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Policy implications of managing reservoir water for multiple uses of irrigation and fisheries in southeast Vietnam

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Abstract: We introduce a dynamic-optimization model developed to determine the trade-offs in the economic value between managing reservoir water for irrigation and for fisheries. The policy implications of managing reservoir water for multiple uses of irrigation and fisheries in Vietnam are investigated. Results indicate that dominantly managing reservoir water for irrigation is more lucrative than for fisheries. To improve the economic performance of managing reservoir water for multiple uses, three policies are introduced: (1) switching crops, (2) extending irrigation area, and (3) redistributing income. The results also indicate that, given the dominant use of water for irrigation, income can be diverted from rice production to fisheries without much reduction in rice-production income. The method used in this study could be applied to manage other reservoirs in Asian countries for multiple uses where reservoir water is often used for fisheries as a secondary purpose.

Key words: water management, multiple uses, reservoir water, irrigation, fisheries, optimization, Vietnam.

1. INTRODUCTION

Freshwater reservoirs can have many uses, including irrigation, fisheries, recreation, hydroelectricity, and flood control. Many scientists have studied the management of reservoir water to maximize its benefits (Connelly *et al.*, 2007; Hanson *et al.*, 2002; Rogers *et al.*, 2014; Chatterjee *et al.*, 1998). As commonly observed in other cases of multiple-use resources, managing water from a reservoir for a primary use often generates negative impacts on the secondary use (Lorenzen *et al.*, 2000; Renwick, 2001; Ward *et al.*, 1996; Tran *et al.*, 2011) as well as creates conflicts of interest (Lorenzen *et al.*, 2003; Nandalal and Simonovic, 2003). These conflicts often center on the quantity and timing of water distribution for the different uses (Nguyen-Khoa and Smith, 2004; Yoffe and Ward, 1999). The recent increase in the number of reservoirs in Vietnam has caused conflicts of interest in reservoir water use to become more widespread and prominent. This highlights a key need to establish management policies to lessen or facilitate conflicts within an existing agricultural production system that uses water from a reservoir for multiple uses.

In southeast Vietnam, the main purpose of reservoirs is to provide water for irrigation in the dry seasons. Managing reservoirs for the dominant use of irrigation often creates negative effects on fisheries. In particular, to avoid reduction in crop yields in cases of drought, water is maintained at high levels in reservoirs to act as a buffer. This results in low fish yields because fish are not easily harvested when the reservoir water levels are high (Schilizzi, 2003; Tran *et al.*, 2010). However, a large segment of the population engaged in reservoir fisheries is the poor whose livelihoods depend on them. Dominantly managing reservoirs for irrigation may be detrimental to the poor fishers.

A number of previous studies have examined the economics of developing reservoir fisheries to improve livelihoods of poor fishers in Vietnam (Truong, 2007; Nguyen *et al.*, 2001; Lorenzen *et al.*, 2003; De Silva, 2003; Ngo and Le, 2001; Petersen *et al.*, 2005). However, these studies mainly focused on the technological perspectives of reservoir fisheries and assumed that reservoir water was predominantly used for fisheries. This assumption was not reasonable as most reservoirs were managed for irrigation. In reality, policy makers are concerned with the problem of managing reservoir water for both irrigation and fisheries. This study investigates the policy implications in order to improve the economic performance of managing reservoirs for multiple uses.

The optimization model has been used to investigate the problem of managing reservoir water for irrigation (Rani and Moreira, 2010; Georgiou and Papamichail, 2008; Senzanje *et al.*, 2008; Georgiou *et al.*, 2006; Reca *et al.*, 2001). However, the application of the optimization model to manage reservoir water for conflicting uses is rare (Ghahraman and Sepaskhah, 2002; Tilmant *et al.*, 2002; Wolf, 2002; Li *et al.*, 2005; Tran *et al.*, 2011). In this study, a dynamic-optimization model for reservoir water management for irrigation and fisheries in southeast Vietnam (Tran *et al.*, 2012) was used to evaluate the trade-offs in the economic value of a unit of water used for irrigation and fisheries. These values were then used as a benchmark for policy makers to specify policies to improve the economic performance of managing reservoir water for multiple uses. A modeling approach is appropriate, such as incorporating the complexity of the biological characteristics of rice and fish production as well as an intertemporal problem of water resource management. A feature of this study is to specify policies for different classes of reservoirs in southeast Vietnam where managing reservoir water for multiple uses has challenged policy makers.

