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Service Capability In Meeting Irrigation Water Availability At Cengklik Reservoir

***Dyah Julia Syifa[1], Sri Sangkawati[2], Hari Nugroho[3]**
[1,2,3]Master of Civil Engineering, Faculty of Engineering, Diponegoro University, Semarang
*)Corresponding autor: dyahjulias@gmail.com

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Abstract

Cengklik Reservoir, located in Boyolali Regency, is mainly used to supply water for irrigation. However, changes in hydrological conditions and increasing irrigation water demand have created an imbalance between available water and irrigation needs. This study aims to evaluate the reservoir's ability to meet irrigation water demand and assess the performance of the irrigation network. The F.J. Mock method was used to estimate the dependable discharge, which had an average value of 0.338 m³/s. In addition, water from the Watuleter Supplementary Supply was considered as an extra source, providing an average discharge of 0.296 m³/s. The irrigation system serves an area of 1,460 ha with a rice–rice–secondary crop planting pattern, requiring an average irrigation water demand of 1.239 m³/s. The water balance analysis showed a surplus during seven periods, although water deficits still occurred in the remaining periods. The recommended alternative was to change the planting pattern to rice–secondary crop–secondary crop, which increased the number of surplus periods to 16, compared with the existing condition. The irrigation network performance assessment showed a score of 65.55% under existing conditions, while the proposed planting pattern improved the score to 68.93%. Although the performance improved, it still fell into the poor category. Therefore, better operation and maintenance are needed to improve the effectiveness of irrigation services.

Keywords: *Cengklik Reservoir, Dependable Flow, Irrigation Water Requirement, Irrigation Network Performance*

INTRODUCTION

A reservoir is a water storage structure that functions to store and regulate water availability so that it can be used for various purposes, one of which is supplying irrigation water for agricultural land [1]. Cengklik Reservoir in Boyolali was constructed by the Mangkunegaran Kingdom and the Dutch Colonial Government between 1923 and 1931. The reservoir serves multiple purposes, including irrigation, fisheries, tourism, and supplying water for plantations and the Colo Madu Sugar Factory.

The name "Cengklik" was derived from the nearest settlement to the reservoir, namely Cengklik Hamlet. Cengklik Reservoir is located in Sobokerto and Ngargorejo Villages, Ngemplak District, Boyolali Regency, Central Java Province, Indonesia. The reservoir is managed directly by the Bengawan Solo River Basin Authority (BBWS Bengawan Solo). According to BBWS Bengawan Solo (2020), Cengklik Reservoir has a watershed area of 9.09 km². In 2025, the reservoir supplied irrigation water to approximately 1,460 hectares of agricultural land with a Rice–Rice–Secondary Crop cropping pattern, where the planting season begins in early November.

Based on the historical technical data of Cengklik Reservoir, several important reservoir parameters have changed over time. Technical records show that the watershed area (DAS) was originally recorded as 10.69 km² in the Buku Bendungan Besar Indonesia (1995) and several later inspection reports, but it decreased to 9.09 km² based on the 2020 inspection results. In addition, changes have occurred in the reservoir storage characteristics and the irrigation service area according to technical evaluations carried out over the years. These changes indicate that the reservoir system has experienced both physical and operational changes that may affect its ability to provide a sustainable water supply for irrigation.

These changes in the reservoir's technical characteristics, together with increasing irrigation water demand and changes in hydrological conditions, highlight the need to re-evaluate the service capability of Cengklik Reservoir. This evaluation is important to determine whether the available water from the reservoir can still meet the irrigation water demand for the current service area of 1,460 ha. It also helps identify more effective management alternatives if there is an imbalance between water availability and irrigation water demand.

In operation, a reservoir must be able to supply enough water to meet crop water requirements throughout the year. Modern reservoir management increasingly focuses on optimizing reservoir operation to balance water demands from different sectors while improving the efficient use of available water resources [2]. However, water availability in a reservoir depends on the hydrological conditions of the watershed, including rainfall, evapotranspiration, infiltration, and surface runoff [3]. Meanwhile, irrigation water demand is influenced by several factors, such as crop evapotranspiration, percolation, effective rainfall, and irrigation network efficiency [4].

