第 48 卷 第 11 期
2021 年 11 月

湖南大学学报（自然科学版）
Journal of Hunan University（Natural Sciences）

Vol. 48 No. 11
November 2021

Open Access Article

Optimization Model of the Way Rarem Reservoir Operation Pattern by Using Stochastic Dynamic Programming

Tisno Subroto[1*], Mohammad Bisri[2], Lily Montarcih Limantara[2], Widandi Soetopo[2]

[1] Doctoral Program in the Department of Water Resources, Faculty of Engineering, University of Brawijaya, Jl. MT Haryono No 167 Malang, Indonesia

[2] Department of Water Resources, Faculty of Engineering, University of Brawijaya, Jl. MT Haryono No 167 Malang, Indonesia

Abstract: The effective storage of the Way Rarem reservoir is about 59.9 million m^3. It began to be operated in 1984 as a multi-function reservoir whose main function is supplying irrigation. However, the other function is flood control in the rainy season. Part of the reservoir inflow has not been functioning, and there is overflow through the spillway in the rainy season. The irrigation area ready to be served was 17,612.75 ha in 2017. Based on the potency of water availability that is high enough, this research intends to optimize the function of the reservoir. The methodology consists of collecting the information or data about the water availability (reservoir data and characteristics), irrigation water need, and the behavior of the farmer cultivating the fields. Stochastic dynamic programming is used for solving the optimization model. Using stochastic dynamic programming for two cropping seasons results in the optimal outflow policy and maximal objective function. The result shows that in the rainy season (MT-I), from the first two weeks of November until the second two weeks of March, the water need fulfilling is about 156.26%. However, in the dry season (MT-II), from the first two weeks of April until the second two weeks of August, the water need fulfilling is about 124.73%, and it is identical with 196.36% of crop intensity. If the irrigation area that will be served is 22,000 ha according to the initial plan, the crop intensity is 177.14%.

Keywords: reservoir operation, stochastic dynamic programming, outflow policy, crop intensity.

基于随机动态规划的方式稀有油藏作业模式优化模型

摘要：方式稀有水库的有效储存量约为 5990 万立方米。1984 年作为以灌溉为主的多功能水库开始运行。但是，另一个功能是雨季的防洪。部分水库进水没有发挥作用，雨季有溢洪道溢流。2017 年可供灌溉的灌溉面积为 17,612.75 公顷。基于足够高的可用水量，本研究旨在优化水库的功能。该方法包括收集有关可用水量（水库数据和特征）、灌溉用水需求和农民耕种行为的信息或数据。随机动态规划用于求解优化模型。对两个种植季节使用随机动态规划可得到最优流出策略和最大目标函数。结果表明，在雨季（公吨-I），从 11 月的前两周到 3 月的后两周，需水量满足约 156.26%。然而，在旱季（公吨-II），从 4 月的前两周到 8 月的后两周，需水量满足约 124.73%，与作物强度的 196.36%相同。如果按照初步计划服务的灌溉面积为 22,000 公顷，则作物强度为 177.14%。

关键词：水库运行、随机动态规划、流出政策、作物强度。

1. Introduction

Management of water resources intends to solve the need and supply of water resources for a certain region by considering some dimensions like time, space, environment, politics, other aspects. In addition, water management means the reconciliation of water

Received: July 24, 2021 / Revised: September 22, 2021 / Accepted: October 21, 2021 / Published: November 30, 2021

About the authors: Tisno Subroto, Doctoral Program in the Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, Indonesia; Mohammad Bisri, Lily Montarcih Limantara, Widandi Soetopo, Department of Water Resources, Faculty of Engineering, University of Brawijaya, Malang, Indonesia

Corresponding authors Tisno Subroto, tisno.syh57@gmail.com; Lily Montarcih Limantara, lilymont2001@gmail.com

conservation for all users and ensures that there is enough water before the need arises using the related area resources [1, 2, 3].

Some rivers in Indonesia have rapidly developed lately. The boundary of surface water resources mainly in the dry season indicates the demand of operation and optimal capacity for the multi-function reservoir system [4, 5, 6]. The monitoring of quantitative surface water resources is needed for determining the water availability in order to be able to verify the consumption norm (for irrigation) and for analyzing the substance load that is leaving the watershed [7, 8]. Therefore, the distribution of water use is necessary to be carried out as efficiently and effectively as possible.

The system of optimal reservoir operation is very important and complex when designing and managing water resources. Part of what the simulation and optimization models give us is the ability to analyze and evaluate the reservoir operation, which has been developed in recent decades. The model is based on the procedure of water balance for tracing the water movement through the system of the reservoir flow [9, 10].

There are two seasons in Indonesia, the rainy season and dry season. In the rainy season, there is so much water that it causes flooding. However, in the dry season, there is drought. So, a reservoir is needed for solving these extreme conditions. The Way Rarem reservoir is a multi-function reservoir in which the main function is supplying water to the Way Rarem irrigation area, and an additional function is for decreasing flooding in the rainy season [15]. The normal capacity of the reservoir is 56.90 x 10^6 m^3 on the water level of 54.00 m.

This research intends to evaluate the relation between water availability and the reservoir operation pattern in fulfilling the water need.

2. Material and Method

2.1. Material

Data needed in this research consist of water availability (inflow and reservoir characteristics), irrigation water need, and irrigation area. The reservoir inflow data is from 1985 until 2019; however, the rainfall data is from 2009 until 2019.

2.2. Methodology

The methodology consists of: 1) literature study; 2) data collecting: reservoir inflow, reservoir characteristics, and irrigation water need, then it is continued with the data test mainly for reservoir inflow data; 3) water need analysis; 4) carrying out the optimization model for obtaining the optimal reservoir operation pattern by using stochastic dynamic programming.

2.2.1. Reservoir Inflow Discharge

The reservoir inflow discharge of the Way Rarem is available for 35 years (1985-2019) (Fig. 1).

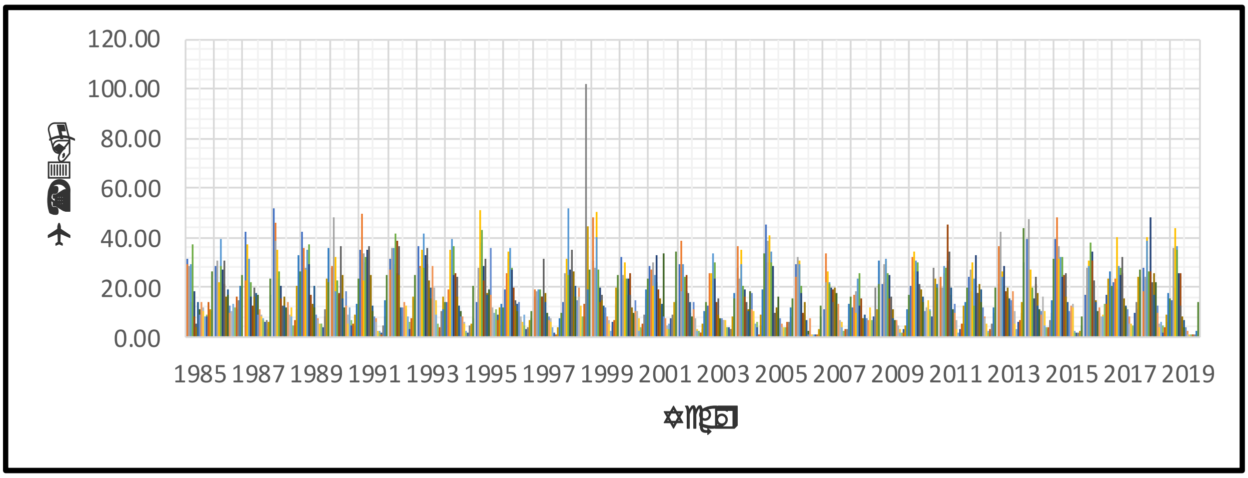

Fig. 1 Inflow of the Way Rarem reservoir (m^3/s) [14]

