 1, 2005, to December 31, 2024. These data included estimates of long-term climatological averages, meteorological quantities, and surface solar energy fluctuations

3.2.4 Canal Blocking

Canal blocking functions to maintain water level when the tide is high in channel and soil moisture in the land needed for rice plant growth. The location of canal blocking structure as shown in Fig. 2 is on the Main Drainage Channel (SDU-3U) which is +/- 20 m from the Tertiary-1U channel.

Canal blocking construction was made of coconut tree trunks, which were selected as the main material due to availability, resistance to water immersion, strength against shear and overturning forces, and easy workability. The inner filling material of canal blocking was in the form of sacks filled with local soil to achieve solid structure and reduce decomposition. For the outer side, sacks containing a mixture of sand and cement (1: 4) were installed to withstand erosion by water flow (see Fig.3a).

As shown in Fig. 3a, the width of canal blocking was 12 m with a height of 2.80 m from the bottom of channel. At the beginning to end of the width, 15-10 inch PVC pipes were installed to allow water to

enter channel (Fig. 3c). The pipes also serve as a water retention boundary in the rice plant root zone and drainage when there is excess water during high rainfall.

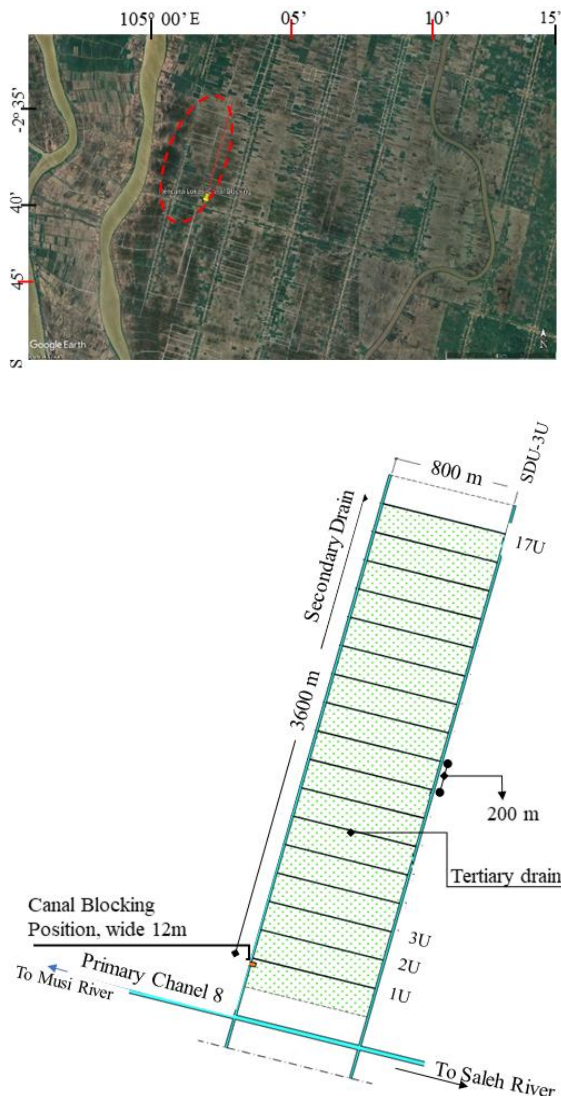


Fig. 2 Installation site for Canal Bulkhead building

The installation of pipes was arranged into 2 rows with different heights (Fig. 3c), namely :

- a. The outer part of canal blocking (the beginning of the incoming tide)
 - (1) The first row of PVC pipes height is set based on the lowest tide level. This allows for high tide to enter, which is + 60 cm from the bottom of channel.
 - (2) The second row is installed at a height of 153 cm from the bottom of channel which is useful for dividing water pressure load when the tide is high on canal blocking structure.
- b. The inner part of canal blocking (the high tide enters the secondary channel)

