Optimum Operation of Haditha Dam

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Abstract

Limited water resources formed a great challenge for the specialists in water resources engineering. This challenge is represented by" design and manage the projects" connected with water resources in such a way that insure providing suitable quantity and quality of water.

In this research, the discrete differential dynamic programming approach is used to find the optimal monthly operation of Haditha Dam by adopting an objective function to minimize the release and storage penalty. The historical inflow data of 240 months, from Oct. 1987 to Sep. 2007, formed the input data to the optimization model to find the (upper and lower) rule curves.

Preserved the logical state of reserve storage, i.e., save minimum operation storage just before the expected start of the effective flood and maximum operation storage at the end of the flood season.

The optimum operation policy showed that Haditha reservoir can contain the probable maximum flood of Euphrates flood during the considered operation period, 240 months, and the water level in the reservoir above the operation level of the reservoir during the same period, while this policy gave deficit in satisfying the demands downstream Haditha Dam The deficiency was noticed during (152) months.

التشغيل الامثل لسد حديثة

الخـــــلاصـــــة

مصادر المياه المحدودة شكّلتْ تحدي عظيم للإختصاصيين في هندسة الموارد المائية. هذا التحدي مُمَثّلُ "كَيْفَ يتم التخطيطوالتصميمَ وادراة المشاريع "بطريقة ترتبطَ بمصادرِ المياه بحيث يُزوّدُنا بكميةِ ونوعيةِ الماءِ المناسبةِ.

استخدمت البرمجة الديناميّكية التفاضلية المنفصلة في هذا البحث لإيجاد التشغيل الشهري الأمثل لسد حديثة بعد تهيئة دالة الهدف للوصول إلى اقل الخسائر المتعلقة بالإطلاق والخزين.البيانات الهيدرولوجية التاريخية لمدة (240) شهراً (من تشرين أول 1987إلى أيلول2007) شكلت بيانات الإدخال لنموذج ألا مثلية لاستخراج أعلى واقل منحنيات التشغيل.

تمت المحافظة على الحالة المنطقية للخزين, أي توفير اقل خزين للتشغيل قبيل البدء المتوقع للفيضان المؤثر وتوفير أعلى خزين للتشغيل عند انتهاء موسم الفيضان.

إن سياسة التشغيل الأمثل بيّنت ان سد حديثة يمكنه استيعاب اقصى فيضان محتمل في نهر الفرات خلال فترة التشغيل (240) شهر ولوحظ ان مستوى الماء يبقى اعلى من مستوى التشغيل للخزان خلال نفس الفترة, ولكن بينت عجزاً في تلبية الاحتياجات المائية مؤخر سد حديثة وقد لوحظ العجز خلال (152) شهراً.

Introduction

The problems in water resources management arise when water is frequently available at a certain time and in excessive quantities (which may be destroy the agricultural lands in the neighborhood). A water-resources system supply water for consumptive, hydroelectric and sanitary purposes. It

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may provide storage reservation for flood protection and maintain minimum level for recreation or drought periods.

Dams and their respective reservoirs are usually built and operated such that they preserve water from the season when the water is ample and could be useful during the season when water is scarce. The design of a dam is frequently based on date that accrued in the past whereas their actual use would be in future.

Haditha Dam is a high dam on the Euphrates River valley. The project was completing in 1985.

The major objective of this research is to determine the optimum operation policy for Haditha dam that reflects the benefits of constructing this dam, namely ,satisfaction of water demands and flood control.

The Case Study

Haditha Dam is a high dam that has been constructed on the Euphrates River valley at Abu-shabur settlement , 7km to the north of Haditha town in the middle west of Iraq.

Haditha Dam is a multi-purpose dam. It serves flood control, regulation of the flow of Euphrates River, and for power generation.

