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Optimum Operation of Makhool Dam

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Abstract

In this research, the discrete differential dynamic programming approach is used to find the optimal monthly operation of Makhool Dam by adopting an objective function to minimize the release and storage penalty. The historical inflow data of (480) months (from Oct. 1960 to Sep. 1999) formed the input data to the optimization model.

To preserve 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, a new constraint has been introduced. The new constraint also ensured the smoothness of the resulting optimum rule curves (lower, average, and upper). A simulation model is built accordingly.

Besides, the developed optimization model is applied to two hypothetical operation scenarios that represent the extreme cases, namely, two consecutive relatively-wet years and two consecutive relatively-dry years, beside the consideration of the non-existence and existence of Bekhma Dam.

The optimum operation policy has shown deficit in satisfying the demands downstream Makhool Dam. The deficiency was noticed during (30) months when Bekhma Dam is not existing and (21) months when Bekhma Dam is operational.

الخلاصة

استخدمت البرمجة الديناميّة التفاضلية المنفصلة في هذا البحث لإيجاد التشغيل الشهري الأمثل لسد مكحول بعد تهيئة دالة الهدف للوصول إلى اقل الخسائر المتعلقة بالإطلاق والخزين.البيانات الهيدرولوجية التاريخية لمدة (٤٨٠) شهراً (من تشرين أول ١٩٦٠ إلى أيلول ١٩٩٩) شكلت بيانات الإدخال لنموذج ألا مثلية.

لغرض المحافظة على الحالة المنطقية للخزين (وذلك بتوفير اقل خزين للتشغيل قبيل البدء المتوقع للفيضان المؤثر وتوفير أعلى خزين للتشغيل عند انتهاء موسم الفيضان) فقد ادخل محدد جديد في البرنامج والذي أمّن ، إضافةً لِما سبق ، انسيابية منحنيات التشغيل الحاكمة المثلى المشتقة بموجبه (الأعلى والمعدل والأدنى). وبالاعتماد على منحيات التشغيل تم إعداد نموذج محاكاة تشغيل المنظومة .

إضافة إلى ذلك تم تشغيل نموذج الأمثلية المطور بهذا البحث لحالتين افتراضيتين لتمثيل حالات قصوى وكانتا سنتين رطبتين متواليتين وسنتين جافتين متواليتين ، آخذين بالاعتبار وجود وعدم وجود سد بخمة.

التشغيل الأمثل بيّن عجزاً في تلبية الاحتياجات المائية مؤخر سد مكحول خلال (٣٠) شهراً من فترة التشغيل الكلية المعتمدة في هذا البحث والبالغة (٤٨٠) شهراً عند عدم وجود سد بخمة، و(٢١) شهراً عند اعتبار سد بخمة شغالا .

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1. INTRODUCTION

Iraq has a vast area under irrigation. This irrigated area is continuously increased so as to establish ensured irrigated cropping and avoid cropping failure due to famine or untimely water. To secure the benefits of irrigated land, a tremendous amount of capital has been invested in irrigation projects. Moreover, projects constructed at the upstream (in Turkey and Syria) for storing and consuming water have resulted in reducing the quantity and quality of water that arrives to Iraq. Since irrigation water is a costly commodity, and then there should be no wastage during its flow from the source to the fields. This necessitates to control, operate, and manage the Iraqi water resources systems more efficiently and optimally.

Water in Iraqi rivers is usually ample during flood time (Oct. - Jun.) whereas almost always deficit during (Jun. - Oct.). Dams are constructed on the rivers to control the inflow-outflow rating. In this respect, Tigris River is not an exception. Makhool Dam is a dam on the Tigris (under construction meanwhile), whereas Bekhma Dam is a proposed dam on the Greater Zab (a main tributary of the Tigris that ends upstream of Makhool Dam).

Summarized water-budget for the location of Makhool Dam is shown in Table (1). 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 Makhool Dam has been chosen as the case study. The basic design parameters of the dam that concern the aim of this research are given in Table (2).

The major objective of this research is to determine the optimum operation policy for Makhool Dam that reflects the benefits aimed at by the construction of the dam, namely**,** satisfaction of water demands, flood control, and hydro-power generation.

Of the many 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 discrete 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 (1). 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 (2), was 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 (3). Thus, DDDP has been adopted in solving the formulated DP model to obtain the optimum operation rules.

2. THE OPTIMIZATION MODEL

An optimization model constitutes the objective function and the set of imposed constraints. For the operation of a dam, the constraints are commonly storage constraints, release constraints, and continuity constraints.

For the case study, the following constraints are valid:

2-1 Storage Constraints

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:

$$OS\ \min \leq S(i\ ,j) \leq OS\ \max \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

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.

2-2 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:

$$D(j) \leq R(i\ ,j) \leq MPF \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

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, which represents the flood capacity of the river reach downstream of the dam.

