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Evaluation of Tigris River discharges at Baiji station comparison with discharges of the upstream and downstream stations / Iraq

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ABSTRACT

Measuring the discharges of Tigris River in Baiji is very important because it gives the final result of the flows coming from the Mosul Dam and the upper and lower Zab River, which are sent downstream towards the control system in Samarra.

In this paper, the records of levels measured manually using the scale inserted in the station were reviewed, which are translated into discharges according to the discharge-level equation deduced from the traditional measurement data, or the measured discharges using the Acoustic Doppler Current Profiler (ADCP), and a significant discrepancy was found between the measured discharges by the two methods, There is a great exaggeration in the discharges measured in the first method, compared to those measured in the second method, or in comparison with the total discharges coming from Al-Shirqat stations on Tigris and Al-Debs on the Lower Zab River, above the Baiji station, or those discharges sent to Al-Alam and Tikrit stations below the Baiji station.

The hydrographs of the flood waves observed in the station under study and other related stations on Tigris River before and after the concerned station, were analyzed in order to monitor the disagreement in the recorded discharges between one station and another to evaluate the station's performance in terms of the other stations, as there is no justification for the disparity of discharges between Baiji station under study and Al-Shirqat station (In addition to the discharges sent from Al-Debs Dam on the Lower Zab River) on the one hand, and between Baiji, Tikrit and Al-Alam stations on the other, in this study the flood wave for the year (2013) and the flood wave for the year (2019) were dealt with.

This discrepancy indicates the inaccuracy of the measurement in the traditional staff gauge, especially at high levels, and no justification found for increasing the discharges in Baiji over the discharges received from Al-Shirqat and Al-Debs stations together, as there are no tributaries or additives to the discharges, and also that the measurements by ADCP were more in agreement with those from Al-Shirqat and Al-Debs, at the Baiji and Al-Alam stations than it is for traditional measurements.

1. Introduction

Reviewing and analyzing the discharge records is very important in hydrological studies, especially in the current study that is concerned with evaluating the stations, as through these records, it is possible to detect the maximum and minimum levels and discharge that were recorded in the station, and what the records were affected and what are the effects on the river course during the recording of these discharges, and based on these records and comparing the stations with each other, or the recordings of the same station in other equipment, the efficiency of the measurement stations is evaluated, their eligibility is determined, and the suitable sites are selected away from geomorphological, geometric and hydrological influences, and other effects such as erosion and sedimentation.

Discharges values are recorded and organized by the competent authorities represented by the Ministry of Water Resources and its directorates in the governorates, where the employees working in these departments record daily readings, or automatic recording of data, in order to form an integrated database for each station, according to analyze of these records is done designing dams, protective seals, bridges, culverts, riverside facilities, domestic water projects and all other hydraulic establishments, according to the criteria determined by the previous records of discharges and levels.

The data used in this research was obtained after obtaining official approvals of the Directorate of Water Resources in Salah al-Din Governorate, a new equation was devised to find the discharge in terms of the level of the stations under study, where the

stations were compared among themselves through the discharges data obtained by traditional methods, through the cross-sectional area and the average velocities, with the discharges data that were found using Acoustic Doppler Current Profiler (ADCP), and the stations were compared among themselves using hydrographs, which represent (time - discharge) for two flood waves, the first for 2013 and the second for 2019.

There are many previous studies, including: (Hamada, 2008) mentioned that the water discharge measuring station in Baiji is of great importance because it reflects the combined effects of the upper Zab, which is known as its random flow system, and the Lower Zab, which is known as the operational flow system, and the outputs of Mosul gauging station affected by the operational flow system of the Mosul Dam since 1986, according this study the maximum daily discharge in Tigris River during the previous years was (16360 m³/sec), and the minimum daily discharge was about (200 m³/sec).

(Hamza, 1987) established the relationship between the hydraulic and morphological characteristics of five discharge measuring stations on Tigris River (Tusman, Hammam Al-Alil, Al-Fatha, Baghdad, Al-Kut) and found empirical relationships between the variables of surface width, average depths, velocities, cross-sectional area of flow with discharge at every point.

(Al-Anbari, 2006) studied the geometry and hydraulics in the reach of 202 km on Tigris River, from Mosul in the north and downstream to near Baiji at Al-Fatah bridge, using the Leopold method at the maximum and minimum discharges, and concluded that there are differences in the geometric characteristics of the sections along the course of the river in terms of length, width and average depth.