This study aims to quantify (1) trade-offs in the economic value of a unit of water used for irrigation and fisheries and (2) amount of income that can be diverted from farmers to fishers as reservoir water is dominantly managed for irrigation. The remaining sections of the paper are organized as follows: Section 2 describes the study area, section 3 describes the research methodology and tools, section 4 presents data and parameters used in the model, section 5 presents findings and discussions, and section 6 provides conclusions.

2. THE STUDY AREA

The structure of an agricultural production system that uses water from a reservoir in southeast Vietnam is presented in Figure 1. It includes the reservoir, irrigated rice production in the surrounding areas, and fish production within the reservoir.

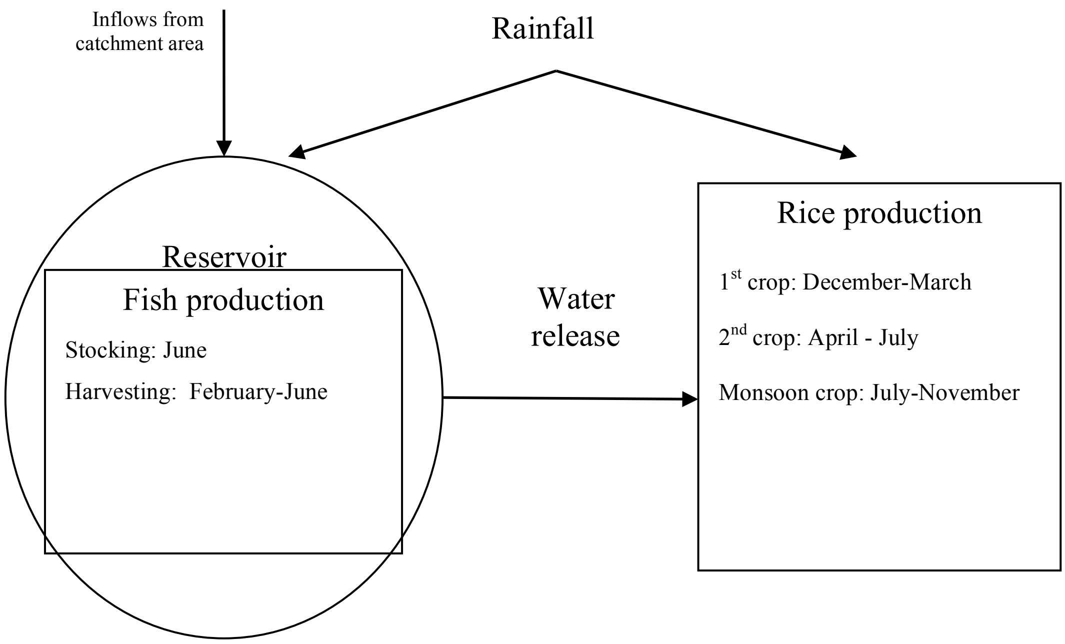

Figure 1. The structure of an agricultural production system using water from a reservoir for both irrigation and fisheries in southeast Vietnam.

Water availability in the reservoir varies throughout the year depending on the rainfall and inflows from catchment areas. Water is regularly released from the reservoir for rice production during the dry season from December to June (or July), and it is replenished by rainfall and inflows during the wet season from June to November (Table 1). Water availability in the reservoir at the end of the wet season depends on reservoir size, stored water from the previous year, and rainfall. The reservoir usually holds its highest water level at the end of the wet season (November), which is the start of the irrigation season. As water is released for irrigation in the first rice season (December to March), the water level declines. At the beginning of the second rice crop season (April), water usually remains at intermediate levels. Water may be released continuously until the end of the irrigation season (June or July).

Table 1. Climatic season, reservoir operations, and seasonal calendar for rice and fish production

Months	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Climatic season	Dry season						Wet season					
Reservoir operations	Release								Storage			
Rice production	First rice crop				Second rice crop				Monsoon crop			
Fish production				Fish-harvest season			Stocking					
Recreation	Recreational fishing service											

Over a one-year period, three rice crops are consecutively cultivated around the reservoirs (Table 1). The first crop is grown from December to March. The second crop is grown from April to July. These two crops must be irrigated from December to June because of low rainfall levels during this period. The third crop (monsoon crop) is grown from July to November. This crop does not require irrigation due to the high frequency of rainfall during this period.