The storage capacity of Haditha Reservoir, 9800 MCM, between design operation water level of 147 m.a.s.l. and lower operation water level of 129.5 m.a.s.l., **[Al-Janabi 2004]** is to be utilized for irrigation and power generation. The operation rules for Haditha Reservoir are to be modified based on the following factors:

1- Irrigation and power generation are carried out within the range of the storage capacity 8200 MCM, **[Al-Janabi 2004].**

2- Maximum discharge from power outlets is, 4730cumecs, **[Ali, 1994]**.

3- Operation is done so that spillage is minimum.

4- Operation for power generation is performed in such a manner that the necessary irrigation water is secured even in fairly dry years.

The summery of mean monthly inflow and water requirements for the location of Haditha Dam is shown in Table (1) and (2), respectively. The recognized shortage in the natural supply during some months and its ampleness during others delineates the necessity of the optimal operation of the dam. Consequently, the basic design parameters of the dam that concern the aim of this research are given in Table (3), **[Ishaq: 1998]**.

The Optimization Model

Several optimization techniques in use, the most widely used one in Water – Resources Engineering is the dynamic programming, DP, due to its ability to deal with dynamic models with no limitation on the type of equations governing the system constraints or the objective function. Accordingly, DP is used in this research to formulate the optimization problem.

The solution of a formulated DP model was commonly achieved by the conventional DP procedure which considers all possible combinations of alternatives. However, this method of solution generally encounters two great difficulties in application, namely, the excessive computer time and large memory requirements. These two obstacles limit the use of the conventional DP solution in water resources system analysis, which often involves many variables. However, the discrete differential dynamic programming technique, DDDP **[Heidari *et. al.*, 1971]**, was

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developed and used as an iterative technique for solving (DP) problems in such a way that the problems arising from high dimensionality of the (DP) technique are overcame **[Chow and Cortes, 1974]**. Thus, DDDP has been adopted in solving the formulated DP model to obtain the optimum operation rules.

1-The Governing equation

Continuity constraints consider the transfer of the reservoir storage from the beginning of one period to the beginning of the next. This indicates the inflow – outflow activity of the reservoir and can be represented as:

$$R(i , j) = S(i , j) + I(i , j) – S(i+1 , j) + ET(j) \qquad \textbf{(1)}$$

where, being all in consistent units : R: Release (L^3); I : inflow (L^3); S: storage(L^3) ; ET: net monthly water (gain or loss) from the reservoir during the j-th month (L^3), given by:

$$ET(j) = [Pr(j) – Ev(j)] \times A(i , j) \qquad \textbf{(2)}$$

where: Pr : precipitation (L); Ev: evaporation(L); A: area of the reservoir's water surface (L^2).

An optimization model constitutes the governing equation, if any, the objective function, and the set of imposed constraints. For the operation of a dam, the governing equation is the equation of continuity (conservation of mass),the objective function is usually set as a function of the storage and release ,and the constraints are commonly storage constraints and release constraints.

For the considered case study, the following constraints are valid:

A- Storage constraints

The three major components of reservoir storage are dead storage for sediment collection, active storage, and flood storage for reduction of downstream flood damages **[Chin, 2006]**

The storage at the start of the first operation period should be a known quantity. However, storage in other periods should be within the set of admissible limits as specified by the design criteria of the dam. That is:

$$OS\ min \leq S(i , j) \leq OS\ max \qquad \textbf{(3)}$$

where : (OS min) and (OS max) are minimum and maximum operation limits of storage, respectively ; (S) is 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 the operation schedule.

B- Release (outflow) constraints

The release R(i , j) during the j-th month of the i-th year should be within the range of feasible limits, that is:

$$D(j) \leq R(i , j) \leq MPF \qquad \textbf{(4)}$$

$$\text{If } R(i , j) \leq minPF \text{ then } R(i , j) = minPF \qquad \textbf{(5)}$$

where : R(i , j) : release from the reservoir during i-th year and j-th month ; D(j) : total water requirements during the j-th month (Irrigation + Industrial + Environmental); MPF : maximum permissible flow and minPF: minimum permissible flow, which represents the flood capacity of the river reach downstream of the dam.

