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Optimization In Searching Daily Rule Curve At Mosul Regulating Reservoir, North Iraq Using Genetic Algorithms

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Abstract
To obtain optimal operating rules for storage reservoirs, large numbers of simulation and optimization models have been developed over the past several decades, which vary significantly in their mechanisms and applications. Rule curves are guidelines for long term reservoir operation. An efficient technique is required to find the optimal rule curves that can mitigate water shortage in long term operation. The investigation of developed Genetic Algorithm (GA) technique, which is an optimization approach base on the mechanics of natural selection, derived from the theory of natural evolution, was carried out to through the application to predict the daily rule curve of Mosul regulating reservoir in Iraq. Record daily inflows, outflow, water level in the reservoir for 19 year (1986-1990) and (1994-2007) were used in the developed model for assessing the optimal reservoir operation. The objective function is set to minimize the annual sum of squared deviation from the desired downstream release and desired storage volume in the reservoir. The decision variables are releases, storage volume, water level and outlet (demand) from the reservoir. The results of the GA model gave a good agreement during the comparison with the actual rule curve and the designed rating curve of the reservoir. The simulated result shows that GA-derived policies are promising and competitive and can be effectively used for daily reservoir operation in addition to the rational monthly operation and predicting also rating curve of reservoirs.
Keywords: Optimization; genetic algorithms; rule curve; reservoir operation

إستنباط الامثلية في قواعد التشغيل اليومي لخزان سد الموصل التنظيمي باستخدام الخوارزميات الوراثية

الخلاصة
هنالك العديد من نماذج المحاكاة والامثلية قد تم تطويرها في العقود الماضية للحصول على منحنيات قواعد التشغيل الامثل للخزانات والتي تعرف على انها الخطوط الاساسية للتشغيل طويل الامد. وللحصول على أمثل تشغيل في الخزان يتطلب تواجد تقنيات كفوءة قادرة على تخفيف ومجابهة شحة المياه. في البحث الحالي تم إستخدام تقنيات الخوارزميات الوراثية والتي تعتبر أحد طرق الامثلية المستخدمة في حل العديد من المسائل الهندسية وتعتمد على ميكانيكية الاختيار الطبيعي والمشتق من نظرية التطور الطبيعي لاستنباط منحني التشغيل اليومي لخزان سد الموصل التنظيمي في العراق. تم إعتماد البيانات اليومية للتصاريف الداخلة والخارجة ومنسوب المياه في الخزان ولفترة 19 سنة (1986–1990) و (1994–2007) لتطوير نموذج لتخمين أمثل تشغيل للخزان، حيث تمثل الهدف في تصغير وتقليل المجموع السنوي لمربع الانحراف من التصاريف المطلقة المرغوب فيها وحجم الخزين المرغوب فيه في الخزان. كما تمثلت القيود في التصاريف المطلقة اعتمادا على الطلب على المياه مؤخر السد وحجم الخزين والمنسوب.

أعطت نتائج نموذج الخوارزميات الوراثية تطابق جيد خلال المقارنة مع منحني قواعد التشغيل الحقيقي وكذلك مع منحني التقدير التصميمي للخزان. كما أوضحت نتائج المحاكاة على ان تقنيات الخوارزميات الوراثية تعتبر طرق واعدة ومن الممكن إستخدامها بشكل كفوء في التشغيل اليومي للخزانات إضافة الى التشغيل الشهري الاعتيادي مع إمكانياتها في إستنباط منحني التقدير في الخزانات.
الكلمات الدالة: الامثلية، الخوارزميات الوراثية، تشغيل الخرانات.

Introduction

Reservoir operation is a complex problem that involves many decision variables. Traditionally , reservoir operation is based on heuristic procedures, embracing rule curves and subjective judgments by the operator. This provides general operation strategies for reservoir release according to the current reservoir level, hydrological conditions water demands and the time of the year.

Reservoir operation is an important element in water resources planning and management. It consists of several control variables that defines the operation strategies for guiding a sequence of releases to meet a large number of demands from stakeholders with different objectives such as flood control, hydropower generation and allocation of water to different users.

It would be valuable to establish an analytic and more systematic approach to reservoir operation based not only on traditional probabilistic /stochastic analysis but also on the information and prediction of extreme hydrologic events and computational technology in order to increase the reservoir efficiency for balancing the demands from the users.