(Rojas M. et al., 2020) studied the stability analysis of the level-discharge relationship based on historical evaluations of the stability of the discharge curves at six stations for discharge measuring in the state of Iowa, USA, to examine the temporal variation of their relations between the level-discharge, the studied sites have a discharges records for 10 years, the shifts of the discharge curve reflect a change in the geometry of the sections caused by sediment deposition, the correlation of shifts in the discharge curve after floods and droughts over time has been studied, the study found that most of the changes of the level-discharge curve occur during Spring and Summer which are the seasons with the most rainfall in Iowa.

2. The equation for calculating the discharge in terms of the level

An equation was deduced for the station under study and the other stations located upstream, represented by Al-Shirqat and Al-Debs stations, and downstream, represented by the Al-Alam and Tikrit stations, to find the discharge at each level, and these equations were found by referring to the levels – discharges

records in the Ministry of Water Resources. The equations were derived and the discharges represented graphically using Grapher and Excl program.

2.1 Level measuring in Al-Sharqat station

The level-discharge curve of Figure (1) was derived from the data measured by traditional methods, and then the following equation was found:

$$Y = -118510041.1 + 2425055.568 * X - 16543.55976 * X^2 + 37.62507031 * X^3$$

Coefficient of determination, R²= 0.99

Correlation coefficient, R = 0.99

Y= Discharge

X= Level

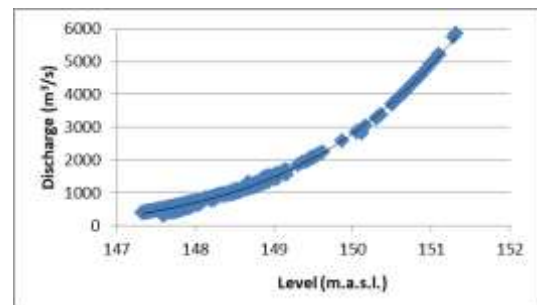


Fig. 1: Level – discharge curve measured by the traditional methods of Al-Shirqat station.

Where the recorded minimum discharge is approximately (350 m³/sec) at the level (147.32 m.a.s.l.), while the discharge approaches (6000 m³/sec) at the level (151.31 m.a.s.l.).

The level-discharge curve was also derived in Figure (2), which was deduced from the data measured by ADCP device, and the following level-discharge equation was found:

$$Y = -6218058.684 + 134595.4847 * X - 971.828652 * X^2 + 2.339928665 * X^3$$

R²= 0.99, R = 0.99

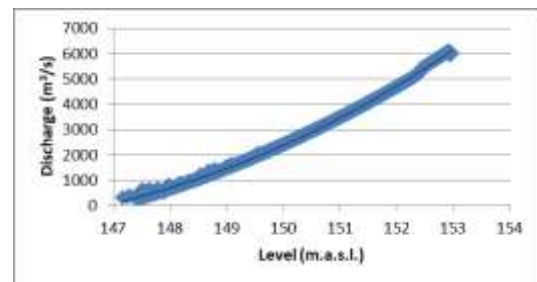


Fig. 2: Level-Discharge curve measured by ADCP device for Al-Shirqat station.

it is found that the recorded minimum discharge is approximately (317 m³/sec) at the level (147.17 m), while the discharge approaches (3600 m³/sec) at the level (151.31 m).

2.2 Level measuring in Baiji station

The level-discharge curve was derived in Figure (3), through the data recorded by traditional methods, and the equation for calculating the discharge in terms of the level was found:

$$Y = -41879886.64 + 1239614.948 * X - 12232.74229 * X^2 + 40.24545058 * X^3$$

$R^2 = 0.99$, $R = 0.99$

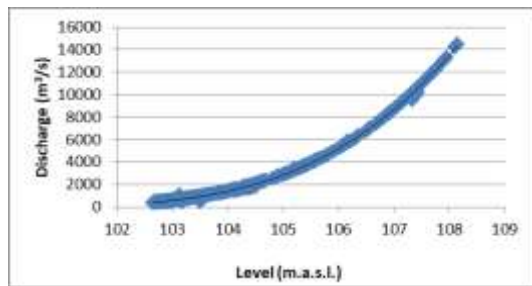


Fig. 3: level- Discharge curve according to the data of conventional methods for Baiji station.

