Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 1 Volume 26 January 2020

Chemical, Petroleum and Environmental Engineering

Design of Expert System for Managing the System of AthTharthar Lake

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ABSTRACT

The operation and management of water resources projects have direct and significant effects on the optimum use of water. Artificial intelligence techniques are a new tool used to help in making optimized decisions, based on knowledge bases in the planning, implementation, operation and management of projects as well as controlling flowing water quantities to prevent flooding and storage of excess water and use it during drought.

In this research, an Expert System was designed for operating and managing the system of AthTharthar Lake (ESSTAR). It was applied for all expected conditions of flow, including the cases of drought, normal flow, and during floods. Moreover, the cases of hypothetical operating of flow under extreme conditions were considered. The results showed a good capability of the designed expert system to operate the potential cases for those discharges and with high efficiency. Also the results showed the inability of AthTharthar Lake System to pass the discharge up to 12600 m^3/s during floods. It was recommended to accomplish Tigris River training and increasing the level of levees, reshaping the cross-sections and longitudinal section of the river. It was suggested to expanded AthTharthar Head Regulator and the intake canal to accommodate more flood discharges.

Keywords: management, Expert System, AthTharthar Lake System, Samarra Barrage.

تصميم نظام خبير لإدارة منظومة بحيرة الثرثار

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الخلاصة

إن تشغيل وإدارة مشاريع الموارد المائية لها تاثير مباشر وهام على الاستخدام الأمثل للمياه. ان تقنيات الذكاء الاصطناعي هي أداة جديدة تستخدم للمساعدة في اتخاذ القرارات المثلى، والتي تستند إلى أسس المعرفة في تخطيط المشاريع وتنفيذها وإدارتها وكذلك التحكم في كميات المياه المتدفقة لمنع الفيضانات وتخزين المياه الزائدة واستخدامها في أوقات الجفاف.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2020.01.11

Article received: 27/2/2019
Article accepted: 6/5/2019
Article published: 1/1/2020

في هذا البحث تم تصميم وبناء نظام خبير لتشغيل وإدارة منظومة بحيرة الثرثار. تم تطبيق النظام الخبير (ESSTAR) لجميع ظروف التصاريف، بما في ذلك حالات الجفاف، حالة التصريف الطبيعي، والفيضان، كذلك تم تبني حالات التشغيل الافتراضي للتصاريف في ظل الظروف المتطرفة لاختبار أداء تشغيل النظام المصمم، أظهرت النتائج جدوى نظام الخبراء المصمم لتشغيل الحالات المحتملة لتلك التصاريف وبكفاءة عالية. كما أظهر النظام المصمم عدم قدرة منظومة الثرثار على استيعاب وتمرير تصريف يزيد عن 12600 م^3/ثا خلال حدوث الفيضانات، الأمر الذي يتطلب إجراء اعمال تهذيب لنهر دجلة ورفع مستوى الحواجز واعادة تشكيل المقاطع العرضية والطولية للنهر، كذلك يتطلب توسيع ناظم الثرثار الرئيسي وقناة المأخذ لاستيعاب المزيد من تصاريف الفيضان.

الكلمات الرئيسية: تقنيات الذكاء الاصطناعي، نظام خبير، منظومة بحيرة الثرثار، سدة سامراء، ناظم الثرثار الرئيسي.

1. INTRODUCTION

Water resources systems must be operated optimally and efficiently in practical situations that require an adequate and a comprehensive experience of the systems. The main problem in management of water resources having multiple objectives is that the difficultly to meet these objectives at the same time in real-time operation. Moreover, constrains imposed by these objectives add sometimes complexity to the operating conditions. The requirements of some objectives may conflict with other objective constraints. Hence, there is a need for mathematical systems that is capable to obtain the optimal discussion about these objectives together with their constraints under different operating conditions.

At the beginning of the 1970s, the computer expert systems was introduced, which is considered one of the most sophisticated artificial intelligence stages. The aim of this technique is to provide the necessary expertise in different operating situations. This system is characterized by quick and clear processing of the data entered by conducting a dialogue between the operator and the system and getting results, conclusions and recommendations necessary for operation, it is also characterized by its ability to update information and data during program operation, **(Fischer and Schultz, 1991)**.

The knowledge within the expert system is structurally separated from inference engine, this distinguishes the expert system and makes it different from other computer programs, where the system can be developed in a language closer to the language of the developer than the language of the expert system, thus, the system knowledge base can be developed by people who are not computer programmers.

Many researchers tends to introduced solutions for managing water resources projects, through preparing the expert system for the optimal operation of the head structures system of Al-Dhuluiya irrigation project, using Visual C++ language, called Admiral, by **(Al-Zangana, 2000)**. The expert system was applied to the different operating conditions. The results were accurate and consistent with the operational results. Another expert system was designed using Clips 6.0 language, by **(Abd-Elhamid, et al., 2011).** The expert systems used to diagnose types and categories of problems that may arise in the various elements of Masonry Barrage the user interface was designed using Visual Basic 6.0 language, the developed expert system has been tested on several real situations. As well as expert systems were programmed using Visual Basic language within the Windows environment, and used for managing Al-Hindiya Barrage and Haditha Dam, which were developed by **(Alwan and Al-Qazwini, 2011)**, and (**Othman, 2013)**, respectively, the researchers obtained good results compared with observed operation results.

In this research, the programming language of **C#** within a Microsoft Visual Studio environment is used, as it is the most accessible and most appropriate language among other languages. It has the ability to connect to databases via the Internet, **(Fischer and Schultz, 1991)**.

2. THE SYSTEM OF ATHTHARTHAR LAKE

AthTharthar Lake is the largest artificial reservoir in Iraq and the second largest artificial reservoir in the world. Its area covers about 2700 km^2 with a maximum storage of about 85 billion m^3. The main functions of AthTharthar Lake are to control Tigris River floods, store excess water, and control irrigation water during the summer season, **(CEB, 2011)**.

The system for controlling AthTharthar Lake, **Fig. 1,** consists of eight structures that are Samarra Barrage and its hydropower station, Al-Ishaqi Head Regulator, the Irrigation Canal, AthTharthar Head Regulator, AthTharthar Outlet Head Regulator, Tigris-Diversion Regulator, and Euphrates-Diversion Head Regulator.

