

Scientific Review – Engineering and Environmental Sciences (2020), 29 (2), 145–154
Sci. Rev. Eng. Env. Sci. (2020), 29 (2)
Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska (2020), 29 (2), 145–154
Prz. Nauk. Inż. Kszt. Środ. (2020), 29 (2)
<http://iks.pn.sggw.pl>
DOI 10.22630/PNIKS.2020.29.2.13

**Nassrin Jassim Hussien Al-MANSORI, Thair Jabbar Mizhir Al-FATLAWI,
Nariman Yahya OTHMAN**

University of Babylon, Faculty of Engineering

Stochastic analysis for prediction of future performance of Mosul storage

Key words: reservoir system, simulation, hydropower generation, reliability

Introduction

Building a simulation model for a water storage system is vital to check the performance depending on the observed and received flows to the system. Modeling is also crucial in seeing the extent of dependence on the expected future performance of the system under average conditions. It is known that the observed and received flows that enter the units of a storage system represent only a limited part of the spectrum of data expected to occur in the future. A recent critical effort has created vigorous speculations and models for the portrayal of these flows over an assortment of execution stages. While these models are essential to empower repeatability, they do not use the captured data to its maximum capacity (Woodman, Hiden & Watson, 2017).

Accordingly, analysis requires the use of a particular type of exploratory model to prepare a hypothetical streaming flow line (stochastic models) to include the minimum of the spectrum of the fluctuating flow. The default outline will enable a system operator to study the reaction of the system in different scenarios for the expected inventory. It is necessary to consider that the hypothetical chains resulting from the developmental methods must maintain at least the statistical parameters of the first three heads of the desired stream, namely the rate, standard deviation and correlation coefficient between the two data parameters consecutively and vice versa. However, this type of stochastic model is hardly satisfactory and does not depend on the flowing energy produced (Abdel-Hameed, 2003).

Karapetyan and Mamikonyan (2005) expressed the strategy and consequences of dynamic parameter estimation for seismic soundness assurance in the working

Geghardalich water stockpiling dam in the Republic of Armenia. By trial hypothetical techniques, the epures of expected maximal horizontal accelerations (EMHA) were built on dam area height in its various profiles. The article's fundamental guidelines can be utilized in the observation of other hydropower developments and nuclear power plants.

A study by Heuts and Anderson (1976) discussed time series analysis in general and for overall forecasting, focussing on the Box–Jenkins method. The method features an autoregressive integrated moving average (ARIMA) and the rate autoregression (AR), which includes self-correlation and a moving average (MA). Anderson found that ARIMA can express well some hydrological activities, including the flow of water in a river, which is the subject of interest in the current research.

Howlett, Piantadosi and Pearce (2005) considered the administration of water stockpiling in two associated dams. The main dam is intended to catch storm water created by precipitation. Water is siphoned from the main dam to the subsequent dam and is in this manner provided to clients. There is no immediate admission of tempest water to the subsequent dam. We accept the irregular timings of precipitation as a known probability distribution and wish to discover functional siphoning arrangements from the catch dam to the inventory dam to limit flooding.

Pereira, Oliveira, Costa and Kelman (1984) developed a model for generating monthly flows for a hydroelectric generation system in Brazil, which is produced from a group of large reservoirs that have a high storage capacity. Kim and Heo

(1997) studied the monthly operating rules for a water storage system located on the Han river in South Korea, which includes three main reservoirs that play an important role in preventing floods. The authors' research was referenced for this work to study the autoregressive moving average model – ARMA (1,1), data to generate monthly flow. Naggar (1999) used the Thomas–Fiering and ARMA (1,1) models to generate monthly flows for a time series covering about 700 years for five rivers in Iraq (Dajla, Al-Azb Al-Kabeer, Al-Azib Al-Sagheer, Al-Azim and Diyala). Naggar (1999) then used these data to simulate growth for the operating systems of the Euphrates and Tigris rivers.