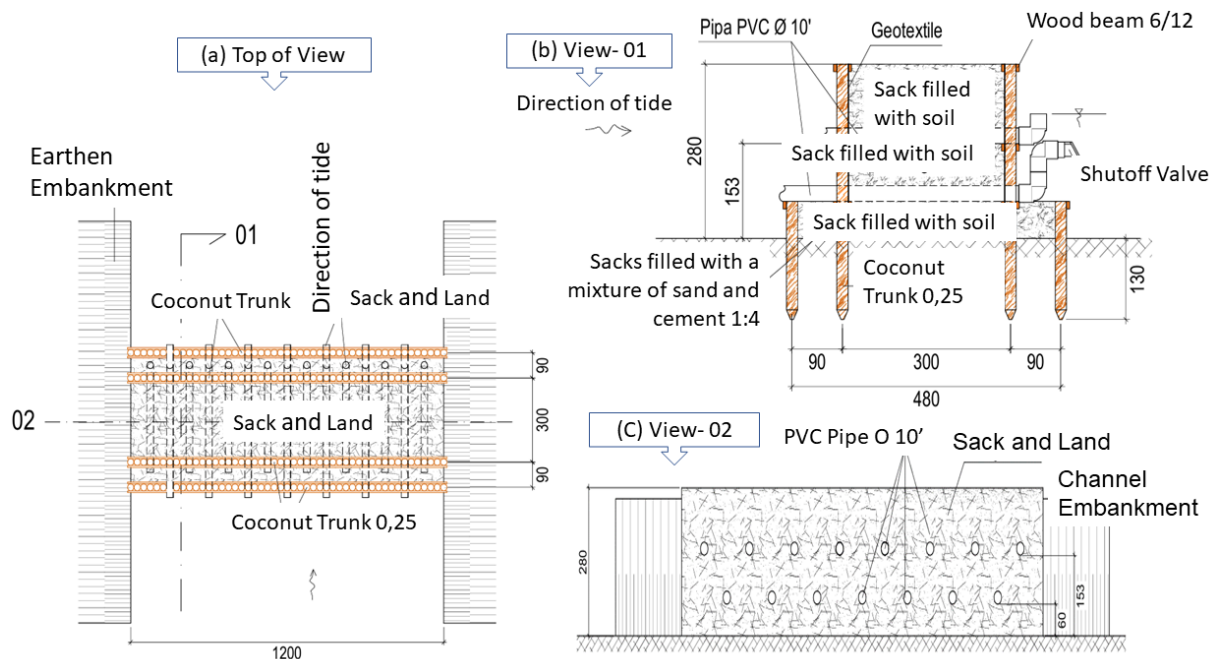


Fig. 3 Canal blocking plan: (a) Top view of canal blocking position;(b) Front view-01, construction of blocking canal;(c) Front view-02, PVC pipe placement

- (1) On the first row, 2, 10-inch L-Bows (Fig. 3b) are connected and 10-inch PVC pipes are installed, equipped with valves useful for closing when the tide is low.
- (2) On the second row (Fig 3b), 10-inch L-Bows (swan model) are connected with a height measured based on the root zone of the rice plant. These L-Bows function to retain water on the land needed for the growth of the rice plant, which is -50 cm from the land elevation.

3.3 Implementation Method

Modeling with the HEC-RAS Program [15] is carried out through 2 stages with 3 trial scenarios or implementations, namely:

3.3.1 Stage 1 (existing condition/baseline):

Scenario 1:

- (1) Unsteady Flow Type
- (2) Boundary Condition:
 - a. flow hydrograph (El Nino/dry season)
 - b. stage hydrograph (observation of tidal height)
- (3) Analysis results:
 - a. Water level elevation in channel
 - b. Water level elevation on land
 - c. Groundwater level elevation

Scenario 2:

- (1) Unsteady Flow Type
- (2) Boundary Condition:
 - a. flow hydrograph (La Nina/rainy season)
 - b. stage hydrograph (observation of tidal height)

- (3) Analysis results:
 - a. Water level elevation in channel
 - b. Water level elevation on land
 - c. Groundwater level elevation

Scenario 3 :

- (1) Unsteady Flow Type
- (2) Boundary Condition :
 - a. flow hydrograph (Normal Condition)
 - b. stage hydrograph (observation of tidal height)
- (4) Analysis results :
 - a. Water level elevation in channel
 - b. Water level elevation on land
 - c. Groundwater level elevation

3.3.2 Stage 2 (installation of canal blocking)

Scenario 1:

- (1) Unsteady Flow Type
- (2) Simulation with the installation of canal blocking structure
- (3) Boundary Condition:
 - a. flow hydrograph (El Nino/dry season)
 - b. stage hydrograph (observation of tidal height)
- (4) Analysis results:
 - a. Water level elevation in channel
 - b. Water level elevation on land
 - c. Groundwater level elevation