In recent years, most irrigation reservoirs in southeast Vietnam have also been used for fisheries operated by aquacultural cooperatives (Ngo and Le, 2001; Schilizzi, 2003). Fishery income comes from two main sources: (1) fish production and (2) recreational fishing service. First, fish-production activities operate on an annual cycle. The stocking of fingerlings into the reservoirs often starts in June when the wet season commences. Five main species are stocked: common carp (*Cyprinus carpio)*, silver carp (*Hypophthalmichthys molitrix)*, grass carp (*Ctenopharyngodon idella)*, bighead carp (*Aristichthys nobilis)*, and mrigal (*Cirrihinus mrigal)* of which 40% to 50% are silver carp and mrigal (Nguyen *et al.*, 2001). Harvesting fish occurs from February to June when the reservoir water is at its lowest levels (Nguyen, 2008) using simple technologies, such as small boats and large drag nets (Table 1). Second, the recreational fishing service occurs from December to July.

3. RESEARCH METHODOLOGY AND TOOLS

This study was first used as a case study of the Daton Reservoir (see Tran *et al.*, 2011, for more information), which was a representative agricultural production system using water from a reservoir for both irrigation and fisheries in southeast Vietnam. The results obtained from this reservoir were then extrapolated to specify management policies for different classes of reservoirs.

First, this study employed the dynamic-optimization model (Tran *et al.*, 2012) to calculate incomes of rice and fish production. Second, these incomes were used to quantify how much income could be diverted from farmers to fishers without causing a negative impact on farmers. Third, the net income received by each enterprise, after redistributing income from farmers to fishers, was compared to evaluate how much fishers' incomes had improved and how much farmers' incomes had declined.

3.1 Model outline

The description of the complex dynamic-optimization model for reservoir water management in southwest Vietnam (Tran *et al.*, 2011) was revised by Tran *et al.* (2012). The model depicts the optimal strategy to manage reservoirs in Vietnam where water is used for two competing production systems (irrigation and fisheries), which differ with respect to their needs for quantity and timing of water release. The model comprises two dynamic-simulation components, one based on dated water production functions for rice production and another that represents the bioeconomics of a reservoir fishery. The intertemporal problem of water management is also considered in the model by incorporating stochastic rainfall, irrigation requirements (IR), and the demand for low water levels for fish harvesting.

An eight-stage stochastic dynamic-programming model was coded in Matlab to find the maximum value of the expected net present value (ENPV) of income streams obtained by managing the reservoir water. Detailed information regarding the optimization procedure (climatic and hydrological data employed to estimate ENPV of the income) is presented in Tran *et al.* (2011).

3.2 Objective of the model

To define the trade-offs in the economic value of a unit of water used between two conflicting and competing uses (irrigation and fisheries), this study employed the dominant-use management approach for multiple uses (Klemperer, 1996; Bowes and Krutilla, 1989). According to this approach, water is optimally managed for a dominant use to obtain a maximum value generated by that use. The values generated by the other uses are assigned to that maximum value to form the maximum total value generated by the system. This approach is well suited for dominantly managing reservoir water for irrigation (Scenario 1) and dominantly managing reservoir water for fisheries (Scenario 2). For Scenario 1, where water is dominantly managed for irrigation, fish are still harvested to a limited degree and recreational fishing service still occurs. As a result, the fishers still expect to achieve positive income from fish production and recreational fishing service. Therefore, the maximum total income for the management of reservoir water for multiple uses must be the sum of the maximum income obtained from optimized rice production and the additional sum of income obtained from nonoptimized fish production and recreational fishing service. For Scenario 2, where water is dominantly managed for fisheries, recreational fishing service also occurs and rice is still cultivated. Therefore, farmers still expect to achieve positive income. The maximum total income for the management of reservoir water for multiple uses must be the sum of the maximum income obtained from optimized fish production and the sum of the additional income obtained from nonoptimized rice production and recreational fishing service. The objective function of the model is as follows:

If the reservoir is dominantly managed for irrigation,

$$I = I_r^* + I_f^{'} + I_t. \tag{1}$$

If the reservoir is dominantly managed fisheries,

$$I = I_f^* + I_r^{'} + I_t \tag{2}$$

where I_r^*, I_f^* are the maximum income obtained from the optimal water management for irrigation and fisheries, respectively; $I_r^{'}$ is rice income determined according to the optimal management strategy for fisheries; $I_f^{'}$ is fish income determined according to the optimal management strategy for irrigation; and I_t is income obtained from recreational fishing service, which is an additional income regardless of reservoir being dominantly managed for either irrigation or fisheries.