Al-Mamosi (2007) used the Thomas–Fiering and ARIMA models to generate the flow for the two stations of Asakkalak and Mankoba on the Al-Azb, Al-Aalaa and the Khazir rivers, respectively, as examples of permanent flowing rivers. The author examined the al-Mathee'q station on the Al-Azim river as an example of a seasonal river. There are many attempts that have been done for generating discharge data. These works, however, have not focussed on details indicating that the generating chains are descended from the statistical community itself as a product of the system. That is, the data for the observed chains was used in the generation of the data, which is why these generations do not refer to these parameters. The model must conform to the observed parameters of the chains if researchers want to rely on the outputs of these generation models.

In addition, this study confirms the relative conformity of the statistical features that have been calculated with the

generated flow data. The results conform with their counterparts returning to the observed flow data, ensuring the model is appropriate and reliable in generating new flow data.

Bormann and Martinez (2014) investigated important attributes and distinguished appropriate markers to be used to appraise the appropriateness of existing dams and supplies for introducing an extra siphoned vitality stockpiling framework. The indicators incorporate physical and natural attributes. An impact investigation and a conflict examination for previously existing water employments for single or multipurpose dams altered the analysis. In light of the markers discovered as well as possible conflicts, an indicator-based system was created. The framework described a procedure to examine the appropriateness of existing dams for vitality stockpiling, measuring the physical possibilities of a site, considering the ecological limitations and establishing requirements regarding compromises among competing water employments.

Bormann, Ahlhorn and Klenke (2012) conducted a participatory investigation of network methods to handle provincial adjustments to environmental changes. Options for adapting water management in response to regional changes of climate were developed. Partners representing the Wesermarsch County in northern Germany participated in the study, which developed plans looking to 2050. Data on expected local environmental changes and a study modelling hydrological changes indicated that the adjustment of water management would be necessary until 2050. A provincial stakeholder discussion defined a vision

of how the Wesermarsch should appear in 2050. Both regional partners and researchers took a dynamic part in the participatory learning process as required by European Union (EU) mandates.

Buena and Carta (2006) proposed the establishment on Gran Canaria island (Canarian Archipelago) of a suitably managed, wind-powered, siphoned hydro capacity framework. The findings from the use of an optimal financial model for such a framework demonstrated that influx of renewable energy could be expanded by 1.93% (52.55 GWh·year⁻¹) at a reasonable expense for the unit vitality provided. These outcomes assumed the use of the two most expansive reservoirs on the island (with a height difference of 281 m and a limit of around 5 million m³ each) as capacity stores.

Anagnostopoulos and Papantonis (2008) presented a quantitative methodology for the ideal sizing of different segments of a reversible hydraulic system intended to recoup electric power from wind farms that have been dismissed because of limits to the power grid. The method was applied to formulate a functional case utilizing time-variance information of the dismissed force from various wind farms on the island of Crete, Greece. The outcomes indicated that an all-around upgraded configuration might be essential for the technical and financial suitability of the inspected framework.

Ding, Hu and Song (2012) proposed another coordination activity method for a wind farm (WF) and pumped-hydro storage plant (PHSP) in view of day-ahead wind power yield estimates. A deterministic, mixed-integer programming (MIP) definition was fabricated considering the

imperatives of unit absolute start-up and shutdown frequencies, and also unit state rejection among generating and pumping. Moreover, the paper describes the chance-limited and situation-based streamlining formulations to manage errors in projected wind power. Sensitivity analyses and case studies showed that the coordination of WF and PHSP could ease the negative impact of wind power changes on the power network while raising profits.

This study was carried out on the Mosul reservoir to exploring the capability of the future system to generate hydroelectric power using a simulation by Simulink technique on the MATLAB platform.

Material and methods

Study area

The Mosul dam reservoir is located on the northern Tigris river, about 50 km from Mosul city. The area of the feeding basin in the upstream of the reservoir is 50,200 km², and the design of the dam is six units for generating hydroelectric power with a maximum capacity of 1,536 MW (Al-Gazzal, 2002). The reservoir can be considered as multipurpose, including developing the tourism sector in Iraq, generating hydropower, controlling floods, and feeding an irrigation area of about 2.26 million acres.

