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RESEARCH ARTICLE

Two Threshold Smart Irrigation System for Increasing Crop Yield

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Abstract. The objective of this research is to create an automated irrigation system using two threshold method for rice farming in the Jorolot irrigation area, Cimahi City, West Java Province, Indonesia, which addresses the problem of fluctuating water supply. This issue includes water deficits during the dry season, which threatens rice growth, and excess water during the rainy season, leading to flooding and crop destruction. The method used includes one-dimensional hydraulic modeling of irrigation channels to determine two threshold of channel water level elevation, as well as water availability quantification based on flood, normal, and dry clusters. Furthermore, the system's design involved utilizing the Decision Supporting System (DSS) data communication to monitor and respond to dry or flood events in real time, thereby increasing the system's overall performance. The Jorolot irrigation area, which covers 15.5 hectares, sources its water from the Jorolot Dam, with a primary channel length of 1135 m and a secondary channel length of 536 m. The results showed that the water level in the primary canal for normal conditions is 0.1 m<Ynp<0.6 m. Additionally, the proposed system, which allows for real-time water supply monitoring, can increase rice production from two to three harvests per year.

1. Introduction

Water supply is a critical factor in determining the success of rice farming through irrigation. Water availability fluctuates, with its deficit during the dry season and excess water during the rainy season, causing floods and damaging rice crop (Mediawan et al., 2021). In the Wanir irrigation area of Ciparay District, Bandung Regency, farmers face challenges accessing water during long dry spells, while in the rainy season, flooding from the Citarum river destroys crop and settlements (Nurseto & Nugraha, 2019). Competition for water usage, such as in fish farming, further complicates water availability, making effective irrigation water management crucial (Desvo Saputra, Maharani, 2019; Nurhayati et al., 2021; Hamdani, 2018). Therefore, efficient water management is necessary to increase productivity and expand planting area, involving timely and targeted delivery of the appropriate amount of water to cover a large area (Syamsiar et al., 2016).

An alternative solution to tackle water availability problems in rice farming is developing an automatic irrigation network system that uses real-time monitoring of water levels and an automatic control system. This system provides information on water levels in the fields to maintain the required water demand for plants, leading to increased productivity and efficient irrigation water use (Sirait et al., 2015). By utilizing automatic sensors, intelligent irrigation system can continuously monitor water levels and regulate the amount required by plants while automatically stopping the water supply when the plants have received sufficient water. This approach saves water and reduces costs and labor requirements (Gagandeep et al., 2018).

Earlier research has indicated that smart irrigation system utilizing IoT can monitor water availability and other parameters online but are limited to measuring irrigation network performance. Two threshold methods can measure irrigation network's performance, allowing for a comprehensive understanding of intake to rice fields. Effective irrigation water monitoring can be achieved by maintaining regulated parameter limits and utilizing an early warning system. Two threshold system is implemented using an input and output threshold, as depicted in Figure 1. The difference between these two threshold creates an early warning system that alerts farmers in advance, assuming parameter limits are exceeded, cannot be met, or are deficient, enabling boundary condition parameters to be monitored effectively online. (Safarina A.B et al., 2017;Yasin & Ghazal, 2020).

Two threshold automatic irrigation method is a novel approach allowing real-time monitoring of irrigation network performance. Feasibility studies have demonstrated its effectiveness as a flood early warning system and its potential application in an automatic irrigation system, particularly in irrigation channels where water flow is relatively steady and uniform. In contrast to the complex parameters and two-dimensional unsteady flow properties of watershed-based flood warning system, the scope of two threshold automatic irrigation method is simpler and more manageable (Safarina A.B, Chairunnisa, Lestari, et al., 2021; Safarina A.B, Chairunnisa, Farfian et al., 2021).

