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Simulation of Mosul Dam Reservoir Operation for Irrigation and Hydropower Generation

Abstract- The current research aims to build a simulation model to study the effect of Jazeera irrigation projects (North, East and South) water requirements on hydroelectric power generation from Mosul dam hydropower plant. The simulation was applied from January 1988 to December 2006 on a monthly basis. A simulation model was built utilizing (HEC-ResSim 3.0) Package, which showed high efficiency in representing and simulating the actual operation of the reservoir. Simulation model operation has been carried out through five scenarios with two cases of priority; the first was to maximize the hydroelectric power generation, and the second was to minimize the shortage in fulfilling the water requirements of Jazeera irrigation projects. The results showed that when the priority is given to meet the irrigation water requirements, the water deficit is decreased but the hydropower generation deficit is increased, and when the priority is to maximize the hydroelectric power generation, the hydropower generation increases, but the irrigation water is decreased. The study concluded that when the East and South Jazeera irrigation projects are completed and operated along with North Jazeera project, the reservoir would not be able to meet their requirements, in addition to an obvious shortage in hydroelectric power generation.

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1. Introduction

Surface water from fresh rivers and lakes represents an important source of water and a key pillar of any country's economy. This resource is subject to variation over time. It is, therefore, necessary to develop the management and operation facilities of water storage to maintain the sustainability of this resource. One of the main means of managing and controlling water resources is through the storage of surplus water, which is done by building dams to meet the water requirements for various purposes in the future [1].

In order to achieve good management of the reservoir, the researchers build simulation models to answer a large number of questions of (what if). Moreover, the simulation model needs to adopt a predefined operational policy to provide a comparative basis for model performance with the actual system performance, and this is common when it comes to water storage systems. The operation of a water storage system is a complex process. It involves many physical, operational, legal, environmental and other determinants imposed by the actual system. Therefore, this subject has attracted the interest of many researchers over the past decades, e.g., [2,3,4].

One of the objectives of water resources management is to ensure adequate water supply for different purposes, but it is not clear how to achieve this goal, especially in multi-purpose reservoirs because depletion of stored water or inflow shortage into the reservoir reduces the amount of generated hydropower. There is a clear contradiction between satisfying the needs of irrigation on the one hand and hydropower generation on the other. Several national and regional studies have been conducted to discuss the relationship between irrigation water supply and hydropower generation, e.g., [5] for the Aral Sea region, [6] for the Mekong River. Other studies were conducted in different countries such as [7] in Tanzania, [8] in Turkey, [9] in Pakistan, and [10] on a number of countries in the world, have shown different types of relations between the needs of irrigation and hydropower generation.

HEC-ResSim is a water resources simulation program designed by the US Army Corps of Engineers, an advanced version of the well-known HEC-5 program. This program offers a remarkable development in decision support tools for water management engineers [11]. The program has

great ability in simulating water storage systems, supporting practical decision-making to manage and operate them to meet different requirements such as flood control, hydropower generation, irrigation, water supply and environmental conservation with different operating policies [12]. This program is used in many countries in the world to simulate the operation of reservoirs and other objectives, e.g., [13] for the Tekeze reservoir in Ethiopia, [14] for the Tueurui reservoir in Brazil, [15] for the Mosul dam reservoir in northern Iraq. The researchers concluded that this program is a powerful tool that can support decision making for the administrators and operators of this reservoir. The literature includes a number of researches that used this program in modeling and simulating single or multi-reservoir systems to study future impacts such as climate change, increasing water requirements, water scarcity on reservoir operation and using different future scenarios [16,17].

The current research aims to improve the management and distribution of water for the Mosul dam reservoir between hydropower generation and meeting the water requirements of the Jazeera irrigation projects presently and in the future after completion of the proposed irrigation projects using the HEC-ResSim 3.0 program adopting a number of proposed scenarios for the operation of the reservoir.

2. Study Area Description

The study considered the Mosul dam reservoir as well as the Jazeera irrigation projects. Mosul dam is located on the Tigris River in the northern part of Iraq about 60 km north of Mosul city. It is an earth dam of 113 m height. It is a multi-purpose dam used to supply the Jazeera irrigation projects, flood mitigation, and to generate about 772 MW of hydroelectric power. The reservoir storage capacity is 11110 MCM including 8160 MCM of live storage.