2-3 Continuity Constraints

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:

$$R(i\ ,j) = S(i\ ,j) + I(i\ ,j) - S(i+1\ ,j) + ET(j) \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

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

$$ET(j) = [Pr(j) - Ev(j)] \times A(i\ ,j) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

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

The operation of any system is considered optimum (ideal operation) if all the aimed targets of such an 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.

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

2-3-1 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:

$$\text{Minimize PR} = \sum_{i=1}^{N} \sum_{j=1}^{12} LR(i\,,j) \quad \ldots\ldots (5)$$

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:

$$LR(i\,,j) = a\,[R(i\,,j) - D(j)]^2 \quad \ldots\ldots (6)$$

If $R(i\,,j) > MPF$ then:

$$LR(i\,,j) = b\,[R(i\,,j) - MPF]^2 \quad \ldots\ldots (7)$$

and, If $D(j) \le R(i\,,j) \le MPF$ then:

$$LR(i\,,j) = 0 \quad \ldots\ldots (8)$$

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) in this research have been both taken equal to (one)}.

2-3-2 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:

$$\text{Minimize PS} = \sum_{i=1}^{N} \sum_{j=1}^{12} \text{LS}(i+1, j) \quad \ldots\ldots\ldots\ldots \quad (9)$$

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:

$$LS(i+1, j) = c \times [S(i+1, j) - OS\ min)]^2 \quad \ldots\ldots\ldots\ldots \quad (10)$$

If $S(i+1, j) > OS\ max$ then:

$$LS(i+1, j) = d \times [S(i+1, j) - OS\ max]^2 \quad \ldots\ldots\ldots\ldots \quad (11)$$

If $OS\ min \leq S(i+1, j) \leq OS\ max$ then:

$$LS(i+1, j) = 0 \quad \ldots\ldots\ldots\ldots \quad (12)$$

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) in this research 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:

$$OTP = \text{Minimize } F = \sum (LR(i, j)) + \sum (LS(i+1, j)) \quad \ldots\ldots\ldots\ldots \quad (13)$$

3. OPTIMUM OPERATION RULE CURVES (ORC)

The continuity equation, Eq.(3), 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 operation of Makhool Dam, using historical stream flow records for (480) month (from Oct. 1960 to Sep. 1999).

The initial runs of the formulated model indicated a noticeable deficit in the supply, besides oscillating rule curves (upper, average, and lower).

To smoothen the rule curves and decrease the times of deficit supply, an additional (new) constraint to obtain the optimal operation for each month has been used. This has been achieved by introducing the parameter (e) which takes variable values such that it ensures the smoothness of the respective rule 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. Thus, with the compulsory constraints stated in Eqs. (1) and (2), have resulted in decreasing the period of deficient supply.

Mathematically, the aforementioned procedure has been performed as follows (4):

If j = m then:

$$P(S_j) = e \times (S\,max - S(j)) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

where, m: the month under consideration; e: constant;
{Values of (e) used in the research where in the range (0.01-1000), 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 has been obtained by averaging the values of the storage obtained by the model over the considered period (40 years). The upper and lower rule curves have been derived depending on the non – exceeding probability values of (90%) and (10%) of the probability distribution of the optimal storage, respectively. The normal probability distribution is used to determine these rule curves.

Bekhma Dam is a proposed huge dam on the Greater Zab. Its construction was stared in (1987) and its foundation has been almost completed. However, the construction was postponed due to unavoidable circumstances. When considering Bekhma Dam is operational in this research, its optimal-operation policy according to (5) is considered. The optimal operation rule curves, when Bekhma Dam does not exist and when it is operational, are shown schematically in Figs.(1) and (2), respectively.

4. 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 (6)**.**

Reservoir operation is necessarily to be made in such a manner that it functions according to the respective purpose of design. Makhool Dam is a multi-purpose dam. It serves flood control, regulation of the flow of Tigris River upstream Samarra Barrage, and for power generation.

The storage capacity of Makhool Reservoir, [1478 MCM between design operation water level of (150 m.a.s.l.) and lower operation water level of (140 m.a.s.l.)], is to be utilized for irrigation and power generation. The operation rules for Makhool Reservoir are to be fixed on the bases of the following factors:

1. Irrigation and power generation are carried out within the range of the storage capacity (1478 MCM).
2. Maximum discharge from power outlets is (1240 cumecs).
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 rule curves, Figs.(1) and (2), are used to guide the process of obtaining the real-time monthly operation of Makhool 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. 1960 to Sept. 1999). 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 is as follows [shown in the flowchart in Fig.(3)].

1. Prepare the input data, which should include the inflow, initial storage, and 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 is more than the design operation storage nor less than the minimum operation storage of the reservoir.
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 Makhool Dam site.

