The Optimal Operation of Haditha Reservoir by Discrete Differential Dynamic Programming (DDDP)

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Abstract

The aim of the present research is to find the best optimal policy for monthly operation of Haditha Reservoir for 24 years (from 1990 to 2014) in order to minimize the total penalties taken place due to both releases and storage when exceeded the limited allowable values by using Discrete Differential Dynamic Programming (DDDP). The results of this study used to find a suitable probability distribution of the values of storage. The log normal distribution for three parameters was found to be the best distribution for determination the operation curves values.

Key words: optimal operation, probability, dam, reservoirs.

الخلاصة:

الهدف الرئيسي من هذا البحث لايجاد افضل تشغيل شهري لخزان حديثة لمدة 24 سنة من عام 1990 الى 2014 ..لايجاد اقل فواقد تحدث نتيجة كلا التجهيز والخزن عندما يتجاوز الحد المسموح بأستخدام برمجة التفاضلية الحركية المنفصلة . النتائج استخدمت لايجاد التوزيع الاحتمالي لقيم الخزن ..وقد تبين ان التوزيع الطبيعي لثلاث محددات هو افضل توزيع لايجاد افضل منحني التشغيل.

الكلمات المفتاحية: التشغيل الأمثل، الاحتمالية، السدود، الخزانات

1. Introduction

Water is an essential resource for all life on the planet. The water resources on Earth only three percent of it is fresh and two-thirds of the freshwater locked up in ice caps and glaciers. Much effort in water resource management directed at optimizing the use of water and in minimizing the environmental impact of water use on the natural environment. Successful management of any resources requires accurate knowledge of the resource available, the uses to which it may put the competing demands for the resource, measures to and processes to evaluate the significance and worth of competing demands and mechanisms to translate policy decisions into actions on the ground. Reservoir operation is an important element in water resources planning and management. It consists of several control variables that defines the operational strategies for guiding a sequence of releases to meet a large number of demands from stakeholders with different objectives. (Loucks and Beek 2005)

The application of optimization techniques is most challenging in water resources systems area, due to the large number of decision variables involved, the stochastic nature of the inputs and multiple objectives. Applying optimization a techniques for reservoir operation is not new idea and has become a major focus of water resources planning and management. Various techniques applied in an attempt to improve efficiency of reservoir operation. One of these techniques is uses Discrete Differential Dynamic Programming (DDDP) that decrease time and memory in large amount to get an optimum plane for monthly operation of Haditha reservoir.

2. Study Area and Data

The Discrete Differential Dynamic Programming (DDDP) applied to find the optimum monthly operation of Haditha Reservoir. It was located on the Euphrates River in the Middle West of Iraq (8 km) upstream from Haditha Town. Central and southern parts of Iraq get the benefit of irrigation water from its reservoir. For the flow records data, monthly inflow, precipitation and evaporation at the reservoir for (24 years) are used. The study shows that storage decreases at the interval enclosed

between June and to October and increases at the remaining interval of the year (November to May).

3. Methodology

Differentiated dynamic programming (DDP) is an optimal control algorithm of the trajectory optimization class. The algorithm uses locally quadratic models of the dynamics and cost functions, and displays quadratic convergence. It is closely related to Pantoja's step-wise Newton's method.(Liao and Shoemaker 1992)

The DDDP is an iterative technique in which the recursive equation of dynamic programming which used to find an improved trajectory among the discrete states in the neighborhood of a trial trajectory. Consider the dynamic system whose state equation is:

$$S(n) = \varphi \, [S(n\text{-}1) \, , \, u(n\text{-}1) \, , \, n\text{-}1], \, n = 1,2,3,\ldots,N \tag{1}$$

Where n is an index specifying a stage (beginning of a time increment), N is the total number of time increments into which the time horizon has been divided, $S(n)$ is a dimensional state vector at stage n ,then the optimal step can be defined as $F_n \, (S_n)$ (Alias ,1995):

$$F_{(n)} \, (S_{(n)}) = \min[\{r_{(n)} \, (S_{(n)} \, , \, D_{(n)})\} + F_{n\text{-}1} \, \{S_{\, n\text{-}1}\}] \tag{2}$$

Where D(n) is the decision from state (n)