2-The Objective Function

The operation of any system is considered optimum (ideal operation) if all the targets of such operation are satisfied. There are usually two targets for the operation of a dam. One concerns the storage level, (WL), which should be within two limits, design and minimum operation levels. The other concerns the release, which should be within two limits, the minimum and maximum flows permissible in the downstream.

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Applying a penalty function to delineate the extent of any deviation from the targets, the objective functions of release and storage (which are to be minimized) have been formulated as follows:

A: Objective function of storage:

In the optimum operation of any reservoir, the storage should be less than the maximum design level during the flood periods and not less than the minimum operation level during the drought periods. This could be represented as follows:

$$\text{Minimize PS} = \sum_{i=1}^{N} \sum_{j=1}^{12} \text{LS}(i+1 , j) \quad \textbf{(6)}$$

where : PS : total penalty due to storage ; LS(i, j): loss function of the storage at the end of the considered stage which could be expressed as follows:

If S(i+1 , j) < OS min then $LS(i+1 , j) = c \times [S(i+1 , j) - OS\ min]^2$ **(7)**

If S(i +1 , j) > OS max then $LS(i+1 , j) = d \times [S(i+1 , j) - OS\ max]^2$ **(8)**

If OS min $\le$ S(i+1 , j) $\le$ OS max then LS(i +1 , j) = 0 **(9)**

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

{Values of (c) and (d) have been both taken equal to (one)}

Accordingly, the objective function of the system will be:

Optimum Total Penalty (OTP) = F = Min. P(R) + Min. P(S). That is:

$$\text{OTP} = \text{Minimize F} = \sum (\text{LR}(i , j)) + \sum (\text{LS}(i+1 , j)) \quad \textbf{(10)}$$

B: Objective function of release, PR:

The aim is to minimize the penalty associated with a failure in supplying the demand, no less or more. This is set as:

$$\text{Minimize PR} = \sum_{i=1}^{N} \sum_{j=1}^{12} \text{LR}(i , j) \quad \textbf{(11)}$$

where: PR : total penalty due to release ; LR (i , j) : loss function of the release in the j-th month of the i-th year, which could be expressed as follows:

If R(i , j) < D(j) then $LR(i , j) = a\, [R(i , j) - D(j)]^2$ **(12)**

If R(i , j) > MPF then $LR(i , j) = b\, [R(i , j) - MPF]^2$ **(13)**

and, If D(j) $\le$ R(i , j) $\le$ MPF then LR(i , j) = 0 **(14)**

where: a , b : constants that represent weighting factors to reflect the effect of violating the constraints concerning irrigation demand and flood control in the river, respectively; their values depend on the consideration of the decision maker.

{Values of (a) and (b) have been both taken equal to (one)}

Optimum Operation Rule Curves (Oorc):

The continuity equation, Eq.(1), is one of the physical constraints of dynamic programming. It represents the relationship between the inflow, outflow, evaporation, precipitation, and the storage at each stage.

The formulated (DP) model has been solved by the (DDDP) approach to determine an optimal rule curve of Haditha Dam, using historical stream flow records for (240) month (from Oct. 1987 to Sep. 2007), **[Water Resources: 2008].**

To smoothen the rule curves and decrease the times of deficit supply, constraint to obtain the optimal operation for each month has been used. Values of the variables ensure the smoothness of the respective rule

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curves. Besides, a subsidiary aim was sought, namely, directing the storage to be close to the minimum just before the start of the flood time and close to the maximum just after its end. This, with the compulsory constraints stated in Eqs. (3) and (4), have resulted in decreasing the period of deficient supply.

Mathematically, the aforementioned procedure has been performed as follows **[Motlib, 2004]**:

If j = m then

$P(S_j) = e \times (S\max - S(j))$ **(15)**

Where: m: the month under consideration; e: constant;

{Values of (e) used in the research where in the range (5–1200), depending on the respective inflow, storage, and demands during the considered month}

The respective rule curves (upper, average and lower) have been obtained accordingly, taking into consideration that they should fall between the minimum and design operation storage.