Model simulation

A model was built to simulate the northern storage system (Fig. 1), provided by Simulink software and using various simulation techniques on MATLAB systems. The technology is represented by a

set of ready-made templates (icons). These templates are logically linked so that the model represents the system to be studied realistically. Note this technology is new in the application of water resources in general and the operation of storage systems in particular (Al-Mohsen, 2008). The model can take advantage of the capabilities of Simulink, which are mainly based on high-quality MATLAB software that focuses on processing mathematical vectors and matrices in a highly efficient manner.

To know more about the operation of this technology, one can refer to an attached Simulink library (MATLAB, 2004). The current research focuses on the topic of future performance of the system for hydroelectric generation, and not on the simulation model used to evaluate this performance for the purpose of identifying the details of a problem (Al-Ageli, 2009).

The simulation model has been in operation for a period of 30 months, from June 2015 to July 2018, representing the period for the actual operation of the Mosul reservoir (depending on operational data). To verify its results with the observed data, the simulation process was done as follows: operating the Mosul reservoir, depending on the observed data (incoming flow and the volume of releases from the reservoir), adding the water produced from the runoff surface from the bottom of the reservoir to the Al-Fattah region by adopting the one-way method that depends on unit runoff output (Kottagoda, 1980).

After the above operation and calibration process, the generation of monthly flow chains to the unit of the system was performed.

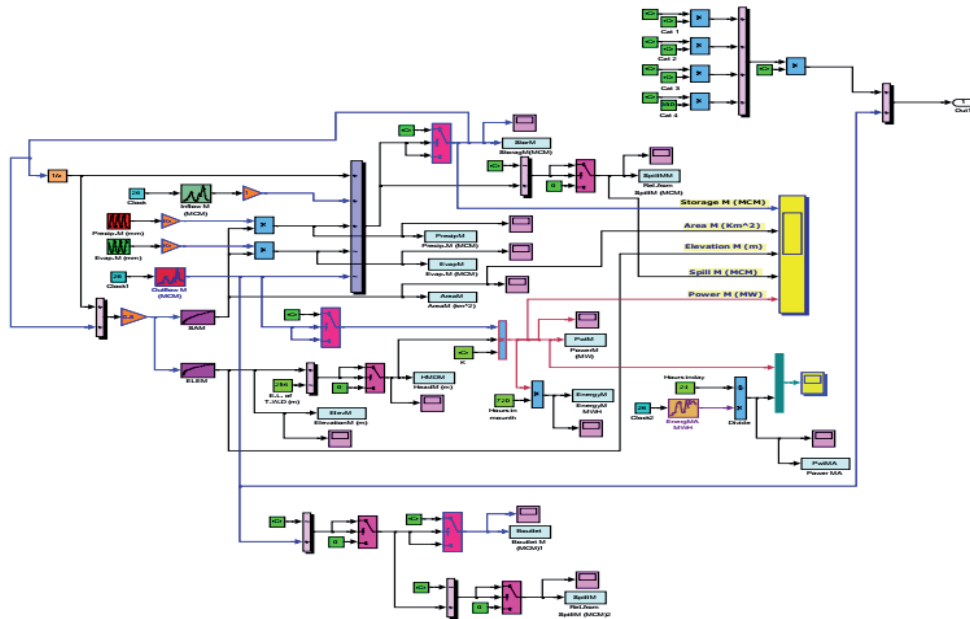


FIGURE 1. The storage system units using the technology (Simulink)

Stochastic model

Kottagoda (1980) declared many stochastic models, such as Markov, ARMA and ARIMA of different ranks. However, the difficulty in adopting and selecting any of these models lies in understanding the effectiveness of the product, that is, the time series to be modelled. The ARMA model is valid for a stationary time series model (non-change of the statistical parameters of effectiveness with time), whereas ARIMA models are successful in the non-stationary time series (changing the statistical parameters of effectiveness with time).