The Jazeera irrigation projects include three projects, namely Northern, Eastern and Southern Jazeera projects. The Northern Jazeera Irrigation Project (NJIP) is about 100 km north-west the city of Mosul. The total area of the project is 60,000 hectares. The discharge of the main channel is 45 m^3/s. The Eastern Jazeera Irrigation Project (EJIP)

area starts 30 km north of the city of Mosul on the eastern bank of the Tigris River and extends parallel to the river. The project is under construction with a total area of 85,000 ha and the capacity of the main channel is 60 m^3/s. The South Jazeera Irrigation Project (SJIP) is about 40 km southwest of Mosul city. It is a planned but not constructed project. The total area is about 187,500 ha. Its main channel capacity is 125 m^3/s [18].

Figure 1 shows the location of Mosul Dam reservoir with the NJIP, EJIP and SJIP. It should also be noted here that the main channels of the three irrigation projects are supplied directly from the reservoir by means of pumping, therefore, the water outflows from the hydropower station could not be utilized for irrigation.

The HEC-ResSim 3.0 program was used to build the reservoir simulation model based on the monthly data observed for inflows into the reservoir, the rainfall and evaporation depths from the surface of the reservoir to meet the water requirements downstream the reservoir. The irrigation requirements within the system focused on the irrigation requirements of NJIP, EJIP and SJIP, which were determined considering the maximum capacity of the main channels (45, 60 and 125 m3/s, respectively)

Five different scenarios were proposed for the simulation model and two different prioritizations, the first to maximize hydropower generation and the second to reduce the deficit in fulfilling the water requirements of Jazeera irrigation projects. Below is a brief explanation of the proposed scenarios:

Scenario 1: To maximize generated hydropower ignoring the water requirements of irrigation projects.

Scenario 2: Giving priority for maximizing generated hydroelectric power and considering the water requirements of NJIP.

Scenario 3: Giving priority for maximizing generated hydroelectric power and considering the water requirements of NJIP, EJIP and SJIP.

Scenario 4: To generate hydropower with a priority of fulfilling the water requirements of the NJIP.

Scenario 5: To generate hydropower with a priority of fulfilling the water requirements of the NJIP, EJIP and SJIP.
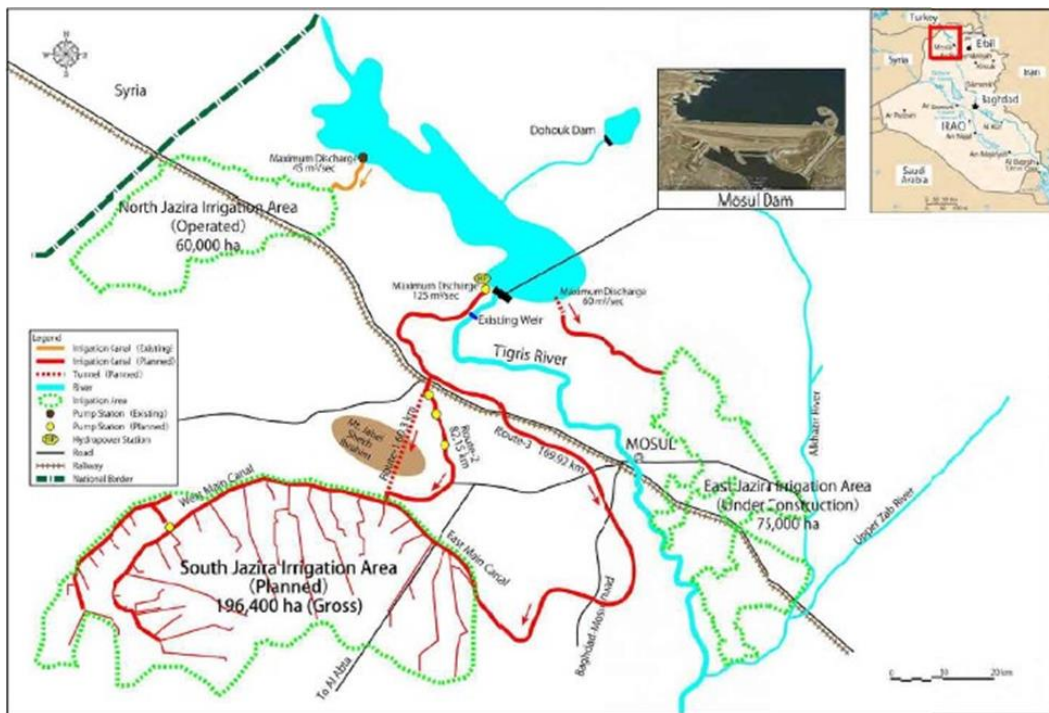
Figure 1: Mosul Dam and reservoir with the Al-Jazeera irrigation projects [23]