4. Constraint and Aim Function

The constraints consist of continuity equation (mass balance) on reservoir content from the beginning to the next step. It tends to be in a permanent equilibrium state when it expressed in the following equation (Stedinger and Haith 1981):

$$R_{(i)} = I_{(i)} + S_{(i)} \, - S_{\, i+1} \, - EVP_{(i)} \qquad (\, i = 1, 2, 3, ..,12 \,) \tag{3}$$

Where R(i) is the outflow in the month (i) , $S(i)$ and $S_{\, i+1}$ are the reservoir storage in the beginning and in the end of the month (i), I(i) is the inflow to reservoir in the month (i), EVP(i) is the evaporated or added water to the reservoir in the month (i) in million cubic meters (MCM), which can be expressed as :

$$EVP_{(i)} = A_{(i)} \, (EVAP_{(i)} - P_{(i)}) \tag{4}$$

Where $EVP_{(i)}$ is the evaporated amount of reservoir in the month (i) .m, $P_{(i)}$ is precipitation amount on the reservoir in the month (i),m. $A_{(i)}$ is the surface area of the reservoir ,Km^2 , which can be expressed as : (Stephen *et.al.,*2007)

$$A(i) = 1.7014E - 10(S'_{(i)}{}^3 - 4.8163E - 6S'_{(i)}{}^2 + 0.655S'_{(i)} + 14.4469 \tag{5}$$

Where S' (i) is the average storage in the month, (MCM).

This equation can be solved by applying equation No.(2):

$$F_{(i+1)} \, [S_{(i+1)}] = \min [\, \textstyle\sum loss(R_{(i)} \,) + loss \, (S_{(i+1)} + F_{(i)} \, S_{(i)} \,)] \tag{6}$$

Where loss $(R_{(i)})$ are the loss from reservoir when it excesses the maximum and minimum limit, loss($S_{(i)}$) is the loss from reservoir when it excesses the maximum and minimum operating limit.

Aim function defined as the decreasing of the losses that deviate from theoretical operation as:

$$\text{Min Penalty} = \textstyle\sum [\, Loss \, (R_{(i)} + \, Loss(S_{(i+1)}] \tag{7}$$

Where loss $(R_{(i)})$ is the loss resulting from reservoir discharge.

If $R_{(i)} < Dem_{(i)}$, then:

$$\text{Loss} \, (R_{(i)}) = \alpha \, [R_{\, (i)} - Dem_{(i)} \,]^2 \tag{8}$$

If $R_{(i)} > MF$, then:

$$\text{Loss} (R_{(i)}) = \beta[R_{(i)} - MF]^2 \tag{9}$$

If $Dem_{(i)} \leq R_{(i)} \leq MF$, then:

$$\text{Loss} (R(i)) = 0 \tag{10}$$

Where Dem (i) is the water demand in the month (i), its constant each year., (α = 21.57, β = 0.01) (Vongkunghae and Chumthong, 2007) are constants depends on probability of outflow is less than active demand or more than allowable maximum flow., Loss ($S_{(i+)}$ is the losses result from storage in reservoir.

If $S_{(i+1)} < RulL_{(i+1)}$, then:

$$\text{Loss} (S_{(i+1)}) = \delta[S_{(i+1)}) - RuI L_{(i+1)}]^2 \tag{11}$$

If $S_{(i+1)} > Rul U_{(i+i)}$, then:

$$\text{Loss}(S_{(i+1)}) = \mu [S_{(i+1)} - RuI L_{(i+1)}]^2 \tag{12}$$

If $RulL_{(i+1)} \leq S_{(i+1)} \leq RulU_{(i+1)}$, then:

$$\text{Loss } S_{(i+1)} = 0 \tag{13}$$

Where $RulL_{(i+1)}$ is the minimum limit for reservoir operation., $RulU_{(i+1)}$) is the maximum limit for reservoir operation, ($\delta = 0.124, \mu = 0.174$) are constants depend on the probability of storage at the end of the month , if it is higher than maximum or less than minimum operation storage.(Fadhil , 1990).