The Thomas–Fiering model has proven its high potential as a model for the monthly time flows for many rivers (Thomas & Fiering, 1962). The Thomas–Fiering model is considered one of the images of the Markov model from the first rank. Clarke (1984) has recom-

mended using this method when modelling the time series in river flow and generating it when the model is in the middle of the month. Accordingly, the Thomas–Fiering model was chosen in this research to generate time series for the monthly flow coming into the units of the Mosul storage system, where Equation (1) shows the mathematical formula for this model.

$$Q_{i+1} = \bar{Q}_{j+1} + b_j(Q_i - \bar{Q}_j) + t_i\sigma_{j+1}(1-r_j^2)^{0.5} \quad (1)$$

where:

- Q_{i+1} – flow in month $i + 1$,
- \bar{Q}_{j+1} – average of flow in month $j + 1$,
- b_j – gradient of line between the flow in month $j + 1$ and the flow in month j ,
- Q_i – flow in month i ,
- \bar{Q}_j – average of flows in month j ,
- t_i – normal random function,

σ_{j+1} – standard deviation for flows in month $j + 1$,
 r_j^2 – correlation coefficient between flows of months j and $j + 1$.

Also, note that most (if not all) stochastic models used to generate flows are based on the hypothesis that observed flows used to build the model are subject to a normal distribution. Thus, this condition must be verified and guaranteed before initiating steps to build a reproductive model. If a normal distribution is not the case, resorting to the method of transformation as prepared by Box–Cox (see Eq. 2) is considered an approved method for converting the monitored flows into a distribution (Clarke, 1984). This transformation is used here and given by the following equation:

$$Y_t = \frac{(X_t^\lambda - 1)}{\lambda} \quad (2)$$

where:

Y_t – monthly flow after transforming to a normal distribution,
 X_t^2 – observed monthly flow,
 $\lambda - 1 \leq \lambda \leq 1$.

Observed and registered flows are available for each of the Tigris river at the Mosul station and the metering station in Askye-Klak on the top Al-Zab and the Mankoba station on the lower Zab for a period of 816 months from June 1931 to September 1999. A set of flow chains has been generated and is statistically compared with the chains monitored for the extent of knowledge of the validity of the approved model in generating monthly flow expenses.

Application of the Thomas–Fiering model

Depending on the values resulting from the transformation process and subject to the normal distribution, the SPSS program was used to calculate the statistical parameters used in the Thomas–Fiering model, which was formulated in Equation (1). This model includes both the mean and standard deviation for each month separately, and the correlation coefficient and regression coefficient between every two consecutive months. Simulink techniques were used for representing the Thomas–Fiering model de-

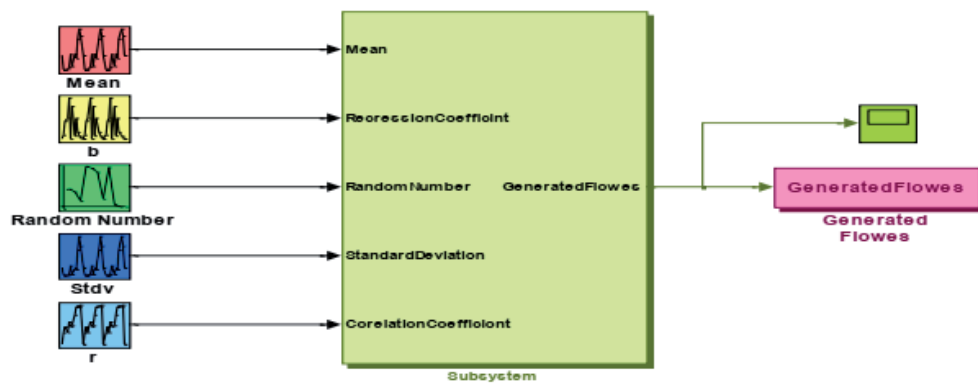


FIGURE 2. The general plan for the Thomas–Fiering model using Simulink

pending on the statistical data calculated to generate ten strings along the same observed string, which is 816 months. Figure 2 shows the general plan for the Thomas–Fiering model using Simulink.