The simulation was carried out on a monthly basis for the period from January 1988 to December 2006, consisting of (228) months. Monthly data for the releases and generated hydropower for the entire simulation period were also provided. Monthly data for the period from December 1988 to June 1989 for the reservoir elevation were collected. The simulation model was operated and its performance was tested by comparing its outputs with the observed data. The model performance was tested using three statistical formulas as shown below:

a. The Index of Agreement (IA)
The index was proposed by [19] to compare the results obtained from the simulation model with the historical observed data. Its value ranges between 0 and 1 and can be expressed in the following form:

$$IA = 1 - \sum_{i=1}^{n}(o_i - e_i)^2 / \sum_{i=1}^{n}(|o_i - \bar{o}| + |e_i - \bar{e}|)^2 \quad (1)$$

b. Coefficient of Efficiency (NSEF)
This coefficient is used to describe the predictive accuracy of the model when there is recorded data, which can be expressed by the equation below [20]:

$$NSEF = 1 - \sum_{i=1}^{n}(o_i - e_i)^2 / \sum_{i=1}^{n}(o_i - \bar{o})^2 \quad (2)$$

c. Correlation Coefficient (r):
It is a measure of the degree of linear correlation between two independent variables. It ranges from -1 to 1, and can be determined by the following equation [21]:

$$r = \sum_{i=1}^{n}(o_i - \bar{o}).(e_i - \bar{e}) / \sqrt{\sum_{i=1}^{n}(o_i - \bar{o})^2 . \sum_{i=1}^{n}(e_i - \bar{e})^2} \quad (3)$$

Where o_i is the observed data in period time i, e_i is the calculated data in the time period i, $\bar{o}$ is the average of observed data, $\bar{e}$ is the average of calculated data and n represents the total number of data.

3. Results and Discussion

The results of the current model were verified with the observed data for the actual reservoir operation for both release from the reservoir and generated hydroelectric power as shown in Figures 2, 3 and 4. The results indicated that the model is highly efficient in representing the real system.
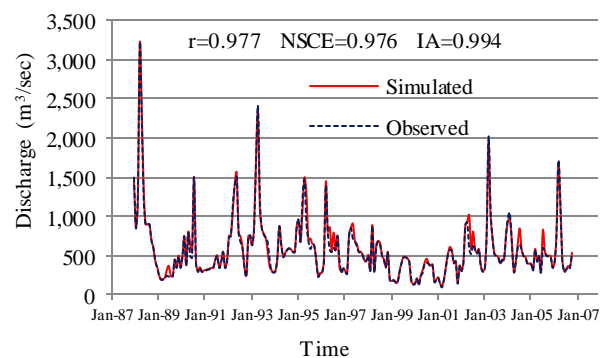

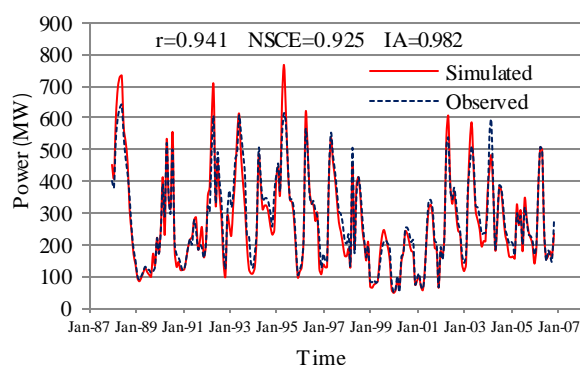**Figure 2: Simulation of the Mosul dam reservoir releases**