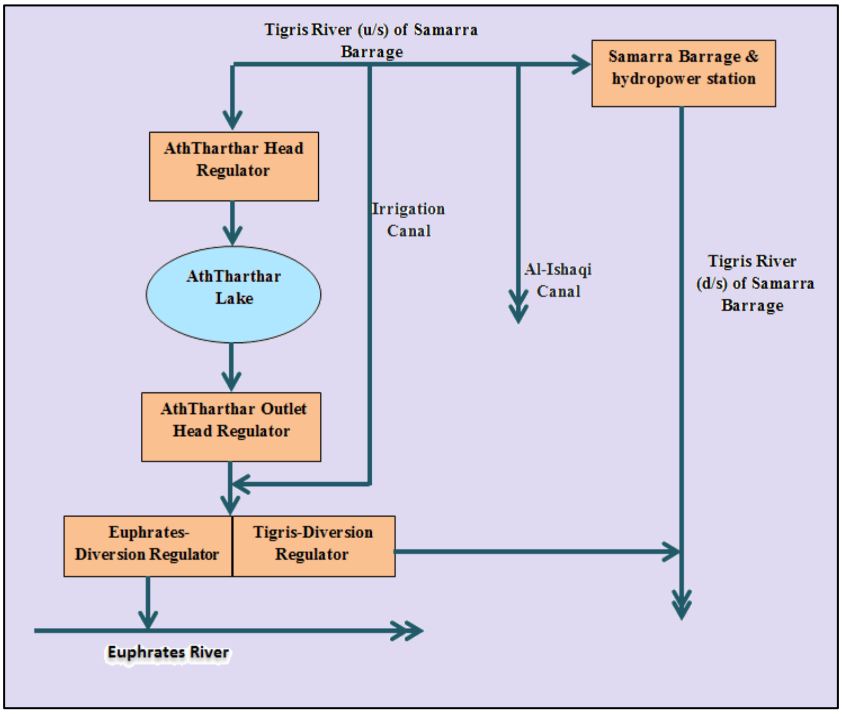


Figure 1. A scheme diagram of AthTharthar Lake System.

The operation of such water resources system and water projects were managed nowadays by The Ministry of Water Resources of Iraq by few number of a staff of experts, whom they have high level of comprehensive experience after along years they spend in the operating and managing of these system. Most of these experts become aged, and they may be retirement soon. Therefore, it is necessary to prepare an alternative staff compensates their positions and doing their jobs.

3. AIM OF THE RESEARCH

The main objectives of this study are to:

a. Designing and building an expert system for managing and operating of AthTharthar Lake System.

b. Testing the validity of the designed system by testing a various predicted flow situations, including water scarcity and floods that may occur, and defining their seriousness and giving an alarm to the managers to finding solutions to avoid these risks.
c. Preparing an interface system enables the (new) staff with low level of experience to manage and operate AthTharthar Lake System or other system without need for high level of experience.

4. METHODOLOGY

The following steps have been followed to achieve the aim of the research;

4.1 Hydraulic operation of AthTharthar Lake System

The operation of AthTharthar Lake system is started by defining the incoming discharges that reached upstream of Samarra Barrage which delivered through the stream of Tigris River, north of the barrage, and the contribution of its tributaries such as Al-Khabour, the Little Zab, and Great Zab rivers, and the recorded water level at the barrage; (from Directorate of Samarra Barrage). These discharges are distributed according to the water demand of the cities located on the Tigris River at the downstream of Samarra Barrage (including Baghdad City), In the case of normal operation, the discharge up to 820 m^3/s have passes through the power station only at the structure of Samarra Barrage, and the surplus flowrates passes through the irrigation gates of the barrage, and taking in to account the diversion of the whole water demand of Al-Ishaqi Project or reducing it by a percentage when there was a shortage of inflow (Time of Scarcity). Then the priority is diverting the excess water using the Irrigation Canal up to 250 m^3/s to meet the demand of downstream branches. Then diverting the excess water by AthTharthar Head Regulator and stored in AthTharthar Lake and to benefit from the water stored and exploit it during the summer season. The outflow discharges from the lake are controlled by AthTharthar Outlet Head Regulator.

Water is diverted from AthTharthar Lake to the Tigris River to accomplish the water demand in the river by Tigris-Diversion Regulator, or from AthTharthar Lake to the Euphrates through Euphrates-Diversion Regulator. On the operation basis mentioned above, the system was operated according to the processes that summarized in the flowcharts shown in **Figs. 2, 3, and 4**. The flowcharts illustrate the a graphical representation of the computer program of the expert system in relation to its sequence of functions as distinct for the data it processes, including the computation of released flowrates, using the equations (1, and 2) mentioned below, from each structure of the eight structures that consist AthTharthar Lake System, and define the number of gates would opened to pass each flowrates, and the height of the opened gates.