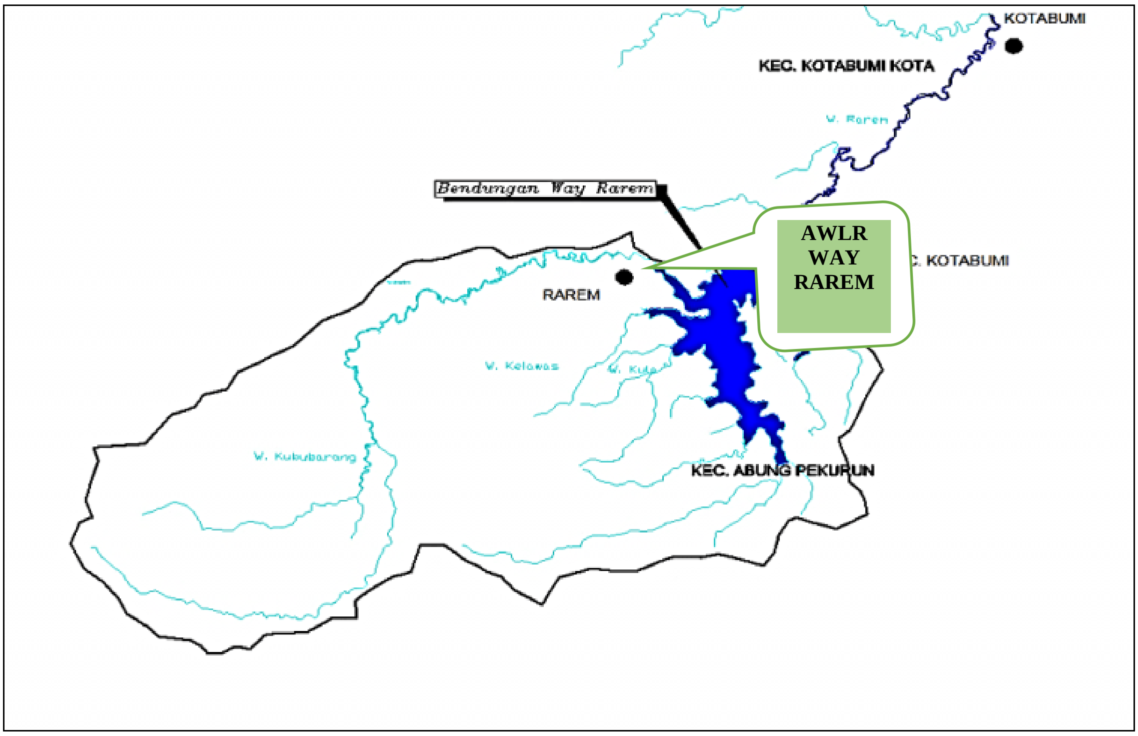

Fig. 2 Map of the Way Rarem reservoir watershed and the location of AWLR [14]

The Chi-Square test is as follow:

$$\chi^2 = \sum_{i=1}^{N} \frac{(O_f + E_f)^2}{E_f} \quad (1)$$

where:

χ^2 - the value of chi-square;
E_f - observed frequency;
O_f - theoretical frequency;
N - number of members in a group.

The chi-square test is used for evaluating the serial data of reservoir inflow that consists of 4 distribution types for analyzing the design flood as follow:

1. *Normal Distribution*

$$X = \bar{X} + K.S \quad (2)$$

where:

$\bar{X}$ - mean of the sample;
S - deviation standard of sample;
K - factor of frequency.

2. *Log-Normal Distribution*

$$\text{Log } X = \overline{\log X} + K.S \quad (3)$$

where:

X – the data of the sample;
S – the deviation standard of the sample;
K – the factor of frequency.

3. *Gumbel Distribution*

$$X = \bar{X} + KS \quad (4)$$

where:

$\bar{X}$ - mean of the sample;
S - deviation standard of sample;
K - factor of frequency.

4. *Log-Pearson III Distribution*

$Y_i = \log X_i$

$$Y = \bar{Y} + K.S \quad (5)$$

where:

$\bar{Y}$ - mean of Y_i;
K - factor of frequency (from the table of Pearson III);
S - standard deviation of Y_i.

Then, the result is selected based on the most qualified distribution.

2.2.2. Reservoir

A reservoir is an artificial container formed due to the dam construction holding the river flow, and the container is used as the water store that overflows from the spillway in the rainy season. So, it can be used to fulfill the water need and control the destructive power of water.

Water that enters the reservoir is classified into three conditions: the reservoir inflow in the wet, normal, and dry conditions. The reservoir inflow comes from the river, the area surrounding it, and the rainfall directly dropping on the reservoir surface. Determining inflow to the river is based on the wet, normal, and dry conditions. The wet year condition is the dependable discharge with a 35% probability. The normal condition is the dependable discharge with a 50% probability. The dry condition is the dependable discharge with a 65% probability.

2.2.3. Irrigation Water Need

The irrigation water need is affected by some factors as follow [11]:

a. Area preparation (LP)

Van De Goor and Zijlstra developed the method as follow:

$$IR = (M.e^k/(e^k-1) \quad (6)$$

where:

k = M x T/S

M = Eo + P (water losses due to the P and Eo)

Eo = 1.1 * Eto

Eto - potential evaporation, T - number of days in a month, S - water for soil saturation.

b. Effective rainfall (Re)

Effective rainfall is the rainfall dropping during the crop growth to fulfill consumptive crop use. The effective rainfall is determined by about 70% of the mean half monthly rainfall, with a failure probability of 20% (R_{80}). The effective rainfall is 70% x R_{80} per observed period.

c. Water layer change (WLR)

The water layer change is generally carried out two times, along 50 mm (3.30 mm during 15 days), one month, and two months after cropping.

d. Percolation (P)

The percolation rate depends on the soil characteristics, and the value is about 1-3 mm/day and depends on the soil characteristics.

e. Consumptive use (evapotranspiration, etc.)

The consumptive use is as the amount of water that is evaporated through the vegetation and it can be analyzed by the formula as follow:

$$Etc = kc \times Eto \quad (7)$$

where kc is crop coefficient, and Etc is evapotranspiration.

$$Eto^* = W (0{,}75\ Rs – Rn1) + (1 – W).\ f(u).\ (ea – red) \quad (8)$$

$$Rs = (0{,}25 + 0{,}54\ n/N)\ Ra \quad (9)$$

where:

W - factor that is related with temperature and elevation;

Rs - radiation of short wave in evaporation unit (mm/day);

Ra - radiation short wave that affects out boundary of atmosphere (mm/day);

Rn1 - net radiation of long wave = f(t) x f(ed) x f(n/N);

f(t) - function of temperature;

f(ed) - function of vapor pressure = 0.34 – 0.044 x $ed^{0,5}$;

f(n/N) - function of brightness = 0.1 + 0.9 x n/N;

f(U) - function of wind velocity = 0,27 x (1 + 0,864U);

(ea-ed) - different of saturated vapor pressure: (ed) = ea x RH with the real vapor pressure (ea);

RH - relative humidity (%).

f. Water needs in the paddy field (paddy: NFR1 and second crop: NFR2)

Water need in the paddy fields is analyzed by using the formula as follow:

$$NFR = Etc + P + WLR + LP – Re \quad (10)$$

g. Efficiency of irrigation (EI)

The efficiency of irrigation (EI) is the water losses in the taking channel from intake until paddy d=field (it is determined as 65%).

So,

the irrigation water needs in intake = NFR/EI (11)

2.3. Optimization of Reservoir Operation Pattern

Factors that affect the simulation process are water availability (inflow), irrigation water need, and irrigation area (DI). Optimization is carried out for determining the reservoir operation pattern and the optimal water balance. However, the water availability and water need are the factors determined by time and dimension, so the irrigation area which can be cropped is the optimization decision.

Soetopo [12] said that it is necessary to inventory the water balance of the reservoir for a certain period of the inflow to the reservoir and outflow from the reservoir. The water balance of the reservoir can be formulated as follows:

$$S_{t+1} = S_t + I – O \quad (12)$$

If Inflow (I) > Outflow (O) so the formulation-11 becomes as

$$S_{t+1} = S_t + I – O – O_{st} \quad (13)$$

where S_{i+1} is the storage on the period-t, S_t is the initial storage on the period-t, I is the total inflow during the period-t, and O is the total outflow of water from the reservoir during t, and O_{st} is the water that overflows through the spillway (spill out).