Figure 3: Simulation of the power generated by the Mosul dam Hydropower plant
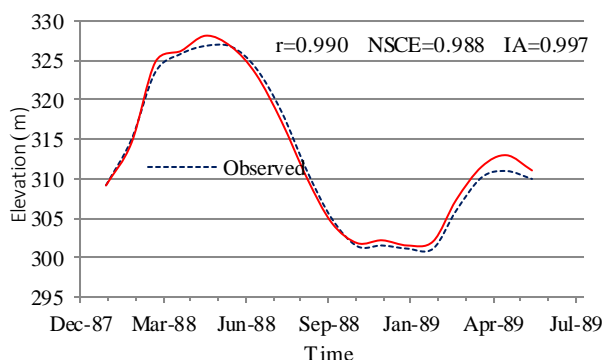

Figure 4: Simulation of Mosul dam reservoir elevation (ASL)

The simulation process included the estimation of storage size, surface area, and elevation as well as the water releases through the hydropower plant, bottom outlets and spillway. The characteristics of the generated hydroelectric power and the reservoir operation properties were also obtained during the simulation period for the proposed scenarios. Table 1 shows the average values of the operation characteristics of the reservoir and the generated hydroelectric power obtained from the model operation.

From Table 1, we note that the rate of hydroelectric power generated by the simulation model for scenario (1) is 272.6 MW. This is very close to the actual value of 270 MW, which confirms that the simulation model represents the real system effectively. When considering irrigation projects (Scenarios 2 and 3), we note a decrease for generated power, especially when priority is given to reduce the deficit in meeting the water needs of irrigation projects (Scenarios 4 and 5). This justified due to the fact that these projects take their water requirement directly from the reservoir which causes a drop in the water head and thus affects the amount of generated hydropower.

In terms of meeting the water requirements of the Jazeera irrigation projects, Table 2 shows the annual generated energy rate and the annual deficit rate for the irrigation project requirements. When the priority is given to hydropower generation and taking the water requirements of the irrigation projects in consideration, it is noted that there is a shortage in meeting these requirements like an annual average of (202.92 MCM) for Scenario 2 and (1681.90 MCM) for Scenario 3. On the other hand, the generated hydroelectric power is reduced by (8.2%) and (30%) for Scenario 2 and Scenario 3, respectively. When the priority is given to meet the requirements of NJIP only (Scenario 4), we note that there is no shortage in water requirements meeting due to the low amount of required discharge (45 m^3/sec). When the priority is given to meet the requirement of the total Jazeera projects (Scenario 5) there will be an annual average shortage of (165.36 MCM) due to a large amount of discharge needed (230 m^3/sec). Meanwhile, the generated hydroelectric power is reduced by (9.4%) and (40.35%) for scenarios 4 and 5, respectively, as shown in Figure 5.

Table 1: Properties of reservoir and hydropower plant operation during the simulation period

Properties	Variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Reservoir operation	Elevation A.S.L (m)	313.2	312.1	312.1	312.0	310.5
	Storage (MCM) x10^6	5.74	5.71	5.71	5.67	5.22
	Surface Area (m^2)	257.7	251.56	251.56	250.72	237.27
Hydropower plant operation	Generating Efficiency %	0.93	0.93	0.93	0.93	0.92
	Water Head (m)	59.0	58.0	58.5	58.0	57.2
	Hydraulic Loss (m)	1.2	1.1	0.6	1.0	0.3
	Generated Power (MW)	272.6	250.3	190.8	247.0	162.6
	Ave. Monthly Generated Energy (MW.h)	198998	182719	139284	180310	118698
	Plant Factor	0.353	0.324	0.247	0.320	0.210
	Turbine Discharge (m^3/s)	505.5	472.8	357.0	466.5	315.0