The minimum discharge recorded in this method was about (310 m³/sec) at the level (102.65 m), while the maximum recorded discharge was about (15000 m³/sec) at the level (108.15 m).

The level-discharge curve was derived in Figure (4), through the data measured by the ADCP device, and the following equation was found to calculate the discharge in terms of the level:

$$Y = -8939118.321 + 261292.5275 * X - 2553.108227 * X^2 + 8.33925489 * X^3$$

$R^2 = 0.99$, $R = 0.99$

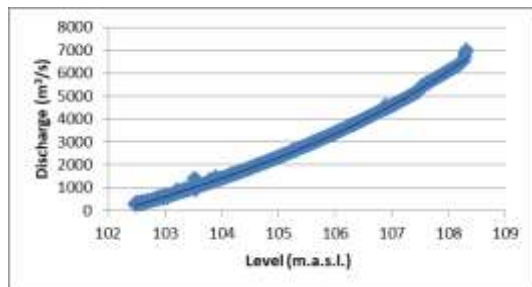


Fig. 4: Discharge-level curve measured by ADCP device for Baiji station.

The minimum discharge recorded in this way, approximately (290 m³/sec) at the level (102.65 m), while the highest discharge was about (6500 m³/sec) at the level (108.15 m).

2.3 Level measuring in Al-Alam station

The recorded data using ADCP device, the level-discharge curve was derived in Figure (5), and the equation for calculating the discharge in terms of the level was derived:

$$Y = -2073481.003 + 75024.03884 * X - 911.6082202 * X^2 + 3.716394325 * X^3$$

$R^2 = 0.99$, $R = 0.99$

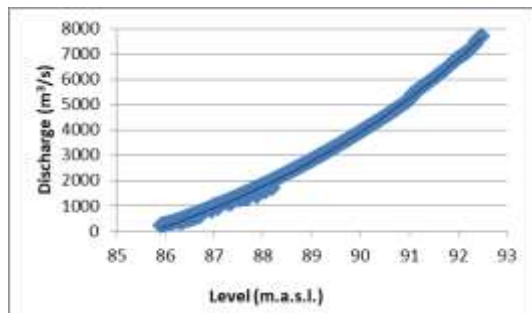


Fig. 5: level-discharge curve of the data recorded by ADCP device for Al-Alam station.

Whereas, the minimum discharge that was recorded in this station was (210 m³/sec) at the level (85.9 m), while the maximum discharge was (7700 m³/sec) at the level (92.5 m).

2.4 Level measuring in Tikrit station

Through the data measured by the traditional method, the level-discharge curve was derived in Figure (6), through which the equation for calculating the discharge in terms of the level was found:

$$Y = -30812924.28 + 1125537.449 * X - 13710.61926 * X^2 + 55.69707008 * X^3$$

$R^2 = 0.99$, $R = 0.99$

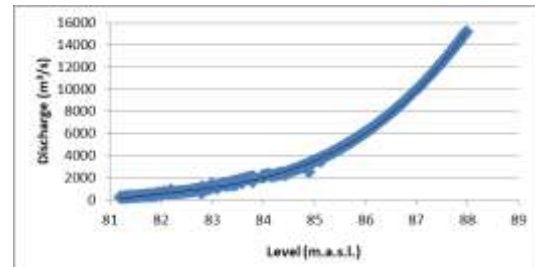


Fig. 6: level-discharge curve recorded by the traditional method of Tikrit station.

The minimum discharge recorded in this station was about (190 m³/sec) at the level (81.2 m), while the largest discharge was at the level of (15,200 m³/sec) at the level (87.99 m).

3. Selected Hydrographs from stations records

The objective of this paragraph is to analyze the hydrographs of flood waves observed at the station under study and other stations on the reach of Tigris River upstream and downstream the concerned station, in order to monitor the discrepancy in the observed discharges between one station and another to evaluate the performance of the station in terms of other stations, as there is no equipment for disparity of discharges between Baiji station Under study and Al-Shirqat station (in addition to the discharges sent from Al-Debs Dam on the Zab River) on the one hand, and between the Baiji, Tikrit and Al-Alam station on the other hand. In this study, the flood wave for the year (2013) and the flood wave for the year (2019) were taken.

