



Optimizing competitive uses of water for irrigation and fisheries

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ABSTRACT

Choosing the appropriate reservoir water management strategy can be difficult when the water has multiple uses. This study examines this problem for reservoir managers where water use involves irrigation and fisheries. A stochastic dynamic programming (SDP) model is developed to facilitate reservoir management, using a case study illustration for southern Vietnam. The model includes the response of rice and fish yields to key factors including reservoir water levels, the timing and quantity of water release, and climatic conditions. The model also accounts for variation in rainfall patterns, irrigation requirements, and the demand for low water levels during the fish harvest season. Three production scenarios are examined where the reservoir's water is used for: only producing rice (scenario 1), only producing fish (scenario 2), and producing rice and fish (scenario 3). Key findings are: (1) for scenario 1, adequate water should be released to meet rice growing water requirements and residual water should be stored as a source of water in case of low rainfall; (2) for scenario 2, sufficient water needs to be released prior to the fish harvest to maximize this harvest; and (3) for scenario 3, water should be released prior to fish harvest, but sufficient water should remain to satisfy the water requirements of rice. When the reservoir is managed for joint production of rice and fish, net benefits are 6% greater than when the reservoir is managed solely for rice production. The SDP model developed in this paper could be adapted and applied to other multiple-use resources such as forests, river basins, and land.

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1. Introduction

Reservoir water is often managed for multiple uses including hydroelectricity, irrigation, flood control, fisheries and recreation. The challenge of managing a reservoir to achieve maximum use benefits can be difficult, where uses can be rivalrous, mandated, complementary, seasonal or climate-dependent (2003). Water release decisions are often based on the amount of water available in the reservoir, the water requirements of the various uses, and the forecast rainfall conditions (Jain and Singh, 2003; Nandalal and Bogardi, 2007).

In Vietnam, the primary use of reservoirs is for hydroelectricity, irrigation, and flood control. However, reservoirs also serve a number of secondary purposes such as the provision of drinking water, recreation, fisheries, and maintaining biodiversity. Managing reservoirs for the primary uses often generates negative impacts

on secondary uses; and conflicts of interest can arise. For example, to reduce the risk of low rice yields in times of drought, water is stored in reservoirs to act as a buffer. However, maintaining high levels of water in the reservoir may cause a reduction in fish yields as a result of lower fish harvest efficiencies (Tran et al., 2010). While income from fish may be a small proportion of total income derived from use of the reservoir's water, nonetheless the fishery may play an important role in alleviating poverty and supplementing people's protein diet (Schilizzi, 2003). For poor people living around the reservoir whose main income comes from fish production, water storage for rice production may be problematic when this reduces the productivity of fishing effort.

There have been studies on reservoir water release strategies using dynamic programming models, particularly for irrigation (Abdallah et al., 2003; Dudley, 1971a,b; Ghahraman and Sepaskhah, 2002; Reza et al., 2001a,b; Shangguan et al., 2002; Umamahesh and Sreenivasulu, 1997; Vedula and Mujumdar, 1992). However, their application to multiple and potentially conflicting uses is rare. We construct a stochastic dynamic programming model to address the situation where irrigated rice production and fish production are potentially conflicting uses of stored reservoir water. The model captures the seasonally varying demand for water for rice and fish

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Table 1

The two-crop growing cycle and associated fish harvests during the dry season.

Months Stages	December 1	January 2	February 3	March 4	April 5	May 6	June 7	July 8
Rice crop seasons		The first rice crop				The second rice crop		
Approximate rice growth periods ^a	Ini.	Dev.	Mid.	Lat.	Ini.	Dev.	Mid.	Lat.
Fish harvest periods				Period 1	Period 2	Period 3	Period 4	

^a Ini.: initial period; Dev.: development period; Mid.: mid-season period; Lat.: late-season period.

production. The model is used to identify optimal release strategies for reservoir management given the water demands of these enterprises when reservoir inflows are stochastic. Optimal dynamic water release decisions are identified for particular management settings such as a sole focus on rice production, currently the most often observed practice, or a joint focus on rice and fish production. Weather conditions are found to affect the optimal release strategies of the reservoir, when the reservoir is used solely for fish, or for both rice and fish production. However, due to the low market value of fish relative to rice, managing the reservoir solely for fish production is not an economically rational use of reservoir water.