Scenario 2:

- (1) Unsteady Flow Type
- (2) Simulation of Canal Blocking Structure
- (3) Boundary Condition:
 - a. flow hydrograph (La Nina/rainy season)
 - b. stage hydrograph (observation of tidal height)

Table 1. Maximum rainfall return period

P(x >= Xm) Probability	T Repeat Period	Rainfall Characteristics (mm) according to Probability							
		Normal		Log-Normal		Gumbel		Log-Person III	
		X _T	K _T	X _T	K _T	X _T	K _T	X _T	K _T
0,9	1,1	40,926	-1,282	47,933	-0,987	45,239	-1,100	50,950	-1,063
0,5	2,	71,423	0,000	68,536	-0,121	67,513	-0,164	64,686	-0,207
0,2	5,	91,450	0,842	86,676	0,641	88,543	0,719	83,616	0,713
0,1	10,	101,919	1,282	97,996	1,117	102,466	1,305	99,318	1,330
0,05	20,	110,564	1,645	108,450	1,556	115,822	1,866	117,000	1,917
0,02	50,	120,294	2,054	121,556	2,107	133,110	2,592	144,285	2,668
0,01	100,	126,781	2,326	131,162	2,510	146,064	3,137	168,549	3,225
0,001	1.000,	144,959	3,090	162,320	3,820	188,870	4,936	279,968	5,044

X_T = Annual rainfall plan; K_T = Frequency factor

(4) Analysis results:

- a. Water level elevation in channel
- b. Water level elevation on land
- c. Groundwater level elevation

Scenario 3:

- (1) Unsteady Flow Type
- (2) Canal Blocking Building Simulation
- (3) Boundary Condition:
 - a. flow hydrograph (Normal Condition
 - b. stage hydrograph (observation of tidal height)
- (4) Analysis results:
 - a. Water level elevation in channel
 - b. Water level elevation on land
 - c. Groundwater level elevation

4. RESULT AND DISCUSSION

4.1 Rainfall Frequency Analysis

Rainfall frequency analysis was carried out using four methods namely Log Normal Distribution, Log Pearson III Distribution and Gumbel Distribution to predict the probability of rain with a certain intensity in a period of time (Table 1).

The results of the Chi-Square test showed that the best distribution was using Log Pearson III (Table 2), with a Chi-Critical value = 3.841 and a Chi-Square value of 1,500.

Table 2. Chi-Square test CH maximum

Class	P(x >= Xm)	Ef	R (mm)	Of	Ef - Of	(Ef-Of) ² / Ef	
5	0,200	0 < P <= 0,2	4,000	83,616	3,000	1,000	0,250
	0,400	0,2 < P <= 0,4	4,000	69,232	6,000	2,000	1,000
	0,600	0,4 < P <= 0,6	4,000	60,888	4,000	0,000	0,000
	0,800	0,6 < P <= 0,8	4,000	54,316	3,000	1,000	0,250
	0,999	0,8 < P <= 0,995	4,000	45,135	4,000	0,000	0,000
			20,000		20,000	Chi-Square	1,500
					DF =	1	
					Chi-Critical =	3,841	

R= Rainfall; Ef= frequency according to class division; Of= Distribution Frequency; DF= Degrees of Freedom

4.2 Nakayasu Method Unit Hydrograph

This research uses the Nakayatsu unit hydrograph with the dimensions of SCS (Soil Conservation Service) [16].

4.3 Hourly Rainfall Calculation

The calculation of rainfall intensity uses the Mononobe method [17], with return periods of 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years as well as duration ranging from 5 minutes to 360 minutes, as shown in Table 3.