The optimization by Stochastic Dynamic Programming (PDS) is based on the effective storage, water need, and inflow probability, using the Software of Microsoft Office Excel Macro written with the language of visual basic (vb).

The elements in the optimization by using stochastic dynamic programming for reaching the target are as follows [13]:

1. *Stage*

This research uses 35 years' data, and there are 24 stages in every cycle. The stage is the opposite of the half-monthly time series. If half monthly (i) = 1, 2, …. N, so the stage-1 is beginning from half-n

2. *Decision variable*

The decision variable is the outflow of half-monthly (i) = X_i.

3. *Return (r_1)*

Return is the random variable that consists of the outflow function (X_i) and it can be formulated as follow:

$$r_1 = r_1(X_i) \quad (14)$$

$$r_1 = \text{factor } k = \frac{X_i}{Q_{ri}} \quad (15)$$

where:

X_i - outflow on stage i;

r_1 - water need on stage i;

K - accessibility dimension of water need finding;

Accessibility factor (k) - the ratio between outflow and water need.

4. *State Transformation Function*

State Transformation Function is a formula that shows the storage transformation inter operation period (stage), and it is formulated based on the principle of continuity or water balance equation of the reservoir by backward calculation:

$$S_{i-1} = t_i(S_i, X_i, I_{ik}, Q) = S_i + I_{ik} - Q \quad (16)$$

where:

S_{i-1} - storage on i-1;

S_i - storage in Stage 1;

I_{ik} - representative inflow in stage i and class k;

Q - volume of the water needed.

5. *Objective Function*

The objective function is maximizing the return value that is to maximize the factor-k mean (ratio between outflow and water need). The return is the function of outflow (Xi).

Max r = to maximize mean factor =

$$\in \left[\frac{1}{n}\sum_{i=1}^{n} r_i\,(X_i)\right] \quad (17)$$

Max r = to maximize mean factor =

$$\in \left[\frac{1}{n}\sum_{i=1}^{n} \frac{X_i}{Qr_i}\right] \quad (18)$$

6. *Constraint*

a. Storage constraint is the state variable limited by minimum and maximum operation storage.

b. $S_{min} \leq S_i \leq S_{max}$ (19)

where:

S_{min} - minimum storage of the reservoir;

S_{max} - maximum storage of the reservoir.

7. *Outflow constraint*

Outflow constraint is the state variable limited by the amount of water outflow from the reservoir. The amount of water outflow has to be between the minimum discharge (Xmin) and maximum discharge (Xmax).

$$X_{min} \leq X_i \leq X_{max} \quad (20)$$

where:

X_{min} - minimum outflow during stage i;

X_{max} - the potency of maximum outflow of the reservoir during stage i.

8. *Recursive Equation*

The recursive equation expresses the relation between the status variable as the optimization result on a stage with the state variable input and the decision on the stage reviewed. As the inflow in every stage has the stochastic characteristic, the state variable is expressed by the probability distribution as follows:

$$f_i(S_i) = \max_{X_i}\left\{\sum_{k=1}^{K} P_{ik}\left[\frac{1}{m}(r_i(X_i) + (m-1) + (f_{i-1}(S_{i-1}))\right]\right\} \quad (21)$$

$$f_i(S_i) = \max_{X_i}\left\{\sum_{k=1}^{K} P_{ik}\left[\frac{1}{m}(r_i(X_i) + (m-1) + (f_{i-1}(t_i(X_i)))\right]\right\} \quad (22)$$

where:

P_{ik} - the transition probability of inflow on stage i and inflow class k;

M - the end position of the stage in the iteration process during x cycle stage.

3. Results and Discussion

3.1. Statistical Analysis of Inflow

The data series of half monthly inflow discharge that the unit is m^3/s is changed into m^3 as presented in Fig. 3.

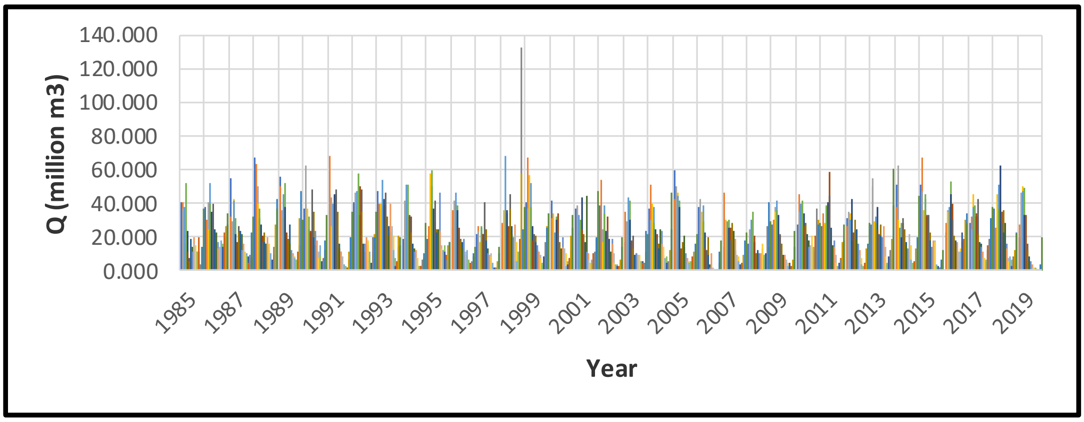

Fig. 3 Inflow of the Way Rarem reservoir (million m^3)

Then, the Chi-Square test analysis for each distribution is carried out as follows: 1) Normal distribution, 2) Log-Normal distribution, 3) Gumbel distribution, and 4) Log-Pearson-III distribution. Based on the analysis result, all distributions have been qualified (Table 1). The Log-Normal distribution is selected to analyze the Expected Value (EV) on the Stochastic Dynamic Programming procedure.

Table 1 Normal distribution test analysis result

Rank of Data	1	2	3	4	5	6	7	8	9	10	11	12
Mean	34.71813	39.10098	38.07926	34.4459	40.0662	38.42789	32.66811	27.57251	27.72091	22.60333	17.91614	16.40134
Deviation standard	13.63822	12.81537	10.04106	10.49661	9.948319	9.509631	9.276811	10.35542	12.23456	7.65275	5.114072	7.318553
Skewness	0.43306	1.0321	0.737207	-0.03261	0.34117	0.364387	0.783694	1.016484	0.343762	0.104218	0.012859	1.545845
Number of data	35	35	35	35	35	35	35	35	35	35	35	35
χ^2	0.857143	3.428571	1.142857	0.857143	1.428571	0.857143	4.285714	2	6.285714	3.714286	3.428571	3.714286
χ^2critic	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465
H	0	0	0	0	0	0	0	0	1	0	0	0

Rank of Data	13	14	15	16	17	18	19	20	21	22	23	24	Total
Mean	15.00159	14.85137	11.23422	9.949857	6.884062	6.389329	6.329329	7.949771	13.57623	16.44323	21.24446	29.33661	
Deviation standard	7.33315	6.775499	5.16112	5.266476	4.326498	4.238029	4.625065	6.092357	22.02118	11.14181	10.21244	10.61116	
Skewness	2.31664	1.691861	0.773294	0.40236	0.676949	0.950152	1.468535	0.977238	4.889946	1.594329	0.782446	0.687847	
Number of data	35	35	35	35	35	35	35	35	35	35	35	35	
χ^2	8.571429	6.857143	7.714286	6.571429	5.428571	1.142857	9.428571	2.285714	33.71429	6.285714	1.714286	4.285714	
χ^2critic	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	
H	1	1	1	1	0	0	1	0	1	1	0	0	8