3.3 Rice-production income

In the model, rice-production income was calculated as follows:

$$I_r = A_r q_r p_r - c_r \tag{3}$$

where c_r was total rice-production cost measured in million Vietnam Dong (10^6 VND; 1 US$ ~ 21,500 VND—price in February, 2015); A_r was irrigated areas (ha); p_r was the price of rice (10^6 VND); and q_r was rice yields (tonnes/ha) estimated using a water production function, which was adapted by Tran *et al.* (2011) from its original form developed by Rao *et al.* (1988).

$$q_r = Y_p\left(1 - \sum_{n=1}^{8} k_{y_n}\left(1 - \frac{W}{W_0}\right)_n\right) \tag{4}$$

where Y_p was the potential yield of rice (tonnes/ha), k_{y_n} was the yield response factor at stage n, W_0 was the rice water requirements [% reservoir capacity (RC)], and W_n was total water supply at stage n (%RC).

3.4 Fish-production income

In the model, fish-production income was calculated as follows:

$$I_f = TR_f\left(1 - PCE\right) - c_f \tag{5}$$

where c_f was total fish-production cost (10^6 VND) and TR_f was total fish revenue (10^6 VND) estimated using a bioeconomic model for reservoir aquaculture in Vietnam (BRAVO), which was adapted by Truong and Schilizzi (2010) from the original model developed by Petersen *et al.* (2007).

$$TR_f = \sum_{i=1}^{\alpha}\sum_{j=1}^{\beta} W_{H_{ij}} P_{H_i} \tag{6}$$

where $W_{H_{ij}}$ was the weight of each species i (tonnes) at harvest j, P_{H_i} was the price of each species i (10^6 VND/tonne), α was the number of species, and β was the number of harvesting periods. To account for fish revenue in response to fluctuations in reservoir water levels, these revenues were then multiplied by the physical concentration effect (PCE) coefficient developed by Tran *et al.* (2011).

$$PCE_n = \left(\theta\gamma\omega A_0^{(\theta+1)} s_t^{(\gamma\theta-1)}\right)\left(\frac{s_t}{Y_f}\right)\left(\%\Delta s\right) \tag{7}$$

where θ was the parameter obtained from the reservoir hypsographic equation, $A = A_0 s^{\theta}$, which indicated the relationship between reservoir surface area A (ha) and RC, s (%RC); A_0 was the reservoir surface area at full level of water (ha); and γ and ω were parameters obtained from Nguyen *et al.* (2001), who indicated the relationship between fish yields and reservoir surface area as $Y = \gamma A^{\varpi}$.

4. DATA AND PARAMETERS USED FOR THE MODEL

Data and parameters for this study can be found in more detail in Tran *et al.* (2011). Here, we provide key information, which is useful for the appraisal of the model outcomes.

4.1 Rice-production data

Rice-production data were collected from both primary and secondary sources. First, 60 farmers were interviewed to gather information related to cultivated areas; cropping patterns; average, minimum, and maximum crop yields; prices of inputs (seeds, fertilizes, chemicals and labor); rice price; and prices of capital. The information was then used to calculate rice-production costs. The average production cost per ha was 11.87 (10^6 VND) and 8.6 (10^6 VND) for the first and second rice crops, respectively. The average rice price in 2014 was 5.0 (10^6 VND) per tonne. Second, the rice water requirement was simulated using the CROPWAT model (Swennenhuis, 2006) (Table 2). Then, they were fed into the water production function (Equation 4) to estimate rice yield in response to different levels of applied irrigation. Total revenue and total costs of the rice cultivated areas were estimated by multiplying these average values by the actual cultivated areas. Total rice income was estimated by subtracting the total cost from the total revenue.

Table 2. Potential yield of rice (Y_p), yield response factor (k_y), and rice water requirements (W_0)

Parameter	Units	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Y_p	tonnes/ha	6.5	6.5	6.5	6.5	6	6	6	6
k_y	no.	1	1.09	1.32	0.5	1	1.09	1.32	0.5
W_0	Mm	252.5	80.3	124.6	132.1	209	131.7	85.1	103.7

4.2 Fish-production data

Fish-production data were collected at the Daton Aquaculture Cooperatives, including the weight of each species at harvest time, market prices of each species at harvest time, yearly interest rate, stocking and restocking rates, stocking and restocking costs for each species, size of fingerlings, prices of fingerlings, costs of capital replacements (boats, nets, machines, etc.), costs of labor, and miscellaneous costs. These data were fed into the BRAVO model (Truong and Schilizzi, 2010) to calculate total fish yield for four harvest periods (Table 3). Technical parameters used for the biological model in the BRAVO model, such as the fish length and the growth coefficient of each species, were employed from data derived by Petersen *et al.* (2007). As mentioned previously, the other income source of fisheries was the income that the Daton Aquaculture Cooperatives obtained from the recreational fishing service. The information of the recreational fishing service was collected from the annual report of the cooperatives. The report indicated that the income of this service has fluctuated from approximately 0.5% to 2% of total annual fish-production income. In this study, the income from the recreational fishing service was chosen at 1% of the total annual income of fish production.

