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Optimization of Water Distribution in the Manikin Irrigation Area, Kupang Regency, Using Dynamic Programming

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Abstract: This study aims to optimize water distribution in the Manikin Irrigation Area, Kupang Regency (200.98 ha), using deterministic dynamic programming to enhance irrigation efficiency and agricultural productivity. The cropping pattern follows a rice–rice–fallow system, wherein rice is cultivated in the first two seasons and land is left fallow in the third. Data used includes rainfall (2014–2023), irrigation discharge, crop water requirements, climatological parameters, and economic variables. The model maximizes profit as the objective function while considering three constraints: water availability, land area per season, and land area per irrigation stage. The study divides the irrigation network into eight stages and applies forward recursive and backtracking procedures to determine optimal water allocation. Before optimization, only 90 ha (44.78%) were irrigated in the first season and 170 ha (84.59%) in the second. After optimization, coverage increased to 190.23 ha (94.65%) and 200.98 ha (100%), respectively. Corresponding profits rose by 117% in the first season and 18% in the second. These results demonstrate that dynamic programming effectively improves water use efficiency and land productivity in water-limited agricultural systems.

Keywords: Agricultural productivity; Dynamic programming; Irrigation optimization; Water distribution

Introduction

Indonesia is an agrarian country with vast agricultural potential, where irrigation plays a crucial role in ensuring food security and sustainable farming. However, many regions, especially in eastern Indonesia, face significant water management challenges due to climatic variations. One such region is the Manikin Irrigation Area (DI Manikin) in Kupang, East Nusa Tenggara (NTT), which experiences an arid to semi-arid climate (Lake et al., 2021). The rainfall pattern in this region is highly seasonal, with heavy rains occurring only between December and March, followed by an extended dry season lasting from April to November (Bale et al., 2023). This stark imbalance in water availability makes it difficult for farmers to maintain consistent crop yields, as water scarcity during the dry season limits agricultural productivity. As a result, vast areas of farmland remain underutilized, leading to economic losses and exacerbating food insecurity (Zhang et al., 2019). The current irrigation system in the Manikin Irrigation Area relies on a single intake at the Manikin Dam. However, limited water supply has constrained farmers to cultivate crops only in two planting seasons (Padi-Padi-Bero) instead of the optimal three-season cycle. This suboptimal use of irrigation resources reduces overall productivity, limits farmers' income, and affects the region's agricultural sustainability (Paramitha et al., 2020). To address these challenges, this study aims to develop an optimal

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irrigation strategy using a deterministic dynamic programming approach. By employing this method, water allocation can be optimized to maximize land utilization, improve water efficiency, and enhance agricultural profitability (Li et al., 2020). This research seeks to provide a scientific foundation for better irrigation management, helping policymakers and farmers develop more resilient and sustainable farming systems (Zhang et al., 2021).

Method

The study was conducted in the Manikin Irrigation Area (DI Manikin), Kupang Regency, which covers a potential irrigable area of 3,100 hectares, with 200.98 hectares currently under active irrigation.

Figure 1. Study location

Data collection involved various types of information from multiple sources (Triwidianto et al., 2022). Rainfall data were obtained from three nearby rainfall stations—Tilong, Tarus, and Baumata—for the years 2014 to 2023, sourced from BMKG Kupang, to analyze rainfall trends that influence irrigation planning. Irrigation discharge data from the Manikin Dam were collected using current meters and automatic water level recorders (AWLRs), enabling the determination of average seasonal discharge (Gong et al., 2020). Soil classification and water retention properties were analyzed through field sampling and laboratory testing, which included methods such as soil texture classification and permeability testing to evaluate infiltration rates (Nait et al., 2022). Climatological parameters, including temperature, wind speed, humidity, and solar radiation, were gathered from BMKG Kupang and measured with standard agroclimatic instruments to support the calculation of crop water needs (Indriani et al., 2020). Economic data on agricultural inputs and outputs were collected through structured interviews with local farmers and records from the local agriculture department, allowing an assessment of farming profitability (Salimah et al., 2024).

The objective function of the model was to maximize total profit across the two planting seasons, expressed as:

$$\Sigma f * = F^*_{MT\,I} + F^*_{MT\,II} \quad (1)$$

Explanation:
Σf : Total profit
$F^*_{MT\,I}$: Profit on First Planting Season
$F^*_{MT\,II}$: Profit on Second Planting Season

Furthermore, the forward recursive equation for each season is expressed as:

$$F^*_{Si} = \max_{di} \left[R_i + F^*_{(Si-1)}\right] \quad (2)$$

Explanation:
F^*_{Si} : The objective to be achieved, representing the total profit based on the allocated water for each stage in one planting season, in Rupiah.

The first formula, ∑f* = FMT I + FMT II, is used to calculate the total seasonal profit by adding the profits obtained from the first and second planting seasons. This reflects the overall financial outcome from two rice planting periods within one year. The second formula, FSi = max [Ri + F(Si–1)], is a recursive equation used in dynamic programming to determine the maximum profit at each irrigation stage. In this formula, FSi represents the profit at stage i, Ri is the revenue generated at that stage based on the allocated water, and F(Si–1) is the accumulated profit from the previous stage. By applying this formula, the model evaluates all possible water allocation options at each stage and selects the one that yields the highest combined profit. (Feng et al., 2023). This step-by-step process continues through each irrigation structure, ensuring that water is distributed in a way that maximizes total profit across the entire irrigation network.