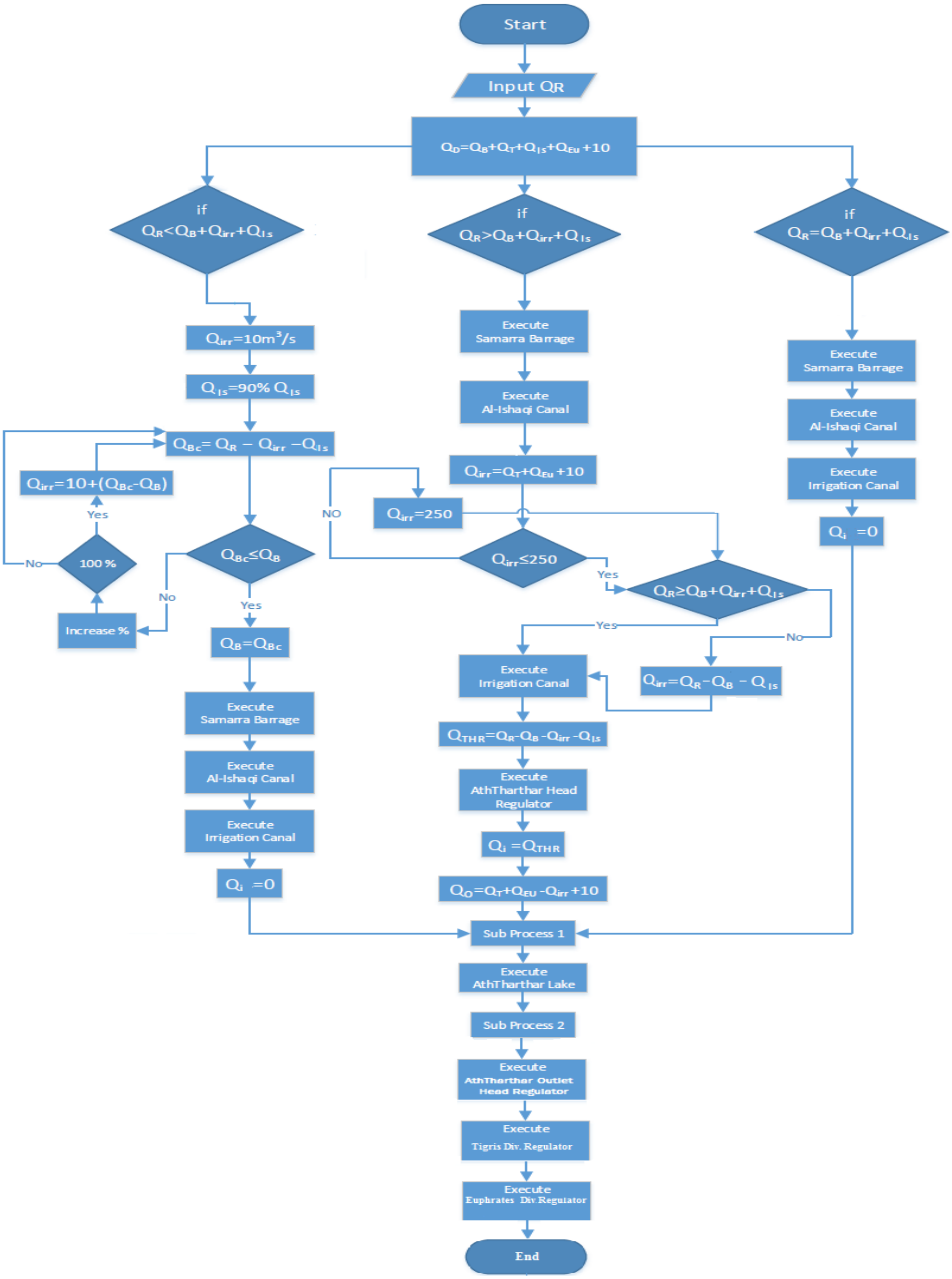


Figure 2. Flow chart showing the operation of AthTharthar Lake System.

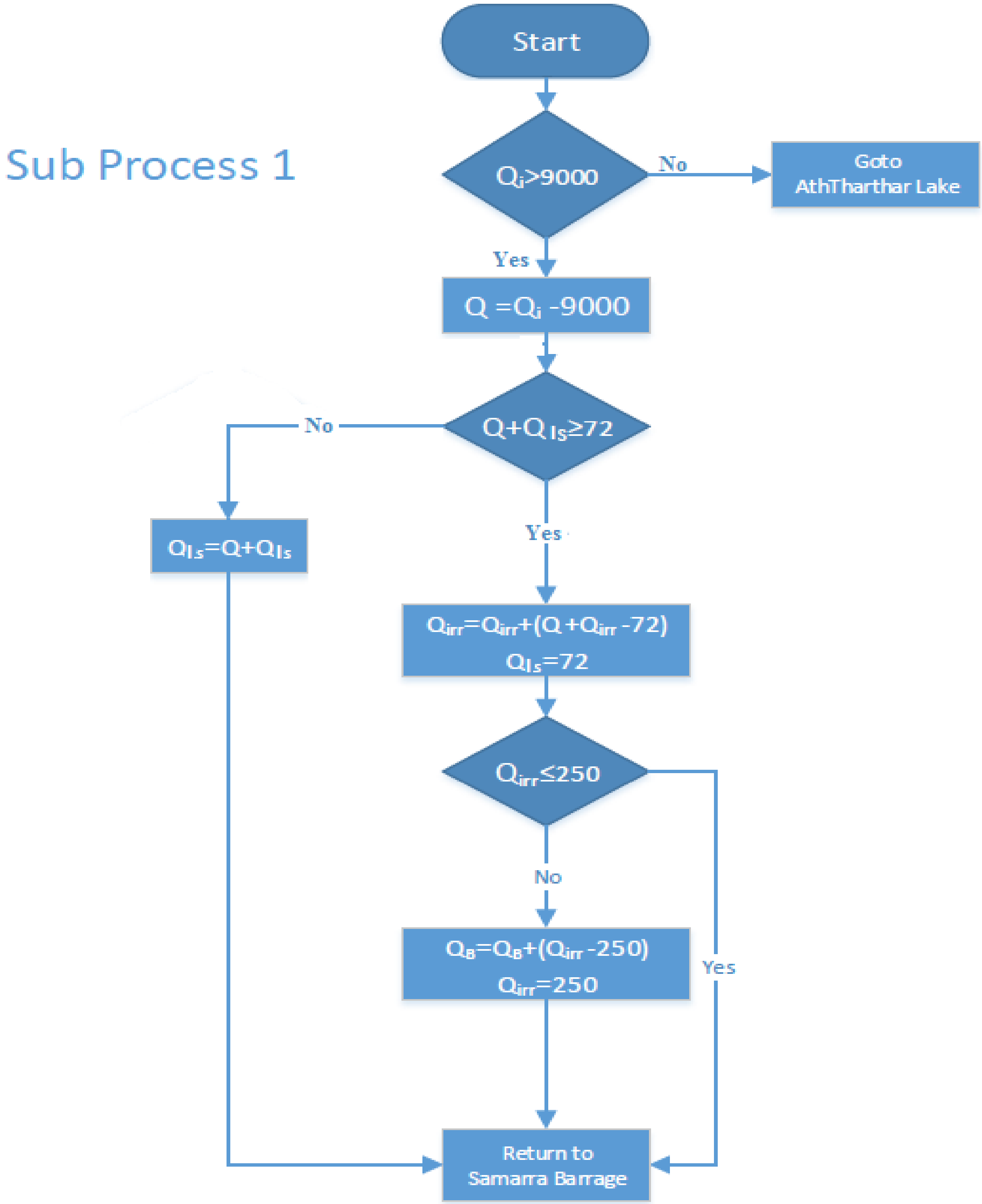


Figure 3. The first sub-program.