Table 3. Hourly rainfall count

T (hour)	1	2	3	4	5	6
Distribusi (%)	0,550	0,143	0,100	0,080	0,067	0,059
R2	42,936	23,615	6,142	4,308	3,430	2,896
R5	52,051	28,628	7,445	5,223	4,158	3,511
R10	56,896	31,293	8,138	5,709	4,545	3,838
R20	60,887	33,488	8,709	6,109	4,864	4,107
R50	65,326	35,929	9,344	6,555	5,218	4,407
R100	68,234	37,529	9,760	6,847	5,451	4,603

When the peak discharge (Qp) and the delay time for an effective rainfall duration are known, the unit hydrograph can be estimated (Fig. 4). The parameters used to calculate the Nakayasu designed hydrograph are:

- Watershed Area : 3.04 Km²
- Channel Length (L) : 3.8 Km
- Concentration Time (tc) : 0.729
- Nakayasu Coefficient (α) : 1.362
- Flow coefficient : 0.45

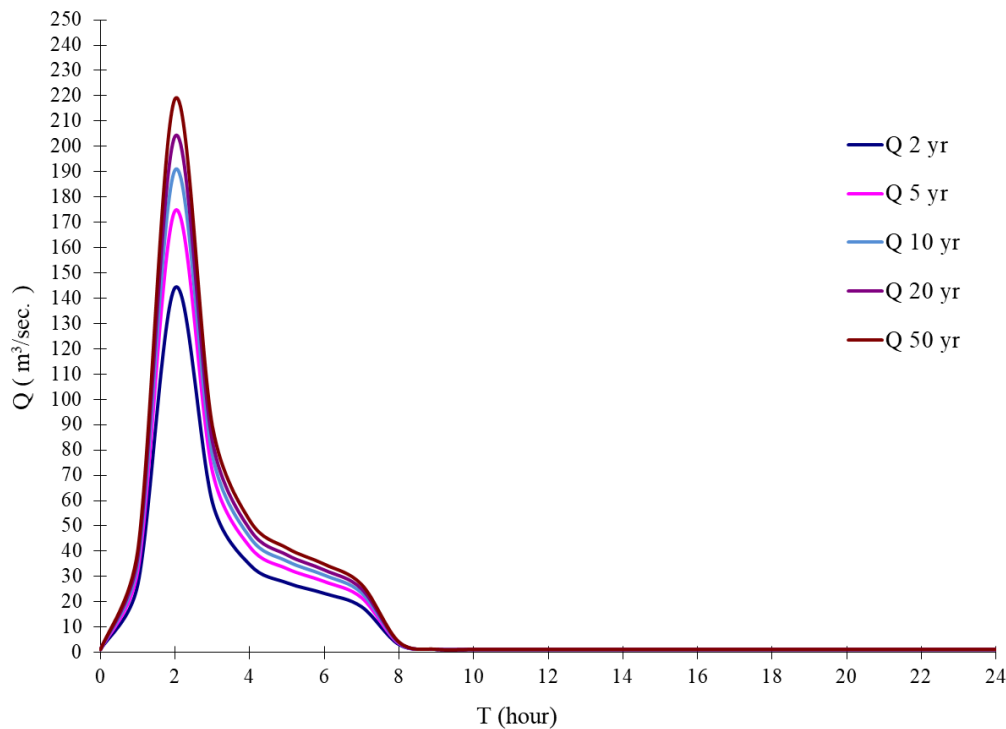


Fig. 4 Flood discharge hydrograph using the Nakayasu method

4.4 Analysis of Canal Blocking Modeling

Coconut (*Cocos Nucifera*) is the only member of the *Cocos* genus from palm family or *Arecaceae*. This tree grows in coastal areas and lowlands, with heights ranging from 15 m to 30 m, and trunk diameter of 0.25 m to 0.40 m. The part of the coconut tree trunk that can be used for construction wood (strength class I to IV) is the tip from the base to $\frac{3}{4}$ of the length and the top from the base to half the length. In this research, the type of coconut tree trunk used for canal blocking structure is arranged with the following provisions:

- (1) Channel functions as a navigation path with low to medium usage level.
- (2) Canal acts as a barrier downstream of channel where the upstream uses a backfilling compacted peat dam in adaptive and protected areas.
- (3) Canal blocking is constructed on channel with a width of > 10 m and a length of 8 m to 50 m.
- (4) One end of the coconut pole that will be stuck vertically (hereinafter referred to as the coconut pole tie) is sharpened using an axe. The number and size of the coconut pole ties are made wide at 8 m and the depth of the mineral soil.
- (5) The pile driving process takes place until the coconut pole reaches the required depth 2-4 m (mineral soil or the wood can no longer be moved).

