Application of Sine-Product Model for Operation of Irrigation Reservoir

Widandi Soetopo

Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia

Abstract: This paper studied about the application of a Sine-Product model as the production function in the dynamic programming model for the optimization of irrigation reservoir operation. The method was to use the real data of an irrigation reservoir, attach the Sine-Product model to the dynamic programming optimization model and run the optimization on two data series of dependable inflow into reservoir. The results showed that the Sine-Product model enabled the using of the dynamic programming for optimizing the operation of a reservoir serving a single planting schedule irrigation block in a multiple cropping seasons. Future researches could be attempted to make the optimization model is also applicable to multiple planting schedule irrigation blocks.

Key words: Sine-product model · Dynamic programming · Irrigation reservoir

INTRODUCTION

Although optimization of irrigation have been a subject of research for at least four decades, it seemed that no rigorous and systematic optimization procedures are being used in production agriculture [1]. If a farm field has a limited land area but abundant water, then the optimization can be done block by block. The situation became more complicated if it involves a large number of blocks and many kind of crops, while the amount of water was limited. Comprehensive analyses for this kind of farm field can employ mathematical programming techniques such as Linear Programming and Dynamic Programming. As an alternative there were more recent techniques such as Genetic Algorithm (GA) and Simulated Annealing (SA), which were belong to Simulation for Optimization method. For example the GA has been used as the optimization technique for modeling an optimal operation strategy of a reservoir for irrigation dealing with various kind of crops [2].

For optimizing a single reservoir, Dynamic Programming was considered as a good technique due to the sequential decision making and ease in handling non-linear objective functions and constraints [3]. The use of Dynamic Programming was quite extensive. A stochastic dynamic programming model has been developed for stream water quality management incorporating a fuzzy decision model [4]. For transbasin diversion system, subject to hydrologic uncertainty, transition probabilities of inflows and its related uncertainty, an optimization procedure that include Dynamic Programming, Stochastic Dynamic Programming, Simulation and Trial and Error adjusment of risk coefficient has been developed and applied to determine the optimal operation policy [5]. There was also a model of merging simulation and optimization by using approximate dynamic programming to produce near-optimal or at least high quality solutions [6].

In this research, a mathematical function which represent the crop productive function was used. The mathematical function, which fit the curve of general form of relationship between the applied water and the crop yield, was the result from a previous study and was called Sine-Product Model [7]. This function was made up of a series of functions, each of which to represent a period or stage of a process. It can be integrated conveniently to the Recursive Equation in the Dynamic Programming model and also to the procedure of Simulation for Optimization model. In this research, the implementation of this Sine-Product model for optimizing the operation of irrigation reservoir by dynamic programming was being investigated. The study used the case of Pejok reservoir in the District of Bojonegoro – East Java, Indonesia. The reservoir was designed to supply an irrigation area with 3 cropping seasons.

Corresponding Author: Widandi Soetopo, Department of Water Resources, Faculty of Engineering,
University of Brawijaya, Indonesia
Address:Jl. M.T. Haryono 167 Malang – 65145 - Indonesia

MATERIALS AND METHODS

The Irrigation Water Application in Dynamic Programming Model: One month was divided into 3 teen-day periods of water application released from the reservoir. Therefore there were 36 teen-day periods in one year. With 3 cropping seasons in a year, then a cropping season consisted of 12 teen-day periods of water application, which for a single irrigation block can be depicted as Figure 1.

The Sine-Product Model as the Production Function: The Irrigation Production Function as the Objective Function was represented by a Sine-Product model. This mathematic production function was proposed in a previous studi [7]. To fit the function to the general shape of relationship between Applied Water and Crop Production as presented by English [1], an approach has been made to use a model with sine functions for each period of water application as shown Equation (1).

$$Yr_i = \left[Sin\left\{ \left(\left[AWr_i - a.Sin(AWR_i.2.\pi) \right] \times \left[1 - b.Sin(Awr_i\pi) \right]^c \right)^d \pi/2 \right\} \right]^e$$

(1)

with Yr_i is the representation of Y_r (Crop Production/Yield) at each period/stage and AWr_i is the applied water at the corresponding period/stage.

The values of the parameters of a=0.06, b=0.25, c=1.3, d=0.15, and e=0.99.

The Crop Production Function for a cropping season is described as Equation (2).

$$\text{Crop Production Function} = Yr = Yr_1 \times Yr_2 \times Yr_3 \times \ldots \times Yr_n$$

(2)

with n is the number of period/stage in the cropping season (=12 periods).

The Optimization Model of Dynamic Programming for Reservoir Operation: The optimization model of dynamic programming for reservoir operation in one cropping season can be depicted as the Figure 2.