Table 2 Log-normal distribution test analysis result

Rank of Data	1	2	3	4	5	6	7	8	9	10	11	12
Mean	3.467901	3.619139	3.607127	3.485693	3.659583	3.618115	3.447879	3.250649	3.217606	3.052348	2.841989	2.701547
Deviation standard	0.413298	0.304204	0.257814	0.352897	0.256129	0.255397	0.283024	0.372024	0.481801	0.391758	0.309654	0.465331
Skewness	-0.25041	0.545612	0.134134	-1.12934	-0.3415	-0.43498	-0.09943	-0.13964	-0.43698	-1.12025	-0.6195	-0.85363
Number of data	35	35	35	35	35	35	35	35	35	35	35	35
χ^2	8.285714	2	3.428571	3.142857	6	0.857143	3.142857	1.142857	2.571429	2	6.857143	4
χ^2critic	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465
H	1	0	0	0	1	0	0	0	0	0	1	0

Rank of Data	13	14	15	16	17	18	19	20	21	22	23	24	Total
Mean	2.596467	2.607274	2.293085	2.117779	1.685282	1.589222	1.558489	1.705223	2.077749	2.573938	2.932091	3.313684	
Deviation standard	0.5209	0.437912	0.568137	0.687887	0.805582	0.854919	0.869198	1.006053	1.009028	0.726296	0.538058	0.373411	
Skewness	-1.54147	-0.36504	-1.49156	-1.33568	-1.26284	-1.47138	-1.27151	-1.07976	-0.11763	-0.61932	-0.85868	-0.30084	
Number of data	35	35	35	35	35	35	35	35	35	35	35	35	
χ^2	6	2.285714	8.285714	6	4.285714	2	4.857143	9.142857	3.142857	2.285714	1.142857	3.714286	
χ^2critic	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	
H	1	0	1	1	0	0	0	1	0	0	0	0	7

Table 3 Gumbel distribution test analysis result

Rank of Data	1	2	3	4	5	6	7	8	9	10	11	12
Mean	34.71813	39.10098	38.07926	34.4459	40.0662	38.42789	32.66811	27.57251	27.72091	22.60333	17.91614	16.40134
Deviation standard	13.63822	12.81537	10.04106	10.49661	9.948319	9.509631	9.276811	10.35542	12.23456	7.65275	5.114072	7.318553
Skewness	0.43306	1.0321	0.737207	-0.03261	0.34117	0.364387	0.783694	1.016484	0.343762	0.104218	0.012859	1.545845
Number of data	35	35	35	35	35	35	35	35	35	35	35	35
Yn	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402
Sn	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285
χ^2	6.571429	1.142857	1.714286	2	5.142857	0.857143	2.285714	1.142857	3.714286	2	7.714286	6.571429
χ^2critic	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465
H	1	0	0	0	0	0	0	0	0	0	1	1

Rank of Data	13	14	15	16	17	18	19	20	21	22	23	24	Total
Mean	15.00159	14.85137	11.23422	9.949857	6.884062	6.389329	6.329329	7.949771	13.57623	16.44323	21.24446	29.33661	
Deviation standard	7.33315	6.775499	5.16112	5.266476	4.326498	4.238029	4.625065	6.092357	22.02118	11.14181	10.21244	10.61116	
Skewness	2.31664	1.691861	0.773294	0.40236	0.676949	0.950152	1.468535	0.977238	4.889946	1.594329	0.782446	0.687847	
Number of data	35	35	35	35	35	35	35	35	35	35	35	35	
Yn	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	0.5402	
Sn	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	1.1285	
χ^2	6.571429	10.28571	3.142857	2	3.142857	2.285714	6.285714	0.571429	28.57143	2.571429	1.142857	5.142857	
χ^2critic	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	5.991465	
H	1	1	0	0	0	0	1	0	1	0	0	0	7

Table 4 Log Pearson III distribution test analysis result

Rank of Data	1	2	3	4	5	6	7	8	9	10	11	12
Mean	1.50609	1.571772	1.566555	1.513817	1.589337	1.571327	1.497395	1.411739	1.397389	1.325618	1.23426	1.173267
Deviation standard	0.179493	0.132114	0.111967	0.153261	0.111236	0.110918	0.122916	0.161568	0.209243	0.170138	0.134481	0.202091
Skewness	-0.25	0.546	0.134	-1.129	-0.342	-0.435	-0.099	-0.14	-0.437	-1.12	-0.62	-0.854
Number of data	35	35	35	35	35	35	35	35	35	35	35	35
χ^2	8.285714	1.428571	3.428571	0.857143	6	0.857143	3.142857	1.142857	3.714286	6.571429	4.285714	2.285714
χ^2critic	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459
H	1	0	0	0	1	0	0	0	0	1	1	0

Rank of Data	13	14	15	16	17	18	19	20	21	22	23	24	Total
Mean	1.127631	1.132325	0.995874	0.91974	0.731909	0.69019	0.676843	0.740569	0.902355	1.117847	1.273391	1.439115	
Deviation standard	0.226224	0.190183	0.246739	0.298745	0.34986	0.371286	0.377488	0.436923	0.438215	0.315426	0.233676	0.16217	
Skewness	-1.541	-0.365	-1.492	-1.336	-1.263	-1.471	-1.272	-1.08	-0.118	-0.619	-0.859	-0.301	
Number of data	35	35	35	35	35	35	35	35	35	35	35	35	
χ^2	9.428571	3.142857	5.714286	0.857143	3.142857	1.142857	5.428571	1.428571	3.142857	1.428571	0.857143	2.571429	
χ^2critic	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	3.841459	
H	1	0	1	0	0	0	1	0	0	0	0	0	7

The range of inflow discharge is expressed in the form of a volume grid unit. The volume grid unit is obtained by dividing the inflow gradation probability until grid-600; however, the active storage capacity of the Way Rarem reservoir is divided into 200 grids. The analysis result of inflow discharge distribution is obtained on every period (2 weeks), so there are 24 periods as presented in Fig. 4 for the 13th period of the probability distribution.

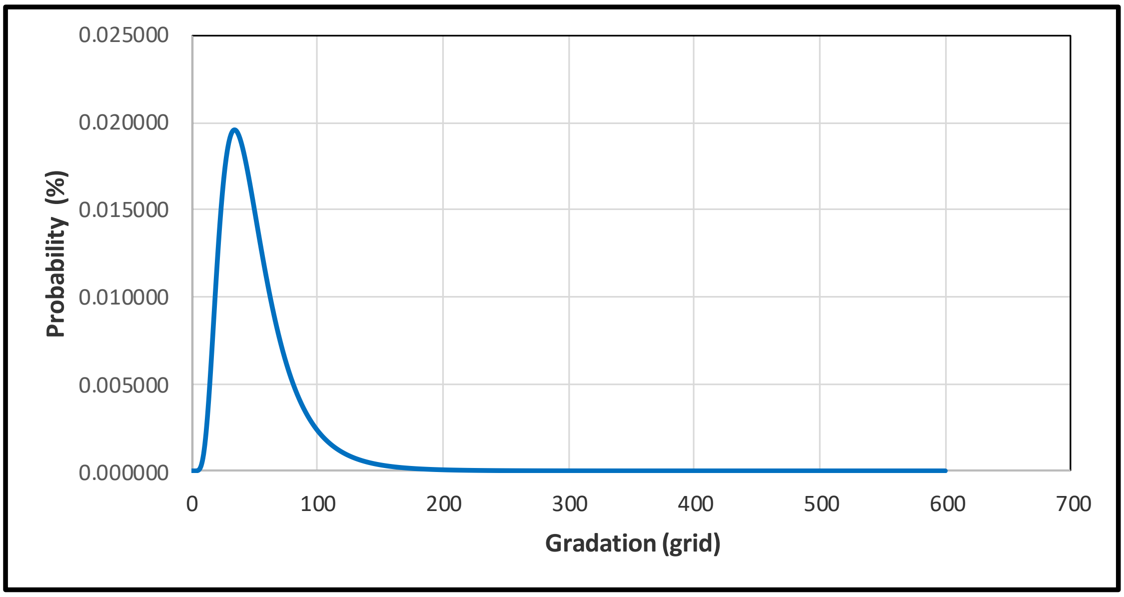

Fig. 4 Result of probability distribution analysis in Period 13 (Own study, 2021)

3.2. Analysis of Reservoir Outflow

The irrigation water need or reservoir outflow supplies the irrigation area that is affected by the area preparation, rainfall, percolation, evapotranspiration, etc. The analysis result of the need is presented in Table 5.