These conditions can lead to an imbalance between water availability and irrigation water demand. When irrigation water demand increases without sufficient water availability, a water deficit may occur. On the other hand, when water availability exceeds irrigation demand, a water surplus is created, which can be used to support other water needs.

The success of an irrigation system depends not only on water availability but also on reservoir management strategies and water distribution policies in the irrigation area. Evaluating reservoir operating rules is important to determine how well the current operation can meet irrigation water demand and improve the reliability of reservoir water supply [5]. An adaptive reservoir operation approach can improve irrigation efficiency, especially when water availability is limited [6].

In addition, irrigation system performance is influenced by the physical condition of the irrigation network, operation and maintenance practices, management organizations, and the participation of water users' associations [7]. A well-maintained irrigation network can deliver water effectively and efficiently to agricultural fields. On the other hand, damaged irrigation structures, sediment accumulation in canals, water leakage, and inadequate maintenance can increase water losses and reduce the overall performance of the irrigation system.

Evaluating irrigation network performance is an important step in assessing how well an irrigation system functions based on the condition of its physical infrastructure, operation and maintenance practices, and irrigation water delivery. The results of this evaluation can be used to identify problems within the irrigation network and determine the improvements needed to enhance the effectiveness and reliability of irrigation services.

A previous study [8] evaluated the performance of Cengklik Reservoir based on the relationship between planned water releases, actual water releases, and reservoir storage conditions. The study mainly focused on the operational performance of the reservoir in meeting water demand. However, it did not analyze water availability using dependable flow, estimate irrigation water demand based on cropping patterns, or evaluate the reservoir's irrigation service capability through water balance analysis and irrigation network performance assessment.

Based on the issues described above, this study evaluates the irrigation service capability of Cengklik Reservoir. The objectives are to assess the reservoir's ability to meet irrigation water demand, analyze the irrigation network performance index based on the existing condition of the irrigation system, and recommend the most suitable cropping pattern, planting schedule, and planting area based on the results of the water balance analysis and reservoir service evaluation. The findings are expected to provide a comprehensive understanding of the reservoir's ability to supply water to its irrigation service area and to support more effective irrigation management.

RESEARCH METHODS

This study involves several analyses and methods, as illustrated in the flowchart. The data processing steps are described as follows:

1. Areal rainfall was determined from the average rainfall recorded at one or more rainfall stations located within and/or surrounding the study area [9]. This study used ten years of daily rainfall data (2014–2023) obtained from the Cengklik Reservoir Rainfall Station (POS WD Cengklik), provided by the Bengawan Solo River Basin Authority (BBWS Bengawan Solo).

2. Evapotranspiration refers to the loss of water from the earth's surface to the atmosphere through evaporation and plant transpiration processes [10]. Climatic data are required to estimate the magnitude of evapotranspiration. The main climatic factors affecting evaporation include air temperature (°C), relative humidity (%), wind speed (m/s), and sunshine duration (%) [11]. In this study, evapotranspiration was calculated using the Modified Penman Method. The calculation was based on ten years of climatological data (2014–2023) collected from the Cengklik Reservoir Station and obtained from BBWS Bengawan Solo.

3. Flow analysis was carried out to estimate dependable flow, which represents water availability. This study used the F.J. Mock method, a widely applied hydrological model for estimating river discharge based on rainfall, evapotranspiration, and watershed characteristics [12]. Before running the simulation, the Model Mock parameters were determined, as presented in **Table** 1. The calculation procedure for estimating streamflow using the F.J. Mock method is described as follows:
Stage I – Limited Evapotranspiration (Et)
Stage II – Surface Water Balance
Stage III – Runoff and Groundwater Storage
Stage IV – River Discharge Calculation

Table 1. Mock Model Parameter

Parameter	Value	Unit
Watershed Area	9.09	km^2
m	20 – 50	%
SMC	200	mm/month
I	0 – 1.0	
k	0 – 1.0	
V(n-1)	100	mm

4. Dependable flow analysis was carried out to estimate the amount of water that can be reliably supplied to meet water demand at a specified level of reliability. This type of analysis is widely used in water resources planning [13]. In this study, dependable flow was determined using the Basic Year method, which selects a representative year as the basis for planning. The annual average discharge was calculated for each year, ranked from the highest to the lowest, and the flow corresponding to an 80% reliability level (Q80) was selected to represent the available water supply.