Based on an available hydraulic data (5) the following relationship has been derived:

$$WLr = 0.092715\, R \wedge {}^{0.482024} + 116.2275 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

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 (5):

$$H = WL - WLr - 3 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

10. Compute power production:

$$P(j) = Eff. \times [Qp \times \gamma \times H] \times 10^{-6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (17)$$

where: P: power production, (MW); Eff.: efficiency of the power-generation units, [taken in the research as (93 %) (5); Qp: flow through the power outlets, (cumecs); γ: unit weight of water, taken as (9800 N/m^3).

11. Repeat the respective steps for the following months.

5. SELECTED OPERATION SCENARIOS

According to available inflow record (Oct. 1960 to Sep. 1999 inclusive), the water years (1988) and (1999) may be considered to represent a wet year and a dry year, respectively. The inflows during these considered extremists, with and without Bekhma Dam, are given in Table (3).

Two operation scenarios are considered in this respect, namely:

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

6. THE RESULTS

Two cases for monthly simulation models that depend on whether Bekhma Dam is not existing or operational are considered. The results are summarized in Tables (4) and (5), respectively.

The results of running the monthly operation model for the two aforementioned operation scenarios are summarized in Tables (6) and (7), respectively.

The Analysis of the results indicates the following:

6-1 Running the Simulation Model

6-1-1 Bekhma Dam is Not Existing

1. According to such a plan, there will be a deficit in satisfying the demands. The monthly deficiency would be in the range (20.8 to 772.9 cumecs), with maximum deficit in September, (1999). Quantitatively, the total deficit

represents (0.021 %) of the total demand. The deficiency would exist during (30) months from the total operation period (which is 480 months).

2. The operation of the reservoir has been contained within the upper and lower rule curves.
3. The maximum discharge of (1240 cumecs) from the power outlets makes the bottom outlets to be used in (33.9 %) of the total operation period, with an average period of (124) day per year.
4. The power station would be operating in full capacity for the (124 day) period.

6-1-2 Bekhma Dam is Operational

1. According to this plan, a deficiency in supply will still exist but to a lesser extent. The quantitative monthly deficiency would be in the range (16.8 to 592 cumecs), with maximum deficit in September, (1989). Quantitatively, the total deficit represents (0.016 %) of the total demand. The deficiency would exist during (21) months from the total operation period.
2. The operation of the reservoir has been contained within the upper and lower rule curves.
3. The maximum discharge of (1240 cumecs) from the power outlets makes the bottom outlets to be used in (45.4 %) of the total operation period, with an average period of (166) day per year. The power station would be operating in full capacity for the same period.

6-2 Results of the Selected Operation Scenarios

For the two hypothetical operation scenarios:

1. For two consecutive wet years, the optimal operation would be capable of fully controlling the expected floods and satisfying the downstream demands in full, whether Bekhma Dam is not existing or operational.
2. For two consecutive dry years, it is obvious that the expected floods would be fully controlled. However, the deficiency in supply would be noticeable, lasting for six months during each operation year.

This deficiency would be:

a) Without Bekhma Dam: The deficiency would be in the range (184.5-704.1 cumecs), representing (35 %) of the total demand.

b) ***With Bekhma Dam in Operation:*** The deficiency would be (33.4-530.4 cumecs), totaling to (21.6 %) of the whole demand.

7. CONCLUSIONS

Based on the obtained results, the following conclusions are abstracted:

7-1 Through Running the Simulation Model for (40-Year) Monthly Historical Data

1. Bekhma Dam significantly affects the optimum operation of Makhool Dam through working as a hydrologic safeguard. Its existence would decrease the amount and period of deficit supply of the demands downstream of Makhool Dam.
2. The operation shows deficit in satisfying the demands.
   a) Without Bekhma Dam, the deficiency is in the range (20.8-772.9 cumecs), totaling to (0.021 %) of the whole demand. The deficiency is during (30) months out of the (480 month) operation period.
   b) With Bekhma Dam operational, the deficiency would be in the range (16.8-592 cumecs). The total deficit represents (0.016 %) of the total demand. The deficiency will be faced during (21) months.
3. The flood has been completely controlled during the considered operation period whether Bekhma Dam is not existing or when it is operational.
4. As an average, the power station operates in full capacity for (124) day per year when Bekhma Dam is not existing and for (166) day per year when Bekhma Dam is operational during the total operation period, without being completely idle for any time.

7-2 Results of the Selected Operation Scenarios

1. The water demands have been fully satisfied during the two consecutive wet years when Bekhma Dam is not existing and when it is operational.
2. The operation for two consecutive dry years indicated deficiency in satisfying the demands.
   a) Without Bekhma Dam, the deficiency would be in the range (184.5-704.1 cumecs), with maximum deficit in November. Quantitatively, the total

deficit represents (35%) of the demand. The deficiency is during (6) months in each year of the operation period.

b) With Bekhma Dam Operational, deficiencies would be in the range (33.4-530.4 cumecs), with maximum deficit in August. Quantitatively, the total deficit represents (21.6%) of the demand. The deficiency is during (6) months in each year of the operation period.

3. The flood has been completely controlled during the two consecutive wet and dry years when Bekhma Dam is not existing and when it is operational.