The application of optimization techniques is most challenging in water resources systems area, due to the large number of decision variables involved, stochastic nature of the inputs and multiple objectives. Applying optimization techniques for reservoir operation is not new idea and has become a major focus of water resources planning and management. Various techniques have been applied in a n attempt to improve efficiency of reservoirs operation. These techniques include Linear Programming; Nonlinear Programming; Dynamic Programming; Stochastic Programming and Heuristic Programming such as Genetic algorithms, Fuzzy logic and Neural Networks.

During the last two decades, heuristic algorithms have been developed for solving reservoir optimization problems. These algorithms use a set of points simultaneously in searching for the global optimum. [1] proposed an approach to identifying reservoir operating rules using genetic algorithms (GA) leading to effective solution. [2] successfully applied real-coded GA in combination with a simulation model to optimize 10 day operating rule curves of a major reservoir system in Taiwan. Moreover .a comparison between binary coded and real coded GA was exploited in optimizing the reservoir operating rule curves [3]. In order to solve the uncertainty of hydrological information as well as define the objectives and constraints, fuzzy set theory has been successfully used. [4] applied fuzzy rule–based control model for multipurpose real-time reservoir operation. [5] used simulation model to carry out a suitable length of inflow record for searching optimal rule curves for reservoirs.

A rule curve or rule level specifies the desired storage to be maintained in a reservoir as closely as possible during different times of the year while trying to meet various demands. Water allocation is usually dictated by rule curve that is generally derives by operation studies using historic or generated flows which depends on the type of the reservoir and the purposes to be served.. A rule curve shows the minimum water level requirement in the reservoir at a specific time to meet the particular needs for which the reservoir is designed. It is important to note that rule curve shall be followed except during periods of extreme drought that when public interest so requires.

As a results of global climate change and many nature or human causes, make the frequency and intensity of a lot of hydrological events such as drought and flood change, the existing reservoir operation rules need to change.

The Aim

This paper aims at daily reservoir operation rule curves and applies to newly rising evolution algorithms to optimize reservoir operation systematically. The research work will change traditional reservoir operation by combining real-time data (reservoir levels and flows) and inflow forecasts with historical data in order to optimize operation strategies taking advantage of the rapid development in combination techniques.

The development framework will be tested on the reservoir of Mosul regulating reservoir north Iraq which has been in operation for since 1986.

Study Area and Data

The proposed developed genetic algorithm (GA) model was applied to search the optimal daily rule curve of the Mosul regulating reservoir. It is located 8 km downstream Mosul main along Tigris river, (Figure 1). The regulating reservoir is constructed to verify the main purpose which is the regulation of the outflow released from the upstream main Mosul dam according to the downstream water requirements along Tigris river in such away that a minimum discharge of 330 m3/sec can be maintained over as long as possible, in-addition to satisfy enough water head for the operation of pump storage lake scheme constructed beside the regulating reservoir. The regulating reservoir began in the operation since 1986 to verify its function. The storage volume-surface area stage curves of the reservoir is shown in Figure (2). For the flow record data, two periods of daily inflow, outflow and water level at the reservoir (1986-1990) and (1994-2007) were used. The case study reservoir may be classified as short term reservoir in which the storage fluctuation occurs daily according to its construction function.

Material and Methods

Rule curves are fundamental guidelines for long term reservoir operation. Normally Rule curves are searched by reservoir simulation, model and optimization techniques. The monthly input data of reservoir simulation includes historic inflows, rainfall, evaporation , infiltration, physical characteristics of the reservoir and conditional rule curves. This paper developed the genetic algorithm optimization technique (GA) connected with simulation model for searching optimal daily rule curve of the Mosul regulating reservoir. The recorded inflows and water level for 17 years (1986-1990) and (1994-2007) are used in the developed model for assessing the reservoir operation.