3.1 Flood Hydrograph (2013)

Tigris River levels data were obtained after the official approvals from the stations of Al-Shirqat, Al-Debs, Baiji and Tikrit from the Directorate of Water Resources in Salah Al-Din Governorate, and using the equations used to calculate the discharge in terms of level that was derived during the current study, the discharge was found for each level, and then the data used to plot flood hydrograph, discharges were selected for the months of December (2012) - February (2013).

The flood hydrographs for the mentioned stations and referred period are shown in figures 7-11, by different methods of measuring.

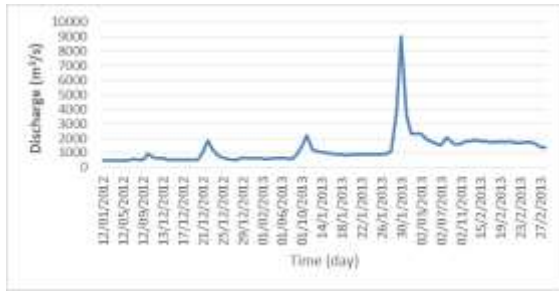


Fig. 7: The flood hydrograph observed at Al-Shirqat station Dec 2012 – Feb 2013, which is derived from the traditional equation.

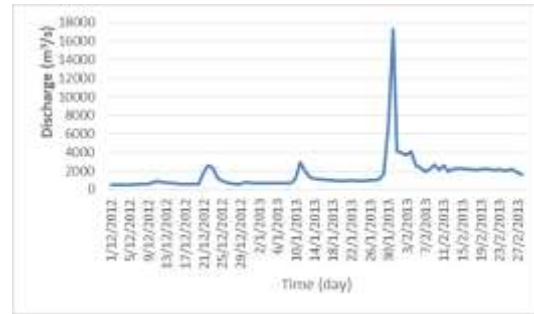


Fig. 11: The flood hydrograph observed at Tikrit station Dec2012-Feb 2013, and derived from the traditional equation.

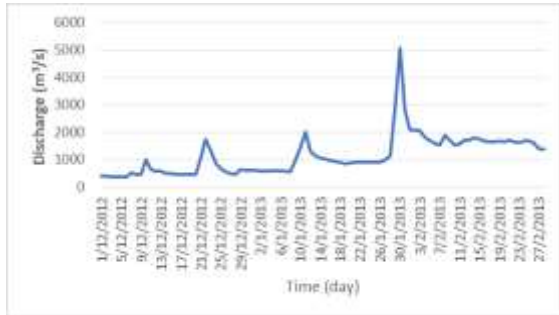


Fig. 8: The flood hydrograph observed at Al-Shirqat station Dec2012-Feb 2013, which was derived from the ADCP equation.

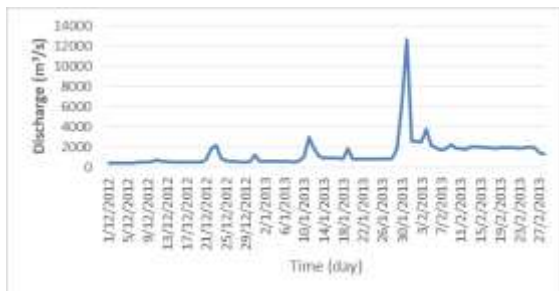


Fig. 9: The flood hydrograph observed at Baiji station Dec2012-Feb 2013, and derived from the conventional equation.

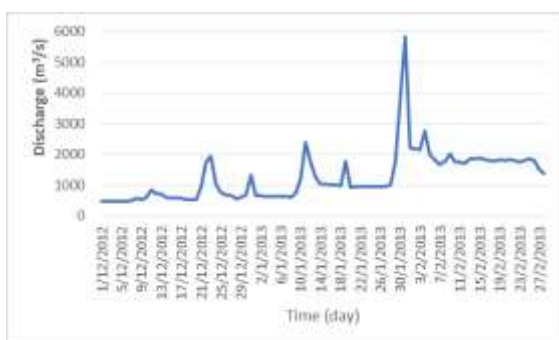


Fig. 10: The flood hydrograph observed at Baiji station Dec2012-Feb 2013, and derived from the equation derived from ADCP data.