5. Rule curves for different probabilities

The storage results that obtained it from optimum strategies of monthly operation of Haditha Reservoir used to find the best probability distribution for water level in the reservoir, so, the following distribution was tested:

1. Normal distribution
2. Log Normal distribution for two variables
3. Log Normal distribution for three variables
4. Logarithm Pearson distribution, Type III.
5. Pearson Type III Distribution.
6. Extreme value distribution, Type I.
7. Extreme value distribution, Type III.

To check, the best probability distribution, the following methods are used:
1. Chi-Square test.
2. Kolmogorov-Smirnov test.
3. The standard error (SE).
4. The gross error (GE).
5. The absolute deviation average test.
6. Efficiency test.

The distribution gives minimum value of all tests except efficiency test, it will be the best distribution, the distribution gives value equal or more than 97% , it can be considered as acceptable distribution.

For this research, Log Normal distribution for three variables is the best and the optimum one for different probabilities. (20%,10% and 5%) .

Regression analysis is used to find the relationship of the storage with time for different probabilities ,Table (1) shows regression coefficients for the equations and correlation coefficients with values of (0.998,0.995 and 0.993) for all the states.Hence, the equation of the storage with time was:

$$S_{(t)} = A + Bt + Ct^2 + Dt^3 + Et^4 \qquad (14)$$

Where t: time in months (1,2,3,…,12)., (A, B, C, D, E,) are regression coefficients., S(t) is the storage at reservoir for a month,(MCM)., and this equation can be applied for any probability with any month. Figures (1) to (3) show the rule curve for different probabilities, This figures show that no excess in maximum or minimum operation storage of Haditha Dam.

6. Discussion

One of the important goals of water resource management is the establishment of realistic reservoir operating policies for water allocation, especially during periods of drought and floods. Reservoirs can be used to balance the flow in highly managed systems, storing in water during high flows and releasing it again during low flows.

Monthly discharge for (24 years) taken as the required data used in the previous program assumed that the dam was operated all that period to get the optimum operation of reservoir with minimum expected losses.

From the research results ,the role curves had been got that represent the relation ship between the storage and time for three different level (maximum., mean, minimum.),minimum storage was recorded for (24 years) , 3980 MCM from July to October ,while maximum storage was recorded for operating period ,it was 11000 MCM at June, from these numbers ,it can be explain that the storage value extract by using Discrete Differential Dynamic Programming (DDDP) lie within the maximum and minimum storage and achieve state of water equilibrium.

On the other hand, the minimum release discharge from reservoir was within the water demand for the region below the reservoir. The optimum management of the reservoir include fill it during high flow from January to May, or from January to June in another seasons , then release it in drought period from June to December.

From previous results, it can explain that maximum release was in May with value (7640MCM),while minimum release was in September with value (276MCM) and average maximum release during operation period was (4018MCM) in April and May. Thus, that will be full the conditions and requirements of water filled demand for the region below the reservoir.

So, it can be concluded that depending on Discrete Differential Dynamic Programming (DDDP) to reach the optimum manage for operating reservoir ,this programming gave optimum results without excess for any constraints, the summation of aim function was equal zero.

And it can be noticed that upper rule curve and lower rule curve didn't excess the maximum and minimum storage in the reservoir, as it explained by applying different types of distribution on the storage values gets from strategies of optimum operation.

Log Normal distribution for three variables was the best one among other distributions because it gives good results without any excess of any aims and values.