Table 3. Fish prices and fish yields obtained from BRAVO model

Fish Species	Prices (10^6 VND per tonne)	Fish yields (tonnes)							
		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Common Carp	36.0	0	0	0	3.506	3.026	2.636	2.262	0
Silver Carp	16.5	0	0	0	8.861	7.666	6.693	5.758	0
Grass Carp	27.0	0	0	0	7.043	6.239	5.573	4.887	0
Bighead Carp	16.5	0	0	0	4.477	3.93	3.479	3.027	0
Mrigal	25.5	0	0	0	4.154	3.584	3.121	2.678	0

Note: In the optimization model (Tran et al., 2011), fish harvesting happens only in periods 4-7.

4.3 Reservoir configurations

To extrapolate the results obtained from the Daton Reservoir to other different classes of reservoir configurations in southeast Vietnam, two criteria were used: the IR of rice production served by reservoir and the RC. First, an increase in irrigation area (IA) requires a higher IR and *vice versa*. Therefore, IA can be used to represent IR. Second, each initial water level of the Daton Reservoir is used to represent a full reservoir for reservoirs of different sizes. That is, when the Daton Reservoir at the beginning of the irrigation season is full, the initial water level of the reservoir can be used to represent another equivalently full reservoir at the beginning of the irrigation season. When the initial water level is lower, at 70% of the Daton Reservoir capacity (DRC), it can be used to represent a full reservoir with a lower maximum capacity than the Daton Reservoir, RC = 70% DRC.

The model results obtained as dominantly managing the Daton Reservoir for irrigation indicated that, when the initial water level of the reservoir was at 70% RC, the amount of reservoir water available for irrigation was sufficient to fully satisfy the water demand for 1,000 ha of rice production. Given this fixed irrigated area, as the initial water level in the reservoir at the beginning of the irrigation season decreased, the ratio $R = \frac{RC}{IR}$ decreased. In particular, when the initial water level was at 30% DRC or lower, the insufficient water supply for irrigation could cause water deficits for rice, leading to a significant reduction in rice income. Therefore, 30% DRC was chosen as a break-even point. When the initial water level was between 40%-60% DRC, water supply was sufficient for irrigation, resulting in significant increases in rice income. In this study, the midpoint of this range (50% DRC) represented another break-even point. In addition, when the initial water level was 70% DRC (or fluctuated around this level), the ratio, R, approached 1. Therefore, 70% DRC was also chosen as a break-even point. For this reason, the following sections used 30% DRC, 50% DRC, 70% DRC, and 100% DRC as the break-even water levels to classify four classes of reservoir configurations (Table 4).

Table 4. Classes of reservoir configurations

Initial water level	Classes of reservoir configurations	Descriptions
30% DRC ($R<<1$)	R_1	Reservoirs are full at the beginning of the irrigation season and have RC *much smaller than* total IR
50% DRC ($R < 1$)	R_2	Reservoirs are full at the beginning of the irrigation season and have RC *smaller than* total IR
70% DRC ($R \geq 1$)	R_3	Reservoirs are full at the beginning of the irrigation season and have RC *greater than* or *equal to* total IR
100% DRC ($R>>1$)	R_4	Reservoirs are full at the beginning of the irrigation season and have RC *much greater than* total IR

5. RESULTS AND DISCUSSION

This section reports and discusses the model results, focusing on (1) optimal water release and storage strategy, (2) trade-offs in the economic value of a unit of water between dominantly managing reservoirs for irrigation and for fisheries, and (3) policy implications for managing different classes of reservoirs for multiple uses.

5.1 Model results

5.1.1 Optimal water release and storage strategy

The optimal water release and storage strategy for the dominant use of irrigation are presented in

Table 5. For the R1 and R2 reservoirs, because of their limited capacity, water is reserved for the last three stages when dry weather may cause a significant reduction in rice yields. Less water stored in the reservoirs enhances the concentration of fish, resulting in high fish yields. Conversely, for the R3 and R4 reservoirs, adequate water is always supplied to satisfy the water requirement for rice production to achieve maximum yields. The remaining water is always stored, in case of drought, to ensure a water supply for subsequent rice crops. With storage, reservoir water levels remain high (22.7% RC and 52.7% RC), which reduces the concentration of fish and negatively affects fish yields.