- (6) The coconut poles that have been installed are connected to the transverse coconut poles (horizontal) using bolts, nuts, and large washers measuring 0.25" x 35-45 cm.
- (7) After the wooden construction is ready or finished, the installation of a layer of non-waterproof fabric or geotextile is continued.

The evaluation of canal bulkhead design is carried out to assess whether each part is functioning appropriately, and provide suggestions for improvements. The methods used to evaluate the design of each part are as follows:

4.4.1 Bulkhead subsidence

The method used to evaluate the design of the coconut tree trunk bulkhead is to measure the subsidence and deformation using waterpass as well as visual observations of installed trunk. Measurement of structural subsidence is carried out by comparing the elevation of the structure after completion and during construction. A major impact of structural subsidence is deformation, which refers to change in shape due to internal or external forces. Based on the results of observations after the installation of the canal divider (January-June, 2025) based on re-measurement of the height of the coconut trunk, using a waterpass, there was a difference in elevation of -2.13 cm.

4.4.2 Maintaining Groundwater/Pool Water Level

Installation of PVC pipes on canal blocking with a 2-row system is effective in reducing water flow during low tide. This maintains fresh water from rain in rice fields and increases water level in the upstream part of canal divider. The change in water level during January–July, 2025, near the canal divider was 0.36–0.48 m. Compared to a distance of approximately 1000 m from the canal divider, it was 0.10–0.12 m.

4.4.3 Reducing flood height or seepage

A strong and precise canal blocking installation system can prevent flooding during high tides and rainfall. Additionally, it is capable of maintaining humidity or water availability for irrigation during the dry season, enabling the achievement of 3 seasons, with a rice-rice-planting pattern. The groundwater level in April–July was approximately 0.32–0.14 m only in the area near the canal, which constitutes approximately ¼ of the observation area.

4.4.4 Reducing sedimentation in channel

Installation of canal blocking on secondary channel with long inundation times can cause anaerobic conditions in channel and potentially lead to shallowing or sedimentation, thereby reducing long-term inundation.

4.5 HEC-RAS Modeling and Analysis

4.5.1 1st Scenario

A canal blocking structure was installed in the drainage channel at a distance of 20 meters from the tertiary channel, with a width of 12 meters. The boundary condition for the model was defined as an unsteady flow input, with the following parameters:

- (1) A 10-year return period flow hydrograph (Q₁₀) for the dry season was assigned as the upstream boundary condition for the secondary channel.
- (2) A stage hydrograph (representing 24-hour observed tidal fluctuation data) was assigned as the downstream boundary condition for the secondary channel, as shown in (Fig. 5).

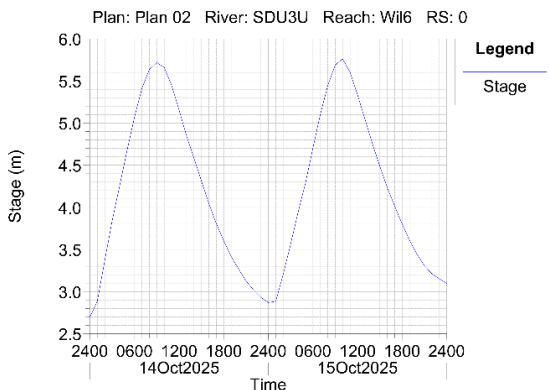


Fig. 5 Recorded Tidal Levels from an Automatic

Water Level Recorder (AWLR)

Analysis Result

The results of the runoff analysis using the HEC-RAS model at the reviewed point STA 3+341 show that the water surface elevation in the secondary and tertiary channels is +4.570 m, while the ground elevation is at +5.05 m. Consequently, the water flow does not inundate the agricultural land (remaining -0.48 m below the paddy field level), as illustrated in (Fig.6-7) below.