Genetic Algorithms

The genetic algorithms (GA) is one of the most promising techniques in solving optimization reservoir operation and has received a great deal of attention regarding complex systems. The GA is essentially a Darwinian natural selection process which combines an artificial survival of the fittest with natural genetic operators. [6]. It represents a solution using strings (or chromosomes) of variables that represents the problem. Each strings comprises a number of genes comprised the string depends on the decision variables of the objective function. During the generation , the individuals in the current population are rated for their effective evolutions and new population of candidate solutions is formed using specific genetic operators such as reproduction, crossover and mutation, [7].Through the genetic evolution method, an optimal solution can be found and represented by the final winner of genetic evolution. The GA is an iterative procedure which maintains a population of individuals that are candidates solutions to specific domain.[1] used GAs to develop operating polices for multipurpose reservoir systems leading to effective solution.

Genetic Algorithms With Stochastic Simulation Model

The GA connected simulation model is developed**.** This model had been constructed on the concept of HEC-3,[8] and used to simulate the reservoir operation. The reservoir operating polices are based on the rule curves of individual reservoirs and principles of water balance concept.

The reservoir system operated along the saturated operating policy is expressed in Eq.(1,2,3).

$$R_{v,T} = D_T + W_{v,T} - Y_T \quad \text{for } W_{v,T} > Y_T + D_T \text{ --------------------(1)}$$

$$R_{v,T} = D_T, \quad \text{for } X_T < W_{v,T} < Y_T + D_T \text{--(2)}$$

$$R_{v,T} = D_T + W_{v,T} - X_T, \quad \text{for } X_T - D_T < W_{v,T} \text{ --------------------(3)}$$

Where:

$R_{v,T}$ is the release discharges from the Mosul regulating reserevoir during the year (v) and period (T), T= 1-24 hour representing 1Am to 12 pm along the day.

D_T is water requirement of T, X_T is lower minimum rule curve at a specific hour in the day; $W_{v,T}$ is upper rule curve of day T and Y_T is the available water calculated by simple water balance as described in Eq.(4).

$$W_{v,T+1} = S_{v,T} + Q_{V,T} - R_{v,T} - E_T \text{----- } (4)$$

where:

$S_{v,T}$ is stored water at the end of the day (T=12pm), $Q_{v,T}$ is daily reservoir inflow, E_T is average value of evaporation loss and D_s is the minimum reservoir storage capacity (capacity of dead storage).

The results of the reservoir simulation are the situations of water shortage and excess release water such as the number of excess release water and average annual shortage. This will be then recorded for using in the GAs model. The GAs model requires encoding schemes that transforms the decision variables (rule curve) into chromosome. Then the genetic operation reproduction, crossover and mutation are performed.

Model Development

The fitness function of the GA model in the present study is minimizing the squared deviation of monthly irrigation demand and squared deviation in mass balance equation. The objective function is given by equation ,[9].

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$$Z = \text{Minimize} \sum_{t=1}^{24} (Rt - Dt)^2 + \sum_{t=1}^{24} (St - St+1 + It - Rt - Et)^2 \text{ -------------------(5)}$$

Where:
Rt =daily irrigation release for the hour‘t’
Dt = daily downstream irrigation demand for the hour ‘t’.
St = Initial storage in the beginning of hour ‘t’.
St+1 = Final storage at the end of hour‘t’.
It = Daily inflow during the period ‘t’,

Et = Daily evaporation loss from the reservoir during the hour ‘t’.

The above fitness function of GA model is subjected to the following constraints and bounds.

A. Release Constraint.

The irrigation release during any month should be less than or equal to the irrigation demand in that month and this constraint is given by

Rt ≤ Dt, t = 1, 2, 3, … 24 ------------(6)

B. Storage Constraint

The reservoir storage in any month should not be more than the capacity of the reservoir, and should not be less than the dead storage. Mathematically this constraint expressed as:
Smin ≤ St
And

St ≤ Smax t = 1, 2, … 24 -------------(7)

Where,
Smin = Dead Storage of the reservoir in MCM and
Smax = Maximum capacity of the reservoir in MCM.

C. Over Flow Constraint

When the final storage in any month exceeds the capacity of the reservoir the constraint is given by:
Ot = S t+1 - Smax t = 1, 2, …. 24
and

Ot ≥ 0 t = 1, 2, ..., 24 -----------------(8)

Where
Ot = Surplus from the reservoir during the hour ‘t’.
The minimum and maximum outflow constraints was fixed according to downstream water demand and capacity of the river channel.
A program in C++ has been developed solving 21 years of daily inflow data, storage volume and water level as input variables, while the released outflow as output variable.

