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A Review of Optimization to the Operation of a Complex Water Resources System Based on Certain Practical Assumptions and Simplification

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Abstract

This research is set out to review of “optimum the water complex resources system by using dynamic programming DP and Discrete Differential Dynamic Programming DDDP, Beside a solution of formulated DP optimization model, the model of simulation was adopt for achieve the operation as close to optimum operation as possible, with the keep level of storage and releases within their targets”. In aiming at the optimal solution of the reservoir – operation problem, (DP) represents a numerical method which is used to determine the optimal sequential decisions, taking into consideration an effective constraints associated with problem. DDDP is the solution procedure of many problems which already formulated as dynamic – programming ones. It is reduce the memory requirements and save computational time.

The Optimization model was applied for “two operations hypothetical represented by the cases of extreme, namely consecutive to the relatively of two wet years and two consecutive the relatively of dry years”.

The data to the historical inflow for “(240) months are (from Oct. 1988 to Sep. 2005) was form to the data input to a model of optimization for found rule curves (lower, average and upper)”. A flooding state within Al_Edhaim Resevoir has been fully avoided. “The policy to the optimization of operation is shown a deficiency in satisfying downstream Al-Edhaim Dam demands”. “The optimization of the operation for two consecutive wet years would be full capable controlling expected floods, so as to the deficiency would be from 9.3–59.1 *cumecs* total of 34.2% of demand, then the optimization of the operation for two consecutive dry years would be from 11.8 – 81.2 *cumecs* total of 57.3 % of the whole demand".

Key words: Optimization, Discrete Differential Dynamic Programming, Complex water resources system, Storage, Release.

1. Introduction

Water has been used for different purposes in human life. The use of irrigation water is an important subject of many scientific and social concerns; it has shown limited in a country such as Iraq because it contains various water resources such as rivers and lakes. “The increase in agricultural and industrial activities led to the consumption of large quantities of water, as a result of spread in agricultural land and limited water of rain and rivers in addition to the suffering of Iraq from the control of some neighboring countries in the amount of Tigris and Euphrates Rivers”,**[1]**.

For securing the “irrigated benefits to the land, an amount tremendous for the capital had invest for the project of irrigation”. “So that, projects constructed at the upstream of Turkey and Syria for storing and consuming water have a resulted in reducing the quantity and quality of water that arrives to Iraq”, **[2]**.

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Dams are built in rainy countries, where water in large amount may be collected and stored in a reservoir, **[3]**. “It is usually ensured the satisfaction of two basic objectives, namely, flood control (during the season of ample water) and keeping of reserve of water for the different water needs (during draughts)”,**[3],[4].**

The main objective of this research is a review for the optimum operation of a complex water resources system, taking “Al_Edhaim Dam” as the case study, based on certain practical assumptions and simplification.

2. Review of Literature

Many studies have been conducted in the field of optimization of operation of the complex water resources system. “Optimization is processing for find a conditions that gives the maximum or the minimum amount to the function”, [5]. “Optimization is of two levels, namely, Comparison of alternate concepts and Optimization within a concept”, [6].

In addition to preparation and analysis of respective hydrologic data, the optimization problems are problems that deal with maximize or minimize to the certain objective function. “The optimization process involves two distinct steps, namely, the formulation of the optimization model, and the solution of the formulated model", [7]. The methods to the solving the optimization problems could be classify follows, [8]:

1- "Linear programming (LP)" has been widely used for reservoir operation problem (ROP) including constrained linear programming (CLP) and stochastic linear programming (SLP).

2- "Nonlinear programming (NLP)" has more applicability in optimizing Multi_Reservoir operations.

3- "Dynamic programming (DP)" including incremental dynamic programming (IDP), incremental programming and successive approximations (IDSA), “stochastic dynamic programming” (SDP), “Reliability–constrained dynamic programming”, “differential dynamic programming” (DDP) and the progressive optimality algorithm.

4-"Simulation" is the methodology of representing problem in a mathematical technique. The simulation process as stated in **[9]** “is the trial and error techniques rather than the process of analytical converges for the optimum global solution”، **[10]** Defined the dynamic programming as a theory of multistage decision processes.