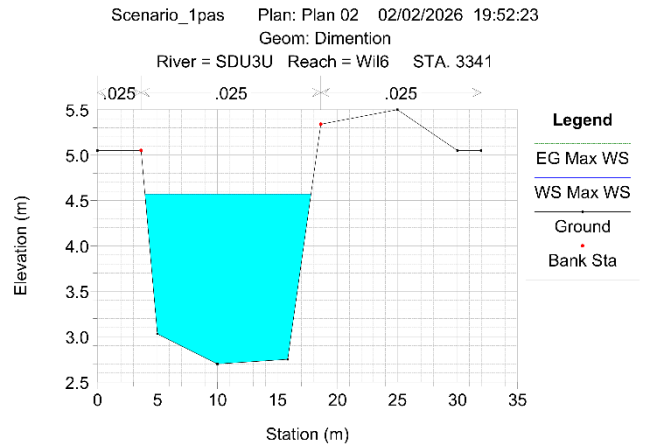


Fig. 6 Water Surface Elevation in the Secondary Channel

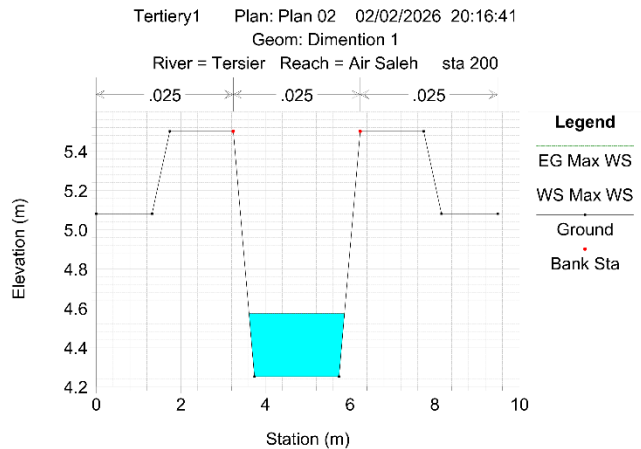


Fig. 7 Water Surface Elevation in the Tertiary Channel

4.5.2 2nd Scenario

Existing Conditions

The boundary conditions were defined using an unsteady flow input, as follows:

- (1) A 10-year return period flow hydrograph (Q₁₀) for the rainy season was applied as the upstream boundary condition of the secondary channel.
- (2) A stage hydrograph, derived from 24-hour observed tidal data, was applied as the downstream boundary condition of the secondary channel.

Analysis Result

The results of the HEC-RAS modeling simulation at the reviewed point STA 3+341 indicate a water surface elevation of +5.28 m in the secondary and tertiary channels. Since the ground elevation is +5.05 m, the water overflows onto the land, inundating the paddy field area to a depth of +0.23 m, as shown in (Fig. 8-9) below.

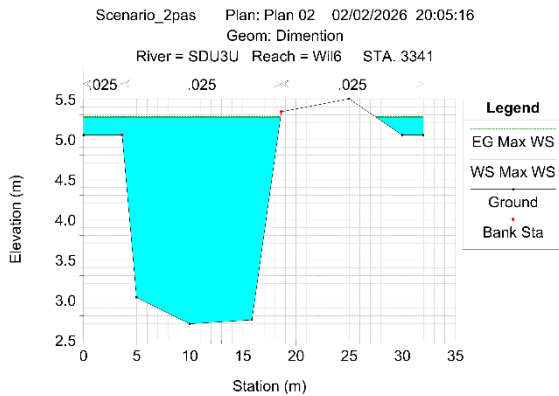


Fig. 8 Water Surface Elevation in the Secondary Channel

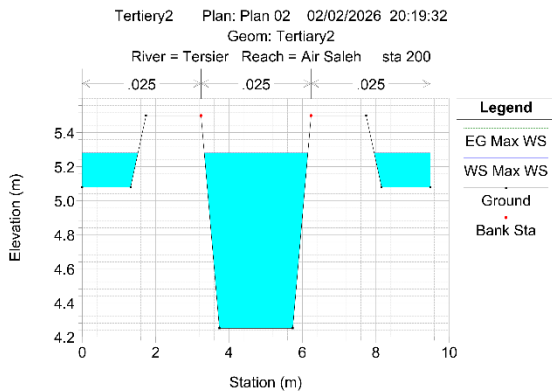


Fig. 9 Water Surface Elevation in the Tertiary Channel

4.5.3 3rd Scenario

Existing Conditions:

The boundary conditions were defined using an unsteady flow input, as follows:

- (1) A 10-year return period flow hydrograph (Q10) for normal rainfall conditions was applied as the upstream boundary condition of the secondary channel.
- (2) A stage hydrograph, representing 24-hour observed tidal data, was implemented as the downstream boundary condition for the secondary channel.