Table 5 Irrigation water need (outflow) analysis result (Own study, 2021)

Month		Nov		Dec		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct	
sub-month		I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Rank of period		21	22	23	24	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Irrigation discharge	[l/s]	5,447.7	14,815.0	17,750.5	16,901.5	12,734.4	10,211.7	8,361.2	3,981.5	1,621.3	5,021.2	9,737.0	14,949.6	19,528.8	21,119.2	12,746.8	13,570.0	14,300.4	10,571.4	8,903.3	3,600.4	0.0	0.0	0.0	0.0
Maintenance discharge	[l/s]	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0
n (1/2 monthly)	[day]	15	15	15	16	15	16	15	13	15	16	15	15	15	16	15	15	15	16	15	16	15	15	15	16
Irrigation discharge	[million m³]	7.060	19.200	23.005	23.365	16.504	14.117	10.836	4.472	2.101	6.941	12.619	19.375	25.309	29.195	16.520	17.587	18.533	14.614	11.539	4.977	0.000	0.000	0.000	0.000
Maintenance discharge	[million m³]	0.648	0.648	0.648	0.691	0.648	0.691	0.648	0.562	0.648	0.691	0.648	0.648	0.648	0.691	0.648	0.648	0.648	0.691	0.648	0.691	0.648	0.648	0.648	0.691

3.3. Optimization Model of the Way Rarem Reservoir by Using Stochastic Dynamic Programming

The optimization process of Stochastic Dynamic Programming (PDS) is based on the effective storage, water demand, and probability of inflow [16]. It is solved by using the Microsoft Office Excel Macro software, written in the visual basic (vb) language, started by building the recursive table with the number of columns corresponding to the effective storage grid division (0 until 200) or the grid unit of 69.9 million m^3/200 = 0.300 million m^3; however, the number of rows is regarded to the reservoir outflow range (1-290), then it is analyzed for every cell from the recursive table, i.e., through the recursive function (Table 6), but the probability of inflow gradation is until 600th grid.

Table 6 Recursive function (Own study, 2021)

RANGE OF				i [No.Grad]	0	1	2	3	4	5	....	6	22	23	24	....	192	193	194	195	196	197	198	199	200
OUTFLOW (Decision Var.)				Si	S0	S1	S2	S3	S4	S5	....	S6	S22	S23	S24	....	S192	S193	S194	S195	S196	S197	S198	S199	S200
Xj				[%]	0	0.5	1	1.5	2	2.5	....	3	11	11.5	12	....	96	96.5	97	97.5	98	98.5	99	99.5	100
j	No.Grad.	[million m³]	[%]	[million m³]	0	0.2995	0.599	0.8985	1.198	1.4975	....	1.797	6.589	6.8885	7.188	....	57.504	57.804	58.103	58.4025	58.702	59.002	59.301	59.601	59.9
1	1	0.30	0.50								....					....									
2	2	0.60	1.00								....					....									
3	3	0.90	1.50								....					....									
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4	4	1.20	2.00								....					....									
19	19	5.69	9.50								....		71.35	71.35	71.35	....									
20	20	5.99	10.00								....	56.67	72.27	73.21	74.15	....									
21	21	6.29	10.50							56.22	....	58.01	71.33	72.27	73.21	....									
22	22	6.59	11.00					53.89	55.61	56.93	....	57.55				....									
23	23	6.89	11.50				53.19	54.87	55.76	56.33	....					....									
24	24	7.19	12.00			52.41	54.05	54.66	55.20		....					....									
25	25	7.49	12.50		51.58	53.14	53.63				....					....									
26	26	7.79	13.00		52.20	52.66					....					....									
27	27	8.09	13.50		51.76						....					....									
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
38	38	11.38	19.00								....					....	151.87	151.87	151.87	151.87	151.87	151.87	151.87	151.87	
39	39	11.68	19.50								....					....	154.34	154.62	154.91	155.18	155.46	155.73	156.00	156.11	156.11
40	40	11.98	20.00								....					....	154.05	154.34	154.62	154.91	155.18	155.46	155.73	156.00	156.26
41	41	12.28	20.50								....					....									156.00
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
289	289	86.5555	144.5								....					....									
290	290	86.855	145								....					....									
f* Max					52.202	53.137	54.049	54.87	55.756	56.93	....	58.011	72.269	73.21	74.152	....	154.34	154.62	154.91	155.185	155.461	155.73	156	156.11	156.26
Decision [million m³]					7.787	7.4875	7.188	6.8885	6.8885	6.589	....	6.2895	5.99	5.99	5.99	....	11.681	11.681	11.681	11.6805	11.6805	11.681	11.681	11.681	11.98
Decision [No of Gradation]					26	25	24	23	23	22		21	20	20	20	....	39	39	39	39	39	39	39	39	40

The recursive function that consists of two parts is related by an operator (Fig. 5).

Water need fulfilling due to the outflow in this period	OPERATOR: The smallest option from two of them	E.V of the Recursive function value on the next period

Fig. 5 The recursive function

Every half monthly period there is optimized in a recursive table. The optimization begins at the end of the cropping pattern and returns recursively to the initial cropping pattern. The Way Rarem reservoir has two crop seasons: November-March (half-monthly of 10 periods) and April-August (half-monthly of 10 periods). Each crop season is optimized separately, mainly for the first recursive table (at the end of the crop season). It is assumed that there is no next period, so the recursive function only fulfills the need on that stage.

In every recursive table, the optimization per column is carried out (per status in the initial storage period). For every column, the maximum value of the recursive function and the related optimal outflow of the reservoir will be obtained. The row of optimal reservoir outflow is copied as the table of optimal outflow policy. Table 7 presents the analysis result of the Expected Value (EV), and Table 8 presents the analysis of the objective function.

Table 7 The expected value (EV) analysis result (Own study, 2021)

No. Grad Inflow		0	1	2	3	4	5	6	7	8	9	10	11	.....	304	305	306	307	.....	593	594	595	596	597	598	599	600
Inflow [million m³]		0.0000	0.2995	0.5990	0.8985	1.1980	1.4975	1.7970	2.0965	2.3960	2.6955	2.9950	3.2945	....	91.0480	91.3475	91.6470	91.9465	....	177.6035	177.9030	178.2025	178.5020	178.8015	179.1010	179.4005	179.7000
Probability of discharge		0.00004	0.00213	0.00732	0.01260	0.01683	0.01993	0.02206	0.02344	0.02424	0.02460	0.02464	0.02445	.....	0.00007	0.00007	0.00007	0.00007	.....	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
S_initial [No.Grad][million m³]		200	59.9																								
Outflow [No.Grad][million m³]		41	12.2795																								
S_end	Inf + Sinitial - Outf [No.Grad.]	159	160	161	162	163	164	165	166	167	168	169	170	.....	463	464	465	466	.....	752	753	754	755	756	757	758	759
Capacity of reservoir active storage [No.Grad.]		200																									
Real	S_end [No.Grad.]	159	160	161	162	163	164	165	166	167	168	169	170	.....	200	200	200	200	.....	200	200	200	200	200	200	200	200
Real	Outflow [No.Grad.]	41	41	41	41	41	41	41	41	41	41	41	41	.....	41	41	41	41	.....	41	41	41	41	41	41	41	41
Real	Outflow [million m³]	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	.....	12.2795	12.2795	12.2795	12.2795	.....	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795	12.2795
Data	Fixed other need [million m³]	0.648																									
Available discharge for irrigation [million m³]		11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	.....	11.6315	11.6315	11.6315	11.6315	.....	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315	11.6315
Data	Irrigation need 100% [million m³]	7.06017556																									
Potensial irrigation area [%]		164.748028	164.74803	164.748028	164.74803	164.748	164.74803	164.74803	164.748028	164.74803	164.748028	164.748028	164.7480278	.....	164.7480278	164.74803	164.74803	164.74803	.....	164.7480278	164.7480278	164.7480278	164.7480278	164.7480278	164.748028	164.7480278	164.748028
Valid probability		0.00004	0.0021305	0.00731901	0.0125957	0.016831	0.0199309	0.0220647	0.02343912	0.0242354	0.02459878	0.02464143	0.02444876	.....	0.00007	0.00007	0.00007	0.00007	.....	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
EV	Potential irrigation area-stage [%]	164.5812																									