The dynamic programming applied to determine the releases setting for minimize the loss function for a long record in which the inflow in each year that given, **[11]**. The technique can used to study any hydrologic inflow situation for which operational hydrology can be generated. Through applying least squares regression strategy to finding the optimal policies using an inflow forecast as a decision variable.

The major objective of the research to **[12]** is determine "optimum operation policy for Makhool Dam that reflects the benefits aimed by the construction of the dam, namely, satisfaction of water demands, flood control, and hydro power generation".**[12]** Introduced "Incremental DP proposed short-term and long-term planning strategies for multi-unit reservoirs, using DP".**[13],** [**14]** “Optimized a demanding reservoir system using discrete differential DP”. **[15]** “Used stochastic optimization scheme to define an operating rules of a multiple reservoir system in a two-river system under set of 28 different constraints”.

[16], [17] Were use "Simulated Annealing (SA) for optimum hydro-scheduling of a multi-reservoir hydropower plant connected in series on river.**[18]** Have presented dynamic programming computer model "DPCM" for accomplish optimum water and power operation strategy for the Shasta-Trinity Division Central Valley Project. Its developed called "Incremental Dynamic programming IDP”. A DP model to “the Missouri River main stem reservoir system” was apply by **[19]** and discussed the operation of the system to serve congressionally authorized purposes, namely, recreation, flood control, irrigation, navigation, water supply and water quality, hydropower generation, and fish and wildlife.

[9] Used "DDDP model for solving the problem of monthly operation of multi – purpose, multi – reservoir system". He applied the model for system of "Diyala – River reservoirs" with 30 years record of monthly inflow historical data. The objective function was pollution, control floods, providing generation of electrical power and irrigation requirements.

[20] Applied the "DDDP approach to find the monthly optimization of operation for the Iraqi water - storage system (Tigris and Euphrates Rivers), inflow for historical data of 420 months yielded optimum monthly releases and storages for period".

[21], [22] Used "DP" approach to find optimum operation monthly operation of "Dokan Dam", a simulation model developed for operating stemming depends on curves of rule with historical data for 348 months formed input data to the optimization modelling.

[23] Applied optimization model using a mathematical model for operation on first part of the Main Outfall Drain. **[24]** "Developed mathematical model to improve water quality of the Third River– northern section by maintaining the electrical conductivity EC and sodium adsorption ratio SAR values within allowable limits for irrigation". **[25]** applied a quality and quantity mathematical model based on the continuity and mass balance equations for calculating discharge and salt concentrations, it starts at "Samara'a Barrage and ends at Al_Qurna city"about 772 km reach.

3. The Modelling of Optimization

The "solution of formulated DP model was commonly achieved by conventional (DP) procedure which considers all possible combinations of alternatives". This "method for solution encounters two great difficulties in application, namely large memory requirements and the excessive computer time, these two limit use of the conventional DP solution in water resources system analysis, which often involves many variables, however, the discrete differential dynamic programming technique DDDP",**[26].**

[27] can be represented as eq.1:

$$R_{(i,j)} = S_{(i,j)} + I_{(i,j)} - S_{(i+1,j)} + ET_{(j)} \qquad \textbf{... (1)}$$

Where *R*: Release; *I*: inflow; *S*: storage; *ET*: net monthly water (gain or loss) from the reservoir during *j*-th month, given by eq.2:

$$ET_{(j)} = \left[Pr_{(j)} - Ev_{(j)}\right] * A_{(i,j)} \qquad \textbf{... (2)}$$

Where: *Pr*: precipitation; *Ev*: evaporation; *A*: area of the reservoir's surface water.

A reservoir operation is characterized by,**[7],[28]:**

1. Whether it is a "single reservoir" or one of a number of reservoirs in systems that are operated conjointly.
2. The allocated storage space and pool elevations.
3. "Constraints on reservoir release" due to downstream flooding and low – flow augmentation requirements.

The model of optimization constitutes an "objective function and set of imposed constraints, so for the operation of dam, the constraints are commonly storage constraints, release constraints, and continuity constraints", **[1]**; the following three constraints are:

I. Constraints of Storage

The "storage limit at start of first period of operation should a known quantity, however, storage in other periods should be within set of admissible limits as specified by design criteria of the dam", **[1], [3]**, as shown eq.3:

$$OS_{min} \le S_{(i,j)} \le OS_{max} \qquad \textbf{... (3)}$$

Where: OS_{min} and OS_{max} are minimum and maximum operation limits of storage, respectively; (*S*): storage; (*i*, *j*) denotes the (*i*-th) year and the (*j*-th) month, (*i* = 1, 2… N; *j* = 1, 2… 12), where (N) is the total number of years considered in operation schedule.