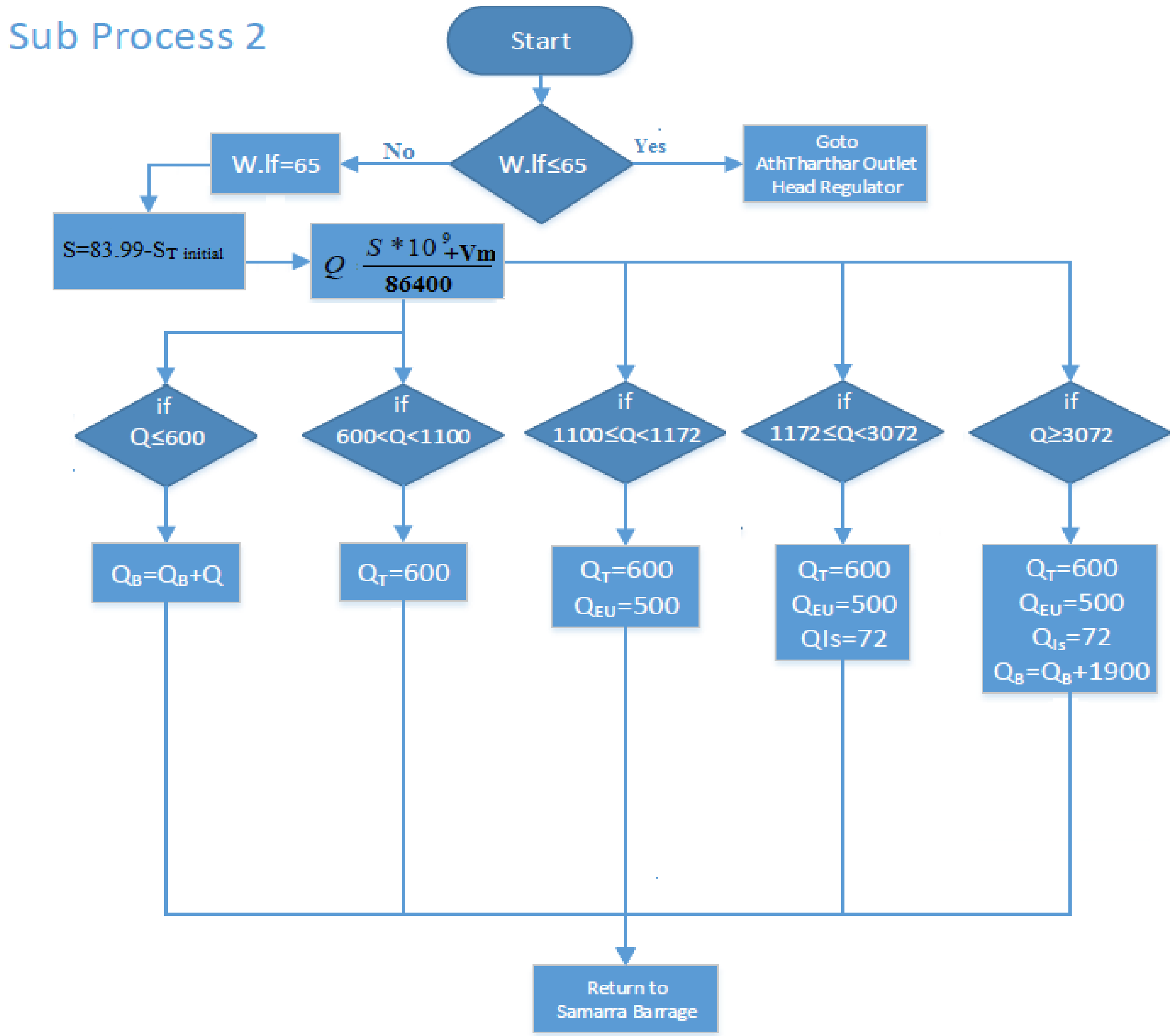


Figure 4. The second sub-program.

By using the hydraulic equation of (Flow Orifice Formula), **Street, et al., 1996,** the discharge will be calculated through the structures.

$$Q = L \times a \times Cd \times \sqrt[2]{2g(H_1 - H_2)} \quad (1)$$

Where:

Q = Discharge of gates (m^3/s).
L =Width of gates (m).
a = Height of gates opening (m).
g = Acc. of gravity=9.81 m/s^2.
H_1 = Head in the upstream (m).
H_2 = Head in the downstream (m).
Cd = Coefficient of discharge.

The coefficient of discharge (Cd) was found using the experimental formula below which depends on the value of the water head in the upstream (H_1) and the height of gates opening (a) as follows, after **(Chow, 1959),** re-edited:

$$Cd=0.031\left(\frac{a}{H_1}\right)^2-0.139\left(\frac{a}{H_1}\right)+0.7264 \quad (2)$$

This equation was extracted by the author as a best fitting from the curve of the relationship between the coefficient of discharge and the ratio of the gate opening to the head in the upstream as in **Fig. 5**.

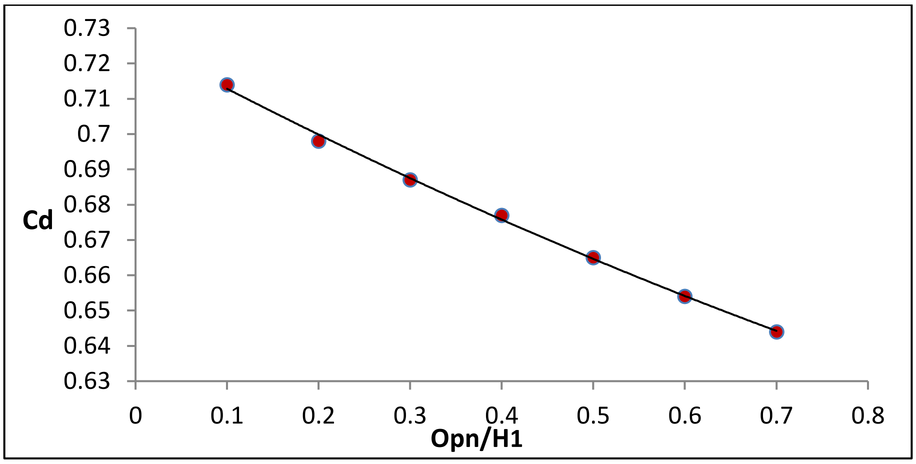


Figure 5. Relationship between Cd and the ratio of (a/H_1), after **(Chow, 1959),** re-edited.

The required data for the hydraulic operation for the eighth structures in AthTharthar Lake System was gathered from the National Center for Water Resources Management, Baghdad, and the Directorate of Samarra Barrage.

4.2 Design of Expert System (ESSTAR)

In this research the expert system program was designed and the following explanation will illustrate the most important details of the system.

4.2.1 Programming language

In order to apply the system steps programmatically the **C#** language was adopted for several reasons; including:

1- The C# language is integrated in terms of programming structure and mathematical functions.

2- The ease of dealing with external data sources and the possibility of linking to databases, especially through the Internet where it is possible to develop the system by adding the ability to link directly with sensors placed in projects and linked with the system through the Internet.

3- It works within a Microsoft Visual Studio environment that contains an integrated library of illustrative examples and help.

4.2.2 Design of Program

This part of the research will explain the inputs types and explain the components of the interfaces.

1- Data sources (inputs): The system inputs are divided into two parts: The first part is constant inputs that do not change for each project (design discharge, width of gates, upstream crest level, and many others) and the data was saved in the file (.csv) using Excel software for each project separately. These file formats have been used for many reasons, including the ease of reading this type of file in c# language and the ease of dealing with the same file even for any user.

The second part of the inputs is those inputs are changeable, and enter the program at the time of implementation, i.e. when operating the program such as (discharge demand, evaporation, precipitation, upstream water level, and other).

2- Program interfaces (Graphical User Interface GUI): An interface was designed for each hydraulic structure at the system, as well as the interface of the combined inputs of all structures, and there was another interface for the results and outputs required form such as pdf files.