Table 8 Analysis of the objective function [f*] (%, irrigation water need fulfilling) (Own study, 2021)

f* Max	Month	1/2 month	Period of ½ month	STATUS OF INITIAL PERIOD RESERVOIR STORAGE																														
(%)/(No Grad)				S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11		S125	S126	S127	S128	S129	S130	......	S190	S191	S192	S193	S194	S195	S196	S197	S198	S199	S200
optimal	Nov	I	21	52.20	53.14	54.05	54.87	55.76	56.93	58.01	58.84	60.23	60.95	62.17	63.28	....	130.68	130.84	131.31	131.78	132.25	132.71	......	153.75	154.05	154.34	154.62	154.91	155.18	155.46	155.73	156.00	156.11	156.26
156.26		II	22	32.90	33.73	34.57	35.44	36.33	37.23	38.15	39.09	40.05	41.02	42.01	43.02	....	129.77	130.53	130.75	131.29	132.04	132.31	......	158.21	158.74	158.83	159.26	159.78	160.30	160.39	160.81	161.33	161.85	161.95
S200	Dec	I	23	41.69	42.56	43.43	44.31	45.20	46.11	47.01	47.94	48.86	49.80	50.74	51.70	....	150.81	151.66	152.11	152.72	153.41	153.78	......	187.76	188.56	188.68	189.59	189.86	190.49	191.16	191.39	192.28	192.47	193.17
		II	24	66.96	67.97	68.97	69.97	70.99	72.01	73.03	74.06	75.09	76.12	77.16	78.20	....	201.25	202.29	202.71	203.78	204.15	205.27	......	246.28	247.00	247.69	248.28	249.10	249.57	250.50	250.85	251.89	252.13	253.28
season	Jan	I	1	108.01	109.38	110.75	112.13	113.52	114.91	116.31	117.71	119.12	120.54	121.96	123.38	....	294.54	295.46	296.76	297.18	298.89	299.27	......	351.80	353.36	353.57	354.91	355.39	356.46	357.20	358.00	359.02	359.53	360.83
1		II	2	160.90	162.66	164.41	166.18	167.95	169.73	171.50	173.28	175.07	176.87	178.66	180.45	....	387.86	388.71	390.50	391.22	393.08	393.73	......	464.81	466.10	467.35	468.22	469.89	470.34	472.43	472.46	474.59	474.97	476.71
	Feb	I	3	217.47	219.84	222.21	224.60	226.99	229.39	231.78	234.17	236.58	239.00	241.41	243.83	....	535.38	538.02	540.66	543.30	545.93	548.57	......	707.21	709.18	711.89	713.68	716.40	718.03	720.75	722.74	724.96	727.44	729.02
		II	4	426.60	431.93	437.25	442.64	448.03	453.42	458.84	464.30	469.75	475.20	480.71	486.23	....	957.04	958.55	959.70	962.35	964.99	965.24	......	1068.45	1070.32	1072.18	1072.40	1074.02	1075.83	1077.63	1079.10	1079.40	1081.14	1082.87
	Mar	I	5	673.45	677.46	681.47	681.81	685.49	689.51	693.53	696.07	697.55	701.57	705.59	709.61	....	1049.39	1052.38	1052.42	1055.33	1058.25	1061.13	......	1147.53	1147.92	1148.28	1148.61	1148.92	1149.20	1149.46	1149.70	1149.92	1150.11	1150.29
		II	6	343.69	347.40	351.11	354.82	358.57	362.31	366.06	369.81	373.56	377.33	381.11	384.90	....	840.14	844.27	848.39	852.52	856.64	860.77	......	1109.86	1114.03	1118.21	1122.39	1126.56	1130.74	1134.92	1139.10	1143.27	1147.45	1151.63
optimal	Apr	I	7	98.96	99.22	99.24	99.52	99.80	100.07	100.35	100.62	100.89	101.15	101.42	101.66	....	121.47	121.58	121.69	121.79	121.90	122.00	......	124.70	124.71	124.71	124.71	124.72	124.72	124.72	124.72	124.72	124.73	124.73
124.73		II	8	74.77	75.35	76.08	76.87	77.38	77.89	78.41	78.99	79.58	80.13	80.64	81.12	....	113.55	113.77	113.99	114.14	114.21	114.43	......	123.69	123.81	123.92	124.03	124.14	124.25	124.35	124.45	124.55	124.64	124.73
S200	May	I	9	52.26	53.09	53.93	54.78	55.63	56.49	57.35	58.22	59.09	59.97	60.86	61.75	....	110.63	110.93	111.04	111.23	111.53	111.82	......	124.56	124.78	125.00	125.22	125.24	125.43	125.65	125.86	126.07	126.28	126.42
		II	10	40.37	41.15	41.94	42.74	43.54	44.34	45.15	45.97	46.79	47.61	48.44	49.27	....	112.62	113.06	113.49	113.55	113.93	114.36	......	131.74	132.02	132.12	132.50	132.87	133.05	133.24	133.61	133.98	134.07	134.35
season	Jun	I	11	61.64	63.12	64.63	65.86	67.11	68.27	69.21	70.13	71.05	71.98	72.69	73.29	....	128.42	128.60	129.10	129.60	130.10	130.24	......	152.76	153.20	153.64	153.81	154.08	154.52	154.96	155.39	155.62	155.82	156.25
2		II	12	44.49	45.70	46.93	48.17	49.42	50.70	51.97	53.27	54.57	55.88	57.22	58.56	....	135.11	135.78	135.96	136.45	137.12	137.66	......	165.32	165.94	166.55	166.61	167.16	167.78	168.32	168.38	168.99	169.60	170.02
	Jul	I	13	36.77	37.85	38.95	40.07	41.20	42.35	43.52	44.70	45.89	47.10	48.31	49.55	....	153.21	153.26	154.29	154.87	155.36	156.44	......	194.64	195.27	195.68	196.73	196.89	197.76	198.50	198.80	199.84	200.12	200.87
		II	14	49.09	50.59	52.09	53.63	55.18	56.73	58.32	59.91	61.52	63.15	64.78	66.43	....	202.26	204.31	204.43	206.36	206.61	208.41	......	267.84	269.26	269.89	271.03	271.94	272.79	273.99	274.55	276.04	276.31	278.07
	Aug	I	15	42.07	43.71	45.40	47.12	48.87	50.67	52.49	54.36	56.24	58.17	60.12	62.09	....	300.67	303.26	305.42	305.86	308.45	310.97	......	417.47	418.97	420.06	422.66	424.75	425.26	427.85	430.45	430.53	433.04	435.64
		II	16	78.28	81.58	84.98	88.49	92.10	95.83	99.68	103.61	107.65	111.80	116.01	120.36	....	767.19	773.15	779.11	785.07	791.03	796.99	......	1154.77	1160.76	1166.76	1172.75	1178.74	1184.74	1190.73	1196.72	1202.71	1208.71	1214.70
	Sep	I	17													....							....											
		II	18													....							....											
	Oct	I	19													....							....											
		II	20													....							....											