Table 5. Optimal water release and storage strategy for the dominant use of irrigation

Classes of Reservoir	Optimal release (% RC)								Optimal storage (% RC)
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	
R1	1.0	5.0	8.0	0.0	2.8	8.0	6.0	7.0	16.0
R2	15.0	5.0	8.0	0.0	8.8	8.0	6.0	7.0	16.0
R3	16.0	5.0	8.0	8.0	13.0	8.0	6.0	7.0	22.7
R4	16.0	5.0	8.0	8.0	13.0	8.0	6.0	7.0	52.7

Optimal water release and storage for the dominant use of fisheries are shown in Table 6. The results illustrate that, for all classes of reservoirs, the maximum amounts of water are released in the first four stages in order to leave reservoir water at the lowest levels prior to fish-harvest season (Stage 4 to Stage 7). However, these releases cause a lack of water for irrigation during latter stages, resulting in significant reductions in rice yields. Rice is highly sensitive to water deficit at these stages. In cases of drought in subsequent years, less water stored in the reservoirs at the end of irrigation season (9.5% RC) may also negatively affect rice production.

Table 6. Optimal water release and storage strategy for the dominant use of fisheries

Classes of Reservoir	Optimal release (% RC)								Optimal storage (% RC)
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	
R1	27.0	0.0	2.0	0.1	0.7	2.0	5.5	0.0	9.5
R2	27.0	19.7	2.2	0.1	0.7	2.0	5.5	0.0	9.5
R3	27.0	27.0	15.0	0.1	0.7	2.0	5.5	0.0	9.5
R4	27.0	27.0	27.0	18.1	0.7	2.0	5.5	0.0	9.5

5.1.2 Trade-offs in the economic value of a unit of water between managing reservoir for irrigation and fisheries

Table 7 illustrates that dominantly managing reservoirs for irrigation is much more lucrative than for fisheries (comparing results across columns 4 and 7). The higher the RC, the larger the economic value generated. However, trade-offs in the economic value of a unit of water used between dominantly managing a reservoir for irrigation and fisheries is lower since those reservoirs hold a capacity greater than their IA. For example, if managing the R4 reservoir for fisheries, in order to gain 1.0 (10^6 VND) income from fisheries, the sacrifice of rice income would be 2.2 (10^6 VND). The trade-off is 2.9 (10^6 VND), counting the R3 reservoir. For these reservoirs, water is sufficient to satisfy rice water requirements to obtain maximum yield. Storing water for irrigation, in this case, does not improve rice yields but reduces fish yields.

Conversely, the trade-offs are much greater for reservoirs where capacity is smaller than IA. For example, the trade-offs are 3.5 and 3.4 for R1 and R2 reservoirs, respectively (Table 7). Regardless of managing these reservoirs for either irrigation or fisheries, water level is also at a low level during the fish-harvest season (Table 6), resulting in positive effects on fish yields. In addition, if managing these reservoirs for irrigation, losses in rice yields may be minimized because more water would be used for rice production.

Table 7. Comparing the income of the two scenarios (10^6 VND)

Classes of Reservoir (1)	Scenario 1 (S1)			Scenario 2 (S2)			Comparison (S2-S1)		**Trade -offs**
	Rice (I_r^1) (2)	Fish (I_f^1) (3)	Total (I^1) (4)	Rice (I_r^2) (5)	Fish (I_f^2) (6)	Total (I^2) (7)	ΔI_r (8)=(5)-(2)	ΔI_f (9)=(7)-3)	**(8)/(9)**
R1	23,871.7	4,811.0	28,682.7	8,432.6	9,176.4	17,609.0	-15,439.1	4,365.4	**3.5**
R2	33,849.6	4,517.1	38,366.7	17,792.6	9,175.9	26,968.6	-16,056.9	4,658.8	**3.4**
R3	41,049.1	3,702.3	44,751.5	25,544.2	9,136.4	34,680.6	-15,504.9	5,434.1	**2.9**
R4	41,342.6	2,416.5	43,759.1	29,494.3	7,889.1	37,383.3	-11,848.4	5,472.6	**2.2**

Results presented in Table 7 also indicate that an increase in RC leads to an increase in total income regardless of managing reservoir water for either irrigation or fisheries, excluding managing the R4 reservoir for irrigation. This is because increasing RC and storing water for irrigation result in high levels of water at fish-harvest season. This leads to a low concentration of fish and causes significant reductions in fish yields. In particular, an increase of 293.5 (10^6 VND) in rice income, from 41,049.1 (10^6 VND) to 41,346.6 (10^6 VND), is insufficient to offset a reduction of 1,285.9 (10^6 VND) in fish income, from 3,702.3 (10^6 VND) to 2,416.5 (10^6 VND) – columns 2 and 3.