Results and discussion

Testing the suitability of the proposed model

For testing the suitability of the proposed model and its fit in the generation of monthly flow strings, the SPSS.10 program was used to calculate the four main statistical parameters. The first was for the observed flow (average, standard deviation, the correlation coefficient between two consecutive months and the skewness coefficient). The same statis-

tical parameters were then used for the ten generating chains. Table 1 lists the results obtained and compares the statistical parameters of the observatory and generator stream and the measuring station of the conductor discharge for clarification.

Based on these results, the model was deemed appropriate and could be to be reliable in generating monthly expenses for the flow.

Evaluating the performance of the system using the observed flows and generated chains

A simulation model of the storage system was used. At this stage, the reservoirs were operated virtually during a period of 84 years from October 1931 to September 2015. The simulation goal

TABLE 1. Statistical parameters of the observatory from 1931–2015 and the generator stream and Mosul measuring station

Month	R_1^2	R_2^2	SC_1	SC_2	ST_1	ST_2	AV_1	AV_2
Oct.	0.363	0.344	2.3379	1.3545	226.22	983.38	481.84	493 380
Nov	0.432	0.592	2.8357	2.6121	411.03	455.33	727.13	770 379
Dec.	0.412	0.636	2.7638	2.3848	794.95	803.37	1 152.59	933 68
June	0.677	0.585	1.7181	1.5779	875.96	887.37	1 464.26	1 440.34
Feb.	0.556	0.5	1.0486	0.8939	848.67	843.33	1 873.19	1 851.33
March	0.586	0.595	1.6432	1.6001	1489.44	3 793.86	3 146.29	3 159.31
April	0.808	0.771	0.8721	0.9183	1738.72	7 883.13	4 507.54	4 499.38
May	0.910	0.909	1.0220	1.0145	1834.65	8 533.71	4 072.24	4 173.38
June	0.951	0.951	0.7860	0.9374	721.77	734.31	1 754.59	1 756.39
July	0.926	0.926	0.6121	0.7296	278.26	886.30	772.47	770.31
Aug.	0.960	0.957	0.6792	0.5279	141.78	403.41	447.25	445.30
Sep.	0.081	0.173	0.8131	0.5418	104.34	103.51	362.66	361.39

R_1^2 – correlation coefficient between generated flow and the flow of next month; R_2^2 – correlation coefficient between observed flow and the flow of next month; SC_1 – skewness coefficient for generated flows; SC_2 – skewness coefficient for observed flows; ST_1 – standard deviation for generated flows; ST_2 – standard deviation for observed flows; AV_1 – average for generated flows; AV_2 – average for observed flows.

was to identify the capacity generated from the reservoir using the observed flow and the generated flow chains. The simulation model was run eleven times. In the first stage, the model was run using the observed incoming and outgoing flows to the Mosul reservoir. In the second phase, the form was run ten times using chains that were generated consecutively. Since the reservoir operates by default during this period, a volume has been determined that releases from the reservoir dependent on regularly providing the volume of monthly water requirements and ensuring the production of the highest possible hydropower.

By operating the simulation model in the manner described above, the average capacity generated per month for the observed flow was calculated. The chains as well as the average annual energy generated from the reservoir are shown in Table 2.

Depending on the results obtained, the generated chains have succeeded

in efficiently generating the expected hydroelectric power from the system. The theoretical potential for generating hydroelectric power of the conductor reservoir is $2.4 \times 10^6 \text{ MW}\cdot\text{h}^{-1}$ for one year. This figure was derived by observing the generation quantities calculated, either from the observed expenditures or the generated chains. Therefore, half of the capacity of the basin in hydroelectric generation can be obtained. It is well known that Iraq's need for electrical capacity as a whole is within the limits of (12,000 MW). This system can cover 1,500 MW, meaning it can meet about 12% of the country's electricity needs.