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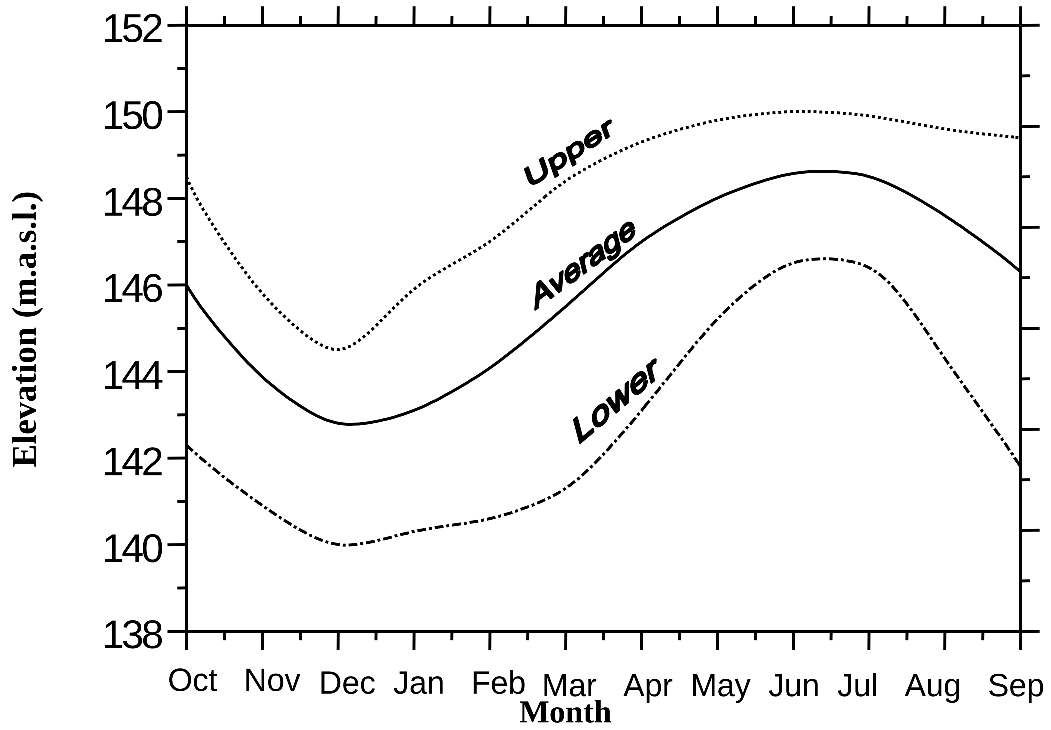
Table (1) Monthly Inflow Mean and Water Requirements at the Location of Makhool Dam After (5)

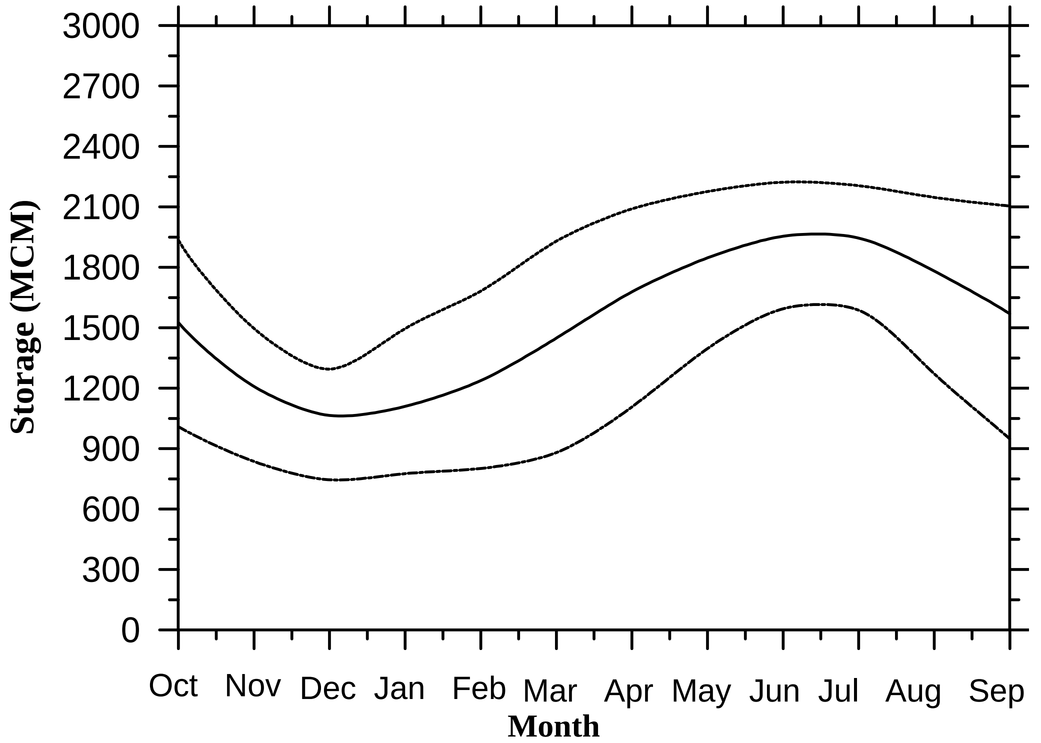
Month	Inflow mean without Bekhma Dam (cumecs)	Inflow mean With Bekhma Dam(cumecs)	Water requirements D/S Makhool Site (cumecs)
OCT.	829	1209	601.3
NOV.	855	1060	438.8
DEC.	920	759	228.4
JAN.	1025	878	270.1
FEB.	1194	968	473.7
MAR.	1643	1355	615.6
APR.	2461	2017	896.6
MAY	2488	2015	880.7
JUN.	1518	1609	1213.2
JUL.	1098	1476	1122.3
AUG.	969	1375	969.8
SEP.	851	1095	666.5
SUM.	**15022**	**14607**	**8377.5**