5.2 Policy implication

As discussed above, dominantly managing reservoirs for irrigation generates higher benefits than for fisheries. This section will discuss three policies that could potentially be applied to improve the economic performance of managing reservoirs for multiple uses.

5.2.1 Switching crops

For R1 and R2 reservoirs where RC is smaller than IR, switching a portion of rice crops to high-value, dry-land crops (e.g., corn or soybean) may not only create a better economic outcome for managing water for irrigation but also positively affect the local cattle-feed processing industry. First, switching crops leads to reductions in rice cultivated areas, resulting in lower IR. The remaining rice-cultivated areas may receive more irrigation, resulting in higher rice yields. In addition, more water used for irrigation brings reservoir water to low levels during fish-harvest season. This increases fish yields because of the higher concentration of fish. Second, increasing in cultivated areas of dry-land crops can supply more raw materials, which are currently imported for the cattle-feed processing industry. However, the switching of crops could be subjected to the growth condition of dry-land crops (e.g., agronomy and climate).

5.2.2 Extending irrigation areas

To improve the economic performance of managing R3 and R4 reservoirs for multiple uses, extension of the rice-growing areas is an accompanying policy that should be considered. The extension of IA will create two positive effects on total income: (1) an increase in rice income because of increases in cultivated areas and (2) an increase in fish income because water would be released for irrigation, which would lead to low water levels during fish-harvest season and higher fish yields (Table 8).

Results obtained from the Daton Reservoir are presented in Table 8. The Daton Reservoir represents the R4 reservoir, where the reservoir water level at the beginning of irrigation season is approximately 95%-100% RC and the reservoir irrigates 1,000 ha of rice production. Table 8 shows that, as the irrigated area is extended to 1,500 ha (+50%) and 2,000 ha (+100%), managing the reservoir for irrigation generates a higher total income than for fisheries, which are 16,367 (10^6 VND) (+34%) and 19,286.3 (10^6 VND) (+37%), respectively.

Table 8. Income of farmers and fishers as extending irrigated areas of the Daton Reservoir (10^6 VND)

Water management		Irrigated areas		
		IA = 1,000 ha	IA = 1,500 ha	IA = 2,000 ha
For irrigation (S1)		**43,759.1**	**64,438.7**	**72,067.6**
	Rice	41,342.6	61,160.9	68,660.1
	Fish	2,416.5	3,277.8	3,407.5
For fisheries (S2)		**37,383.3**	**48,071.7**	**52,781.3**
	Rice	29,494.3	40,182.6	44,892.2
	Fish	7,889.1	7,889.1	7,889.1
Comparison (S1-S2)		**6,375.8**	**16,367.0**	**19,286.3**
	ΔI_r	11,848.4	20,978.3	23,767.8
	ΔI_f	-5,472.6	-4,611.3	-4,481.5

5.2.3 Redistributing income

As previously discussed, the most cost-effective option to manage all classes of multiple-use reservoirs is for irrigation. However, the dominant management of the reservoir in southeast Vietnam for irrigation has created negative effects on fisheries, which are the main source of income for the poor. A possibility is that reservoirs could be dominantly managed for irrigation to maximize income for rice farmers. Then, a transfer payment could be taken from farmers to compensate fishers. The amount that fishers receive would be the difference in fishery income that fishers would receive from two scenarios.

Table 9 illustrates an increase in RC that results in a higher transfer payments (column 4) but with lower payment rates (column 8). In particular, the transfer payments are 4,365.5 (10^6 VND), 4,658.8 (10^6 VND), 5,334.1 (10^6 VND), and 5,472.6 (10^6 VND) for R1, R2, R3, and R4 reservoirs, respectively. The payment rates are 18%, 14%, 13%, and 13% for R1, R2, R3, and R4 reservoirs, respectively. In addition, the payment rates reduce as the extension of irrigated areas are considered for R3 and R4 reservoirs (Table 10). The extension of IA results in two benefits: (1) larger total incomes are generated for society and (2) rice farmers pay less per unit of water for prior use of reservoir water. For example, the payment rate reduces from 13% to 7% as cultivated areas of the R4 reservoir are extended from 1,000 ha to 2,000 ha (Table 10).