5. Irrigation water demand was estimated using a water balance approach that considers the balance between water supply and crop water requirements within the irrigation area. The calculation was based on several key factors, as described below:
a. Land preparation requirements
b. Percolation rate
c. Water layer replacement
d. Effective rainfall
e. Irrigation efficiency

6. Water balance analysis was conducted to evaluate the balance between water availability and irrigation water demand, allowing periods of water surplus and deficit to be identified within the irrigation system [14]. The analysis was carried out using climatological data, reservoir inflow, and irrigation water demand based on the existing cropping pattern. The cropping pattern applied at Cengklik Reservoir is rice–rice–secondary crops, with the planting season starting in early November. The results of this analysis indicate whether the reservoir has sufficient capacity to meet irrigation water demand throughout the entire growing season.

7. If the available water is insufficient to meet irrigation demand, supplementary water supply is incorporated into the analysis. If the combined water supply is still unable to satisfy the irrigation requirements, alternative management scenarios are evaluated to identify the most effective cropping pattern, planting schedule, and planting area to ensure that irrigation services can be maintained.

8. The irrigation network condition index was evaluated in accordance with the guidelines of Minister of Public Works Regulation No. 12/PRT/M/2015. The results of this assessment were used to determine whether the irrigation network requires routine maintenance or rehabilitation to improve its performance and service reliability.

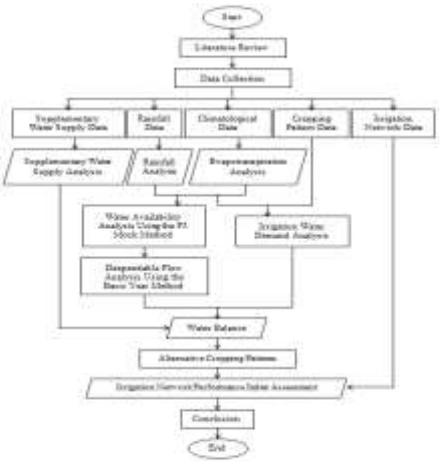


Figure 1. Research Flowchart

RESULT AND DISCUSSION

1. Catchment Area

The catchment area is the land area that receives rainfall and drains water to a specific storage point, which in this study is Cengklik Reservoir. The current catchment area of Cengklik Reservoir is 9.09 km². This area was used as the main parameter for areal rainfall analysis and streamflow estimation using the F.J. Mock method.

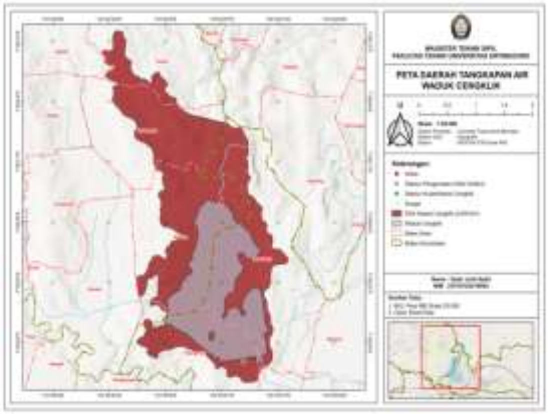


Figure 2. Catchment Area Map of Cengklik Reservoir

2. Water Availability

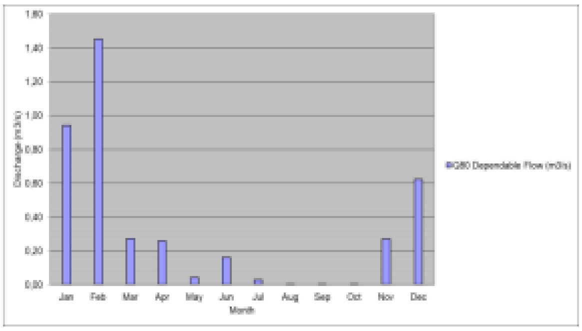
Streamflow was estimated using the F.J. Mock method. The parameters used in the simulation included the watershed area, exposed surface factor (m), soil moisture capacity (SMC), infiltration coefficient (i), groundwater recession factor (k), and initial groundwater storage (V(n−1)). The simulated streamflow was then used to determine the dependable flow (Q80) using the Basic Year (80%) method. The resulting dependable flow is presented as follows:

Table 2. Q80 Dependable Flow Calculated Using the Basic Year Method for the January–June Period

Description	Jan	Feb	Mar	Apr	May	Jun
Dependable Flow (m^3/s)	0.94	1.45	0.27	0.26	0.04	0.16

Table 3. Q80 Dependable Flow Calculated Using the Basic Year Method for the July–December Period

Description	Jul	Aug	Sep	Oct	Nov	Dec
Dependable Flow (m^3/s)	0.03	0.00	0.00	0.00	0.27	0.62



Graph 1. Dependable Flow

The analysis results indicate that the dependable flow fluctuates from month to month, influenced by rainfall conditions and seasonal variations within the reservoir catchment area. The dependable flow tends to increase during the rainy season and decrease during the dry season. The maximum dependable flow occurred in February, reaching 1.45 m³/s, while the minimum flow occurred in August, September, and October, with values close to 0.00 m³/s.

3. Irrigation Water Requirement and Cropping Pattern

In addition to evapotranspiration, irrigation water demand was estimated by considering several factors, including consumptive water use, potential evaporation, percolation, water layer replacement, and effective rainfall. The irrigated area covers 1,460 ha and follows a rice–rice–secondary crop cropping pattern. The first planting season (Season I) begins with rice cultivation from November to February, followed by the second planting season (Season II) with rice cultivation from March to June, and the third planting season (Season III) with secondary crops from July to October. The highest irrigation water demand was recorded during the first period of November, reaching 2.45 m³/s, while the lowest demand occurred during the second period of February, at 0.08 m³/s.

Table 4. Irrigation Water Requirement Calculation

Period	Cropping Pattern	Water Requirement (m^3/s)
Nov I	LP	2.45
Nov II	-	0.00
Dec I	RS-1	2.01
Dec II	RS-1	2.18
Jan I	RS-1	1.85
Jan II	RS-1	1.81
Feb I	RS-1	0.92
Feb II	RS-1	0.08
Mar I	LP	2.32
Mar II	LP	1.87
Apr I	RS-2	2.01
Apr II	RS-2	2.17
May I	RS-2	2.32
May II	RS-2	2.29
Jun I	RS-2	1.41
Jun II	RS-2	0.42
Jul I	LP	1.28
Jul II	SC	0.19
Aug I	SC	0.87
Aug II	SC	1.28
Sep I	SC	0.00
Sep II	SC	0.00
Oct I	SC	0.00
Oct II	Drying Period	0.00

4. Watuleter Supplementary Water Supply

The Watuleter supplementary water supply provides additional inflow to increase reservoir water availability when the reservoir inflow is insufficient to meet irrigation water demand. This supplementary supply is intended to reduce the risk of irrigation water deficits during the dry season, maintain the continuity of irrigation water delivery, and enhance the reliability of reservoir operation and cropping pattern implementation..

Table 5. Watuleter Supplementary Discharge

Period	Supplementary Discharge (m^3/s)
Jan I	0.40
Jan II	0.20
Feb I	0.30
Feb II	0.60
Mar I	0.40
Mar II	0.40
Apr I	0.40
Apr II	0.60
May I	0.50
May II	0.60
Jun I	0.30
Jun II	0.15
Jul I	0.30
Jul II	0.15
Aug I	0.10
Aug II	0.10
Sep I	0.10
Sep II	0.10
Oct I	0.10
Oct II	0.30
Nov I	0.10
Nov II	0.30
Dec I	0.30

Dec II	0.30

5. Water Balance Analysis

The water balance analysis, based on reservoir water availability, supplementary water supply, and irrigation water demand, showed water surpluses during seven periods, namely November II, February I, February II, and from September I to October II. During the remaining periods, water deficits still occurred, indicating that the reservoir could not achieve 100% irrigation reliability, as the available water was lower than the irrigation water demand. The existing irrigation service area of 1,460 ha is too large relative to the available water resources. The average dependable flow of 0.338 m³/s is substantially lower than the average irrigation water demand of 1.239 m³/s, while the Watuleter supplementary water supply is still insufficient to compensate for the deficit. The results of the water balance analysis are presented in the following table and figure.