Deterministic dynamic programming (DDP) in this research use to optimize the allocation of irrigation water with the aim of maximizing agricultural profits. (Hou et al., 2023). The model was implemented using Microsoft Excel, where a recursive procedure was used to simulate water distribution across the irrigation network and calculate the resulting profits (Ma et al., 2024). The optimization process began by calculating the crop water requirement, which included factors such as reference evapotranspiration, crop growth stages, effective rainfall, and water losses due to percolation. The existing cropping pattern in the area follows a rice–rice–fallow rotation based on the 2021 Global Planting

Plan (RTTG), where rice is grown in the first and second planting seasons, while the third season is left fallow due to water limitations. This pattern was integrated into the model to ensure consistency with field practices. (Juwono et al., 2018).

The irrigation system was divided into eight main structures or stages—BMN.1, BMN.2, BMN.3Ka, BMN.4bKa, BMN.3Ki, BMN.4Ki, BMN.5Ki.Ka, and BMN.5Ki.Ki—each representing different water intake points in the field. Water allocation was calculated for each stage, considering the cumulative effect of previous allocations and the potential economic return. The optimization aimed to find the best possible route and amount of water to allocate at each stage to maximize total profit over the planting periods.

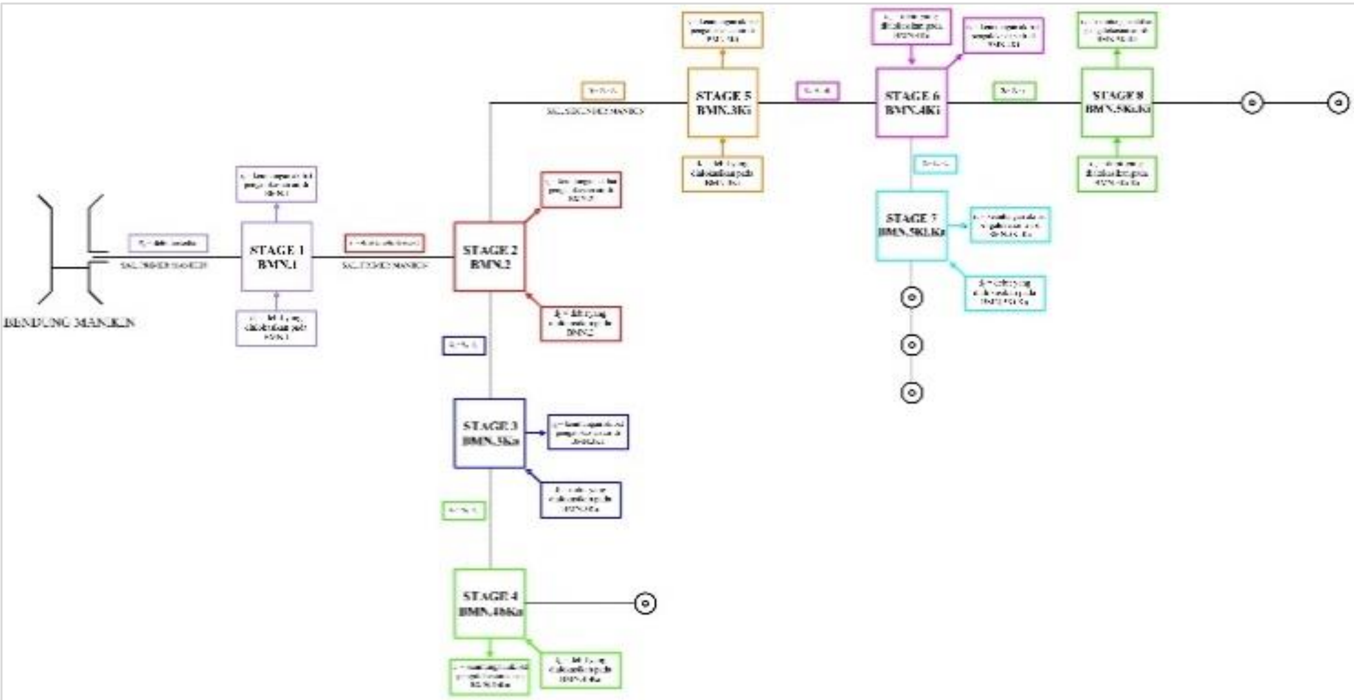

Figure 2. Optimization stage

Three main constraints were considered in the model: the total volume of available water per planting season, which must not be exceeded; the total area of land that can be cultivated in each season, capped at 200.98 hectares; and the maximum area that can be served by each irrigation structure. For instance, a structure with a maximum capacity of 100 hectares cannot be allocated more water than needed for that area. The optimization process used Excel's built-in functions and logic-based modeling tools, such as conditional logic, and iterative calculations (Berbel et al., 2022). After simulating different scenarios, the model was validated through comparison with actual field data, and the results showed high reliability with only minimal deviation, supporting the model's credibility (Hariyadi et al., 2024). To aid comprehension, a flowchart is recommended to visualize the steps taken in the model—from data input, calculation of irrigation requirements, and analysis of cropping patterns, to water availability mapping, profit estimation, and final optimization of water allocation (Ghaisani et al., 2024).

Result and Discussion

Irrigation Water Requirements

The irrigation water requirements in an irrigation area are influenced by several factors, one of which is the cropping pattern used in each planting season. In the Manikin Irrigation Area, the cropping pattern follows the Global Planting Plan (RTTG) for the 2021 period, which consists of a rice-rice-fallow (padi-padi-bero) system.