Each interface consists of windows form and contains several Text Boxes; according to the number of inputs per interface each interface represents one of the eighth hydraulic structures consist the system, and with each (Text Box) there is a (label) indicating the type of input to be entered.

Plus three buttons for each interface, one to move to the next project or interface, the second to return to the previous project if found and the third to exit the program, **Figs. 6, 7, 8, and 9**.

3- Interfaces working mechanism: The interfaces were designed in a form that does not allow to moving to the next interface unless all necessary data are entered. And for each input, the interface was programmed to not allow inputs to be entered outside the range allowed for each input for all projects where the input color changes to red color where the input exceeded the permissible ranges.

Figure 6. Main menu of the designed Expert System (ESSTAR).

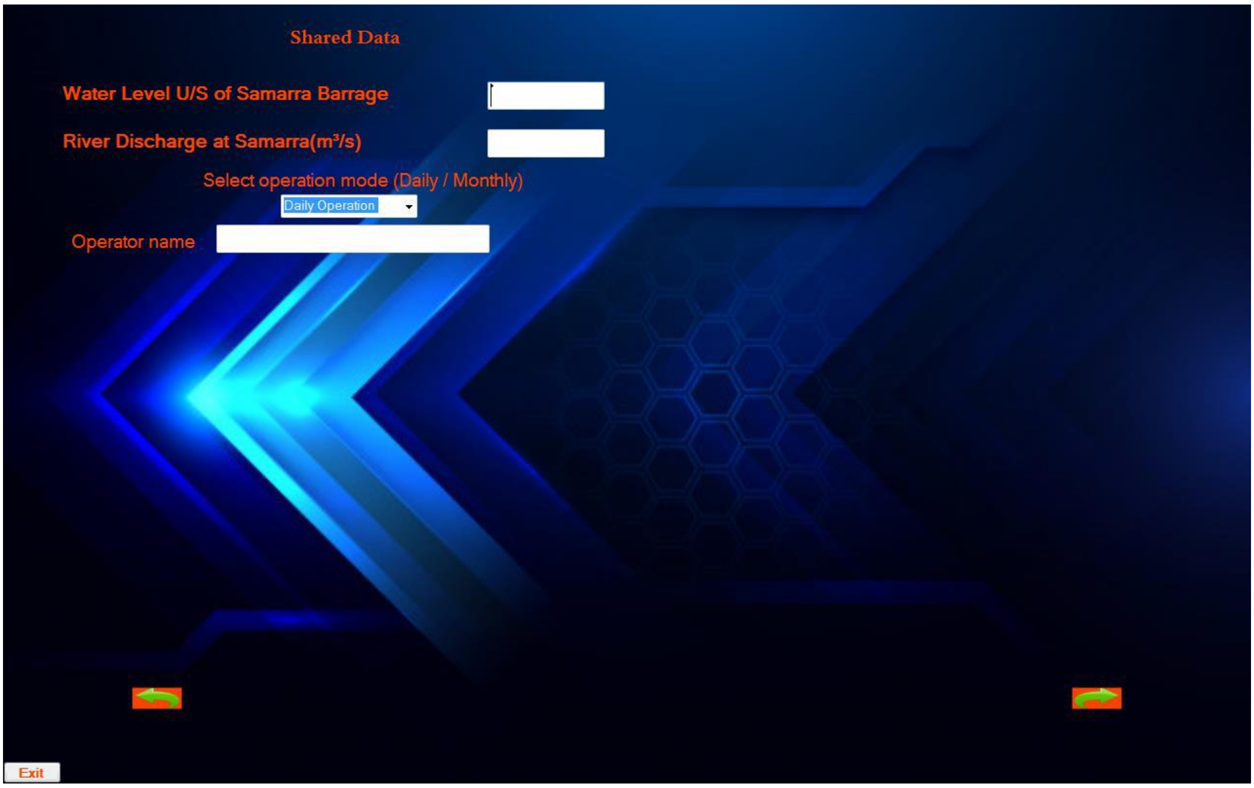
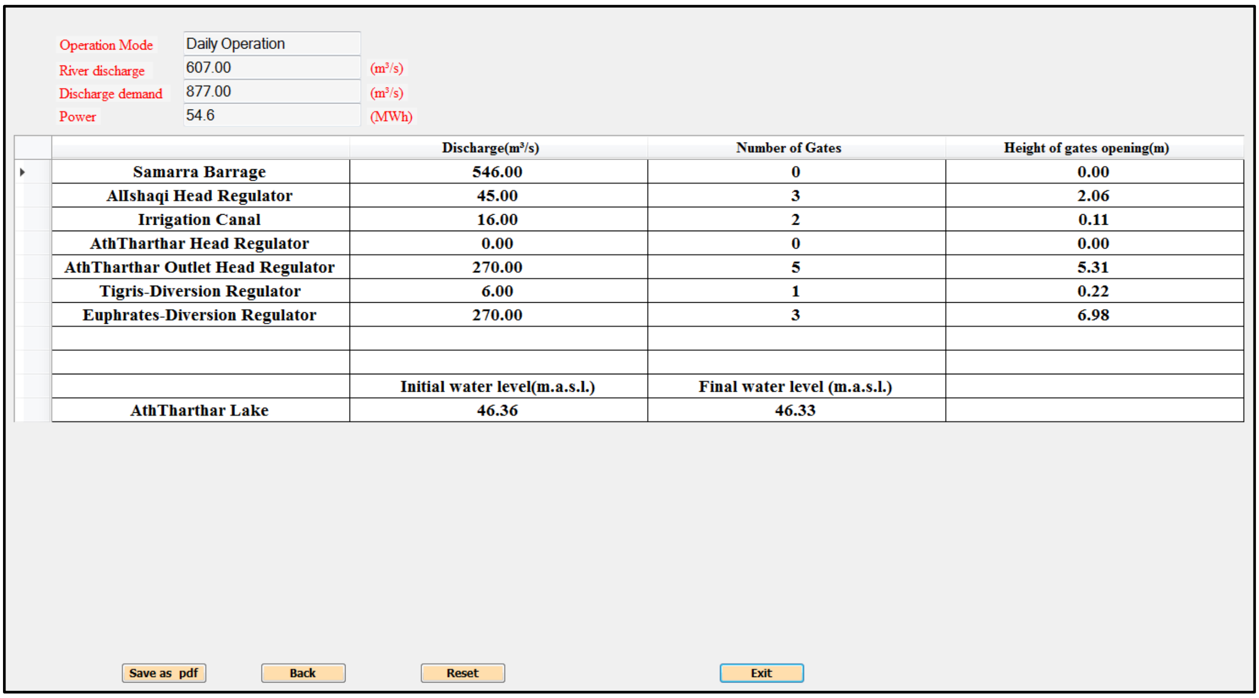


Figure 7. Common input menu.