Analysis Result

The HEC-RAS modeling results at the reviewed station STA 3+341 show that the water surface

elevation in the secondary and tertiary channels reaches +4.91 m, while the ground elevation is at +5.05 m. Consequently, the water flow does not overflow into the agricultural land, remaining 0.14 m below the paddy field level, as shown in (Fig. 10-11) below.

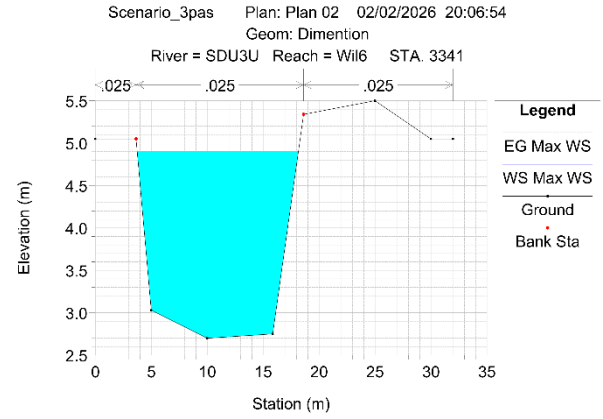


Fig. 10 Water Surface Elevation in the Secondary Channel

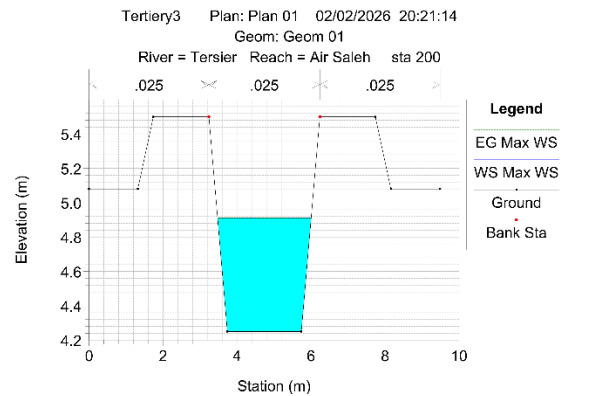


Fig. 11 Water Surface Elevation in the Tertiary Channel

5. CONCLUSIONS

In conclusion, this research explored the potential of irrigation water using a combination of rainfall systems and canal blocking to improve agricultural land productivity. The results obtained were as follows:

- (1) Installation of canal blocking on secondary channel in tidal swamp irrigation areas had a positive impact on increasing agricultural land productivity. Planting and harvesting seasons can be done 3 times a year with rice-rice-rice crops.
- (2) Proper installation of canal blocking affected the height of water level in channel, land, and groundwater. Effectively, during the second and third planting seasons, groundwater levels can

be reached at an average of 0.3–0.12 m. Others are assisted by pumps to raise the water.

- (3) Long inundation due to the construction caused excessive shallowing/sediment in channel. On average, shallowing will occur as high as 0.12 – 0.22 m.
- (4) Construction of canal blocking on channel with coconut tree trunks had a stronger bearing capacity with a geotextile blanket on the outside to reduce seepage. Average decline, about 0.022 m for a period of about 6 months.