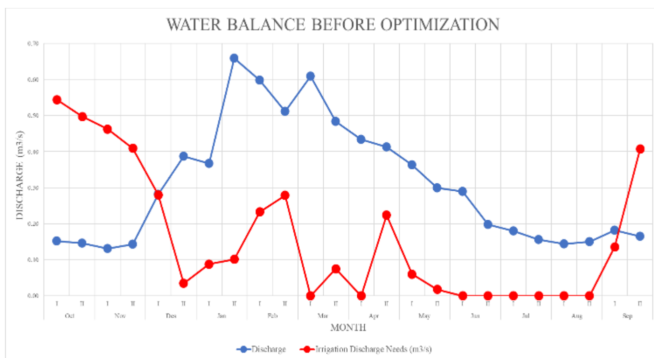

Figure 3. Water balance before optimization

Table 1. Water Balance before Optimization

Month		Discharge 80% (m^3/dt)	Irrigation discharge needs (m^3/dt) Existing	(+) (-)	Condition
Oct	I	0.15	0.54	-0.39	Deficit
	II	0.15	0.50	-0.35	Deficit
Nov	I	0.13	0.46	-0.33	Deficit
	II	0.14	0.41	-0.27	Deficit
Des	I	0.28	0.28	0.00	Surplus
	II	0.39	0.03	0.35	Surplus
Jan	I	0.37	0.09	0.28	Surplus
	II	0.66	0.10	0.56	Surplus
Feb	I	0.60	0.23	0.36	Surplus
	II	0.51	0.28	0.23	Surplus
Mar	I	0.61	0.00	0.61	Surplus
	II	0.48	0.07	0.41	Surplus
Apr	I	0.43	0.00	0.43	Surplus
	II	0.41	0.22	0.19	Surplus
May	I	0.36	0.06	0.30	Surplus
	II	0.30	0.02	0.28	Surplus
Jun	I	0.29	0.00	0.29	Surplus
	II	0.20	0.00	0.20	Surplus
Jul	I	0.18	0.00	0.18	Surplus
	II	0.16	0.00	0.16	Surplus
Aug	I	0.14	0.00	0.14	Surplus
	II	0.15	0.00	0.15	Surplus
Sep	I	0.18	0.14	0.05	Surplus
	II	0.17	0.41	-0.24	Deficit

Based on fable 1 and figure 3, the water balance before optimization illustrates the relationship between available water and irrigation water needs in the Manikin Irrigation Area throughout the year. The chart and table show significant fluctuations in water availability and irrigation demand from month to month. From October to November, there is a consistent water deficit, where irrigation needs (ranging from 0.41 to 0.54 m^3/dt) exceed the available water (only around 0.13 to 0.15 m^3/dt). This shortfall continues until early December, after which a surplus begins to appear, particularly during the rainy season (January to March). During this period, the discharge (Pratiwi et al., 2022) significantly increases—reaching its peak in February and March—while irrigation needs drop, resulting in surpluses as high as 0.61 m^3/dt. From April to August, both the water availability and demand gradually decrease. However, because irrigation needs become minimal or zero during this time, consistent surpluses are observed. In September, the condition starts shifting again: the first half of the month still experiences a surplus, but by the second half, demand increases while discharge decreases, leading to a return of deficit conditions (-0.24 m^3/dt). Overall, this water balance analysis reveals mismatches between supply and demand across the seasons (Mabrur et al., 2021). This reinforces the importance of applying optimization strategies—like dynamic programming—to manage water allocation more efficiently and reduce the frequency and severity of deficits during dry months. This deficit is not considered critical (Zhou et al., 2022).

Available Water Volume

In the deterministic dynamic programming approach, the input used is the average value for each planting season. Table 1 presents the available water volume, which is determined based on the average discharge rate in the Sarangan Irrigation Area. The available water volume is expressed in units of water volume, where one unit is equivalent to 300,000 m^3. The term "one unit of water volume" refers to the number of water units available based on the existing water availability in the study area within a specific interval. The determination of one unit of volume is based on the required calculation accuracy, making it more practical to define one unit as representing 300,000 m^3 of water. (Limantara et al., 2020).

Table 2. Available Water Volume at Each Planting Season

Planting Season	Available Water Volume Unit
I	7
II	16
III	7

Required Water Volume

The required water volume is determined based on a thorough calculation of the irrigation water needs in Manikin Irrigation Area, which takes into account factors such as seasonal water availability and crop water demand (Damayanti et al., 2022). This calculation is essential for ensuring that water resources are efficiently allocated to support agricultural activities. The total required water volume is then used as a basis for estimating the planting area or the land area that can be cultivated, ensuring that the available water is utilized optimally (Shafiya et al., 2022).

As shown in Table 2, the total volume of water needed is analyzed for each planting season, considering the variations in water demand across different growth periods. The calculation of the planting area is conducted for each irrigation structure, which is divided into eight stages to provide a detailed assessment of water distribution and land usage. These stages represent distinct points in the irrigation system, where water allocation plays a crucial role in determining the extent of cultivation (Nalurita et al., 2017).

The maximum cultivable land area is determined by assessing the available water supply within the Manikin Irrigation Area, ensuring that water distribution is aligned with irrigation capacity. This evaluation helps identify potential limitations in land expansion while maximizing the efficiency of water use for sustainable agricultural production.

Table 3. Required Water Volume Each Planting Season

Planting Season	Required Water Volume (m^3/ha)
I	3.014.37
II	1.156.66
III	176.84

Profit Based on Water Allocation

The profit at each stage or irrigation structure is analyzed to evaluate the economic benefits derived from different water allocations until the maximum cultivable land area is fully irrigated. However, once the maximum land area has been effectively irrigated using the minimum required water allocation, any additional water input does not increase profit, causing the profit to remain constant.

The stages examined in this study correspond to specific irrigation structures, namely BMN.1, BMN.2, BMN.3Ka, BMN.4bKa, BMN.3Ki, BMN.4Ki, BMN.5Ki.Ka, and BMN.5Ki.Ki. In the first planting season, the allocation of irrigation ceases at the 7th unit volume, as the available water volume for this season is constrained to 7 unit volumes, as indicated in Table 1.

This study provides crucial insights into water management optimization, ensuring that water distribution is carried out efficiently to maximize agricultural productivity and economic returns while operating within the limitations of available water resources. Table 3 and 4 will show how much profit will collect per stages, after that forward recursive procedure is carried out from the initial stage to the final stage. Because of the existing Planting Pattern in Manikin Irrigation Area the third planting season is not considered or ignored, because if it included it will change the existing planting pattern and cannot be used in the real situation. (Kharistanto et al., 2022).