Figure 8. Input menu of Samarra Barrage.



Operation Mode: Daily Operation
River discharge: 607.00 (m³/s)
Discharge demand: 877.00 (m³/s)
Power: 54.6 (MWh)

	Discharge(m³/s)	Number of Gates	Height of gates opening(m)
Samarra Barrage	546.00	0	0.00
AlIshaqi Head Regulator	45.00	3	2.06
Irrigation Canal	16.00	2	0.11
AthTharthar Head Regulator	0.00	0	0.00
AthTharthar Outlet Head Regulator	270.00	5	5.31
Tigris-Diversion Regulator	6.00	1	0.22
Euphrates-Diversion Regulator	270.00	3	6.98
	Initial water level(m.a.s.l.)	Final water level (m.a.s.l.)	
AthTharthar Lake	46.36	46.33	

Figure 9. Results menu.

4.3 Results and Analysis of Operation the Expert System (ESSTAR)

The expert system was monthly operated for eleven years, (132 months), (for the period from October 2006 to September 2017). As well as, it was daily operated for three months for the year 2016 (January, April, and July). Then the system operated hypothetically for two cases of flow rates (extremely drought, and extremely flood) to check the feasibility and validity of the system for different cases. These results were compared with the actual operating results of the lake system, and the root mean square error (RMSE), was calculated to obtain the accuracy of designed system and the convergence between the two results. The expert system was operated for the following hypothetically cases of flowrates which are:

1- Flow in case of drought, and discharge of Tigris River at Samara barrage was assumed to be between 150 to 350 m^3/s. The month of July was adopted as the most probability month for this situation.

2- Flow in case of flood, assuming a discharge of Tigris River at Samara barrage between 3000 to 15000 m^3/s. April was adopted as the most probability month of flooding in the year.

Fig. 10, illustrates the results obtained by the expert system, which are very close to the recorded operation data for the same period of the water year (2016-2017) for Samarra Barrage, and Ishaqi project respectively, and the computed RMSE for the comparison having insignificant value.

From comparison shown in **Fig. 11**, it was found that there is a slight difference in the released discharges, to the Ishaqi Project, namely for the months of December and January, and this is due to the limitations of operation followed in the expert system, which is differ from the actual (manual) method of operation.

In this research, a special operation was adopted for the Irrigation Canal to ensure the following cases:

- First; to meet the water requirements of irrigation and services spread along the canal , as well as ensure the environmental and the sustainability requirement and aquatic life, where the minimum discharge passing through the canal must not less than 10 m^3/s to meet these requirements.
- Second; maintaining the quality of incoming water from Samarra Barrage and the necessity of delivering it to the diversion regulator with the same quality and to avoid entering of these water into the lake, to prevent of carrying salt concentrations that harm the quality of that water. So the operation of the canal includes passage the water demand for the Tigris and Euphrates arms through the irrigation canal up to 250 m^3/s which represents the maximum capacity of the canal. In other cases where more than that flow rates are available, it will be diverted toward AthTharthar Lake to be stored in the lake, with ensuring the release of the remaining water demand for the Tigris and Euphrates arms from the lake.

Fig. 12 shows the Comparison between the computed and recorded discharges of the Irrigation Canal. It is obvious that there were high differences between the two approaches, because of the limitations adopted to operate the irrigation canal in the expert system is differ from that used in the real operation, as was it mentioned above, the system focused on quality of released water.

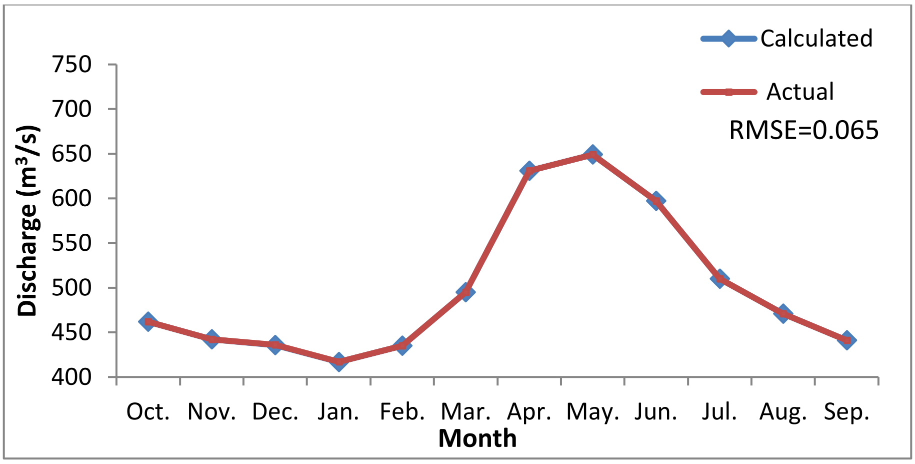


Figure 10. Comparison between the computed and recorded discharges of Samarra Barrage.

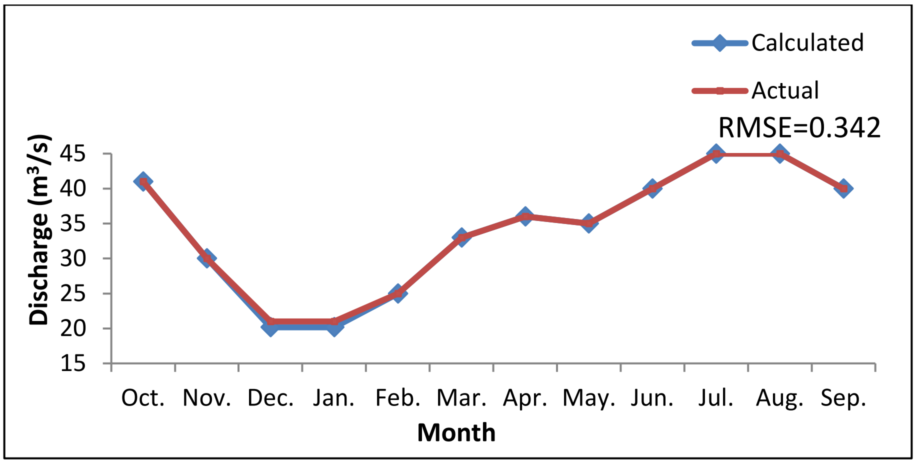


Figure 11. Comparison between the computed and recorded discharges of Al-Ishaqi Head Regulator.