As can be seen, the figure displays various alternatives of paths from the initial storage at the beginning of cropping season to the final storage at the end of cropping season. These paths range within the active storage of reservoir, which in this study were divided into 50 grid (or 51 values of storage state). One of the paths will be the optimal reservoir operation to be obtained by the dynamic programming optimization.

The number of grid division of active storage must be decided so as to achieve a satistactory accuray while not demanding too much of computing memory space. The combination of three the Dynamic Programming models from each of cropping seasons in a year into one continuous annual model can be depicted as Figure 3.

In this continuous model, the final storage of one cropping season will become the initial storage of the next cropping season and the final storage of cropping season 3 must be same to the initial storage of cropping season 1. Hence, there were 3 values of initial/final storage in one year reservoir operation. Each of these values was to be varied for N different storage values, so there were NxNxN combinations of initial/final storage of
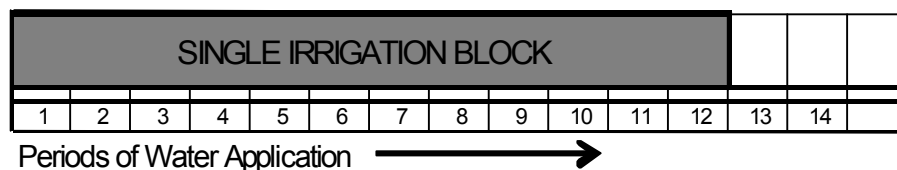

Fig. 1: The Periods of Water Application in a Cropping Season
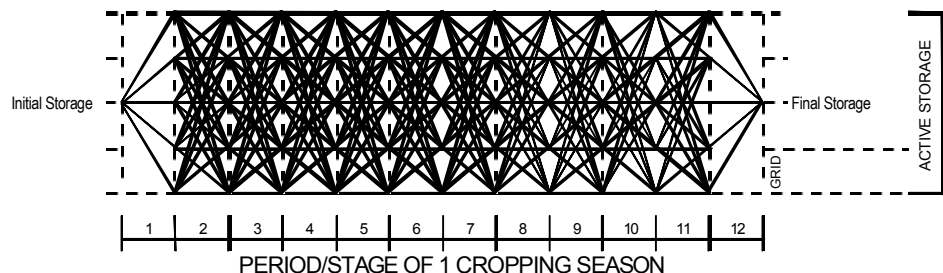

Fig. 2: The Dynamic Programming model for Reservoir Operation in one Cropping Season.
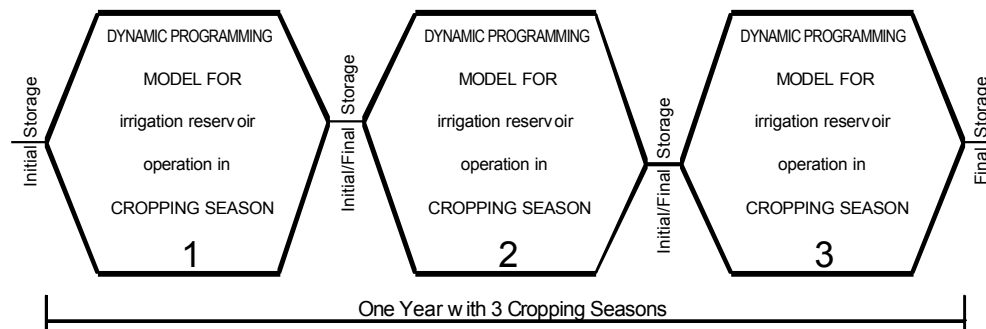
Fig. 3: The Combination of 3 Dynamic Programming models in Annual Reservoir Operation

Table 1: Example of calculation for Annual Objective Function of Dynamic Programing

Cropping Season	Crop Production (Yr)	Weight of Economic value	Economic Value (monetary unit)
1	0.6609	3	1.9828
2	0.2545	2	0.5090
3	0.6775	1	0.6775
Σ = Annual (Overall) Objective Function in monetary unit =			3.1693

Table 2: The Results of Dynamic Programming Optimization for Reservoir Operation

		Dependable inflow 80%			Dependable inflow 97.3%		
Objective function (monetary unit)		4.6208			3.1693		
		Cropping Season			Cropping Season		
Optimal Reservoir Operation at the beginning of period [1000 m³]	Period (Stage)	1	2	3	1	2	3
	1	1083.5	2058.7	650.1	2058.7	1083.5	2383.7
	2	1950.3	2708.8	921.0	2275.4	1625.3	2600.4
	3	1462.8	2708.8	1029.3	1571.1	2221.2	2708.8
	4	216.7	2708.8	975.2	866.8	2546.3	2708.8
	5	0.0	2708.8	812.6	704.3	2708.8	2600.4
	6	0.0	2654.6	650.1	433.4	2708.8	2492.1
	7	379.2	2546.3	433.4	216.7	2708.8	2383.7
	8	541.8	2221.2	379.2	216.7	2654.6	2275.4
	9	595.9	1896.2	162.5	54.2	2546.3	2058.7
	10	162.5	1516.9	0.0	108.4	2492.1	1787.8
	11	0.0	1137.7	325.1	0.0	2383.7	1950.3
	12	758.5	812.6	541.8	758.5	2329.6	1950.3