Table (2) Basic Storage Levels in Makhool Reservoir (7)

Item	*Symbol*	*Unit*	*Value*
Maximum storage level	Lmax	m.a.s.l.	152.15
Maximum storage	Smax	MCM	2665
Minimum storage level	Lmin	m.a.s.l.	132.5
Minimum storage	Smin	MCM	200
Design operation water level	DOL	m.a.s.l.	150.0
Design operation storage	DOS	MCM	2222
Normal operation water level	NOL	m.a.s.l.	145.7
Normal operation storage	NOS	MCM	1478
Minimum operation water level	MOL	m.a.s.l.	140.0
Minimum operation storage	MOS	MCM	744

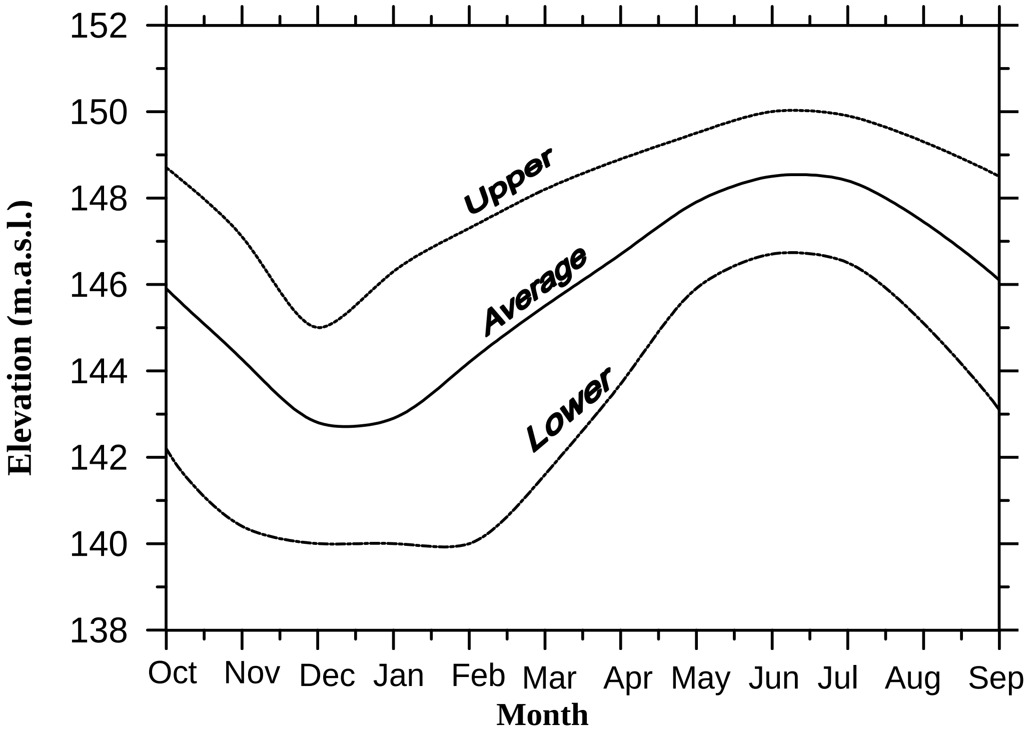


(a) Based on water-surface elevation

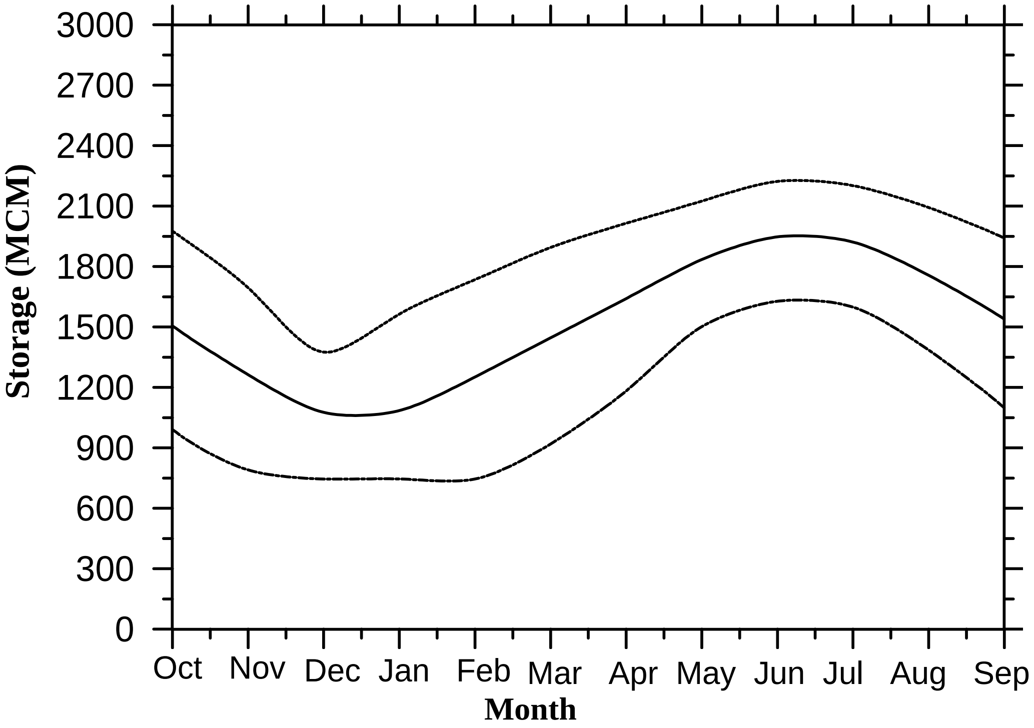


(b) Based on Storage

Fig.(1) Optimum Operation rule Curves (Upper, Average, and Lower) of Makhool Reservoir when Bekhma Dam is Not Existing