Illustrative Application

The proposed GA model was applied to search the optimal daily rule curve of Mosul regulating reservoir. The verification needs daily inflow records and other related data such as requirements supplies by the reservoir, characteristics curve and daily evaporation. The considered water requirement information downstream the case study reservoir was collected from reports of the Ministry of water resources of Iraq ,[10].
In GA one of the important parameter is population size, obtaining optimum population is very important. In water resources applications, its values ranges from 64 to 300 and even up to 1000 [11]. A larger population helps to maintain greater diversity but, it involves considerable computational cost when the full model is being used to generate performance predictions. To find optimum population size in present study different population size has been considered. Initial search was carried out with the probability of crossover of 0.80 and with population size 50, increasing further in step of 25 up to 325. Fig.3 shows that fitness

value reduces resulting in improvement in system performance. System performance improves significantly when the population size is increased up to certain population size. With further increase in population, the system still perform better but no significant improvement occurs. In the present study the significant point occurs at 250 and after that the performance has not improved significantly.

Second important parameter affecting GA performance is the probability of cross over. Its effect on the system performance is studied by varying the probability of crossover from 0.6 to 0.9 with an increment of 0.01 and adopting the obtained optimal population of 250. Results shown in plot of probability of crossover against system performance in Fig.4 show that the system performance improves with the increase in probability of crossover till it reaches 0.75. After this value the system performance decreases with the increase in probability of cross over. In the present paper, a 53 chromosome constitutes the total string length of 250 population size, 0.75 crossover probability and 0.01 mutation probability are chosen.

Results and Discussion

During the first years of reservoir filling (1986-1990) it was observed that the trend of daily inflow to the regulating reservoir is increasing which coincide with the daily water level trend as shown in Figure (5 and 6).This increasing gave an indication that the capacity of the hydroelectric generation of the pump storage scheme have increased too, while during the second period considered in this study (1994-2007) the inflow trend of the reservoir is decreasing coinciding with the water level trend as shown in Figures (7 and 8). This may gave an indication that the capacity of the hydroelectric pump storage scheme have decreased due to many certain technical or managerial reason relating with the downstream water requirements and demands along Tigris river. A comparison between the maximum, mean and minimum values of the inflow, outflow and water level for Mosul regulating reservoir during the two studied periods showed lowering in those values during the second period (1994-2007) as shown in Table1. This lowering is due to the lowering of the released discharges from the Mosul main dam which in-turn reflect the upstream changes in water resources status in Iraq during this period. In the same time it is clear from the table and figures that during the first period of reservoir operation (1986-1990), the inflow is 2.17% more than the outflow from the regulating reservoir while during the second period (1994-2007), the outflow is 5.3% more than the inflow. This is due to the different operation processes of the hydropower of the pump storage scheme.

The above mentioned statements was supported by the predicted daily rule curve of Mosul regulating reservoir for two studied periods as shown in Figure (9).This figure shows that there is some attenuation in the peak value and time to peak of water storage between the first period (1986-1990) and the second period (1994-2007). This conclusion agree with the above one concerning the variation in the operation of the pump storage scheme and downstream water demands.

Comparison of the operating curves obtained from GA with the actual operating curve for Mosul regulating reservoir during the period (2 Jan 2008) is presented in Figure (10). The GA results are based on the best parameter set resulting from sensitivity analysis. The actual operating rule curve is located within the maximum

and the lower curve which have a values of 257.3 and 251.6 m respectively.
Applying the developed GA model in predicting the rating curve (i.e. the relation between discharge difference and water level) in Mosul regulating reservoir as shown in figure (11), it was concluded that GA model simulate the actual rating curve accurately. This model gave another benefit in the simulation process of reservoir operation.