Conclusions

1. Simulink technologies provided by MATLAB software are considered modern technologies, successfully used in many different engineering fields. The model performed well in simulating the water storage system as well as in building the Thomas–Fiering Model for generating expected flow data.
2. Findings revealed that the flow lines generated using the Thomas–Fiering model maintained major statistical parameters of the observed data used in the generation, and thus can be relied upon in extrapolating future performance of the storage system for generating hydroelectric power.
3. At 1.5 GW, the storage system of the Mosul reservoir covers a significant percentage of the overall electricity supply in Iraq, particularly at the present time.

TABLE 2. Average annual energy from Mosul reservoir using observed flows from 1931–2015

Specification	Flow [$\text{MW}\cdot\text{h}^{-1}$]
Observed	2 370 588
1 st generation chain	2 308 676
2 nd generation chain	2 312 353
3 rd generation chain	2 280 735
4 th generation chain	2 501 470
5 th generation chain	2 388 529
6 th generation chain	2 375 147
7 th generation chain	2 386 323
8 th generation chain	2 328 970
9 th generation chain	2 363 382
10 th generation chain	2 330 147
Average of all	2 357 573

References

- Abdel-Hameed, M. (2003). Optimal control of dams using $P\lambda, \tau M$ policies and penalty cost. *Mathematical and Computer Modeling*, 38(11-13), 1119-1123. [https://doi.org/10.1016/s0895-7177\(03\)90112-9](https://doi.org/10.1016/s0895-7177(03)90112-9)
- Al-Ageli, Y.H. (2009). *A simulation model for a storage system on the river Dijma* (master's degree, Water Resources Division, Quantity of Engineering, University of Mosul, Mosul, Iraq).
- Al-Gazzal, A.M.Y. (2002). *Optimal water utilization from Tigris basin reservoirs north of Fatha for hydroelectric power generation* (PhD thesis, University of Mosul, Mosul, Iraq).
- Al-Mamoussi, F. (2007). *Evaluation of some disease developmental outcomes in generating expenses for seasonal and permanent rivers* (master's thesis, University of Mosul, Mosul, Iraq).
- Al-Mohseen, K.A. (2008). A Mathematical Model for Azizya Evaporating Pond Operation Using SIMULINK Techniques. *Al-Rafidain Engineering Journal*, 16(3) 14-24. <https://doi.org/10.33899/rengj.2008.44692>
- Anagnostopoulos, J.S. & Papantonis, D.E. (2008). Simulation and size optimization of a pumped-storage power plant for the recovery of wind-farms rejected energy. *Renewable Energy*, 33(7), 1685-1694. <https://doi.org/10.1016/j.renene.2007.08.001>
- Bormann, H., Ahlhorn, F. & Klenke, T. (2012). Adaptation of water management to regional climate change in a coastal region – hydrological change vs. community perception and strategies. *Journal of Hydrology*, 454-455, 64-75. <https://doi.org/10.1016/j.jhydrol.2012.05.063>
- Bormann, H. & Martinez, I.M.A. (2014). Towards an indicator based framework analyzing the suitability of existing dams for energy storage. *Water Resource Management*, 28(6), 1613-1630. <https://doi.org/10.1007/s11269-014-0569-3>
- Buenoa, C. & Carta, J.A. (2006). Wind powered pumped hydro storage systems, a means of increasing the penetration of renewable energy in the Canary Islands. *Renewable and Sustainable Energy Reviews*, 10(4), 312-340. <https://doi.org/10.1016/j.rser.2004.09.005>
- Clarke, R.T. (1984). Mathematical models in hydrology. *FAO Irrigation and Drainage Paper*, 19, 54-59.
- Ding, H., Hu Z. & Song, H. (2012). Stochastic optimization of the daily operation of wind farm and pumped-hydro-storage plant. *Renewable Energy*, 48, 571-578. <https://doi.org/10.1016/j.renene.2012.06.008>
- Heuts, R.M.J. & Anderson, O.D. (1976). Time series analysis and forecasting: the Box-Jenkins approach. *Journal of the Royal Statistical Society. Series D (The Statistician)*, 25(4), 310-314. <https://doi.org/10.2307/2988092>
- Howlett, P., Piantadosi J. & Pearce, C. (2005). Analysis of a practical control policy for water storage in two connected dams. In V. Jeyakumar, A. Rubinov (ed.), *Continuous optimization. Applied optimization*. Vol. 99 (pp. 435-450). Boston, MA: Springer. https://doi.org/10.1007/0-387-26771-9_16
- Karapetyan, S.S. & Mamikonyan, B.M. (2005). The measuring of dynamic parameters of functioning water storage dams. In *Proceedings of 2005 International Conference Physics and Control*. Saint Petersburg, Russia, 24-26.08.2005 (pp. 853-858). IEEE. <https://doi.org/10.1109/phycon.2005.1514108>
- Kim, T. & Heo, J.H. Application of implicit stochastic optimization in the Han river basin. In *Proceedings of the 4th International Conference on Hydro-Science & Engineering*, Seoul, South Korea, 26-29.09.2000. Seoul: Korea Water Resources Associates.
- Kottagoda, N.T. (1980). Linear stochastic models. In *Stochastic water resources technology* (pp. 111-127). New York: John Wiley and Sons. https://doi.org/10.1007/978-1-349-03467-3_4
- MATLAB (2004). *MATLAB manual*. Natick, MA: MathWorks.
- Naggar, O.M. (1999). *Development of decision support systems in water resources* (PhD thesis, University of Baghdad, Baghdad, Iraq).
- Pereira, M.V.F., Oliveira, G.C., Costa, C.C.G. & Kelman, J. (1984). Stochastic streamflow models for hydroelectric systems. *Water Resources Research*, 20(3), 379-390. <https://doi.org/10.1029/wr020i003p00379>
- Thomas, H.A. & Feiring, M.B. (1962). Mathematical synthesis of streamflow sequences for the analysis of river basins by simulation