Table (1) regression coefficients and correlation coefficients for the equation of storage with time.
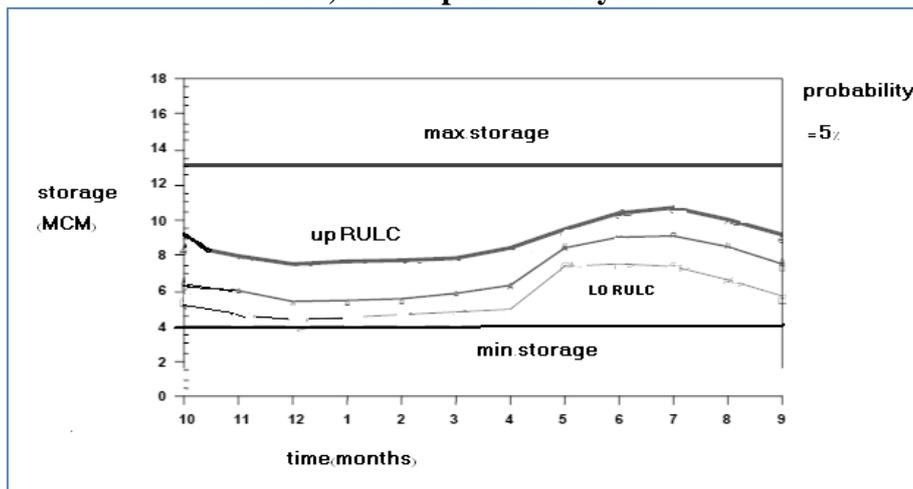
Probability	Regression coefficients					R^2
	A	B	C	D	E	
5%	6123.1	4123.9	-1450.2	199.67	-8.43	0.998
10%	5668.9	4278.6	-1311.6	156.33	-5.12	0.995
20%	4234.8	3759.2	-983.2	78.91	-1.43	0.993
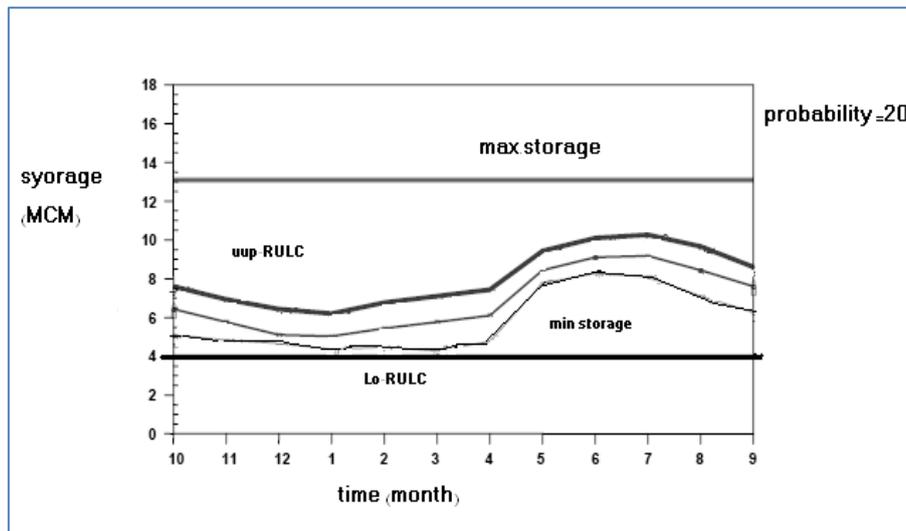
Figure(1): Upper and lower rule curve for Haditha Reservoir with probability 20%, return period =5 years
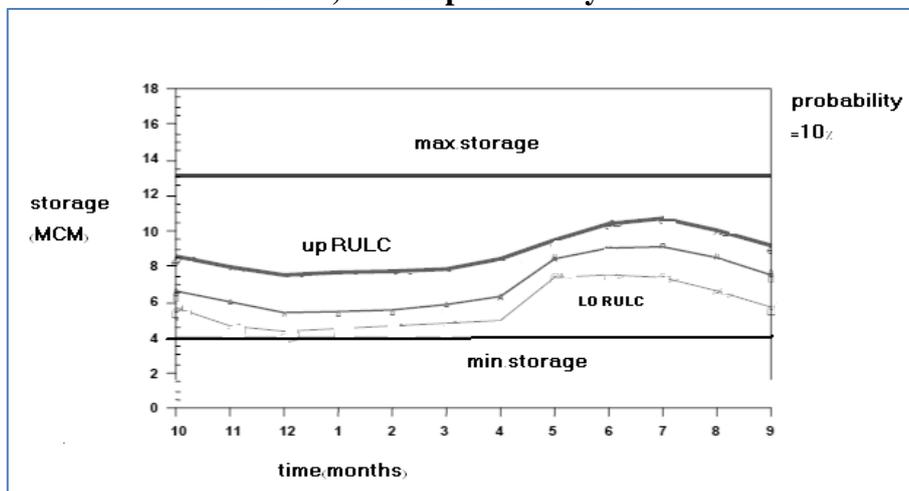
Figure(2): Upper and lower rule curve for Haditha Reservoir with probability 10%, return period =10 years

Figure(3): Upper and lower rule curve for Haditha Reservoir with probability 5%, return period =20 years

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