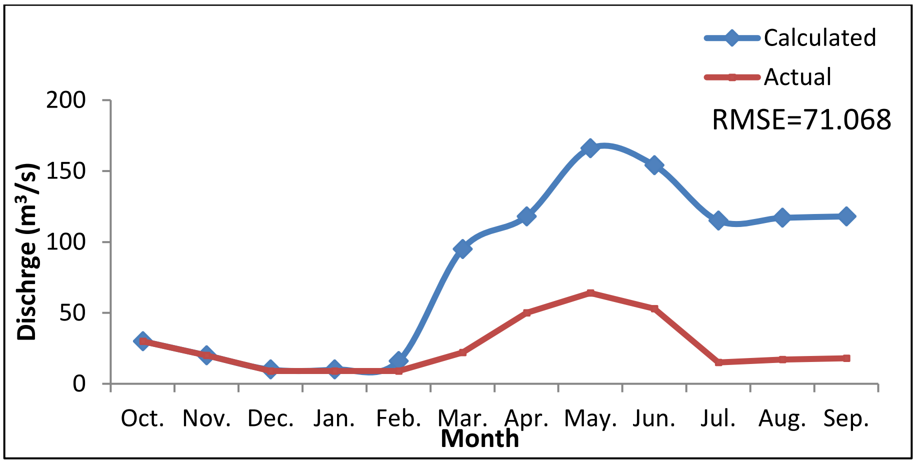


Figure 12. Comparison between the computed and recorded discharges of the Irrigation Canal.

Figs. 13, and **14** show a comparisons between the computed and recorded discharges of AthTharthar Inlet and Outlet Head Regulators, as a results of different operation method adopted for managing discharges to the Irrigation Canal, a different trends were shown at these figures. The difference between discharges shown at these figures was passed through the canal to assure high quality of water that passes through.

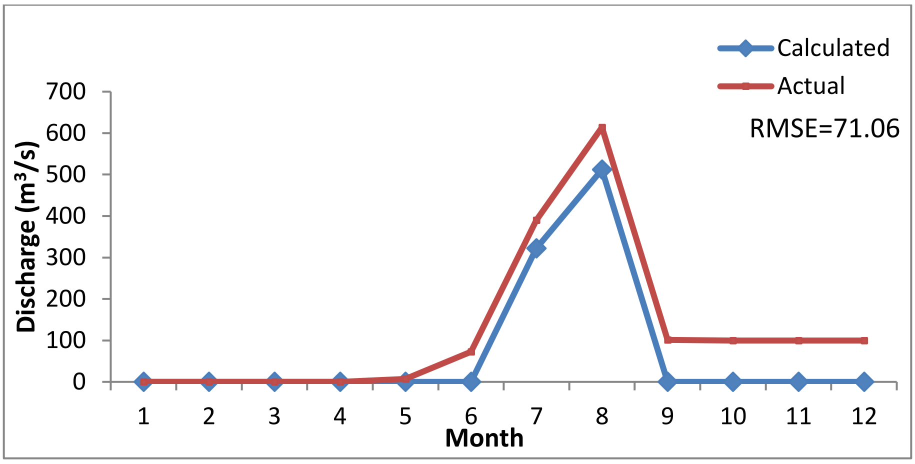


Figure 13. Comparison between the computed and recorded discharges of AthTharthar Head Regulator.

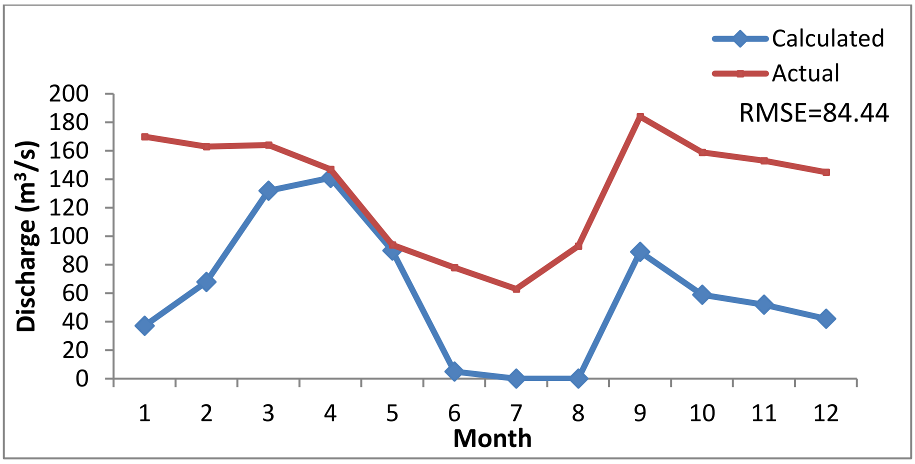


Figure 14. Comparison between the computed and recorded discharges of AthTharthar Outlet Head Regulator.

Figs. 15, and **16** show that there were an exact match between the discharges computed by the expert system, to the arms canals of Tigris and Euphrates with the recorded real discharges. The computed root mean square error equal to zero, where the discharges released from the Tigris and Euphrates Diversion Regulator depends on the water demand downstream these regulators.

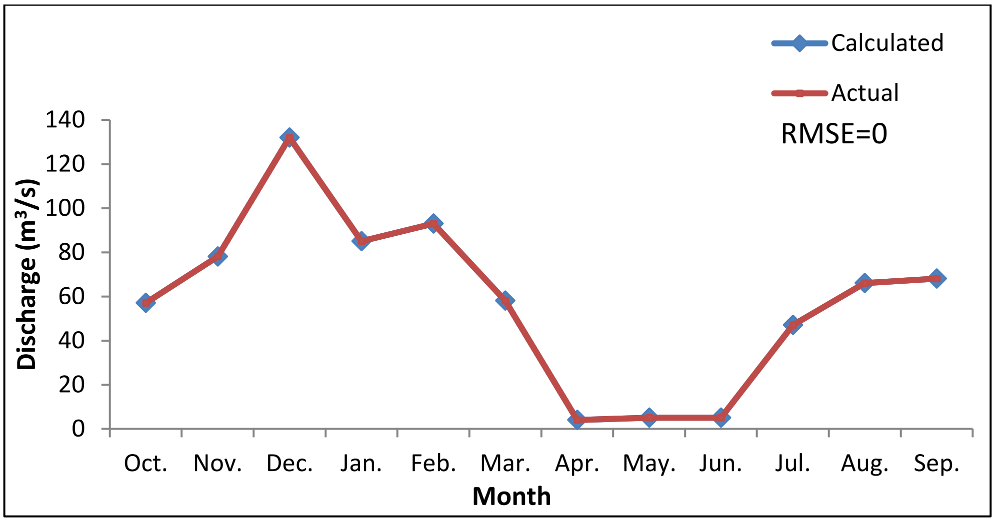


Figure 15. Comparison between the computed and recorded discharges of Tigris-Diversion Regulator.