Table 4. Profit Based on Water Given in the First Planting Season

Stage profit (IDR In Million)							
1	2	3	4	5	6	7	8
124	235	204	98	36	125	1144	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526

Table 4 will shows profit that will be obtained from the optimization process in the second planting season based on the water units that have been analyzed in table 1. Namely 16 units of water.

Table 5. Profit Based on Water Given in the Second Planting Season

Stage profit (IDR In Million)							
1	2	3	4	5	6	7	8
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
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124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526
124	235	204	98	36	125	1175	526

The next step involves calculating the profit using a backtracking procedure, moving from the final stage back to the initial stage. This process helps determine the optimal water allocation path and the number of water units to be distributed at each stage or irrigation structure based on the decision variables at each stage. (Aprilia et al., 2022).

Optimization using Dynamic Deterministic Program

The implementation and impact of the optimization at each stage are further illustrated and clarified through Figure 4, which provide detailed information on irrigated land area, water distribution patterns, and the corresponding profits before and after optimization.

Based on the forward recursive and backtracking procedure that have been carried out, Figure 4 illustrates the optimal route for water allocation across all irrigation structures during each planting season, following the sequence 7-7-6-5-4-3-2-1. This route reflects the most profitable distribution of limited water resources, ensuring maximum economic return. By applying this method in the first planting season, the maximum profit achieved was IDR 2,187,000,000, representing a 111% increase compared to the existing field condition. The same optimization route was applied during the second planting season, resulting in a profit of IDR 2,311,270,000, which marks an 18% increase. These percentage increases in profit were obtained by comparing the optimized results with the baseline field profit data. As shown in Table 6, the initial profit under existing field conditions was only IDR 1,035,000,000 in the first planting season and IDR 1,955,000,000 in the second planting season. The substantial profit improvements in both seasons clearly demonstrate the effectiveness of the deterministic dynamic programming method in enhancing the economic performance of irrigation systems, particularly under conditions of water scarcity and fluctuating demand.

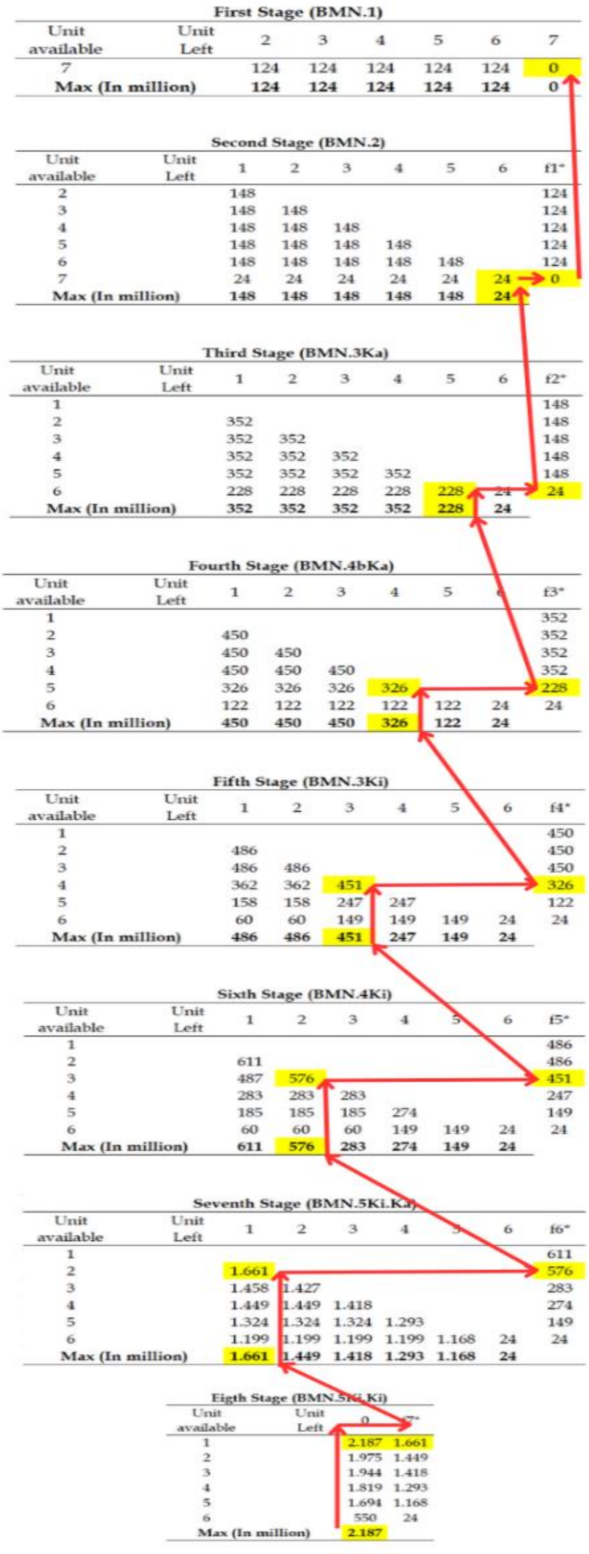

Figure 4. Optimization process using forward recursive and back tracking method

Table 6. Optimization Results Using Dynamic Deterministic Program

Planting season	Optimal water supply route	Before	Profit (IDR) After
1	7-7-6-5-4-3-2-1	1.035.000.000	2.187.000.000
2	7-7-6-5-4-3-2-1	1.955.000.000	2.311.270.000
Total		2.990.000.000	4.498.270.000
Optimized profit gap			1.508.270.000