Table 6. Water Balance Calculation

Period	Water Availability (m³/s)	Supplementary Discharge (m³/s)	Irrigation Water Requirement (m³/s)	Water Balance (m³/s)
Nov I	0.14	0.10	2.45	-2.22
Nov II	0.14	0.30	0.00	0.44
Dec I	0.31	0.30	2.01	-1.40
Dec II	0.31	0.30	2.18	-1.57
Jan I	0.47	0.40	1.85	-0.98
Jan II	0.47	0.20	1.81	-1.14
Feb I	0.73	0.30	0.92	0.10
Feb II	0.73	0.60	0.08	1.24
Mar I	0.14	0.40	2.32	-1.79
Mar II	0.14	0.40	1.87	-1.34
Apr I	0.13	0.40	2.01	-1.48
Apr II	0.13	0.60	2.17	-1.44
May I	0.02	0.50	2.32	-1.80
May II	0.02	0.60	2.29	-1.67
Jun I	0.08	0.30	1.41	-1.03
Jun II	0.08	0.15	0.42	-0.19
Jul I	0.01	0.30	1.28	-0.96
Jul II	0.01	0.15	0.19	-0.03
Aug I	0.00	0.10	0.87	-0.77
Aug II	0.00	0.10	1.28	-1.18
Sep I	0.00	0.10	0.00	0.10
Sep II	0.00	0.10	0.00	0.10
Oct I	0.00	0.10	0.00	0.10
Oct II	0.00	0.30	0.00	0.30

Graph 2. Water Balance of Cengklik Reservoir

These results indicate that the existing system is not yet capable of meeting irrigation water demand optimally. Therefore, alternative management strategies are required to reduce or overcome the water deficits, thereby ensuring a more reliable and sustainable irrigation water supply.

6. Alternative Irrigation Water Management Strategies

Optimal water allocation is a key aspect of reservoir operation, particularly under conditions of limited water resources. Therefore, an efficient water distribution strategy is required to meet the demands of different water users while maximizing the available water supply [15].

Table 7. Alternative Irrigation Water Requirement Calculation

Description	Cropping Pattern	Irrigated Area (ha)	Number of Surplus Periods	Number of Deficit Periods
Existing Condition	Rice – Rice – Secondary Crop	1,460	7	17
Alternative Cropping Pattern	Rice – Secondary Crop – Secondary Crop	1,460	16	8

Based on the results presented above, the alternative cropping pattern of rice–secondary crop–secondary crop (maize) is recommended as the most suitable option for the Cengklik Reservoir irrigation area. Compared with rice, maize has a lower water requirement, thereby reducing irrigation water demand and increasing the number of surplus periods.

This alternative improved the water balance by increasing the number of surplus periods from 7 under the existing cropping pattern to 16. However, water deficits still occurred during several periods, indicating that irrigation water demand could not yet be fully satisfied. These findings suggest that the primary constraint is the limited water availability, which remains insufficient to meet the irrigation water requirements within the service area.

From a hydrological perspective, the available water is insufficient to support the existing cropping pattern and irrigation service area. The dependable flow is considerably lower than the irrigation water demand, while the current service area exceeds the effective capacity of the reservoir. In addition, the available supplementary water supply is not sufficient to compensate for the shortage. Consequently, although alternative cropping scenarios can improve the water balance, water deficits are still expected to occur under the existing water availability conditions.