cropping seasons for the annual Dynamic Programming model, the best of which will be represented in the optimal annual reservoir operation. In this research, the N was set at 26 which resulted in 26x26x26 = 17576 combinations of initial/final storage of cropping seasons.

To calculate the annual (overall) Objective Function, each of the three objective function values (of 3 cropping seasons) was weighted with value which represented the economic values of each cropping seasons. Then these weighted values was added up as in the example shown in Table 1.

The weights of economic value were assumed in this case. The annual objective function was in the monetary unit.

Data and Calculations: The certain data for this research were obtained from previous studies. Based on the data of inflow to the Pejok Reservoir, the irrigation water requirements, the area of irrigation block and the capacity of reservoir, the calculations of water balance for reservoir operation were done for 36 teen-day periods in one year.

The analysis were done based on two data series of dependable inflow into reservoir, with the level of dependable 80% and 97.3% respectively. The volume of irrigation water requirements were based on the irrigation area of 1989 hectares. The capacity of reservoir active storage was 2,078,800 m³.

The calculation analysis was done on IBM-PC Pentium IV dual-CPU 2.66 GHz, with the Microsoft

Window XP operating system. The software for computer programming was the Microsoft Window Excel 2003. The program calculations were done on the pages of worksheet, while the controlling of iteration processes was done with Macro and Visual-Basic. With 50 grid division of the active storage and 17576 combinations of initial/final storage of cropping seasons in one year, the running time of one data series of infow for the 17576 annual model was ±37 minutes.

RESULTS AND DISCUSSION

The presence of nonlinear relationships in the optimization of the irrigation reservoir operation is always problematical. The objective function of the optimization is to maximize the yield (of harvest) at the end of a cropping season. There are two optimization methods for this kind of problems, the Dynamic Programming and the Simulation for Optimization. In the Simulation for Optimization, it will pose no serious problem due to its flexible prerequisite. But for the Dynamic Programming with its more demanding prerequisite, which application is presented in this paper, some special mathtematical function is needed.

The results of the dynamic programming optimization for irrigation reservoir operation using the Sine-Product model as the objective function for each of the two inflow data series are presented in the Table 2.

From these results of the research, there are some points to be accounted in the follow.

Structurally, the Sine-Product model is quite suitable as the objective function in the dynamic programming optimization model for reservoir operation with irrigation purposes. This can be seen by comparing the Equation (2) to the Figure 2, by which former illustrates the various combination of periodic yields corresponding to the irrigation water application, while the latter shows the various alternatives of paths of the reservoir operation.

The Crop Production Function (Yr) in Equation (2) is made up of a series of periodic yields (Yr_i). While Yr is real, but Yr_i's are just abstract since there is no actual production in a single period of a cropping season. This conception worked fine since it can describe the value of water application in a particular period in relation to the corresponding irrigation water requirement in the same period.

The total economic value in one year of crop production from a single irrigation block was the sum of weighted cropping season yields (Table 1). The weights of economic value (which were assumed in this research)

represented the rating value of irrigated crops in the corresponding cropping season.

With the use of the Sine-Product model, the Dynamic Programming was quite effective in obtaining the optimal path of the annual reservoir operation for irrigation. In each dynamic programming model for one cropping season (Figure 2), the range of active storage were divided into 50 grids. The annual model has 3 cropping season models. The 17576 annual models were solved in about 37 minutes. It meant that an annual model was solved in about 0.13 second, which is quite fast.

The dynamic programming model in this research was for a single planting schedule irrigation block. Future researches may reveal the possible approaches for solving multiple irrigation blocks with different planting schedules by dynamic programming with the Sine-Product model as the objective function.

The calibration of the sine-product model used as the production function also seem to be one of the next undertakings, although there are certain difficulties in the way. For the same crop, or pattern of crops, the secondary data may be hard to obtain in sufficient amounts. On the other hand, the direct experimentation in the field could be highly expensive.

CONCLUSIONS

The Sine-Product model enabled the dynamic programming optimization model for solving a reservoir operation serving a single planting schedule irrigation block. It can obtained the optimal annual reservoir operation with multiple cropping seasons. Since the speed of calculation was quite fast, then potentially this method can be used to study various rule curves of reservoir operation.

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