The average rule curve was obtained by averaging the values of the storage obtained by the model over the considered period (20 years). The upper and lower rule curves were derived depending on the non – exceeding probability values of (90 %) upper curve and (10 %) lower curve of the probability distribution of the optimal storage, respectively. The normal probability distribution is used to determine these rule curves.

The Simulation Model For Monthly Operation

Simulation (in operations research) is a methodology of representing the problem in a mathematical form manageable by computer. The simulation process in reservoir – operation problems is a trial and error technique rather than an analytical process that converges to a global optimum solution **[Al-Delewy, 1995].**

Reservoir operation is necessarily to be made in such a manner that it functions according to the respective purpose of design.

The rule curves, Fig (1), are used to guide the process of obtaining the real – time monthly operation of Haditha Reservoir. The basic input to the optimization model is the historical monthly inflow data observed in the vicinity of the site for the period (Oct. 1987 to Sept. 2007). The outputs are reservoir storage, reservoir water level, outflow from power outlet and spillway, and the output of power generation.

The sequence of steps to obtain the monthly operating schedule, fig(2), is as follows:

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

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

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

4- The resulting storage should be within the operation rule curves range and neither be more than the design operation storage nor less than the minimum operation storage of the reservoir.

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5- Determine reservoir water level, (WL), which is a function of reservoir storage.
6- Compare (WL) with the rule curves. If it exceeds the rule curves, then the computed storage and water level are readjusted through readjusting the release.
7- Calculate the outflow from the power generating outlets, (Qp), which should not exceed the capacity of the power outlets. The minimum operation level represents the minimum level for operating the power generators.
8- Calculate the water level of Tigris River downstream of Haditha Dam site. Based on an available hydraulic data **[Ali, 1994]** the following relationship has been derived:

$$WLr = 0.1406 *(R+919.4654)^{0.561} + 94.0496 \quad \textbf{(16)}$$

where : WLr: water level in the river (m.a.s.l.) ; R : outflow from the reservoir, (cumecs).
9- Calculate the rated head (H) (in meters) on the power– generation units, which is given by **[Ali, 1994]** :

$$H = WL – WLr \quad \textbf{(17)}$$

10- Repeat the respective steps for the following months.

Results Conclusions

Results of the monthly simulation models are summarized in Tables (4),which indicates the following distinguished points:

1- The monthly inflow to Haditha Reservoir varied from (130 cumecs) to (2437 cumecs)
2- The maximum outflow from reservoir is (2034.6 cumecs) from power outlet and (1947.5 cumecs) from bottom outlet.
3- Downstream water level for Haditha Reservoir ranged from (89.5 m.a.s.l.) to (95 m.a.s.l.)

Conclusions

Based on these result, the following can be conclude:

1- The flood has been completely controlled during the operation period (240) months.
2- The operation shows deficit in satisfying the demands, the deficiency is in range (5-2157 cumecs), the deficiency is during (152 months) out of the (240 months) operation period.
3- Using the monthly optimum rule curves, which are derived in this research to develop a daily simulation model in order to determine the daily storage, release for Haditha Reservoir.

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Table (1) : Mean monthly inflow into Haditha Dam [after Water Resources: 2008]

month	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Sum**
Inflow mean (cumecs)	382.6	419.5	451.0	519.3	560.7	532.1	671.4	417.2	478.1	453.1	489.5	434.4	**484.1**

Table (2):The Monthly Water requirements downstream Haditha Dam[after Al-Janabi 2004]

month	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Sum**
Water requirements D/S Haditha	1429	1047.3	579.3	747.3	1222.1	1713.5	2157.4	2034.1	2677.3	2757	2309.9	1429.4	**1680.5**

Table (3): Basic storage levels in Haditha Reservoir [after Ishaq: 1998]