Conclusions

Rule curves are necessary guides for long term reservoir operation. The optimization techniques applied to search the optimal rule curves includes simulation, and genetic algorithms. Reservoir inflow is one of required data for operating reservoir. The research developed genetic algorithm optimization tool connected with simulation model provided the optimal daily rule curves as considering the risk of reservoir operation. Furthermore, the proposed model is applicable for multipurpose reservoir systems. A minimum average shortage was applied as the objective function of the search process. The limited bound of searching is used as the conditional constraint to reduce the fluctuation of the obtained rule curve. The developed GA model was applied to simulate the daily rule curves of the Mosul regulating reservoir in Iraq in-addition to the rating curve of the reservoir. The results showed that the pattern of the obtained rule curve and rating curve coincides with the actual existing rule curves and the designed rating curve for the reservoir

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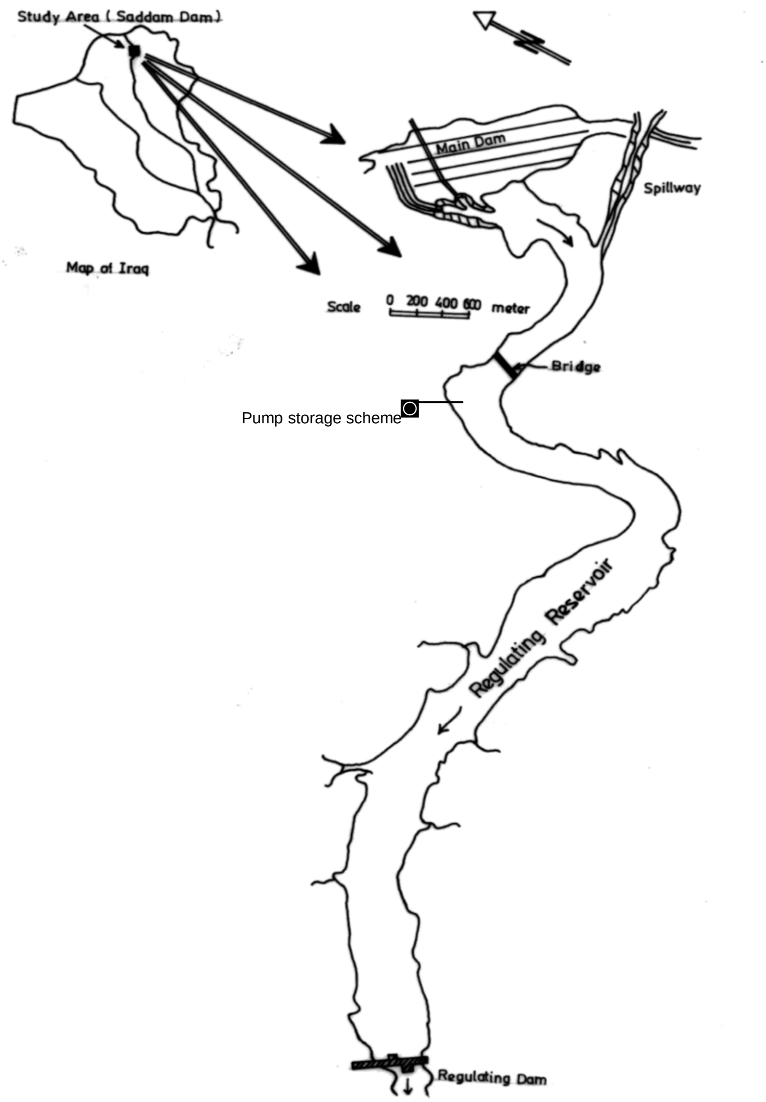

Fig. (1) Location map of the study area

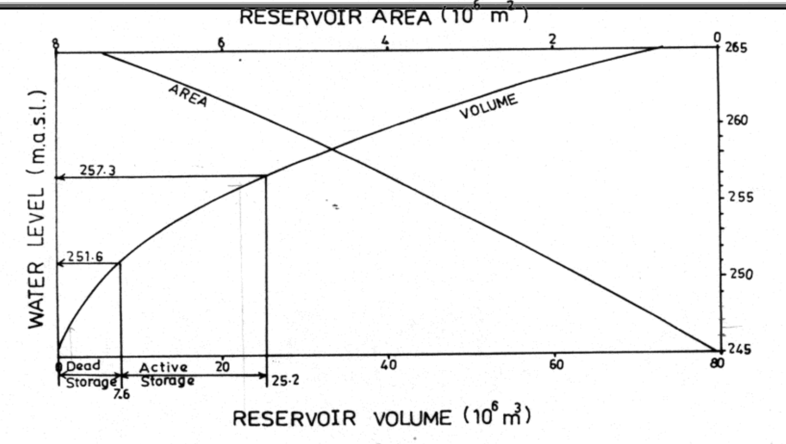

Fig.(2) Volume surface area curves for the reservoir of Mosul regulating reservoir