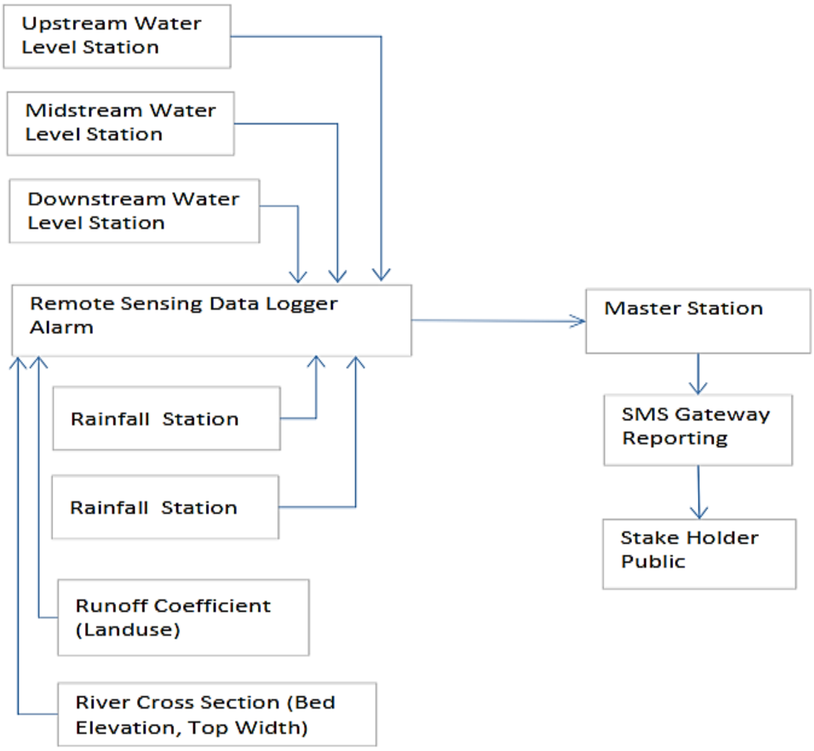

Figure 1. Two Threshold Online Monitoring System Scheme

2. Methods

2.1 Governing Equation of Irrigation Canal Hydraulic

Agricultural irrigation system plays a crucial role in global rice production and are the largest consumers of water. The sustainable use of irrigation system is focused on alternative water resources, innovative technology, and increased water use efficiency (Velasco-Muñoz et al., 2019). Achieving optimal irrigation requires consistent investment in equipment, maintenance and operational expenses, and technical expertise. Technological advancement in irrigation can benefit agriculture with limited water availability, higher profitability, as well as greater technical and economic capacity (García et al., 2020).

The purpose of irrigation is to maintain equilibrium in the water supply for plants during arid periods and expand arable land beyond natural water sources. Utilizing open channels for water transportation on farms is the most convenient and cost-effective method. The gate and weir structures calculate the water level and discharge at each position, which allows for determining the quantity of water allocated to each user (Ye et al., 2019). Due to their conveniences, water meter structures are commonly used to measure water in irrigation canal system. However, there is a scarcity of research focusing on the optimal location of water depth monitoring points upstream and downstream.

Hydrodynamic models of straight and branch channels were evaluated using numerical simulations and hydraulic tests to establish a functional relationship between the width of the sluice gate opening and the location of water depth monitoring points, 14. The results indicated that the optimal location for upstream and downstream water depth monitoring points was 16.26 and 15.51 times the width of the gates, respectively. The average discrepancy between the calculated flow rate and simulation value is 14.37%, while the mean error between calculated flow rates using the modified approach and the simulated value was 3.36% (Conde et al., 2021). The three-dimensional continuity equation for an incompressible open channel, presented in equation (1), was used in the hydrodynamic model (Xu et al., 2021),

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{1}$$

where u, v, and w are the flow velocities in the x, y, and z directions, respectively.

2.2 Two Threshold of Smart Irrigation

Complete automation of an existing irrigation system necessitates consideration of water source discharge. In gravitational water supply system, sensors monitor water level elevation along the channel leading to rice fields and report back to is monitored the master station for control. The control mechanism depends on water availability quantification, which sets threshold for regulation. Typically, a single threshold is utilized, but a 'Flood Early Warning System Method with Rainfall Threshold and River Water Depth' intervention has introduced two threshold parameters for upstream and downstream drainage system in automatic irrigation system.

When using mechanical pumping for pump irrigation from sources such as wells, rivers, and lakes, modification of the water pump is necessary to enable electronic switching by the automatic irrigation system's control unit (Samantha & Almalik, 2019). Manual opening and closing of irrigation channels are a commonly used method, but automatic regulation of irrigation system is possible with an electrode level sensor. Figure 2 shows the use of an ATMega8535 microcontroller to automatically open and close irrigation door by commanding the opening of the water distribution cover (Mufida E, 2017).