II. Constraints of Release (Out Flow)

The following releases $R_{(i,j)}$ during *j*-th month of *i*-th year should be within range of available limits, **[1], and [3]** that is eq.4:

$$D_j \leq R_{(i,j)} \leq MPF \qquad \textbf{... (4)}$$

Where: $R_{(i\,,j)}$ is release from reservoir during i-th year and j-th month; D_j is the total water requirements during the j-th month at (Industrial + Irrigation + Environmental); MPF is a maximum permissible flow, which represents flood capacity of river reach downstream dam.

III. Constraints of Continuity

The "continuity constraints should be consider transfer of reservoir storage from beginning of one period to the beginning of the next period that is indicate "inflow, outflow" activity of reservoir and can be represented eq.5 and eq.6" as:

$$R_{(i\,,j)} = S_{(i\,,j)} + I_{(i\,,j)} - S_{(i+1\,,j)} + ET_j \qquad \textbf{... (5)}$$

Where, I: inflow; S: storage and ET: net monthly water (gain or loss) from reservoir during the j-th month being all in consistent units, **[29]** given by:

$$ET_j = \left[Pr_j - Ev_j\right] * A_{(i,j)} \qquad \textbf{... (6)}$$

where: Pr: precipitation; Ev: evaporation and A: area of the reservoir's water surface.

4. The Objective Function

The problem that deals with maximization or minimization of an objective function is called an "optimization problem", "In general, the case to be optimized could be 'static' (a single_stage problem) or 'dynamic' (a multi_stage problem)", [1], [7]. The former commonly covered by linear programming or non_linear programming.

Many of researches "applying a penalty function to delineate extent of any deviation from the aimed goals, the objective functions of release and storage (which are to be minimized)" had being formulating to the follow:

4.1The Release for Function of objective, OR

The "aim is to minimization penalty associated with a failure in supplying the demand". It is set as:

$$Min.OR = \sum_{i=1}^{N}\sum_{j=1}^{12} LR_{(i,j)} \qquad \textbf{... (7)}$$

Where: total penalty due to release and $LR_{(i\,,j)}$: loss function of release in the j-th month of i-th year, which could be expressed as follows", **[30]**:

If $R_{(i\,,j)} < D_j$ then $LR_{(i\,,j)} = c_1[R_{(i\,,j)} - D_j]^2$ **... (8)**

If $R_{(i\,,j)} > MPF$ then $LR_{(i\,,j)} = c_2[R_{(i\,,j)} - MPF]^2$ **... (9)**

and If $D_j \leq R_{(i\,,j)} \leq MPF$ then $LR_{(i\,,j)} = 0$ **... (10)**

where: c_1 , c_2 : constants represent weighting factors to reflect the effect of violating constraints concerning irrigation demand and flood control in river, respectively; their values depend on the consideration of the decision maker, values of c_1 and c_2 have been both taken as [1, 2, 3, and 4] the result in all these number have been obtained the same, so it's not sensitive,**[31].**

4.2The Storage for Function of objective, OS

The expected drought periods, storage level should be not less than minimum operation level. "It is can be formulated as follows", [31], [32]:

$$Min.OS = \sum_{i=1}^{N}\sum_{j=1}^{12} LS_{(i+1,j)} \qquad \textbf{... (11)}$$

Where OS: total penalty due to storage; $LS_{(i,j)}$: loss function of the storage at the end of considered stage" which expressing as:

If $S_{(i+1,j)} < OS_{min}$ then $LS_{(i+1,j)} = c * [S_{(i+1,j)} - OS_{min}]^2$ **... (12)**

If $S_{(i+1,j)} > OS_{max}$ then $LS_{(i+1,j)} = d * [S_{(i+1,j)} - OS_{max}]^2$ **... (13)**

If $OS_{min} \leq S_{(i+1,j)} \leq OS_{max}$ then $LS_{(i+1,j)} = 0$ **... (14)**

where c and d are the constants represent weighting factors which reflect on effect of violating constraints of (OS min) and (OS max); their values depend on the consideration of decision maker.