In the following section the stochastic dynamic programming (SDP) model is described, followed by its case study application and the presentation of modeling results. Findings are discussed and conclusions are drawn for improved reservoir management in Vietnam.

2. Description of the research area

The Daton reservoir in southern Vietnam is used as a case study application of the model. This multiple-use reservoir has a water storage capacity much greater than the irrigation requirements of the crop areas it services. The reservoir is located in Dong Nai province about 150 km north-west of Ho Chi Minh City. Its surface area is just over 350 ha and it reaches a maximum depth of 20 m. Its maximum capacity is 19.6 cubic hectometres (hm³) and its minimum storage required for safety is 0.4 hm³. The reservoir is replenished by rainfall and inflows during the wet season (from July to November) and water is regularly released for irrigation during the dry season (from December to June). Water availability in the reservoir varies throughout the year depending on rainfall and the amount of water released for irrigation.

The Daton reservoir water is used predominantly for irrigating two consecutive rice crops of approximately 1000 ha each. The first crop is grown from December to March and the second crop from April to July. Each crop lasts about 100 days and is divided into four rice growth periods: initial, development, mid and late season period as defined in the Cropwat model (Swennenhuis, 2006). Each rice growth period in this study is 25 days long and approximately covers one month, reflecting the experimental results obtained by Le and Duong (1998). Two consecutive rice crops each with four growing periods lead to a model with eight 25-day stages (Table 1).

Since 2000, the Daton reservoir has also been used for fish production. The reservoir fishery operates on an annual cycle. Stocking fingerlings into the reservoir typically 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 silver carp and mrigal make up 40–50% of the stocked fingerlings (Nguyen et al., 2001). Harvesting of fish occurs when the reservoir water is at its lowest levels, often lasting approximately 4 months from February to May (Nguyen, 2008). In the eight-stage model the fish harvest season covers four 25-day periods, starting at stage 4 and ending at stage 7 (see Table 1).

3. Water release schedules and the economics of rice and fish

The profits from rice and fish production depend on the timing and quantity of water released. The amount of water released strongly affects rice yields. The rice crop achieves its full potential yield only if all water requirements of the rice are satisfied during each of its growth periods. Any water deficits result in reductions in yield and profit. For fish production, less water in the reservoir means a higher concentration of fish, leading to less harvest effort per quantity harvested and lower costs. Therefore, increases in water release result in higher profits from fish production.

3.1. Rice profit function

To account for crop yields in response to applied irrigation, water production functions have been employed (Bouman and Tuong, 2001; Dehghanisanij et al., 2009; Kang et al., 2000; Rao et al., 1988; Reza et al., 2001a; Shangguan et al., 2002). In the present study, to simulate rice yield responses to water releases at each stage, a water production function (Rao et al., 1988) was adapted using the approach proposed by Paudyal and Manguerra (1990):

$$Y_r = Y_p \left(1 - \sum_{n=1}^8 k_{y_n} \left(1 - \frac{W_n}{W_{0n}} \right) \right) \quad (1)$$

where Y_r is the rice yield (tonnes/ha); Y_p is the potential yield of rice (tonnes/ha); k_{y_n} is the yield response factor at stage n ; W_{0n} is the rice water requirements measured in percentage of reservoir capacity (%RC); W_n is total water supply at stage n (%RC), defined as:

$$W_n = u_n + q_n \quad (2)$$

where u_n is the water release from the reservoir at stage n and q_n is rainfall at stage n , both are measured in %RC; and $W_n \leq W_{0n}$ (also see Eq. (17)). No water conveyance losses and no rainfall losses are assumed. The first assumption is reasonable for irrigated rice production in southern Vietnam, as most irrigation reservoirs only supply water for irrigated areas immediately surrounding the reservoir. This means conveyance distances are short, reducing any conveyance losses. The second assumption is more open to some criticism. Irrigated rice fields are very flat with raised borders, so losses through rainfall run-off are typically small. Moreover, typically high humidity reduces losses through evaporation. However, as shown by evaporation data in Table 3, in stages 3 and 4, evaporation rates can be high relative to rainfall. Therefore the effective rainfall in these stages is less than actual rainfall, causing the irrigation water requirements to be slightly higher in these stages than is suggested by Eqs. (1) and (2).

The profit obtained from rice production at stage n was defined as:

$$V_m = A_r P_r Y_r - C_r \quad (3)$$

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