Table 9 Policy analysis of the optimal outflow (no. gradation) (Analysis result, 2021)

Month	1/2 month	½ month period	STATUS OF INITIAL PERIOD RESERVOIR STORAGE																															
			S0	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	....	S125	S126	S127	S128	S129	S130	....	S190	S191	S192	S193	S194	S195	S196	S197	S198	S199	S200
Nov	I	21	26	25	24	23	23	22	21	21	20	20	19	19	19	....	33	34	34	34	34	34	....	39	39	39	39	39	39	39	39	39	39	40
	II	22	42	42	42	43	43	43	43	43	44	44	44	44	45	....	86	86	86	87	87	87	....	104	104	104	105	105	105	105	106	106	106	106
Dec	I	23	51	51	52	52	53	53	54	54	55	55	56	56	57	....	118	119	119	120	120	121	....	147	147	148	148	148	149	149	150	150	150	151
	II	24	70	70	71	72	72	73	74	74	75	76	76	77	78	....	160	161	161	162	162	163	....	195	195	196	196	197	197	198	198	199	199	200
Jan	I	1	81	82	83	83	84	85	85	86	87	87	88	89	89	....	166	167	167	168	168	168	....	197	197	197	198	198	199	199	200	200	201	201
	II	2	94	95	96	96	97	98	99	99	100	101	102	103	103	....	187	188	188	189	189	190	....	222	222	223	223	224	224	225	225	226	227	227
Feb	I	3	94	95	96	96	97	98	99	100	100	101	102	103	104	....	205	206	207	208	209	210	....	264	264	265	265	266	266	267	268	268	269	269
	II	4	82	83	84	84	85	86	86	87	88	89	89	90	91	....	145	145	146	146	146	146	....	162	162	162	162	163	163	163	163	164	164	164
Mar	I	5	50	50	50	50	51	51	51	51	52	52	52	52	52	....	76	76	76	77	77	77	....	83	83	83	83	83	83	83	83	83	83	83
	II	6	95	96	97	97	98	99	100	101	102	102	103	104	105	....	206	207	208	209	210	211	....	268	269	270	271	272	273	274	275	276	277	278
Apr	I	7	44	44	44	45	45	45	45	45	45	45	45	45	46	....	54	54	54	54	54	54	....	55	55	55	55	55	55	55	55	55	55	55
	II	8	59	59	58	58	58	58	58	57	57	57	57	57	57	....	76	76	76	76	77	77	....	83	83	83	83	83	83	83	83	83	83	83
May	I	9	65	66	66	67	67	68	68	69	70	70	71	71	72	....	96	96	96	97	97	97	....	108	108	108	108	108	109	109	109	109	109	109
	II	10	54	55	55	56	57	57	58	59	59	60	61	61	62	....	113	113	113	113	114	114	....	131	131	132	132	132	132	133	133	133	133	134
Jun	I	11	44	44	45	44	44	44	44	44	44	44	44	44	45	....	73	74	74	74	74	74	....	87	87	87	87	88	88	88	88	88	89	89
	II	12	39	40	40	41	41	42	43	43	44	44	45	46	46	....	82	82	82	83	83	83	....	100	100	100	100	101	101	101	102	102	102	102
Jul	I	13	36	37	37	38	38	39	39	40	40	41	42	42	43	....	97	97	98	98	99	99	....	123	123	124	124	124	125	125	126	126	126	127
	II	14	35	36	37	37	38	38	39	40	40	41	42	42	43	....	101	102	103	103	104	104	....	133	134	134	135	135	136	136	137	137	138	138
Aug	I	15	28	28	29	29	30	30	31	31	32	32	33	33	34	....	118	119	120	120	121	122	....	163	164	164	165	166	166	167	168	169	169	170
	II	16	27	27	27	27	27	28	28	28	29	29	29	30	30	....	131	132	133	134	135	136	....	195	196	197	198	199	200	201	202	203	204	205
Sep	I	17														....							....											
	II	18														....							....											
Oct	I	19														....							....											
	II	20														....							....											

The result of optimization by the stochastic dynamic programming for two crop seasons is the table of optimal outflow policy and maximum objective function. Table 9 presents the policy analysis of optimal outflow; this table shows the decision of reservoir outflow that has to be carried out based on the status of the reservoir storage for the half-monthly initial period.

The table of the maximum objective function for the Way Rarem reservoir will fulfill the maximum water need for each crop season. The crop season from November 1 until March 2 produces the maximum E.V. in the amount of 156.26%; however, the crop season from April 1 until August 2 produces the maximum E.V. in the amount of 124.73%. The values will be reached if the operation of the reservoir outflow follows the rule in the table of optimal outflow policy. Fig. 6 presents the policy pattern of outflow in Way Rarem reservoir.

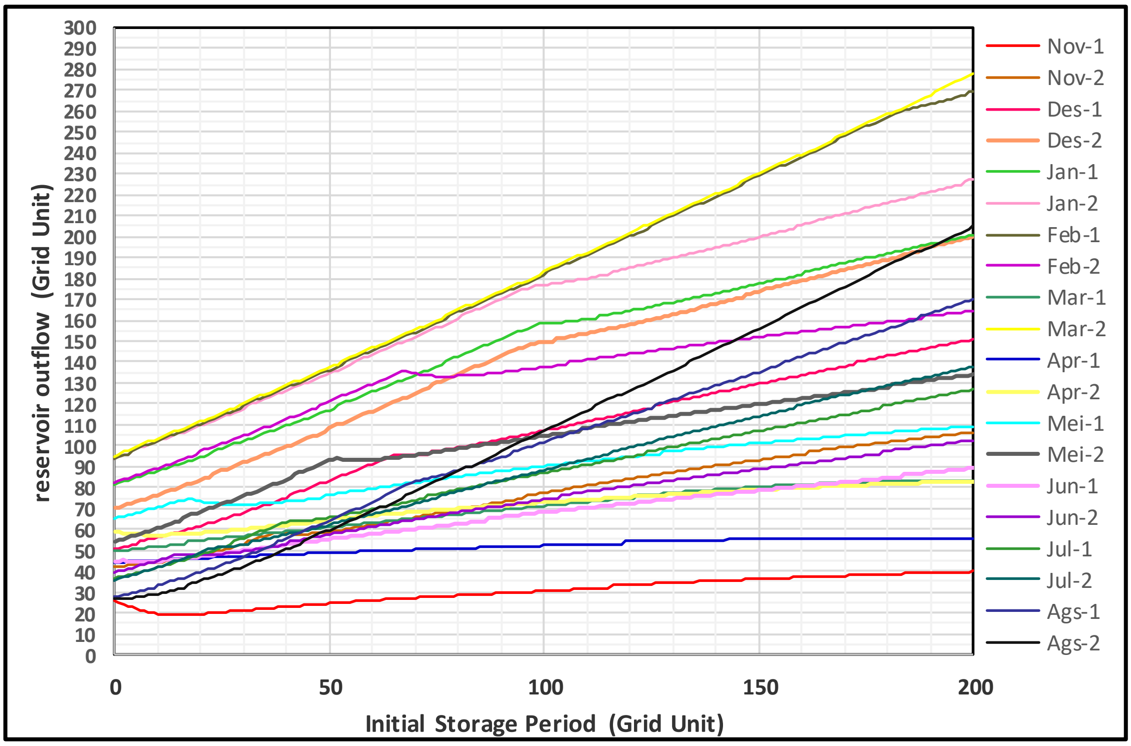

Fig 6. Policy pattern of the outflow in the Way Rarem reservoir (Own study, 2021)

4. Conclusion

In the beginning, the Way Rarem reservoir is supplying the irrigation area of 22,000 ha with the cropping pattern in the rainy season is paddy (MT-I) and in the dry season is paddy/ second crop (MT-II), and the maximum capacity of taking channel is 22.22 m^3/s. In 2015, the reservoir is planned to supply the irrigation area in amount of 15,081 ha, however, only about 14,051 ha can be realized**.**

The available operation pattern of the Way Rarem reservoir until 2015 is able to supply 15,081 ha with a crop intensity of 171.17%, and in 2017, it was planned to supply 17,612.75 ha with a crop intensity of 163.4%. However, the assessment of reservoir operation pattern based on the revised irrigation area will produce the crop intensity in an amount of 177.25%. After carrying out the optimization by using stochastic dynamic programming for two crop seasons, the optimal outflow policy and maximum objective function is produced. The maximum objective function fulfils the maximum need for each crop season. The rainy crop season (MT I), from the first two weeks of November until the second two weeks of March, produces the needed water in the amount of 156.26%. However, for dry season (MT II), which begins from the first two weeks of April until the second two weeks of August produces the crop intensity in amount of 124.73% or identical with crop intensity in amount of 196.36%. If the irrigation area is 22,000 ha as per the initial plan, so the crop intensity is in an amount of 177.14%.