The objective function of the optimization of the whole system TZ, will be:

$$TZ = \sum \quad OS + OR \qquad \textbf{... (15)}$$

Which is to be minimized.

5. Discrete Differential Dynamic Programming (DDDP)

Differential dynamic programming is the solution of procedure problems which are already formulated as dynamic programming ones”. It is reduce memory requirements and save computational time. “DDDP” approach was use for the first degree to corner optimal solution in a small feasible region after a number of grid points have been eliminated,[33]. “The DDDP procedure involves the following four basic steps”,[1]: “1.Establishing the initial trajectory. 2. Constructing a corridor. 3. Optimization and iteration process. 4. Defining and testing convergence criteria. To

Use (DDDP) solution which has been formulated as a DP model, it is necessary discuss four steps mentioned hereinbefore.

The (DDDP) starts with a given initial feasible solution, i.e., a feasible operation policy, the initial trial trajectory is a path within a corridor and it will be either initial trail or optimal trajectory, [9].

[10] Stated that an initial trial trajectory will reduce the time,$\boldsymbol{ST_{(i)}}$ could be assumed as:

$$ST_{(i)} = \frac{S_{max}+S_{min}}{2} \qquad \textbf{... (16)}$$

where S_{max} : maximum allowable storage; S_{min} : minimum allowable storage.

The next step of DDDP procedure consists of constructing a “corridor” around the adopted trial trajectory, then a corridor very important for specifying the limit values of state variables used in system,**[7]**. Figure (1) “illustrates the algorithm in first, second..., N-th periods”, figure (2) “shows the trial trajectory, the corridor, and the optimal trajectory for such a system”,**[26]**

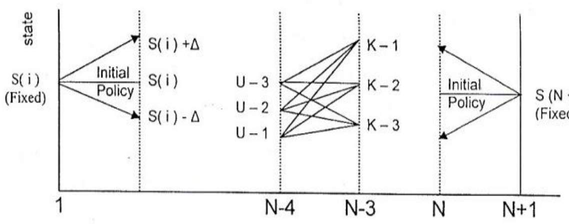

Fig.1: Algorithm in the first and other than first periods

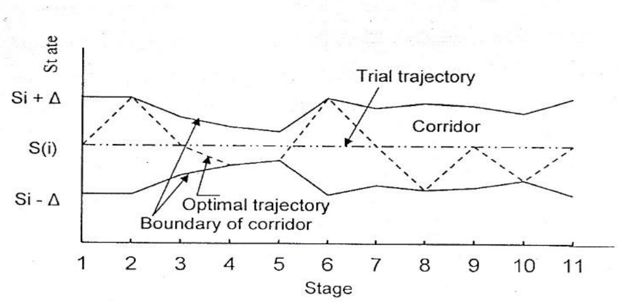

Fig.2: Schematic representation of a trial trajectory

6. Optimization of Operatiing Ruleing Curves (OORC)

It represents from eq.1 that “the relationship between inflow, outflow, precipitation, evaporation, and storage at each stage one of the physical constraints of DP,**[1]**, the formulated of DP model has been solved by (DDDP) approach to determine an optimal rule curve of Al-Edhaim Reservoir, using historical stream flow records for (240) month from Oct. 1985 to Sep. 2005”.

Values of variables ensure that the smoothness of respective rule curves, A subsidiary aim was sought, by, directing storage to be close to minimum just before start of the flood time and close to maximum just after its end, this, with the compulsory constraints stated in eq.3 and eq.4, have resulted the period of deficient supply,[33]. Initial runs of formulated model was indicate a noticeable deficit in supply, besides oscillating rule curves (upper, average, and lower), mathematically, the aforementioned procedure had been performed as follows, [33]:

$$\text{If } j = n \text{ then } PS_j = e \times (S_{max} - S_j) \qquad \textbf{... (16)}$$

Where *n*: the month under consideration; *e*: constant; values of constraint [e] used in the research where in the range (0.01‒1000), depending on the respective storage, inflow and demands during the considered month to get rules curves smoothness and wave shape.

The average rule curve has been obtained by averaging values of the storage obtained by it is model over the considered period 20 years. Then the upper and the lower rule curves have been derived depending on a non-exceeding probability values of 90% and 10% of probability distribution of optimal storage, respectively. Normal probability distribution was used to determine these rule curves.