In A. Mass (ed.), *Design of water resources systems* (pp. 459-493). Cambridge: Harvard University Press. <https://doi.org/10.4159/harvard.9780674421042.c15>

Woodman, S., Hiden, H. & Watson, P. (2017). Applications of provenance in performance prediction and data storage optimization. *Future Generation Computer Systems*, 75, 299-309. <https://doi.org/10.1016/j.future.2017.01.003>

flows) to generate hydropower from the reservoir system under examination. Generally, the annual potential capacity of the Mosul basin for energy generation reaches 20,000 GW·h⁻¹. Realizing that Iraq's energy requirements are approximately 12 GW of power, and the integrating power production of the basin under examination is about 1.5 GW, this would cover around 12% of the total demand, which is significant.

Summary

Stochastic analysis for prediction of future performance of Mosul storage. An investigation of the Mosul reservoir system within the Tigris river basin in Iraq was conducted to determine the ability of the system to generate hydroelectric power. A reproduction model utilizing the Simulink environment on the MATLAB platform was used to imitate the Mosul reservoir system. The reliability of the system under various future scenarios of data sources was also examined by employing a stochastic model used to create an inflow time series. The Thomas–Fiering model was chosen for this reason, which provided a wide range of data sources (in-

Authors' address:

Nassrin J.H. Al-Mansori – corresponding author
(<https://orcid.org/0000-0002-8921-7868>)

Nariman Yahya Othman

(<https://orcid.org/0000-0002-1908-2080>)

University of Babylon

Faculty of Engineering

Department of Environmental Engineering

00964, 80 Street, Babylon, Iraq

e-mail: Eng.nassrin.jassim@uobabylon.edu.iq

Thair Jabbar Mizhir Al-Fatlawi

(<https://orcid.org/0000-0001-8427-0400>)

University of Babylon

Faculty of Engineering

Department of Civil Engineering

00964, 80 Street, Babylon, Iraq