References

[1] GUPTA N., PILESJO P., and MAATHUIS D. Use of geo-informatics for Inter-Basin water transfer assessment. *Journal of Water Resources: Water Resources and the Regime of Water Bodies*, 2010, 37(3): 623–637.

[2] JUWONO P. T., LIMANTARA L. M., SOETOPO W., and NOPEBRIAN A. Optimization of Irrigation Cropping Pattern (Case Study on Karang Anyar Irrigation Area, Malang Regency, Indonesia). *International Journal of GEOMATE*, 2018, 15(50): 197-204. https://geomatejournal.com/geomate/article/view/993

[3] FAGHIHI N., BABAZADEH H., SEDGHI H., and PAZIRA E. Optimization of irrigation planning and cropping pattern under deficit irrigation condition using genetic algorithm. *Indian Journal of Fundamental and Applied Life Sciences*, 2015, 5(S3): 566-577. https://www.cibtech.org/sp.ed/jls/2015/03/063-JLS-S3-008-NEDA-.pdf

[4] MOUTONNET P. *Yield response factors of field crops to deficit irrigation*, 2002. https://www.fao.org/3/y3655e/y3655e04.htm

[5] GAKPO E., TSEPHE J., NWONWU F., and VILKOEN M. Application of stochastic programming (SDP) for the optimal allocation of irrigation water under capacity sharing arrangements. *Agrekon, Agricultural Economics Association of South Africa*, 2006, 44(4): 436–451.

[6] SATTARI T. M., KODAL S., and ÖZTÜRK F. Application of deterministic mathematical method in optimizing the small irrigation reservoir capacity. *Journal of Akdeniz Universitesi Ziraat Fakoltesi Dergisi*, 2006, 19(2): 261–267. https://app.trdizin.gov.tr/makale/TmpJNE9UZzQ/application-of-deterministic-mathematical-method-in-optimizing-the-small-irrigation-reservoir-capacity

[7] MIATKOWSKI Z., & SMARZYŃSKA K. Surface water resources of small agricultural watershed in the Kujawy Region, Central Poland. *Journal of Water and Land*

Development, 2017, 33: 131–140. https://doi.org/10.1515/jwld- 2017-0028

[8] JUWONO P. T., LIMANTARA L. M., and ROSIADI F. Optimization of irrigation cropping pattern by using linear programming: Case study on irrigation area of Parsanga, Madura Island, Indonesia. *Journal of Water and Land Development*, 2018, 39: 51–60. https://doi.org/10.2478/jwld-2018-0058

[9] WURBS R. A. Reservoir-system simulation and optimization models. *Journal of Water Resources Planning and Management*, 1993, 119: 455-472. https://doi.org/10.1061/(ASCE)0733-9496(1993)119:4(455)

[10] HAQUARI M., & AZAIEZ M. N. Optimal cropping patterns under water deficits. *European Journal of Operational Research*, 2001, 130: 133–146. https://doi.org/10.1016/S0377-2217(00)00028-X

[11] DITJEN SUMBER DAYA AIR. *Kriteria perencanaan irigasi 01 (KP-01) (Criteria for irrigation design 01)*. Jakarta, 1986.

[12] SOETOPO W. *Single reservoir operation*. CV. Asrori, Malang, 2010.

[13] LIMANTARA L. M., & SOETOPO W. *Water Management*. Penerbit Andi, Yogyakarta, 2020.

[14] BALAI BESAR WILAYAH SUNGAI MESUJI SEKAMPUNG. 2021. https://sda.pu.go.id/balai/bbwsmesujisekampung/

[15] SUBROTO T., BISRI M., LIMANTARA L. M., and SOETOPO W. The Way Rarem Reservoir's Efficacy in Supplying the Irrigation Area: A Simulation Analysis. *Journal of Southwest Jiaotong University*, 2021, 56(5): 1-10. https://doi.org/10.35741/issn.0258-2724.56.5.1

[16] JUWONO P. T., LIMANTARA L. M., and PUTRA A. R. Optimizing Irrigation Benefits in the Water System Using Dynamic Programming. *Journal of Southwest Jiaotong University*, 2021, 56(4): 890-902. https://doi.org/10.35741/issn.0258-2724.56.4.77

参考文:

[1] GUPTA N.、PILESJO P. 和 MAATHUIS D. 使用地理信息学进行跨流域调水评估。水资源杂志：水资源与水体制度，2010，37(3)：623–637。

[2] JUWONO P. T.、LIMANTARA L. M.、SOETOPO W. 和 NOPEBRIAN A. 灌溉种植模式的优化（印度尼西亚玛琅摄政区卡朗安雅灌溉区的案例研究）。国际地理杂志，2018, 15(50): 197-204. https://geomatejournal.com/geomate/article/view/993

[3] FAGHIHI N.、BABAZADEH H.、SEDGHI H. 和 PAZIRA E. 使用遗传算法优化灌溉不足条件下的灌溉计划和种植模式。印度基础与应用生命科学杂志，2015，5(S3) : 566-577 。 https://www.cibtech.org/sp.ed/jls/2015/03/063-JLS-S3-008-NEDA-.pdf

[4] MOUTONNET P. 大田作物对亏缺灌溉的产量响应因子，2002. https://www.fao.org/3/y3655e/y3655e04.htm

[5] GAKPO E.、TSEPHE J.、NWONWU F. 和 VILKOEN M. 随机规划 (社会发展计划) 在容量共享安排下优化灌溉水分配的应用。阿格里康，南非农业经济学协会，2006，44(4)：436–451。

[6] SATTARI T. M.、KODAL S. 和 ÖZTÜRK F. 确定性数学方法在优化小型灌溉水库容量中的应用。阿克德尼兹大学学报农学院学报，2006, 19(2): 261–267 。 https://app.trdizin.gov.tr/makale/TmpJNE9UZzQ/application-of-deterministic-mathematical-method-in-optimizing-the-small-irrigation-reservoir-capacity

[7] MIATKOWSKI Z., & SMARZYŃSKA K. 波兰中部库贾维地区小型农业流域的地表水资源。水土发展杂志，2017，33：131-140。 https://doi.org/10.1515/jwld-2017-0028

[8] JUWONO P. T.、LIMANTARA L. M. 和 ROSIADI F. 使用线性规划优化灌溉种植模式：印度尼西亚马杜拉岛帕桑加灌溉区的案例研究。水土发展杂志，2018，39：51-60。 https://doi.org/10.2478/jwld-2018-0058

[9] WURBS R. A. 水库系统模拟和优化模型。水资源规划与管理杂志，1993，119：455-472。 https://doi.org/10.1061/(ASCE)0733-9496(1993)119:4(455)

[10] HAQUARI M., & AZAIEZ M. N. 缺水条件下的最佳种植模式。欧洲运筹学杂志，2001，130：133-146。 https://doi.org/10.1016/S0377-2217(00)00028-X

[11] 水资源总司。多年生植物鉴定标准 01 (知识点-01)（灌溉设计标准 01）。雅加达，1986。

[12] SOETOPO W. 单一水库操作。简历。阿斯罗里，玛琅，2010。

[13] LIMANTARA L. M. 和 SOETOPO W. 水资源管理。安迪，日惹，2020。

[14] 双溪明筋实甘榜地区厅。2021. https://sda.pu.go.id/balai/bbwsmesujisekampung/

[15] SUBROTO T.、BISRI M.、LIMANTARA L. M. 和 SOETOPO W. 稀有之路水库在灌区补给中的作用：模拟分析。西南交通大学学报, 2021, 56(5): 1-10. https://doi.org/10.35741/issn.0258-2724.56.5.1

[16] JUWONO P. T.、LIMANTARA L. M. 和 PUTRA A. R. 使用动态规划优化水系统中的灌溉效益。 西南交通大学学报，2021, 56(4): 890-902. https://doi.org/10.35741/issn.0258-2724.56.4.77