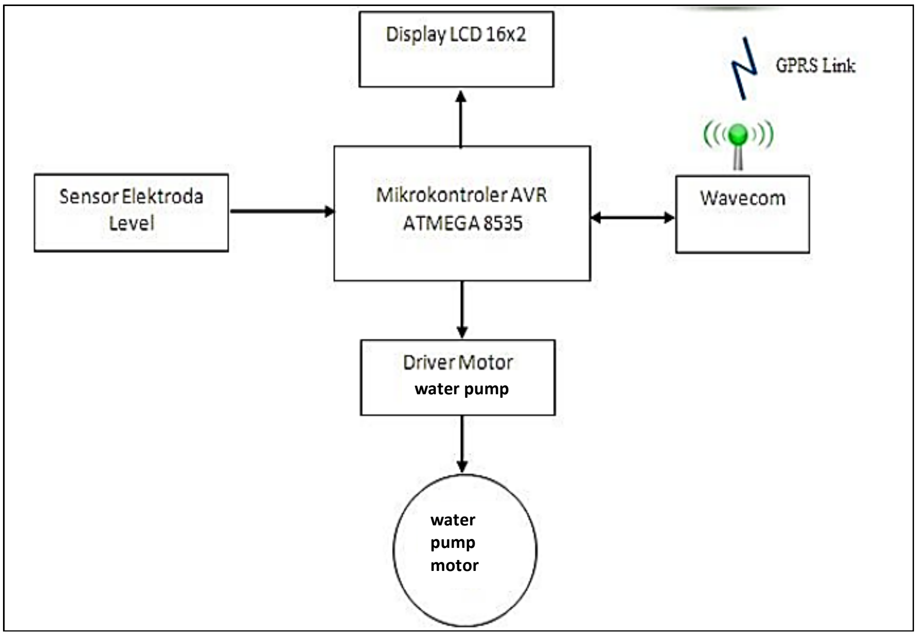

Figure 2. Automatic Irrigation Block Diagram with ATMega8535

A microcontroller-based automatic system aims to provide instantaneous mechanical commands, specifically for opening and closing doors.

2.1 Water Availability Index

The average rice production in Indonesia is currently 5.22 tons/ha but has the potential to increase up to seven tons/ha. (Rosyadi, 2018). However, the major constraint to rice production is the availability of water. Research showed that rice plants constantly flooded to a depth of 10 cm displayed the best growth and production rates when compared to those inundated to zero to three cm or not inundated at all. The results further revealed that land inundated to a depth of five to 10 cm had a higher production of 5.92 t/ha, while land inundated to a depth of zero to three cm and those without inundation recorded production of 5.12 t/ha and 4.80 t/ha, respectively (Rusmawan & Muzammil, 2015).

Improving water usage efficiency in agriculture can increase the economic value of irrigation water. One way to achieve this is by shifting focus from product yield per unit area of land to water productivity, which measures the yield obtained per unit volume of water used. Plant water productivity is calculated as the ratio between yield and the amount of water supplied to the plant, with units of kg yield per m^3 of water used. Applying the concept of crop water productivity through irrigation system makes it possible to increase crop production while using less water (Fuadi et al., 2016).

A hydrograph model is simulated where the river network intersects with the administrative boundary to predict water availability at the sub-district level. The resulting water availability is categorized based on irrigation availability index, shown in Table 1 (Heryani et al., 2020),

Irrigation availability index evaluates the effectiveness of irrigation networks in meeting water requirements. A value of 1 represents the best performance, indicating that irrigation networks can provide more than nine liters of water per second per hectare.

3. Result and Discussion

3.1 Cisangkan River Capacity

With a length of 15.51 km and a watershed area of 10.44 km, Cisangkan River is a tributary of Cimahi River, which flows into the Citarum River, hence, Cisangkan River is a third-order river. In assessing the characteristics of the river catchment, a monthly unit hydrograph is utilized, along with monthly rainfall data with a 50-year return period, to determine the river's maximum capacity. This maximum capacity is then used as a reference for determining the discharge level at the intake of irrigation networks. The peak discharge for Cisangkan River monthly, with a 50-year return period, is reported for the upper reaches of the Leuwigajah sub-district as follows.