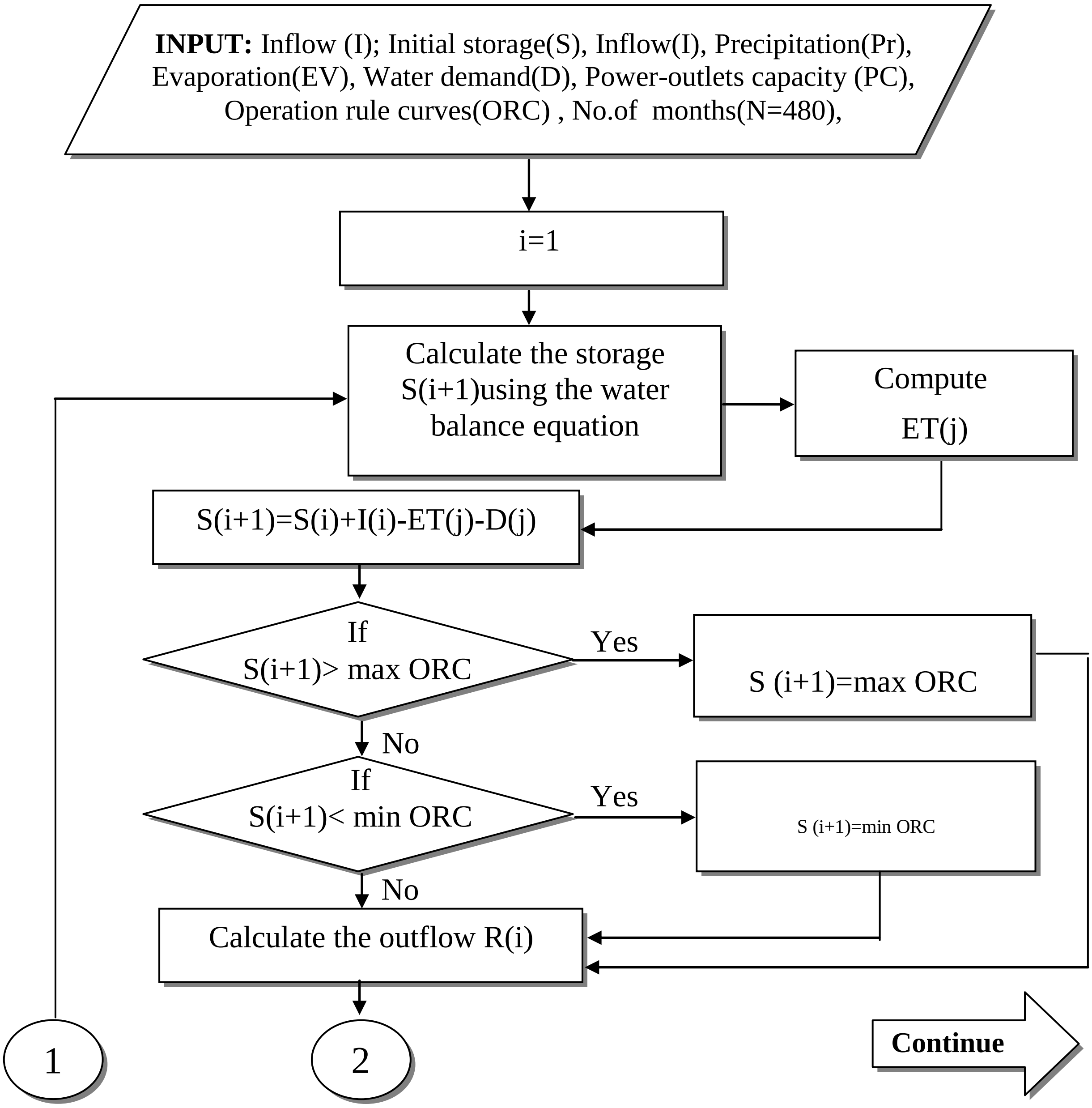


(a) Based on water-surface elevation



(b) Based on storage

Fig.(2) Optimum Operation Rule Curves (Upper, Average, and Lower) of Makhool Reservoir when Bekhma Reservoir is Operational



NOTE:

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

Fig.(3) Flowchart Showing the Simulation Model of Monthly Operation Methodology

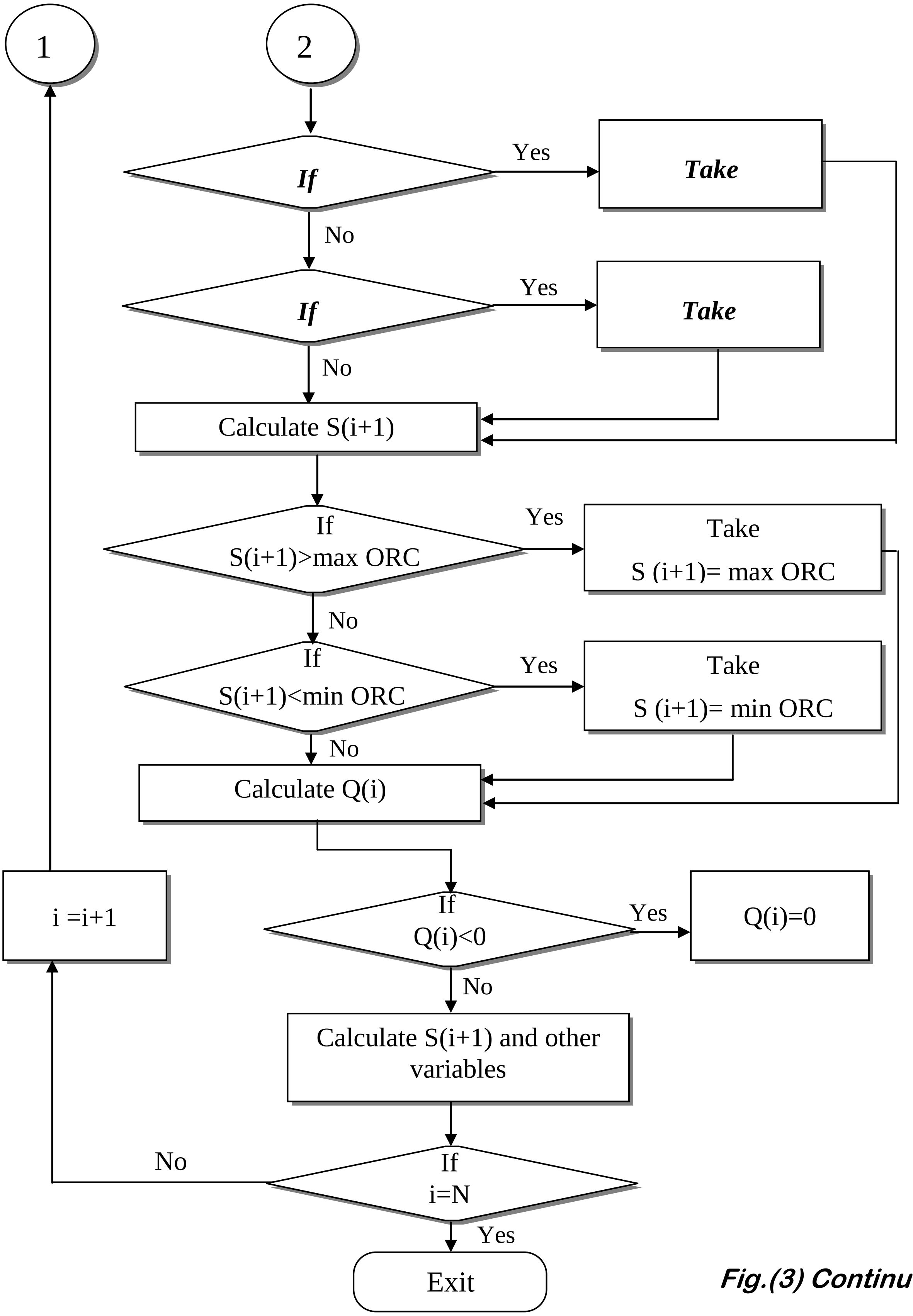


Fig.(3) Continued

Table (3) Inflow Data at Makhool Reservoir in Wet (1988) and Dry (1999) Years

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
(a) When Bekhma Dam is not existing												
1988	831	1075	2204	3115	2204	5518	6990	5530	2876	2080	1798	1638
1999	695	683	615	578	615	490	648	545	455	319	327	380
(b) When Bekhma Dam is operational												
1988	1222	1270	1990	2936	1970	4630	6665	5527	2948	2423	2253	1944
1999	1086	912	574	535	481	529	547	409	749	813	706	601

Table (4) Results of Simulation of the Monthly Operation of Makhool Reservoir when Bekhma Dam is Not Existing

Description	Unit	Monthly		Annual		
		Min.	Max.	Min.	Max.	Mean
Inflow (I)	cumecs	267	6990	529	2988	1323
Outflow (R)	cumecs	229	6981	533	2951	1314
Reservoir Water Level (WL)	m.a.s.l.	141.8	150	145.6	148.2	147.5
Flow from Power Outlets (Qp)	cumecs	229	1240	533	1192	1008
Flow from Bottom Outlets (Q_B)	cumecs	0.0	5741	0.0	1766	309
D/S Water Level (WLr)	m.a.s.l	117.5	122.8	118.1	120.4	119.0
Makhool Rated Head (H)	m	23.5	31.1	27.5	29.1	28.4
Power Output (P)	MW	50.1	315.5	119.5	276.6	235.2

Table (5) Results of Simulation of the Monthly Operation of Makhool Reservoir when Bekhma Dam is Operational

Description	Unit	Monthly		Annual		
		Min.	Max.	Min.	Max.	Mean
Inflow (I)	cumecs	184	6665	662	2982	1318
Outflow (R)	cumecs	229	6656	685	2964	1309
Reservoir Water Level (WL)	m.a.s.l.	143.1	150.0	146.3	148.2	147.9
Flow fromPower Outlets (Qp)	cumecs	229	1240	685	1240	1031
Flow from Bottom Outlets Q_B)	cumecs	0.0	5416	0.0	1732	277