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Item	Symbol	Unit	Value
Maximum storage level	Lmax	m.a.s.l.	150.2
Maximum storage	Smax	MCM	9800
Minimum storage level	Lmin	m.a.s.l.	112
Minimum storage	Smin	MCM	2300
Design operation water level	DOL	m.a.s.l.	147
Design operation storage	DOS	MCM	8200
Maximum Discharge in the River	MOL	CM.	4730
Minimum Discharge in the River	MOS	CM	70

Table (4): Results the simulation model of the monthly operation of Haditha Reservoir

Description	Unit	Monthly	
		Min.	Max.
Inflow (I)	cumecs	**130**	**2437**
Outflow (R)	cumecs	**0**	**2293**
Reservoir water level (WL)	m.a.s.l.	**129.4**	**145.5**
Flow from power outlets (Qp)	cumecs	**0.4**	**2034.6**
Flow from bottom outlets (Q_B)	Cumecs	**0**	**1947.5**
D/S water level (WLr)	m.a.s.l	**89.5**	**95.0**
Haditha rated head (H)	M	**36.9**	**50.6**

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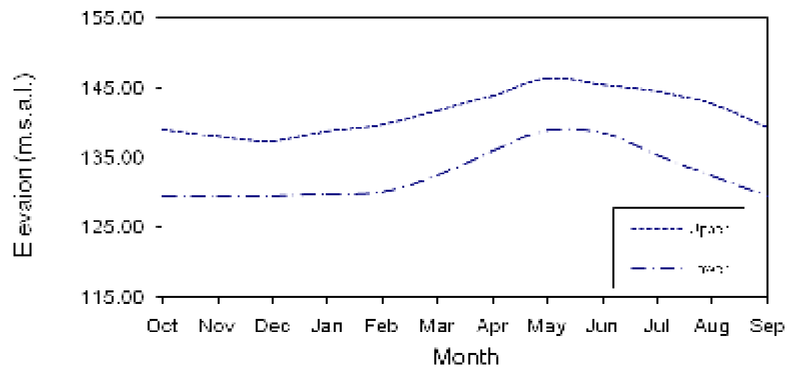

(a)Based on Elevation.

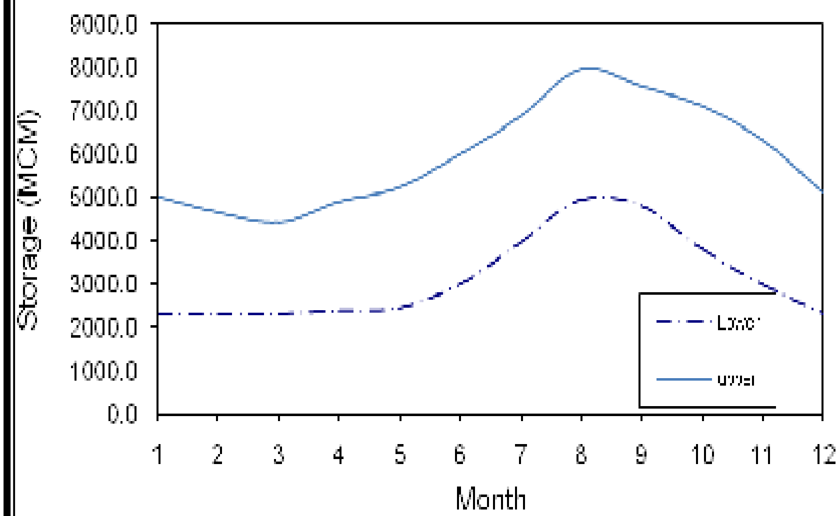

Figure (1) Optimum Operation Rule Curves (Upper and Lower) of Haditha Reservoir.