Table 1. Water Availability Index

Number	Irrigation Water Availability ($l\ dt^{-1}\ ha^{-1}$)	Irrigation Water Availability Index
1	< 0.3	5
2	0.3 - 0.5	4
3	0.5 - 0.7	3
4	0.7 - 0.9	2
5	> 0.9	1

Table 2. Cisangkan Monthly Peak Discharge with a Return Period of 50 years

Month	Q_{50}(m^3/s)	Month	Q_{50}(m^3/s)
January	18.04	July	14.47
February	19.28	August	10.04
March	18.15	Sept	16.31
April	25.21	October	28.65
Mei	27.14	Nov	24.73
June	14.76	December	21.91

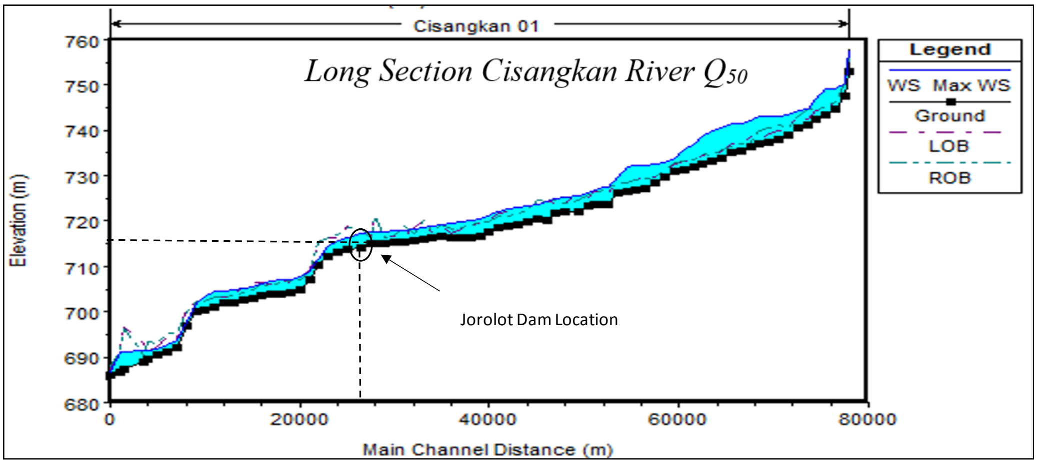

Figure 3. Long Section Cisangkan River Q_{50}

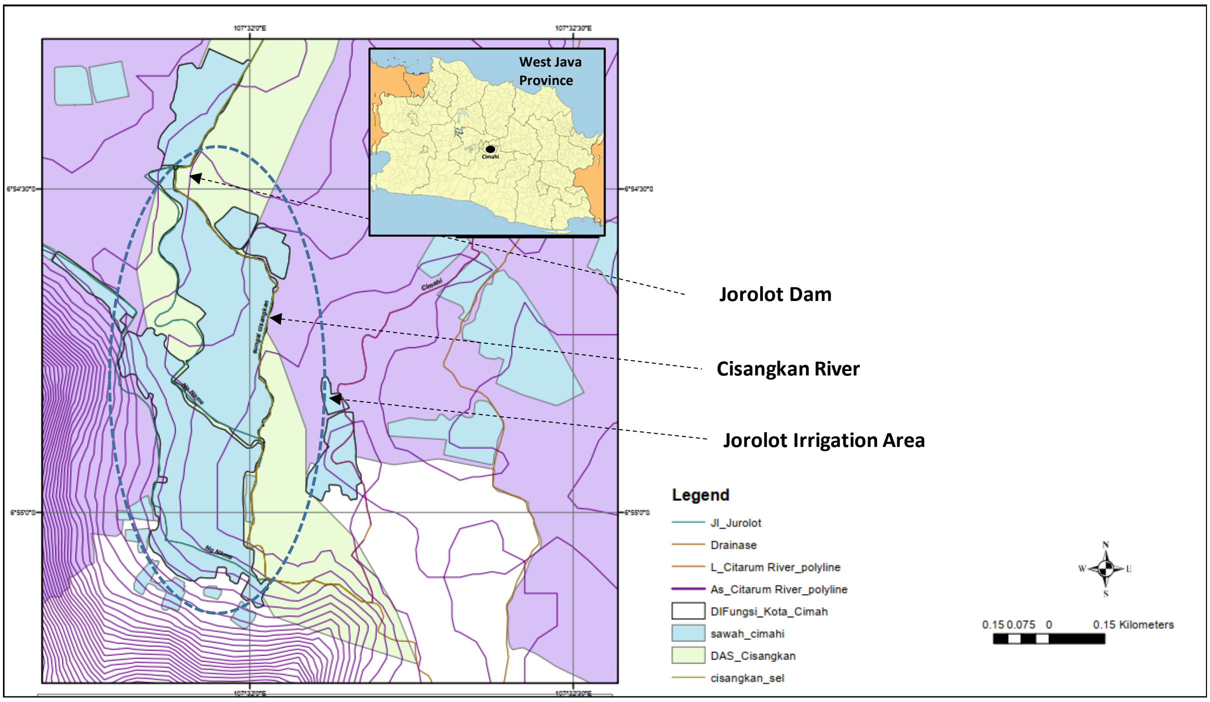

Figure 4. Jorolot Dam and Irrigation Area Map

Table 2 reports the monthly discharge levels for the Cisangkan River at the Leuwigajah section for a 50-year return period. The maximum discharge of 28.65 m^3/s occurs in October, while the minimum discharge of 14.47 m^3/s occurs in July.

The Jorolot Dam serves the Jorolot irrigation area, is situated at 717.5 m MSL on the river embankment and 715.1 m MSL on the river bed. In Figure 3, the longitudinal profile of the Cisangkan river is presented based on one-dimensional unsteady modeling during October (maximum discharge), when the river experiences its maximum discharge for a 50-year return period.

3.2 Jorolot Dam and Irrigation Area Map

Located in the Leuwigajah Sub-District at coordinates -6,9^0 S and 107,5^0 E, the Jorolot Dam spans the Cisangkan River and is depicted in Figure 4. The weir's crest is positioned at an elevation of 718 m MSL.

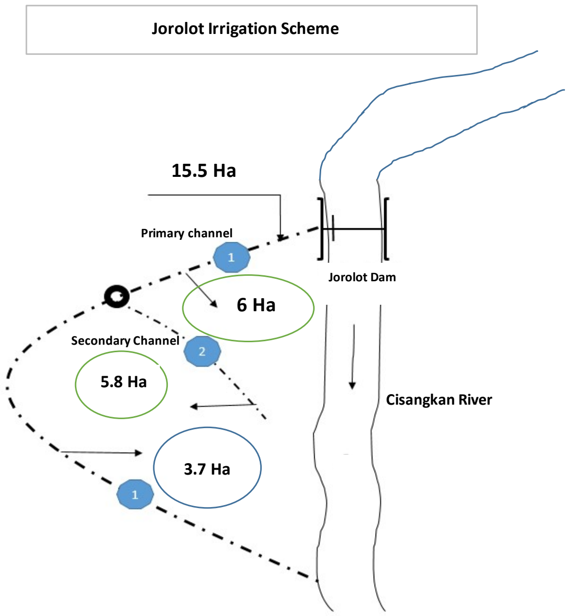

Figure 5. Jorolot Irrigation Scheme