Table 7. Field Optimization

Planting season	Irrigated field area (ha)		Field optimized %	
	Before	After	Before	After
1	90.00	190.23	44.78	94.65
2	170.00	200.98	84.59	100.00

Table 7 provides a comprehensive summary of the optimized water allocations for all eight irrigation structures, along with the corresponding profit generated and the change in irrigated area relative to the conditions before optimization. The data clearly illustrate the impact of optimized water management, showing significant improvements in both land coverage and profitability. Before optimization, the cultivated area in the first planting season was 90 hectares, which represented 44.78% of the total available land area of 200.98 hectares. After optimization, this increased to 190.23 hectares, equivalent to 94.65% of the total land. In the second planting season, the cultivated area before optimization was 170 hectares, or 84.59% of the available land. After optimization, it increased to 200.98 hectares, reaching 100% utilization of the available land optimization. This level of detail is particularly valuable for practical field implementation. Knowing the exact amount of water needed at each intake point allows irrigation managers and field operators to allocate resources more effectively, avoid water wastage, and ensure that critical areas receive adequate supply (Andawayanti et al., 2021).

Moreover, this targeted distribution minimizes the potential for over- or under-irrigation, which can lead to crop stress or inefficient water use (Moslemzadeh et al., 2023). The application of a deterministic dynamic programming approach thus not only enhances water use efficiency but also provides a clear, data-driven framework for daily operational planning within the irrigation system (Palupi et al., 2023). In addition, by aligning water distribution with profit maximization, the model ensures that each cubic meter of water is contributing as much as possible to the economic sustainability of the farming system.

In general, the deterministic dynamic programming approach determines water allocation by focusing solely on maximizing profit, without taking into account the existing water distribution policies. This optimization process aims to allocate water efficiently across different irrigation structures to achieve the highest possible agricultural benefits.

Table 8. Water distribution patterns in first planting season

Structure/ Stage	Field Area (ha)	Irrigated Area (ha)		Profit (IDR in Million)	
		Before	After	Before	After
BMN.1	10.75	10.75	0	124	0
BMN.2	2.04	2.04	2.04	235	235
BMN.3Ka	17.74	17.74	17.74	204	204
BMN.4bKa	8.48	8.48	8.48	98	98
BMN.3Ki	3.14	3.14	3.14	36	36
BMN.4Ki	10.91	10.91	10.91	125	125
BMN.5Ki.Ka	102.16	36.94	102.16	425	1175
BMN.5Ki.Ki	45.76	0	45.76	0	526
Total	200.98	90	190.23	1035	2187

However, one consequence of this method is that in the first planting season, there is one irrigation structures (BMN.1) showed on table 7 that previously received water may no longer be irrigated due to the reallocation of resources. This shift in water distribution can lead to a reduction in profits for specific areas compared to the pre-optimization scenario. Despite this localized decrease, the overall profitability of the irrigation system improves after optimization. (Loong et al., 2024). The increase in total profit indicates that the optimized allocation strategy enhances agricultural productivity on a broader scale, ensuring that the available water resources are used in the most efficient manner possible. (Zhang et al., 2023).

This result highlights the potential trade-offs in irrigation management—while some areas may experience temporary losses, the overall system benefits from higher economic returns and improved land utilization.

Table 9. Water Distribution Patterns in Second Planting Season

Structure/ Stage	Field Area (ha)	Irrigated Area (ha)		Profit (IDR in Million)	
		Before	After	Before	After
BMN.1	10.75	10.75	10.75	124	124
BMN.2	2.04	2.04	2.04	235	235
BMN.3Ka	17.74	17.74	17.74	204	204
BMN.4bKa	8.48	8.48	8.48	98	98
BMN.3Ki	3.14	3.14	3.14	36	36
BMN.4Ki	10.91	10.91	10.91	125	125
BMN.5Ki.Ka	102.16	102.16	102.16	425	1175
BMN.5Ki.Ki	45.76	14.78	45.76	170	526
Total	200.98	170	200.98	1955	2311

Based on the analysis presented in Table 8, the optimization process using deterministic dynamic programming has proven to be highly effective in enhancing the economic performance of irrigation management in the Manikin Irrigation Area. In the first planting season, the total profit achieved after optimization reached IDR 2,187,645,000, with almost all irrigation structures receiving water allocations and contributing to land productivity. However, it is important to highlight a critical outcome of the optimization model: Stage BMN.1 did not receive any water allocation. This result is not an error but rather a direct consequence of the optimization principle embedded in the deterministic dynamic programming approach used in this study. Since the model is designed to maximize total profit rather than ensure equal distribution, it strategically favors irrigation stages that offer the highest economic return per unit of water. As a result, less profitable or marginally efficient areas may be deprioritized when water resources are limited. In contrast, Table 9 shows the results of the second planting season, where the optimization led to a total profit of IDR 2,311,270,000—the highest among the two seasons—with all irrigation structures and field areas fully irrigated. This outcome suggests that water availability in the second season was adequate to support complete coverage of the 200.98 hectares of available land.

Under these favorable conditions, the optimization model was able to fully distribute water across all stages while still achieving maximum profitability. The complete utilization of land and resources in the second season not only enhanced economic outcomes but also reinforced the efficiency and adaptability of the model under optimal conditions (Yekti et al., 2020).

The successful delivery of water across all stages, especially during the second season, reflects an improvement in integrated irrigation planning and resource management. It emphasizes the importance of precision in water allocation, particularly in regions with fluctuating climatic and hydrological conditions. The DDP model thus serves as a robust decision-support tool, guiding irrigation planning in a manner that balances water supply, agricultural demand, and economic outcomes (Wahab et al., 2025).