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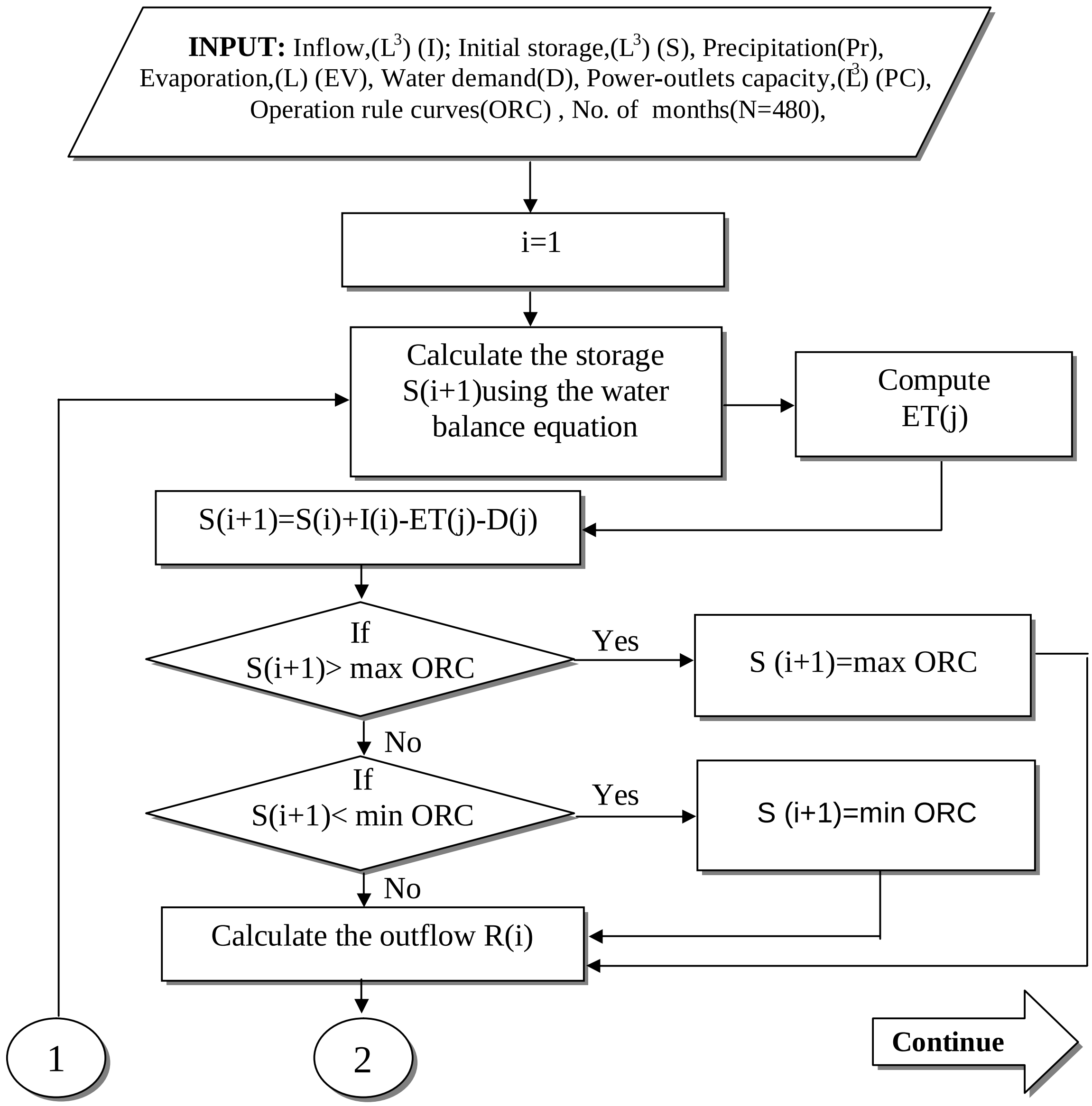

NOTE :
i = serial number of the considered month in the operation period.
j = respective month in the water year.