**Table 2: Average deficits of delivered irrigation water
And generated power during the simulation period**

	Generated Power (MW)	Power Deficit (MW)	Percent of Power Deficit %	Irrigation Water Delivered (MCM)	Irr. Wat. Deficit (MCM)	Percent of irr. Wat. Deficit %
Scenario 1	272.6	-	-	-	-	-
Scenario 2	250.3	22.3	8.2	1420	202.92	14.3
Scenario 3	190.8	81.8	30.0	7253	1681.90	23.2
Scenario 4	247.0	25.6	9.4	1420	0	0
Scenario 5	162.0	110	40.35	7253	165.36	2.3

In addition, the region was exposed to drought events during the period of simulations as indicated in the study of [22]. There were two main drought events, the first period, between January 1989 and January 1999, and the second period between December 1999 and January 2002. This led to an increase in the annual shortage to meet the water requirements of irrigation projects.
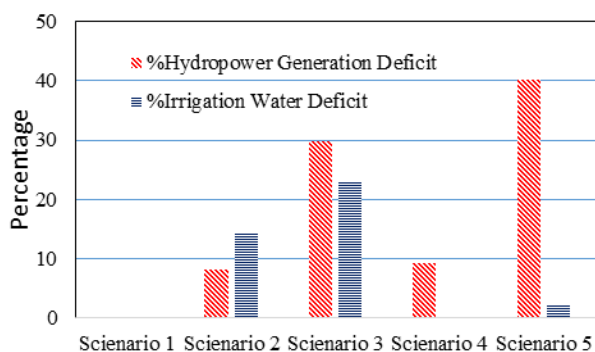

Figure 5: Percent of deficits in irrigation water and hydropower generation for the suggested scenarios

4. Conclusion

• The study showed that the HEC-ResSim 3.0 simulation model, which is one of the most recently used techniques in simulating storage systems, imitated the actual Mosul dam reservoir operation effectively.

• It was shown that when priority is given to reduce the deficit in meeting the Jazeera irrigation projects water requirements, the water deficit is reduced but at the expense of reducing the amount of generated hydroelectric power. While giving priority to maximizing hydroelectric power production, the generated hydroelectric power is increased but the deficit in meeting the irrigation requirements is increased. The study showed that when priority is given to hydroelectric power generation and ignoring the irrigation water requirements, the generated hydroelectric power from the operation of the reservoir is 272.6 MW. When the irrigation requirements of NJIP only is considered, the generated power decreases by (8.2%), and when taking the water requirements of the three irrigation projects into account the

generated power decreases (30%). When the priority is given to meet the requirements of the NJIP only, the generated power rate is decreased by 9.4% and there was no shortage in meeting the irrigation water requirements. When the priority is given to meet the requirements of NJIP, EJIP and SJIP, the rate of generated power is reduced by 40.35%, at the same time, the water requirements deficit decreases by 90.2%.

• We conclude from the current study that when the Jazeera irrigation projects are completed and the three irrigation projects are operated together, the Mosul dam reservoir will not be able to meet the water requirements of these projects fully at least during the maximum demand period, as well as there will be a deficit in the production of hydroelectric power. It is also worthy to note the impact of neighboring countries on the inflows of the Tigris river through the construction of dams, which negatively affects the amount of water stored in the Mosul Dam reservoir.

References

[1] H, Bouwer "Integrated Water Management for the 21st Century: Problems and Solutions," Journal of Irrigation and Drainage Engineering, Vol.128, No.4, 2002.

[2] D.P. Loucks, D.P. Stedinger and D.A. Haith "Water Resources Systems Planning and Analysis," Prentice-Hall, Englewood Cliffs, New Jersey, 1981.

[3] W. Yeh "Reservoir management and operations models: A state-of-the-art review" Water Resources Research, Vol. 20, No. 3, pp 1797-1813, 1985.

[4] R.A. Wurbs "Reservoir-System simulation and optimization models," ASCE, Journal of Water Resources Planning and Management, Vol. 119, No. 4, pp 455-472, 1993.