6. ACKNOWLEDGMENTS

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7. REFERENCES

- [1] Imron M.A, Rachmawati F.D., Dewi T., Albihad D., Simanullang G.M.I., Poor E.E, Effect of canal blocking on biodiversity of degraded peatlands: Insight from West Kalimantan, *Journal Plos ONE*,pp.1-12,Oct.2025.
<https://DOI.org/10.1371/journal.pone.0334014>
- [2] Horton A.J., Lehtinen J., and Kumm. M., Targeted Land Management Strategies Could Halve Peatland Fire Occurrences in Central Kalimantan, Indonesia, *Commun. Earth Environ.*, vol. 3, no. 1, pp. 204, 2022, DOI: 10.1038/s43247-022-00534-2..
- [3] Singh G.A., Singh J., Wani O.A., Egbueri J.C., Agbasi J.C., Assessment of groundwater suitability for sustainable irrigation: A comprehensive study using indexical, statistical, and machine learning approaches, *Groundwater for Sustainable Development*, Volume 24, February 2024, pp 87-95.
<https://DOI.org/10.1016/j.gsd.2023.101059>.
- [4] Siddharam A.L, Gaddikeri V., Jatav M.S., Dimple & Rajput J., Canal Automation and Management System to Improve Water Use Efficiency, *Recent Advancements in Sustainable Agricultural Practices, Harnessing Technology for Water Resources, Irrigation and Environmental Management*, Springer Nature, 2024. pp. 267–282.
- [5] Fan X., Hu X., Yakun W., Chen D., Deep storage irrigation can recharge farmland deep soil moisture and sustain production of summer maize (L.) through flood resources utilization in irrigation districts of northern China, *Journal of Integrative Agriculture* 25(3):1243-1262, March 2026.
DOI:10.1016/j.jia.2025.07.013
- [6] Fraehr N., Wang Q.J, Wu W., and Nathan R., “Supercharging hydrodynamic inundation models for instant flood insight,” *Nat. Water*, vol. 1, no. 10, pp. 835–843, 2023, DOI: 10.1038/s44221-023-00132-2.
- [7] Saad F.I.A., Hassab Y., Teama Z., and Aldahwi S., “Soil Retention Tests For Determining Dispersion Of Clayey Soils” *International Journal of GEOMATE*, Vol. 22, no. 93, pp. 60-66, 2022, DOI: 10.21660/2022.93.3054.
- [8] Miranda A.T., Putranto D.D.A, Taufik A.G, Flood and Inundation Risk Analysis Due To Potential Land Subsidence on Alluvial Plains, *International Journal of GEOMATE*, Vol.28, no. 128, pp. 92-99, 2025, DOI. 10.21660/2025.128.g14224
- [9] Sahdar I, Rohmat D, Pranoto W.A, and Solehudin, Hydraulic Modeling for Flood Control Scenarios in Akelaka Watershed, North Maluku, Indonesia, *International Journal of GEOMATE*, vol. 27, no. 120, pp. 49–59, 2024, DOI: 10.21660/2024.120.4450.
- [10] Pinit. T, Xiao X., Uba S and Seeboonruang U, Managed Aquifer Recharge Feasibility Using Weight Factor Index Method in Suphanburi, Thailand, *International Journal of GEOMATE*, Vol. 28, no. 128, pp. 49-57, 2025, DOI: 10.21660/2025.128.g14123
- [11] Lund R.A.A, Gates T.G.A, Scalia C, Characterization and control of irrigation canal seepage losses: A review and perspective focused on field data. *Agricultural Water Management*, September 2023, pp. 1-21.
<https://DOI.org/10.1016/j.agwat.2023.108516>
- [12] Urahata N., Okajima K., Evaluation of The Effect of Turbid Water in Canals on Underwater Ultrasonic Roughness Measurements, *International Journal of GEOMATE*, June, 2024 Vol. 26, Issue 118, pp. 1-8,
DOI: <https://doi.org/10.21660/2024.118.g13294>
- [13] Chen S., Zheng F., Liu X and Garambois P., Pressure-balanced Saint–Venant equations for improved asymptotic modelling of pipe flow, *Journal Hydro-environment Res.*, vol. 37, pp. 46–56,2023,
<https://DOI.org/10.1016/j.jher.2023.05.001>
- [14] Ulman B.K.M, The potential to manage releases of Bacillus anthracis using bioretention and a high flow media filter: Results of simulated runoff testing with tracer spores Bacillus globigii,” *Journal Environment. Manage.*, vol. 354,pp.12-28,2024, DOI: 10.1016/j.jenvman.
- [15] Ijaz N., Haider. S, Muaaz, Development of a

- hydrodynamic model of the irrigation canal network by using HEC-RAS: a case study of Layyah Canal Division, *J. Modeling Earth Systems and Environment*, April 2025, Volume 11, article number 195
- [16] Nikundabashaka, Ave MT, Niyonkuru R, Bugenimana DE, Effect of Drip Irrigation on Yield and Water-use Efficiency in Five Different Crops in Rwanda, *African Journal of Food, Agriculture, Nutrition and Development* 26(02):28908-28932, March 2026. DOI:10.18697/ajfand.149.26435
- [17] Lawal. A.I, “A new modification to Mononobe-Okabe’s pseudo-static model for passive earth pressure prediction using homogeneous differential equation,” *Mech. Res. Commun.*, vol. 116, p. 103760, 2021, doi: <https://DOI.org/10.1016/j.mechrescom.2021.103760>.

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