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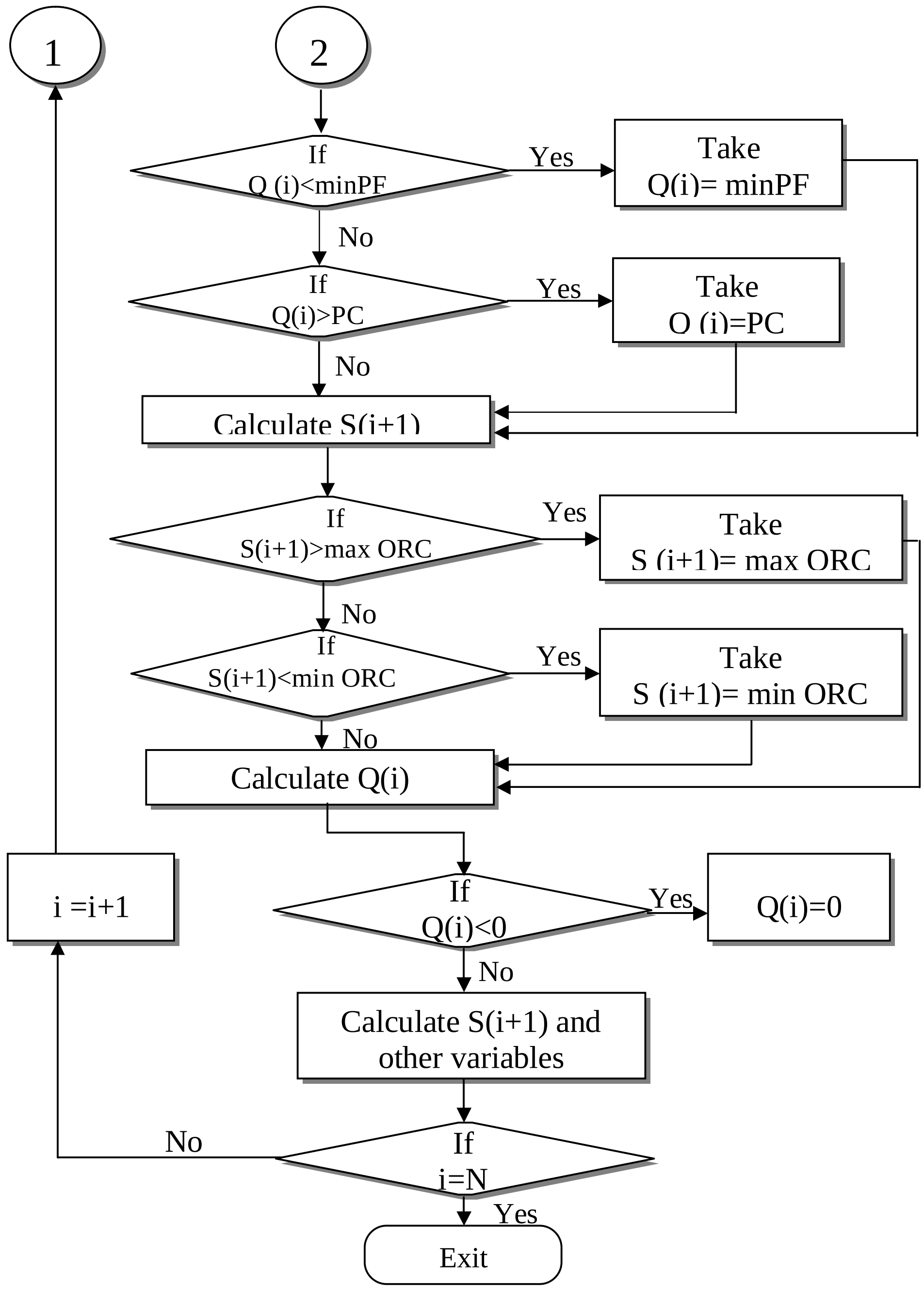

Figure (2) Flowchart showing the simulation model of monthly operation methodology

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