D/S Water Level (WLr)	m.a.s.l	117.5	122.8	118.1	120.4	119.0
Makhool Rated Head (H)	m	24.8	31.0	28.0	29.5	28.8
Power Output (P)	MW	51.3	315.6	156.4	287.1	244.6

Table (6) Results of Operating Makhool Dam for Two Consecutive Wet Years

Description	Unit	Bekhma Dam is not existing			Bekhma Dam is operational		
		Min.	Max.	Anul.	Min.	Max.	Anul.
Inflow (I)	cumecs	831	6690	2988	1222	6665	2982
Outflow (R)	cumecs	817	6949	2971	1136	6614	2964
Reservoir Water Level (WL)	m.a.s.l.	144.5	150.0	149.4	145.8	150.0	148.1
Flow from Power Outlets (Qp)	cumecs	817	1240	1204	1136	1240	1236
Flow from bottom Outlets Q_B)	cumecs	0.0	5709	1766	0.0	5374	1728
D/S Water Level (WLr)	m.a.s.l	118.6	122.8	120.4	119.0	122.7	120.5
Makhool Rated Head (H)	m	24.5	30.0	27.7	25.3	29.7	27.7
Power Output (P)	MW	179.9	305.6	270.9	246.6	301.9	278.1

Table (7) Results of Operating Makhool Dam for Two Consecutive Dry Years

Description	**Unit**	**Bekhma Dam is not existing**			**Bekhma Dam is operational**		
		Min.	**Max.**	**Anul.**	**Min.**	**Max.**	**Anul.**
Inflow (I)	**cumecs**	**319**	**695**	**529**	**409**	**1086**	**662**
Outflow (R)	**cumecs**	**347**	**616**	**527**	**472**	**1033**	**663**
Reservoir Water Level (WL)	**m.a.s.l.**	**141.8**	**148.4**	**145.5**	**142.2**	**147.4**	**146.2**
Flow from Power Outlets (Qp)	**cumecs**	**347.7**	**712.1**	**527.2**	**472**	**1033**	**663**
Flow from Bottom Outlets (Q_B)	**cumecs**	**0**	**0**	**0**	**0.0**	**0.0**	**0.0**
D/S Water Level (WLr)	**m.a.s.l**	**11108**	**118.4**	**118.1**	**117.8**	**118.7**	**118.3**
Makhool Rated Head (H)	**m**	**24.1**	**30.2**	**27.3**	**24.8**	**29.3**	**27.6**
Power Output (P)	**MW**	**92.3**	**162.3**	**117.8**	**80.2**	**237.7**	**147.6**