By comparing water balances before and after optimization, the model's effectiveness in reducing deficits, improving irrigation reliability, and minimizing inefficiencies can be critically assessed. Furthermore, the identification of any remaining mismatches between supply and demand can inform future improvements, policy decisions, and infrastructure upgrades (Wang et al 2021). In conclusion, the optimized irrigation strategy developed through this research marks a significant advancement in the pursuit of agricultural sustainability, water use efficiency, and economic resilience stain ability (Warin, 2023).

Figure 5 illustrates an overall increase in the number of planting season periods that can be sustained by the reliable discharge after optimization. This indicates an improvement in water availability alignment throughout the planting cycle. However, certain periods within the planting year, particularly in the early phase of the first planting season, still experience water shortages. This occurs mainly due to the high water demand required for seedling preparation and land cultivation, which is significantly greater than in the later growth stages.

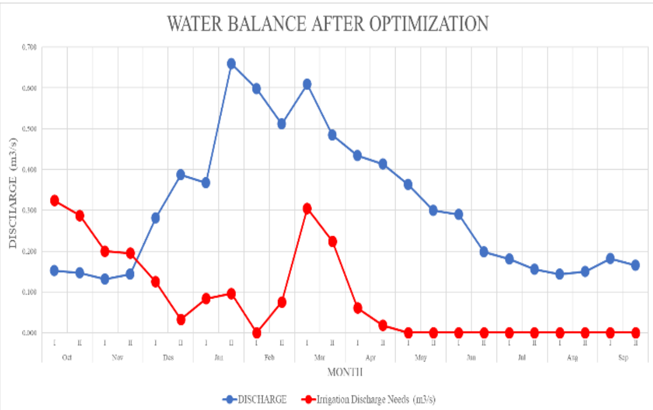

Figure 5. Water Balance after optimization

Table 10. Water Balance after Optimization

Month		Discharge 80% (m^3/s)	Irrigation Discharge Needs (m^3/s) Existing	(+) (-)	Condition
Oct	I	0.15	0.32	-0.17	Deficit
	II	0.15	0.29	-0.14	Deficit
Nov	I	0.13	0.20	-0.07	Deficit
	II	0.14	0.20	-0.05	Deficit
Des	I	0.28	0.13	0.16	Surplus
	II	0.39	0.03	0.35	Surplus
Jan	I	0.37	0.08	0.28	Surplus
	II	0.66	0.10	0.56	Surplus
Feb	I	0.60	0.00	0.60	Surplus
	II	0.51	0.07	0.44	Surplus
Mar	I	0.61	0.30	0.30	Surplus
	II	0.48	0.22	0.26	Surplus
Apr	I	0.43	0.06	0.37	Surplus
	II	0.41	0.02	0.40	Surplus
May	I	0.36	0.00	0.36	Surplus
	II	0.30	0.00	0.30	Surplus
Jun	I	0.29	0.00	0.29	Surplus
	II	0.20	0.00	0.20	Surplus
Jul	I	0.18	0.00	0.18	Surplus
	II	0.16	0.00	0.16	Surplus
Aug	I	0.14	0.00	0.14	Surplus
	II	0.15	0.00	0.15	Surplus
Sep	I	0.18	0.00	0.18	Surplus
	II	0.17	0.00	0.17	Surplus

Even with optimized water allocation, this early-season peak demand can cause temporary deficits. This condition suggests that while optimization improves the overall system performance, the unique water demand characteristics of the early planting stage remain a critical factor that may continue to limit water sufficiency during specific periods.

Conclusion

Based on the analysis and discussion presented, it can be concluded that the Manikin Irrigation Area, utilizing a rice–rice–fallow cropping pattern as outlined in RTTG 2021, can be effectively optimized using a deterministic dynamic programming approach to maximize both cultivated land area and agricultural profit. In the first planting season, before optimization, only 90 hectares were irrigated, generating a profit of IDR 1,035,000,000. After optimization using the 7-7-6-5-4-3-2-1 route, the irrigated area increased to 190.23 hectares (111% increase), with profit rising to IDR 2,187,645,000 (111% increase). Similarly, in the second planting season, irrigated land increased from 170 to 200.98 hectares (18% increase), and profit rose from IDR 1,955,000,000 to IDR 2,311,270,000 (18% increase). Furthermore, a comparison of the water balance before and after optimization, as shown in Table 1 and Table 10, indicates an increase in surplus periods from 19 to 20 within the annual planting cycle. Although the increase is modest, it reflects better alignment between water availability and irrigation demand. However, some deficit periods still remain, highlighting the continued limitation of water availability in the Manikin Irrigation Area.

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Conflicts of Interest

The authors declare no conflict of interest.

References

Adatika, L., Suripin, S., & Darsono, S. (2021). Optimasi Operasi Waduk Dolok dengan Program Dinamik. *Briliant: Jurnal Riset dan Konseptual*, *6*(1), 205-215. https://doi.org/10.28926/briliant.v6i1.595

Andawayanti, U., Muldianto, H., Suhartanto, E., & Soetopo, W. (2021). Analisis Biaya Pengelolaan Air Dengan Metode Sistem Dinamik Pada Waduk Jatigede. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, *12*(2), 197–204. https://doi.org/10.21776/ub.pengairan.2021.012.02.11

Aprilia, H. D., Sayekti, R. W., & Wahyuni, S. (2022). Studi Optimasi Alokasi Air Irigasi Pada Daerah Irigasi Sarangan Kabupaten Madiun Dengan Program Dinamik. *Teras Jurnal: Jurnal Teknik Sipil*, *12*(2), 493-506. https://doi.org/10.29103/tj.v12i2.789

Babba, E. T., Limantara, L. M., & Soetopo, W. (2021). Analisa Optimasi Irigasi Pada Daerah Irigasi Alopohu Kabupaten Gorontalo Dengan Program Dinamik Deterministik. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, *12*(2), 186-196. https://doi.org/10.21776/ub.pengairan.2021.012.02.10