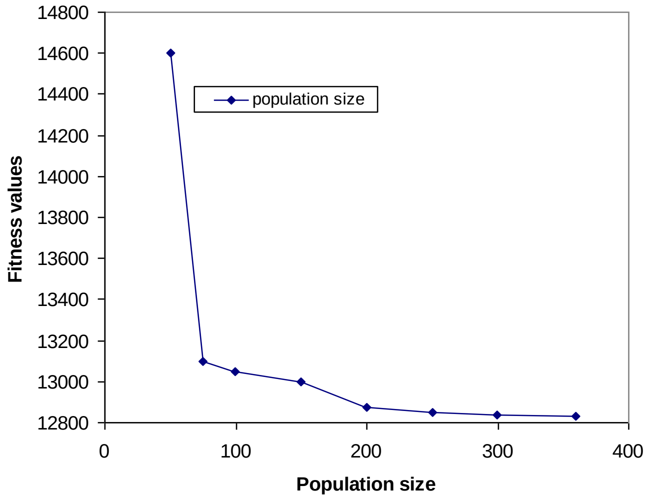

Fig. (3) Fitness value for different population size.

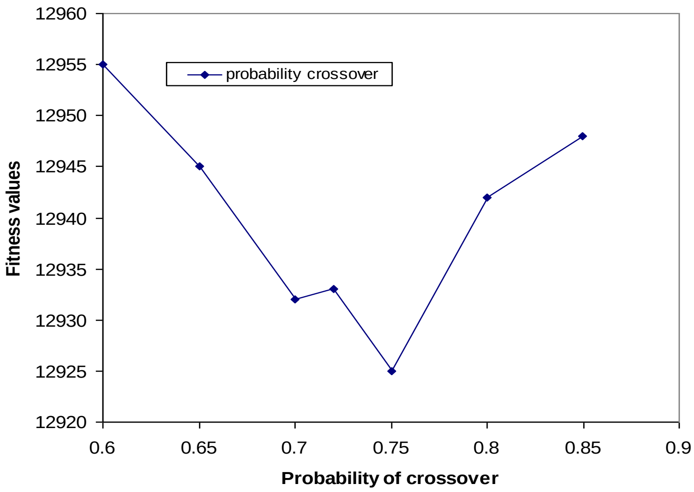

Fig.(4) Fitness value at different probability of crossover.