The Jorolot irrigation area spans 15.5 hectares and comprises primary and secondary channels with lengths of 1135 m and 536.5 m, respectively. Figure 5 presents the layout of the Jorolot Irrigation scheme.

3.3 Two Threshold of Jorolot Smart Irrigation System

Two threshold approach for automatic irrigation was created using two threshold patents for flood early warning (Safarina A.B et al., 2017), which is an innovative method for early flood warning based on a rainfall-runoff model. The patent consists of input and output threshold in a hydrological model. It is currently in the process of being granted and registered, with completion expected in 2017. The same principle is applied in the automatic irrigation system, with the concept of two threshold used in a flow cycle within irrigation network. The upstream and downstream channel water levels serve as the first and second threshold. These two threshold function to monitor channel leakage and water availability. Therefore, when the first (upstream) threshold is reached, the water regulation system can be alerted immediately to prevent water shortages or flooding at the second threshold, which is optimally located close to the water supply for rice fields.

Accurate placement of the monitoring unit in the land is crucial for efficient crop water supply (Ighrakpata et al., 2019). In the Jorolot irrigation system, the primary channel's first threshold is positioned 74.5 m downstream from the intake, while the second threshold is placed 304 m from the first threshold, upstream of the secondary channel. The second threshold monitors the water availability for rice fields. Figure 6 displays threshold location scheme.