7. The Simulatiing Modelling for Months Operatiing

Reservoir operation is very important to be made in such a manner that functions according to respective purpose of design, simulation in operations research is a methodology of the representing problem in a mathematical form manageable by computer, Simulation process in the reservoir operation problems is a trial and error technique rather than an analytical process that converges to a global optimum solution,[1].

The "sequence of steps for obtaining monthly operating schedule is as follows,[3] as shown in Fig.3":

1. Prepare the input data, which should include inflow, precipitation, initial storage, evaporation, and water demands, beside rule curves of reservoir, the initial storage of reservoir for first month of operation period was assumed equal to the average of upper and lower rule curve for the corresponding month on curves.

2. An amount of water equal to or more than water requirement is released from the reservoir and should be neither more than the maximum nor less than the minimum permissible flow of river.

3. Calculate the water losses due to the evaporation from reservoir at that month.

4. Results to "the storage should be within operation rule curves range and neither be more than design operation storage nor less than minimum operation storage of reservoir.

5. Determine reservoir water level WL which is the function of reservoir storage.

6. Compare WL with rule curves, if it is exceed rule curves, then computed storage and water level are readjusted through readjusting release.

7. Calculate outflow from power generating outlets Qp which should not exceed capacity of the power outlets, the minimum operation level represents minimum level for operating the power generators.

8. Calculate the water level of Tigris River downstream of Al-Edhaim Dam site Based on the available hydraulic data, the following relationship has been" derived:

$$WL_r = 0.021R^{0.716} + 89.5 \qquad \textbf{... (16)}$$

Where WL_r is thewater level in the river (*m.a.s.l.*) and R is the outflow from the reservoir, (*cumecs*).

9. Calculate the "rated head (H) (in meters) on the power generation units", which is given by:

$$H = WL - WL_r \qquad \textbf{... (17)}$$

10. Repeat "respective steps for the following months".

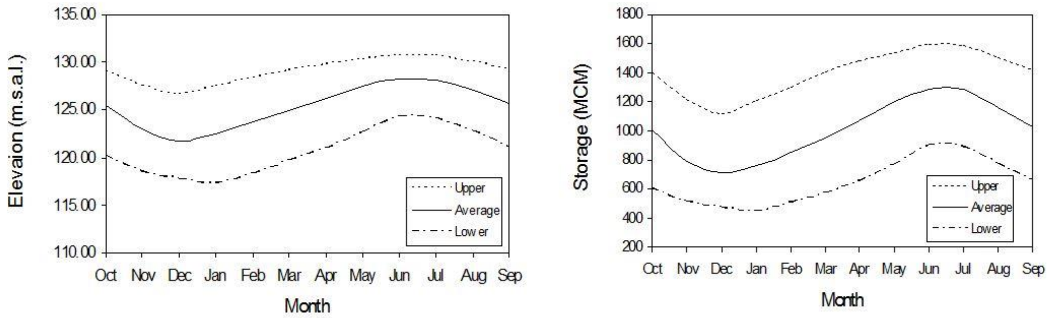

Fig.3: Optimum Operation Rule Curves for the Reservoir

8. Selecting Operatiing Cenarios

"According to the available inflow recorded from Oct. 1985 to Sep. 2005 inclusive the water years (1988, 1991) and (2001, 2004) may be considered to represent the wet year and dry year, table (1) shows Basic storage levels for Al-Edhaim Dam,**[20]**, the inflows during these considered extremists, with and without Al_Edhaim Dam", are gave Table(2). The operating of two scenarios were considering as below, namely:

1. "Two consecutive wet years".
2. "Two consecutive dry years".

Table (1): storage levels for "Al-Edhaim Dam", [20]

Item	Unit	Value
Total storage capacity	*M C M*	3750
Minimum level of storage	*m. a. s. l.*	110
Design operation water level	*m. a. s. l.*	131.5
Normal operation water level	*m. a. s. l.*	131.5
Power and Irrigation level	*m. a. s. l.*	118
Minimum operation of storage	*MCM*	290
Maximum storage level	*m. a. s. l.*	143
The Dead storage	*MCM*	160
Design operation storage	*MCM*	1440
Normal operation storage	*MCM*	1440

9. Results and Discussion

Results for running monthly operating modeling for two aforementioned operation scenarios are showed in "Tables (2)" as below. "The optimal operation for the two consecutive wet years, would not be satisfying downstream requirements in full and would be fully capable controlling expected floods, then the deficiency would be from 9.3 – 59.1 *cumecs* total of 34.2 % of the whole demand".