7. Irrigation Network Performance Assessment
A. Performance Assessment under the Existing Water Balance Condition

Table 8. Irrigation Network Condition Index

No	Assessment Component	Existing Score %	Max %	Min %	Optimum %
1.	Physical Infrastructure	34.3	45	25	35
2.	Cropping Productivity	7.62	15	10	12.5
3.	Supporting Facilities	6.5	10	5	7.5
4.	Organization and Personnel	7.68	15	7.5	10
5.	Documentation	3.5	5	2.5	5
6.	P3A	5.95	10	5	7.5
	TOTAL	65.55	100	55	77.5

Based on the assessment results, the Irrigation Network Condition and Maintenance Index was 65.55%, which falls into the poor category and indicates that improvement is required. This result shows that the irrigation system is still capable of supplying water to the irrigation area; however, its performance is not yet optimal because several components of the irrigation network have deteriorated or sustained damage. Therefore, appropriate operation and maintenance activities, together with rehabilitation of the damaged infrastructure, are necessary to improve the overall performance of the irrigation system and enhance the effectiveness of water distribution.

B. Irrigation Network Performance Assessment under Alternative Irrigation Water Requirement Conditions

This assessment was conducted to evaluate the effects of each alternative on the level of irrigation service, cropping productivity, and the ability to meet irrigation water demand in the Cengklik Reservoir irrigation area. Each alternative produced different irrigation water requirements, which affected the K-factor, the irrigated service area, and the irrigation network performance index. By evaluating all proposed alternatives, the study identified the option that provides the most effective irrigation performance while remaining consistent with the dependable water availability of Cengklik Reservoir.

Table 9. Irrigation Network Performance Index under Alternative Irrigation Scenarios

Description	Cropping Pattern	Irrigated Area (ha)	Cropping Productivity Index (%)	Irrigation Network Performance Index (%)
Existing Condition	Rice – Rice – Secondary Crop	1,460	7.62	65.55
Alternative Cropping Pattern	Rice – Secondary Crop – Secondary Crop	1,460	11.03	68.93

Based on the results presented above, the alternative cropping pattern improved the irrigation network performance compared with the existing water balance condition, increasing the Irrigation Network Condition and Maintenance Index to 68.93%. However, this value still falls within the poor category and indicates that further improvements are required. For the Cengklik Reservoir irrigation network, operation and maintenance measures should include sediment removal from irrigation canals, rehabilitation of damaged irrigation structures, and more efficient water allocation, particularly during the dry season, to ensure the sustainability of irrigation services.

The Irrigation Network Condition and Maintenance Index increased from 65.55% to 68.93%, representing an improvement of 3.38%. This relatively modest increase is attributed to the fact that the other assessment components—including physical infrastructure, supporting facilities, organizational capacity, documentation, and the Water User Associations (P3A)—remained unchanged. In addition, the proposed alternative was not able to eliminate water deficits throughout all planting periods, thereby limiting the overall improvement in irrigation network performance.

CONCLUSION

Based on the findings of this study, it can be concluded that the average water availability of 0.338 m^3/s, together with an average supplementary water supply of 0.296 m^3/s, is insufficient to support the existing cropping pattern, which requires an average irrigation water demand of 1.239 m^3/s. In addition, the current irrigation service area exceeds the effective capacity of the reservoir, while the available supplementary water supply is not sufficient to compensate for the shortage. The water balance analysis showed water surpluses during seven periods, whereas water deficits persisted throughout many other periods. Among the evaluated alternatives, the rice–secondary crop–secondary crop (maize) cropping pattern was identified as the most suitable option. This alternative improved the water balance by increasing the number of surplus periods to 16. However, water deficits still occurred during several periods, indicating that irrigation water demand could not be fully satisfied. These findings suggest that the main limitation is the inadequate water availability, which remains insufficient to meet the irrigation water requirements within the irrigation service area.

The assessment of the Cengklik Reservoir irrigation network yielded an Irrigation Network Condition and Maintenance Index of 65.55%. Under the proposed cropping pattern alternative, the index improved to 68.93%, indicating better irrigation network performance than under the existing water balance condition. However, the improvement was relatively small because the evaluated alternative focused solely on changes in the cropping pattern without considering physical improvements to the irrigation infrastructure, reservoir rehabilitation, or enhancements in water conveyance efficiency. Consequently, the irrigation network performance remained within the poor category, indicating that further improvements are required. Future research should investigate the effects of irrigation system operation and maintenance, improvements in water conveyance efficiency, and reservoir operation optimization on enhancing irrigation service reliability and the irrigation network performance index.

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