When reservoirs are managed for irrigation, applying the payment rates calculated in Table 10 for irrigation charges per ha can be determined for different classes of reservoirs, depending on the number of crops cultivated per year, IA, and reservoir fishery activities. For example, 1,000 ha surrounding the Daton Reservoir cultivate three rice crops a year. The irrigation charge per ha is 1.6 (10^6 VND) VND/year. The charge will be 0.75 (10^6 VND)/year as the Daton Reservoir IA is extended to 2,000 ha.

Table 9. Net income received by rice farmers and fishers before and after redistributing income (10^6 VND)

Classes of Reservoir (1)	Before (S1)		Transfer payment (TP) (4)	After (S1*)		Total income (7)=(5)+(6) or (2)+(3)	Payment rates (8)=(4)/(2)
	Rice (I_r^1) (2)	Fish (I_f^1) (3)		Rice (I_r^{1*}) (5)=(1)-(4)	Fish (I_f^{1*}) (6)=(3)+(4)		
R1	23,871.7	4,811.0	4,365.4	19,506.3	9,176.4	28,682.7	18%
R2	33,849.6	4,517.1	4,658.8	29,190.8	9,175.9	38,366.7	14%
R3	41,049.1	3,702.3	5,434.1	35,615.0	9,136.4	44,751.5	13%
R4	41,342.6	2,416.5	5,472.6	35,870.0	7,889.1	43,759.1	13%

Table 10. Transfer payment rates for different irrigated areas of R3 and R4 reservoirs

Water management		For R3 reservoir		For R4 reservoir		
		IA = 1,000 ha	IA = 1,500 ha	IA = 1,000 ha	IA = 1,500 ha	IA = 2,000 ha
For irrigation		**44,751.5**	**52,664.4**	**43,759.1**	**64,438.7**	**72,067.6**
(S1)	Rice	41,049.1	48,661.2	41,342.6	61,160.9	68,660.1
	Fish	3,702.3	4,003.2	2,416.5	3,277.8	3,407.5
For fisheries		**34,680.6**	**43,267.9**	**37,383.3**	**48,071.7**	**52,781.3**
(S2)	Rice	25,544.2	34,131.4	29,494.3	40,182.6	44,892.2
	Fish	9,136.4	9,136.4	7,889.1	7,889.1	7,889.1
Transfer payment		5,434.1 **13%**	5,133.2 **11%**	5,472.6 **13%**	4,611.3 **8%**	4,481.5 **7%**

Table 11. Comparing gains and losses in farmer income

Classes of reservoir	Rice income (10^6 VND)			Comparison	
	I_r^1 + tax (I_r^{1*})	(I_r^2)	(I_r^1)	(I_r^{1*})/(I_r^2)	(I_r^{1*}) /(I_r^1)
R1	19,506.30	8,432.62	23,871.71	231%	82%
R2	29,190.76	17,792.63	33,849.57	164%	86%
R3	35,615.05	25,544.21	41,049.14	139%	87%
R4	35,870.01	29,494.25	41,342.62	122%	87%

After redistributing income from rice production to fisheries, the maximum total income generated by the reservoir remains unchanged (column 7, Table 9). However, rice-production income would be reduced while fish-production income would increase. Although the net income that rice farmers receive is 82% to 87% of what they receive from managing reservoirs for irrigation, these incomes are significantly high (from 122% to 231%) compared to the income that farmers receive from managing reservoir water for fisheries (Table 11). Consequently, rice farmers may accept reductions.

6. CONCLUSIONS

The implications of managing reservoirs for multiple uses of irrigation and fisheries have been examined in this paper, using a dynamic-optimization model. Results indicate that trade-offs in the economic value of a unit of water used between irrigation and fisheries are higher as RC is small relative to the IA. This study also introduces three policies that could potentially be applied to improve the economic performance of dominantly managing reservoir water for irrigation. First, switching crops may be considered for reservoirs that are full at the beginning of the irrigation season with RC *smaller or much smaller than* total IR. Second, extending IA may be used for reservoirs that are full at the beginning of the irrigation season with RC *greater or much greater* IR. For the Daton Reservoir, as IA is extended to 2000 ha, total income generated by dominantly managing the reservoir for irrigation is 72,067.6 (10^6 VND) (+ 64.7%). Third, redistributing income from rice production to fisheries can be applied to all classes of reservoirs. Results indicate that the income redistribution rates are 13% to 18% of rice-production income, depending on RC and IA.

Overall, this study indicates that dominantly managing reservoir water for irrigation is the most cost-effective option for multiple uses. The significance is that the policy implications discussed in this study can be applied to manage reservoirs for multiple uses in Vietnam and in other regions in Asia where reservoir water is often used for fisheries as a secondary purpose.

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