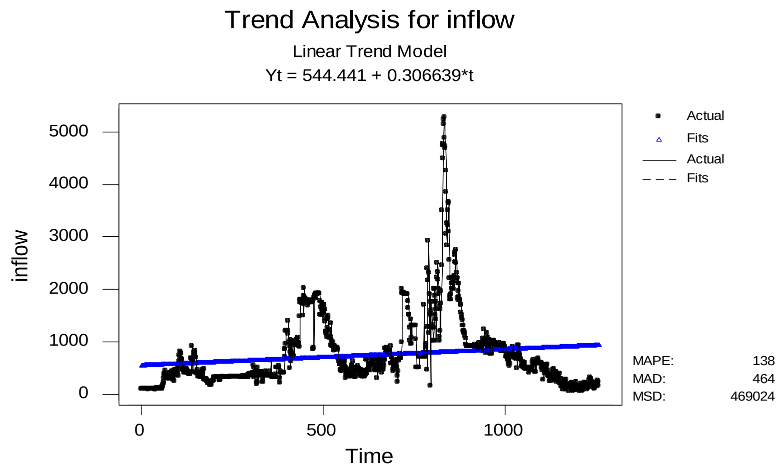

Fig. (5) Daily time series of inflow to Mosul regulating dam for the period

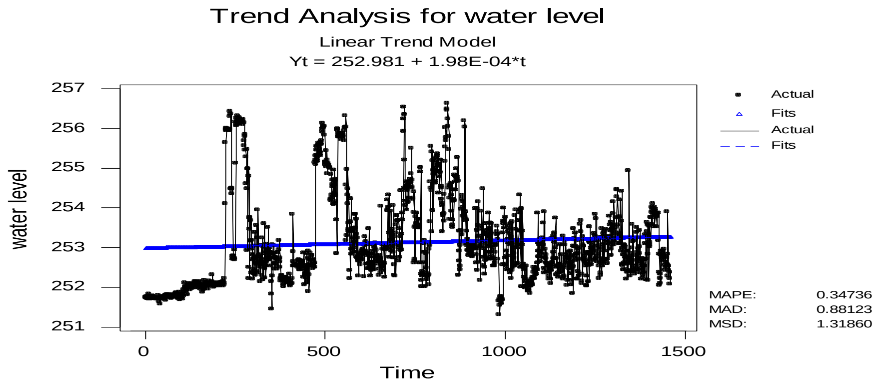

Fig.(6) Daily time series of water level of Mosul regulating reservoir for the period (1994-2007).

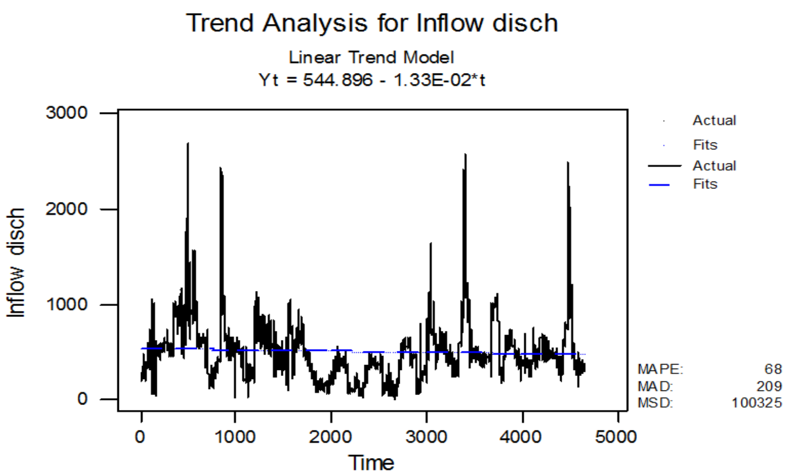

Fig.(7) Daily time series of inflow to Mosul regulating reservoir for the period (1994-2007)

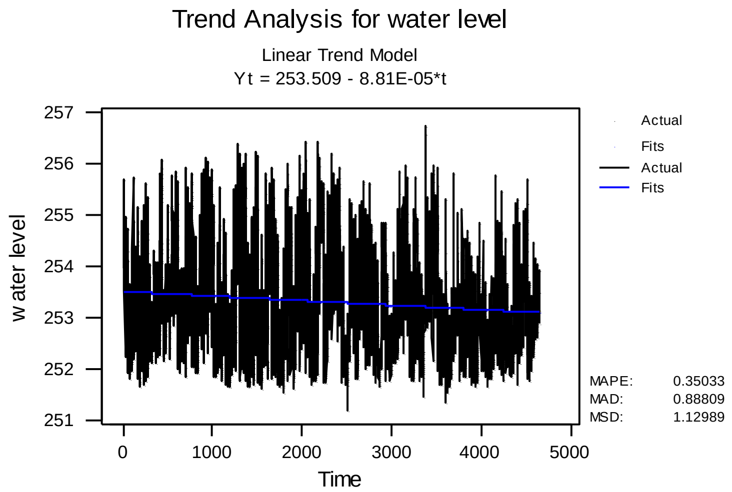

Fig.(8) Daily time series of water level of Mosul regulating reservoir for the period (1994-2007)