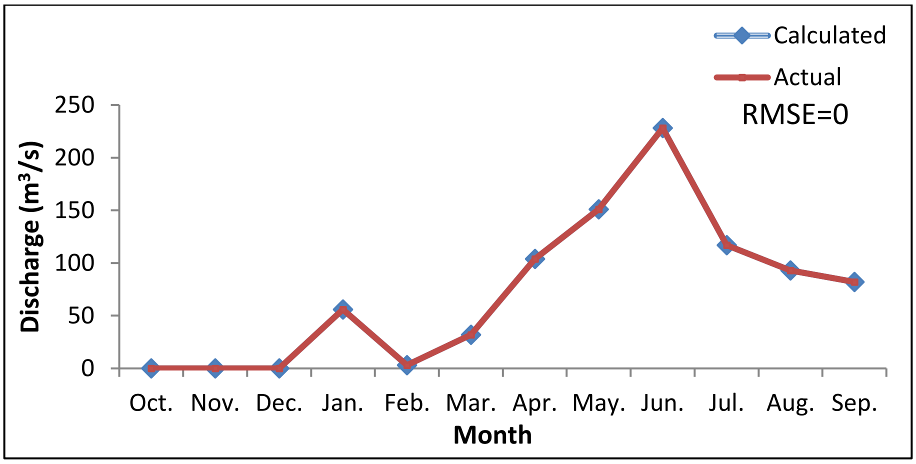


Figure 16. Comparison between the computed and recorded discharges of Euphrates-Diversion Regulator.

It was obvious that the results obtained by the expert system, as shown in the **Fig. 17,** were approach or exceeded the lower rule curve which obtained by **(Hussain, 2010)**, in some months, due to the low flowrates of the Tigris at the periods of drought recently suffered by the river.

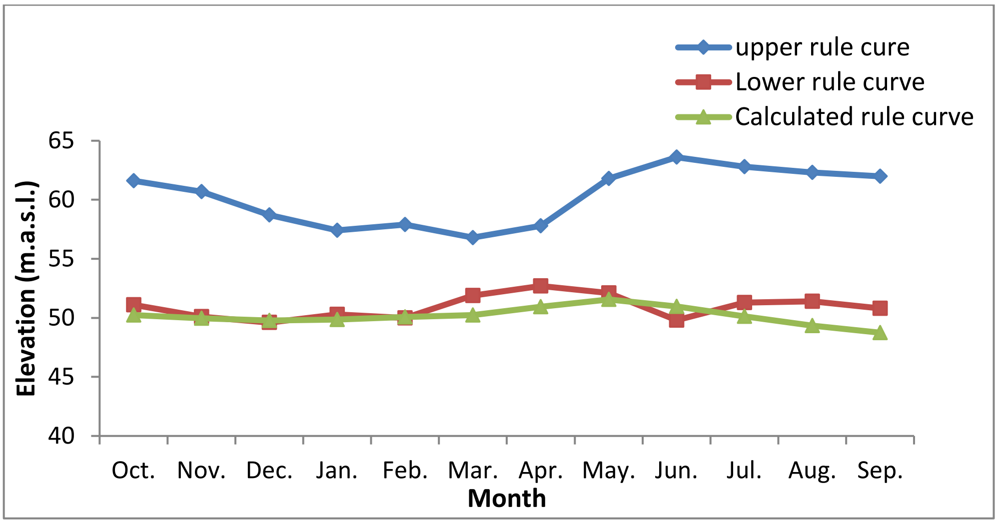


Figure 17. Comparison of releases with the Rule curves of AthTharthar Lake.

The results obtained show the ability of the expert system (ESSTAR) to managing the releases flowrates from all hydraulic structures that AthTharthar Lake System consists. As well as the feasibility of results conducted by using the expert system for managing the two hypothetically cases two cases of flow rates (extremely drought, and extremely flood). Also it was found, that the system of AthTharthar Lake cannot pass a flowrates exceeding 12600 m^3/s, and flooding damage will happened for the scheme of Samarra Barrage, Samarra City, as well as the downstream of the Barrage toward Baghdad City, so an extension of AthTharthar Head Regulator and the intake canal required to pass higher flowrates, aa well as cross section and longitudinal section training works for the Tigris River must be done, and removing of obstruction must be conducted to expand the capacity of the river for higher flowrates. While it was seen in the drought flowrates, the downstream demands cannot be fully covered and it will be achieved from the storage of AthTharthar Lake, as much as possible.

5. CONCLUSIONS

The following conclusions were extracted from the results obtained by operating the Expert System (ESSTAR):

1. The designed Expert System (ESSTAR) was written in **C#** language. It was able to manage AthTharthar Lake System efficiently.
2. The system enables the user with a simple experience, to manage and operate the system.
3. Through the monthly operation of real data for the previous 11 years and also through the daily operation, the results were compatible with the recorded operation of the system through the comparison. This indicates the efficiency of the performance of the Expert System (ESSTAR).
4. By operating the system for extremist hypothetical flow situations involving water scarcity and floods cases. The results indicated that in flood situations, and when the discharge of the river reaches 12600 m^3/s, the lake is unable to store all excess water; which leads to the flooding of Samarra City and the areas downstream of Samarra Barrage southward towards Baghdad City. In addition, the results indicated that in cases of water scarcity there will be no storage in the lake. While there will be withdrawal and compensation of water shortage from the lake to meet the demands of water as much as possible.

5. There is only one difference in flow management in the system where a special operation was adopted for the Irrigation Canal. The aim is to maintain water quality and avoid entering the lake as much as possible to avoid mixing the water with the lake water because it is carried with saline concentrations; which harms the quality of the water. Water is transported through the Irrigation Canal with ensuring a minimum discharge of 10 m^3/s; to meet the water needs on the canal. After adoption of this special operation, acceptable results were obtained and the desired objective was achieved.
6. By the daily and monthly operation of previous years, the storage level in the lake was below the lower rule curve, Because of the scarcity suffered by the Tigris River.

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NOMENCLATURE

L_B: Width of barrage gates (m).

$Q_{B\ designed}$: Design discharge of barrage (m^3/s).

$USCL_B$: Upstream crest level of the barrage (m.a.s.l.).

$DSCL_B$: Downstream crest level of barrage (m.a.s.l.).

$USWL_B$: Upstream water level of barrage (m.a.s.l.).

$DSWL_B$: Downstream water level of barrage (m.a.s.l.).

Q_B: Discharge of barrage (m^3/s).

Q_s: Discharge of hydropower station (m^3/s).

H_1: Head in the upstream (m.a.s.l.).

H_2: Head in the downstream (m.a.s.l.).

a_B: Height of barrage gates opening (m).

$H_{B\ designed}$: Design height of barrage gates opening (m).

N_B: Number of barrage open gates.

Q_{CB}: Discharge calculated of barrage (m^3/s).