[5] X. Cai, D.C. McKinney and M.W. Rosegrant, "Sustainability analysis for irrigation water management in the Aral Sea region," Agricultural systems, Vol.76, No.3, pp.1043-1066, 2003.

[6] T. Räsänen, O. Joffre, P. Someth, C. Thanh, M. Keskinen and M. Kummu "Model-based assessment of water, food, and energy trade-offs in a cascade of multipurpose reservoirs: a case study of the Sesan Tributary of the Mekong River," J. Water Resour. Plann. Manage. Vol.141, No.1, 2015.

[7] R.M. Kadigi, N.S. Mdoe, G.C. Ashimogo and S. Morardet "Water for irrigation or hydropower generation? - Complex questions regarding water allocation in Tanzania," Agricultural water management, Vol.95, No.8, pp. 984-992, 2008.

[8] I. Yüksel "Hydropower for sustainable water and energy development," Renewable and Sustainable Energy Reviews, Vol.14, No.1, pp.462-469, 2010.

[9] Y.E. Yang, C. Ringler, C. Brown and M. A. H. Mondal "Modeling the Agricultural Water–Energy–Food Nexus in the Indus River Basin, Pakistan," Journal of Water Resources Planning and Management, Vol.142, No.12, 2016.

[10] R. Zeng, X. Cai, C. Ringler and T. Zhu "Hydropower versus irrigation—an analysis of global patterns," Environmental Research Letters, Vol.12, No.3, 2017.

[11] D.J. Klipsch and T. A. Evans "Reservoir operations modeling with HEC-ResSim, Hydrologic Engineering Center," US Army Corps of Engineers Davis, CA, pp.530-756, 2009.

[12] Hydrologic Engineering Center (HEC) "HEC-ResSim, Reservoir System Simulation, User's Manual Version 3.0," U.S. Army Corps of Engineers, Report CPD-82, Davis, Calif., 2007.

[13] G. Mebrahtom "Modeling of Tekeze Hydropower Reservoir Operation with HEC–ResSim," M.Sc. Thesis, Civil Engineering, Faculty of Technology, Addis Ababa University, Ethiopia, 2012.

[14] P.G. Lara, J.D. Lopes, G.M. Luz and N.B. Bonumá "Reservoir Operation Employing HEC-ResSim: Case Study of Tucurui Dam, Brazil," Presented in the 6th International Conference on Flood Management, Sao Paulo, Brazil, 2014.

[15] B.E. Jebbo and T.A. Awchi "Simulation Model for Mosul Dam Reservoir Using HEC-ResSim 3.0 Package." Zanco Journal of Pure and Applied Sciences, Vol.28, No.2, pp. 92-98, 2016.

[16] J. Reis, T.B. Culver, P.J. Block and M.P. McCartney "Evaluating the impact and uncertainty of reservoir operation for malaria control as the climate changes in Ethiopia," Climatic Change, Vol.136, No. (3-4), pp.601-614, 2016.

[17] J.M. Ahn and S. Lyu, "Assessing Future River Environments in the Seomjin River Basin due to Climate Change," Journal of Environmental Engineering, Vol.143, No.5, 2017.

[18] I.F. Al-Mustafa, "Future horizons for the optimal operation of Mosul dam reservoir," M.Sc. Thesis, Dams and Water Resources Engineering Department, College of Engineering, University of Mosul, Iraq, 2008.

[19] C.J. Willmott "On the validation of models," Physical Geography, Vol.2, pp.184–194, 1981.

[20] J.E. Nash and J.V. Sutcliffe "River flow forecasting through conceptual models, Part I, A discussion of principles," J. Hydrology, Vol.10, pp.282–290, 1970.

[21] R.A. Johnson and G.K. Bhattacharyya, "Statistics: Principles and Methods," 5th Edition. Wiley.

[22] T.A. Awchi and M.M. Kalyana "Meteorological drought analysis in northern Iraq using SPI and GIS," Sustainable Water Resources Management, 1-13, Springer,

[23] Japan International Cooperation Agency, JICA "The Preparatory Survey on South Jazira Irrigation Project in Republic of Iraq, Final Report," 2011.