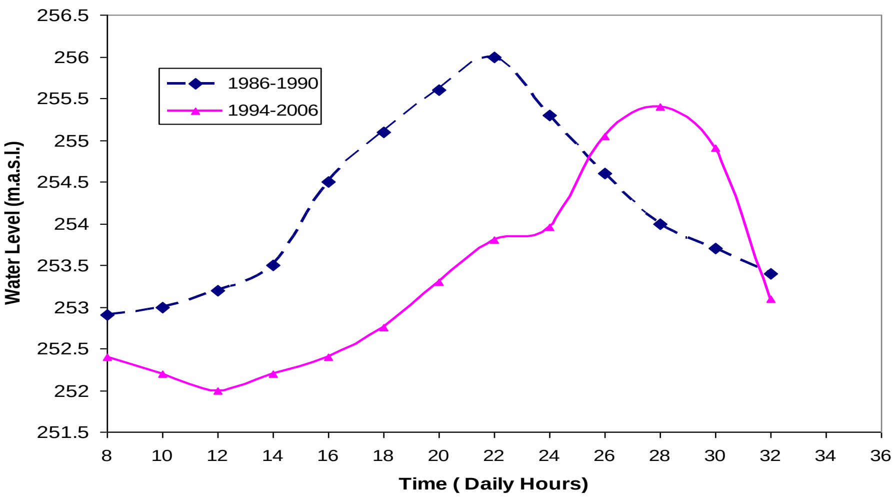

Fig. (9) Actual daily rule curve of Mosul regulating reservoir

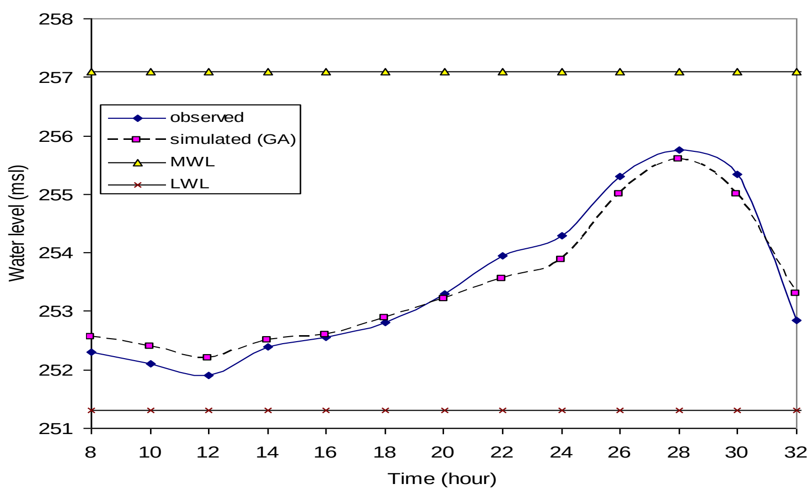

Fig. (10) Observed and genetic algorithm simulated daily rule curve for the operation period (2 Jan. 2008)

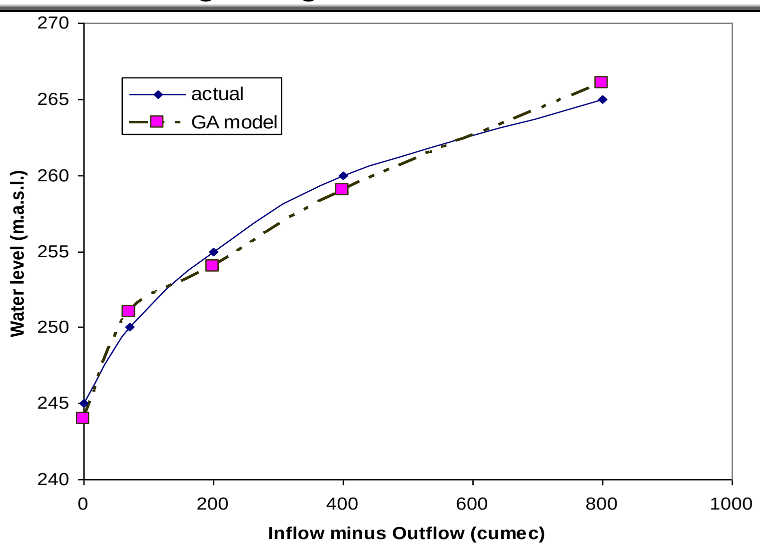

Fig. (11) Application of GA in predicting rating curve at Mosul regulating reservoir.

Table (1) Maximum, mean and minimum inflow and outflow for the Mosul Regulating dam.

	Inflow (cumec)		Outflow(cumec)		Water Level(m.s.l.)	
	1986-1990	1994-2007	1986-1990	1994-2007	1986-1990	1994-2007
Maximum	5290	2685	5300	2500	265.75	256.45
Mean	735	515	719	544	253.35	253.11
Minimum	61	40	76	80	251.6	251.44