Bale, F. J., Bisri, M., & Wahyuni, S. (2023). Optimization Utilization Study Storage of Raknamo Dam Amabi Oefeto District Kupang Region. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, *14*(2), 134–142. https://doi.org/10.21776/ub.pengairan.2023.014.02.4

Berbel, J., & Expósito, A. (2022). A decision model for stochastic optimization of seasonal irrigation-water allocation. *Agricultural Water Management*, *262*, 107419. https://doi.org/10.1016/j.agwat.2021.107419

Damayanti, I., & Santosa, B. (2022). Analisis Optimasi Pola Tata Tanam Jaringan Irigasi Daerah Irigasi Cidurian Tangerang Menggunakan Program Linier. *Teras Jurnal*, *12*(1), 281-294. http://dx.doi.org/10.29103/tj.v12i1.642

Feng, Z. K., Luo, T., Niu, W. J., Yang, T., & Wang, W. C. (2023). A LSTM-based approximate dynamic programming method for hydropower reservoir operation optimization. *Journal of Hydrology*, *625*, 130018. https://doi.org/10.1016/j.jhydrol.2023.130018

Ghaisani, S. F., Yasa, I. W., & Setiawan, E. (2024, July). Optimization Model of Irrigation Water Allocation in Batujai Irrigation Area Using Dynamic Program. In *International Conference on Rehabilitation and Maintenance in Civil Engineering* (pp. 409-417). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-2143-9_44

Gong, X., Zhang, H., Ren, C., Sun, D., & Yang, J. (2020). Optimization allocation of irrigation water resources based on crop water requirement under considering effective precipitation and uncertainty. *Agricultural Water Management*, *239*, 106264. https://doi.org/10.1016/j.agwat.2020.106264

Hariyadi, A., Bisri, M., Juwono, P. T., & Asmaranto, R. (2024). Water Resources Management as a Supporting Optimization Model for the Jatigede Reservoir. *Journal of Hunan University Natural Sciences*, *51*(7). https://doi.org/10.55463/issn.1674-2974.51.5.15

Hou, Y., Liu, Y., Xu, X., Fan, Y., Ma, S., & Wang, S. (2023). Grid-scale crop dynamic layout optimization model considering stakeholders' cropping preferences and practice behaviours. *Ecological Indicators*, *155*, 110963. https://doi.org/10.1016/j.ecolind.2023.110963

Indriani, Y., Limantara, L. M., & Soetopo, W. (2020). Analisis Optimasi Untuk Prioritas Pembangunan Embung Berbasis Ketersediaan Air Di Kecamatan Kedungadem Kabupaten Bojonegoro. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, *11*(2), 94–103. https://doi.org/10.21776/ub.pengairan.2020.011.02.03

Juwono, P. T., Limantara, L. M., Soetopo, W., & Nopebrian, A. (2018). Optimization of Irrigation Cropping Pattern (Case Study on Karang Anyar Irrigation Area, Malang Regency, Indonesia). *GEOMATE Journal*, *15*(50), 197-204. https://doi.org/10.21660/2018.50. 92322

Kharistanto, R. T. K., Montarcih, L., & Limantara, W. S. (2022). Studi Optimasi Pemanfaatan Air Irigasi Menggunakan Program Linier Pada Daerah Irigasi Manikin Kabupaten Kupang. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *3*(1), 487-500. https://doi.org/10.21776/ub.jtresda.2023.003.01.42

Lake, T. C. M., Sayekti, R. W., & Soetopo, W. (2021). Studi Simulasi Pemberian Air Irigasi Berdasarkan Debit Andalan di Daerah Irigasi Bena Kecamatan Amanuban Selatan Kabupaten Timor Tengah Selatan Provinsi Nusa Tenggara Timur. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air*, *1*(2), 839–849. https://doi.org/10.21776/ub.jtresda.2021.001.02.41

Li, M., Xu, Y., Fu, Q., Singh, V. P., Liu, D., & Li, T. (2020). Efficient irrigation water allocation and its impact on agricultural sustainability and water scarcity under uncertainty. *Journal of Hydrology*, *586*, 124888. https://doi.org/10.1016/j.jhydrol.2020.124888

Limantara, L. M., & Soetopo, W. (2020). *Manajemen air (Water management)*. Penerbit Andi.

Long, Q., Gao, X., Hu, Y., Hu, Y., Wang, Z., Mao, W., & Lu, X. (2024). Optimization of ecological network to improve water conservation services in the Nianchu River Basin. *Journal of Environmental Management*, *372*, 123368. https://doi.org/10.1016/j.jenvman.2024.123368

Ma, T., Zhang, Y., Wang, H., & Tan, N. (2024). A multiobjective optimization model for allocating water quantity and quality in the Yangtze and Yellow River basins. *Journal of Environmental Management*, *371*, 123166. https://doi.org/10.1016/j.jenvman.2024.123166

Mabrur, M. A., Wahyuni, S., & Dermawan, V. (2021). Studi Optimasi Alokasi Air Pada Daerah Irigasi Bilokka Kecamatan Panca Lautang Kabupaten Sidrap Provinsi Sulawesi Selatan Menggunakan Program Linear. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air, 1*(1), 170–179. https://doi.org/10.21776/ub.jtresda.2021.001.01.15

Moslemzadeh, M., Farzin, S., Karami, H., & Ahmadianfar, I. (2023). Introducing improved atom search optimization (IASO) algorithm: Application to optimal operation of multi-reservoir systems. *Physics and Chemistry of the Earth, Parts A/B/C*, *131*, 103415. https://doi.org/10.1016/j.pce.2023.103415

Nait, C., Bisri, M., Soetopo, W., Prayogo, T. B., Krisnayanti, D. S., & Limantara, L. M. (2022). Climate change effects on Noel Puames River area rainfall in Kupang District. *Journal of Hunan University Natural Sciences*, *49*(8). https://doi.org/10.55463/issn.1674-2974.49.8.22