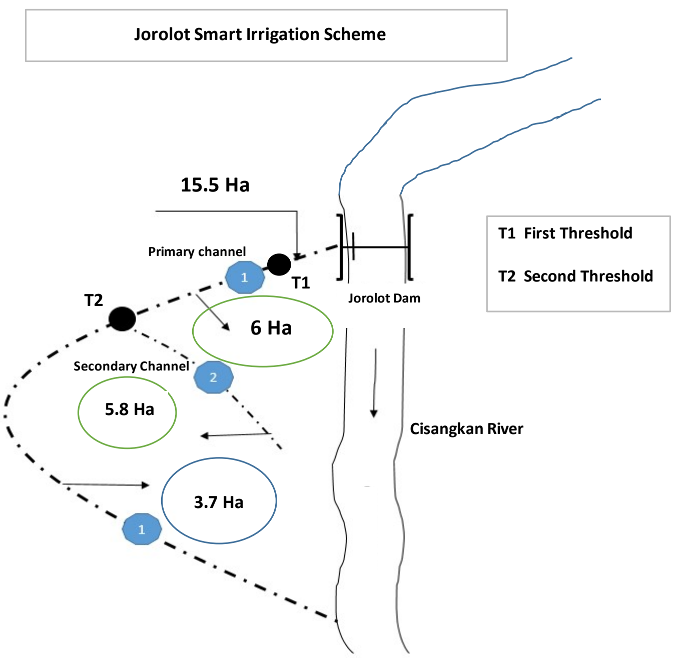

Figure 6. Threshold Location

Table 3. Channel Hydraulic Conditions in Three Water Availability Clusters

Threshold point	Channel type	Channel depth (m)	Discharge Q (m^3/s)	Bed channel Elevation (m)	Water surface Elevation (m)	Velocity Channel (m/s)
		Normal				
1	Primary	0.23	0.088	708.0	708.2	0.293
		Dry				
1	Primary	0.1	0.0636	708.0	708.1	0.489
		Flood				
1	Primary	0.6	0.896	708.0	708.6	1.149
		Normal				
2	secondary	0.2	0.04	704.51	704.55	0.25
		Dry				
2	secondary	0.08	0.0128	704.51	704.52	0.2
		Flood				
2	secondary	0.5	0.104	704.51	704.61	0.26

Irrigation water availability in the Jorolot irrigation area ranges from 0.6 to 0.9 liters/second/ha, which falls under categories 2 and 3, indicating good water availability. Table 3 provides information on the hydraulic conditions and capacity of the Jorolot irrigation canal for the three water availability clusters identified in this research, namely the normal, dry, and flood clusters.

The discharge capacity of the primary channel at the first threshold location under normal conditions is 0.088 m^3/s, as shown in Table 3. The water requirement for rice plants in irrigation system is 1.2 liters/second/ha, equivalent to 0.0186 liters/second/ha for a total area of 15.5 ha. Therefore, there is still an abundant water supply in irrigation system. The discharge capacity at threshold location two under normal conditions for the secondary channel is 0.04 m^3/s. The water required to irrigate 5.8 ha of rice fields in the secondary canal is 0.00696 m^3/s, indicating a sufficient water supply in the secondary canal. It is important to note that the canal measurements in Table 3 were carried out in August and September 2022, during both dry and wet months. Water availability is quite safe for normal, dry, and flood clusters.

The information on monitoring water availability is presented on a dedicated website accessible to stakeholders and the general public. The website accessed at www.watershedresearchcenter.com, plays a crucial role in smart irrigation as communication technologies are essential for the successful operation of IoT devices (Heideker et al., 2020).

4. Conclusion

The novelty of two threshold automatic irrigation method is that it can monitor the performance of irrigation networks in real time. The upstream threshold indicates water availability at the intake, while the downstream threshold indicates water availability for distribution to rice fields. This method can also identify channel leaks in real time using hydraulic model calculations. By comparing the water level elevation at the upstream and downstream threshold, any discrepancies can indicate problems, such as leaks, blockages, or other causes. Overall, this method can effectively measure irrigation network's performance from the intake to rice fields. It is recommended to use multiple pairs of two threshold for large irrigation area to control water availability and canal efficiency in real time, which can lead to optimal irrigation water supply and increased rice production.

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