"The optimal operation for the two consecutive dry years, would be fully controlled for expected floods and then the deficiency would be noticeable, so the deficiency would be from 11.8 – 81.2 *cumecs* total of 57.3 % of the whole demand". Table (3) shows the results of simulation to monthly operation in wet and dry years.

10. Conclusions

The operation of the simulation model shows that the plan is safe along the (240) months of operation, since the maximum storage in the Al_Edhaim reservoir.

The operation of the reservoir has been contained within the upper and lower rule curves. This shows that flood and drought events are controlled satisfactorily by the derived operation policy.

Table (2): The inflow data for "Al-Edhaim Dam", [Water Resources, 2015]

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Wet years												
1988	11	32	12	138	125	88	27	13	8	7	5	4
1991	8	12	98	110	124	61	114	11	6	5	2	2
Dry years												
2001	3	9	18	55	25	9	1	1	1	1	0	0
2004	1	3	9	3	7	51	32	11	1	0	0	0

Table (3): Results of simulation to monthly operation in "wet and dry years".

Descripting	Units	Wet months		Dry months	
		Min.	Max.	Min.	Max.
In flow	cu mecs	2	138	0	55
Outflow	cumecs	1	287	0	25
Flow from power outlets	cumecs	0.7	43	0.3	27
Downstream water level	m.a.s.l	71	95	77	89
rated head	M	35	45	26	31
Reservoir to the water level	m.a.s.l.	132	148	110	119
Flow from bottom outlets	Cumecs	0	271	0	33

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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استعراض الأمثل لتشغيل نظام معقد للموارد المائية استنادا إلى بعض الفرضيات العملية والمبسطه

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الخلاصة :

تم إعداد هذا البحث لمراجعة التشغيل الأمثل للنظام المعقد للموارد المياه باستخدام البرمجة الديناميكية DP والبرمجة الديناميكية التفاضلية المنفصلة DDDP. بالاضافة الى حل نموذج الامثلية البرمجة الديناميكية النموذجي، تم اعتماد نموذج المحاكاة لتحقيق عملية تقريبية للتشغيل الأمثل قدر الإمكان، والحفاظ على مستوى التخزين والإطلاقات داخل المحددات. من أجل الوصول إلى الحل الأمثل لمشكلة الخزان عمليا، تم استخدام طريقة رقمية للبرمجة الديناميكية لتحديد القرار المتسلسل الامثل، مع الأخذ بعين الاعتبار القيود الفعالة المرتبطة بالمشكلة. البرمجة الديناميكية التفاضلية المنفصلة هو إجراء لحل العديد من المشاكل التي تمت صياغتها بالفعل كمخططات ديناميكية وبالتالي تقليل متطلبات الذاكرة وحفظ الوقت الحسابي.

تم تطبيق نموذج الامثلية على عمليتين افتراضيتين تمثلان الحالات القصوى، وهما سنتين متتالية نسبيًا من الرطوبة وسنتين جافتين متتاليتين نسبياً.

شكلت بيانات التدفق التاريخي لــ (240) شهرا (من أكتوبر 1988 إلى سبتمبر 2005) كبيانات الإدخال إلى نموذج الامثلية للحصول على منحنيات القاعدة (العلوي، المتوسط ، المنخفض) .وتم تجنب حالة الفيضان داخل خزان العظيم بشكل كامل وقد أظهرت نظام التشغيل الامثل عجزًا في تلبية متطلبات سد العظيم. وقد بينت النتائج بان التشغيل الامثل للسنتين الرطبتين القصوى مسيطر عليها من ناحية الفيضان ونسبة عجز 9.3–59.1 م^3/ثا من أصل 34.2% من الاحتياج الكلي وللسنوات الجافه القصوى 11.8 – 81.2 م^3/ثا من أصل% 57.3 من الاحتياج الكلي.

كلمات الداله: الامثلية، البرمجة الديناميكية التفاضلية المنفصلة، النظام المعقد للموارد المائية، الخزن، الاطلاق.