Nalurita, S., Limantara, L. M., & Prayogo, T. B. (2017). Studi Optimasi Distribusi Air Irigasi pada Daerah Irigasi Tengoro Kabupaten Banyuwangi dengan Program Dinamik Stokastik. Jurnal Teknik Pengairan: *Journal of Water Resources Engineering, 8*(1), 72–78. Retrieved from https://jurnalpengairan.ub.ac.id/index.php/jtp/article/view/309

Nuf'a, H., Limantara, L. M., & Soetopo, W. (2016). Optimasi air waduk gondang dengan metode dinamik deterministik. *Jurnal Teknik Pengairan*, *7*(1), 25-36. Retrieved from https://jurnalpengairan.ub.ac.id/index.php/jtp/article/view/281

Palupi, K. P. P., Limantara, L. M., & Wahyuni, S. (2023). Studi Optimasi Alokasi Air Irigasi pada Daerah Irigasi Sewu Kabupaten Madiun Menggunakan Program Dinamik. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air*, *4*(1), 312–322. https://doi.org/10.21776/ub.jtresda.2024.004.01.026

Paramitha, A. P., Bella, R. A., Karels, D. W., & Krisnayanti, D. S. (2020). Simulasi Pola Tanam Pada Sembilan Daerah Irigasi Tersebar di Kota Kupang. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, *11*(2), 104–115. https://doi.org/10.21776/ub.pengairan.2020.011.02.04

Pratiwi, M. A., Jayadi, R., & Kironoto, B. A. (2022). Kajian Potensi Pemanfaatan Waduk Bener Untuk Pemenuhan Air Baku dan Air Irigasi. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, *13*(1), 12–22. https://doi.org/10.21776/ub.pengairan.2022.013.01.02

Salimah, G. N., Limantara, L. M., & Prayogo, T. B. (2024). Studi Optimasi Pemanfaatan Air Irigasi Menggunakan Metode Program Linear Pada Daerah Irigasi Babakan Kabupaten Brebes. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air*, *4*(2), 1633–1646. https://doi.org/10.21776/ub.jtresda.2024.004.02.160

Shafiya, A., Sayekti, R. W., & Prayogo, T. B. (2022). Studi improveOptimasi Alokasi Air Irigasi pada Daerah Irigasi Brangkal Bawah Kabupaten Madiun Menggunakan Program Dinamik. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *3*(1), 251-262. https://doi.org/10.21776/ub.jtresda.2023.003.01.22

Subroto, T., Bisri, M., Limantara, L. M., & Soetopo, W. (2021). Optimization Model of the Way Rarem Reservoir Operation Pattern by Using Stochastic Dynamic Programming. *Journal of Hunan University Natural Sciences*, *48*(11). Retrieved from https://jonuns.com/index.php/journal/article/view/864

Triwidianto, H., Limantara, L. M., & Soetopo, W. (2022). Studi Optimasi Pemanfaatan Air Irigasi Menggunakan Program Linier pada Daerah Irigasi Pirang Kabupaten Bojonegoro. *Jurnal Teknologi Dan Rekayasa Sumber Daya Air*, *3*(1), 298–310. https://doi.org/10.21776/ub.jtresda.2023.003.01.26

Wang, J., & Xue, X. (2021). Optimized allocation of water resources in the Jiulong River Watershed under cooperative game based on linear programming. *Desalination and Water Treatment*, *239*, 94-100. https://doi.org/10.5004/dwt.2021.27798

Wahab, W. A., Sayekti, R. W., & Wahyuni, S. (2025). Studi Optimasi Alokasi Air di Daerah Irigasi Pirang Kabupaten Bojonegoro Menggunakan

Program Dinamik. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *5*(1), 162-172. https://doi.org/10.21776/ub.jtresda.2025.005.01.016

Warin, X. (2023). Reservoir optimization and machine learning methods. *EURO Journal on Computational Optimization*, *11*, 100068. https://doi.org/10.1016/j.ejco.2023.100068

Yekti, M. I., Wijakesuma, T. G. R., & Harmayani, K. D. (2020). Evaluasi Pola Operasi Waduk Tamblang di Kabupaten Buleleng Provinsi Bali. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering*, *11*(2), 116–127. https://doi.org/10.21776/ub.pengairan.2020.011.02.05

Zhang, F., Cui, N., Guo, S., Yue, Q., Jiang, S., Zhu, B., & Yu, X. (2023). Irrigation strategy optimization in irrigation districts with seasonal agricultural drought in southwest China: A copula-based stochastic multiobjective approach. *Agricultural Water Management*, *282,* 108293. https://doi.org/10.1016/j.agwat.2023.108293

Zhang, F., Guo, P., Engel, B. A., Guo, S., Zhang, C., & Tang, Y. (2019). Planning seasonal irrigation water allocation based on an interval multiobjective multi-stage stochastic programming approach. *Agricultural Water Management, 223,* 105692. https://doi.org/10.1016/j.agwat.2019.105692

Zhang, X., Guo, P., Zhang, F., Liu, X., Yue, Q., & Wang, Y. (2021). Optimal irrigation water allocation in Hetao Irrigation District considering decision makers' preference under uncertainties. *Agricultural Water Management, 246,106670.* https://doi.org/10.1016/j.agwat.2020.106670

Zhou, Y. X., Li, Y. P., Huang, G. H., Zhang, Y. F., & Ma, Y. (2022). A fixed-mix stochastic fractional programming method for optimizing agricultural irrigation and hydropower generation in Central Asia. *Journal of Contaminant Hydrology*, 248, 104004. https://doi.org/10.1016/j.jconhyd.2022.104004