These hydrographs reflect the clear discrepancy in the discharges between the measurements of different techniques in the same station, and the other stations of the same flood wave. The maximum discharge in Al-Shirqat station from the traditional equation reached (9000 m³/s), while the maximum discharge for the same station using the ADCP equation reached (5000 m³/s), while the maximum discharge in Baiji station using the traditional equation reached (13,000 m³/sec), while the maximum discharge for the same station when using the ADCP equation was approximately (6000 m³/s), as for the Tikrit station, it reached the maximum discharge from the traditional equation (17,000 m³/sec), where the clear discrepancy appears between the readings of the same station, or between one station and another. As mentioned for Al-Shirqat station as a reference station because of the little difference in the discharge values between the traditional measurements and the measurements by the ADCP device, there is significant difference in the measured discharge values in Baiji and Tikrit stations, reached more than (4000 m³/s) in Baiji, and more than (8000 m³/s) in Tikrit, in spite of there are no additives or tributaries between these stations. This means that the station under study have urgent needs to be re-evaluated.

So, there is a conflict in the discharge's values in the same station, which is derived from the traditional equation and the ADCP equation, as well as the existence of a conflict between the station and another, and there is no reason for the existence of this conflict because the region does not have any additional tributaries or any other additives.

3.2 Flood Hydrograph (2019)

This flood was monitored in Al-Shirqat station and Al-Debs dam and Baiji releases only, as the levels and discharges data for this flood wave were obtained from the discharge's records of the Water Resources Directorate in Salah Al-Din Governorate, and a hydrograph was made for the flood wave from its beginning to its end, represented in the months of March and April of the year (2019). Figures (12, 13, and 14) represents the observed hydrograph at Al-Shirqat, Al-Shirqat and Al-Debs dam stations respectively.

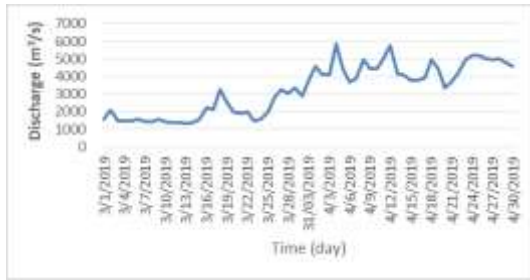


Fig. 12: The flood hydrograph observed at Al-Shirqat station in March and April 2019.



Fig. 13: The flood hydrograph observed at Al-Shirqat station, in addition to the discharge of Al-Debs dam, in March and April 2019.

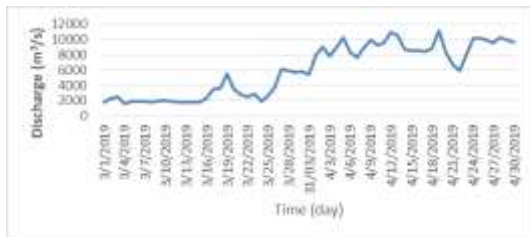


Fig. 14: The flood hydrograph observed at Baiji Station, in March and April 2019.

When representing the flood wave graphically, a difference in the discharges values noticed, where the maximum discharge in Al-Shirqat station reached ($5900 \text{ m}^3/\text{s}$), while the maximum discharge of Al-Shirqat station with the releases of Al-Debs dam reached ($7000 \text{ m}^3/\text{s}$), while in the Baiji station, the maximum discharge reached more From ($11,000 \text{ m}^3/\text{sec}$), that mean there are differences in the discharges values for the same flood wave in one time period of about ($4000 \text{ m}^3/\text{sec}$), and this means that there is a great contradiction and that Baiji station has inaccurate measurements, especially in periods of floods. It is noticed that there is a great discrepancy in the discharge's values between one station and another, which is not justified because the area is free of any addition of tributaries.

4. Evaluation of the current location of the station:

4.1 Comparison of discharges records measured by traditional methods with those measured using ADCP

The discharges measured by the traditional methods were compared with the discharges measured by the ADCP device in the station under study in Baiji, and the difference was clear, especially at high levels, as the minimum discharge recorded in the traditional method was about ($310 \text{ m}^3/\text{sec}$) at the level (102.48

m), while the minimum measured discharge with ADCP device was within ($265 \text{ m}^3/\text{sec}$) at the level (102.48 m), while the largest discharge was recorded by the traditional method about ($15000 \text{ m}^3/\text{sec}$) at the level (108.15 m), while the maximum discharge was recorded by ADCP device at ($6600 \text{ m}^3/\text{sec}$) at the level (108.15 m), and this inconsistency in the monitored data justifies a reconsideration of the station's evaluation (Fig. 15).

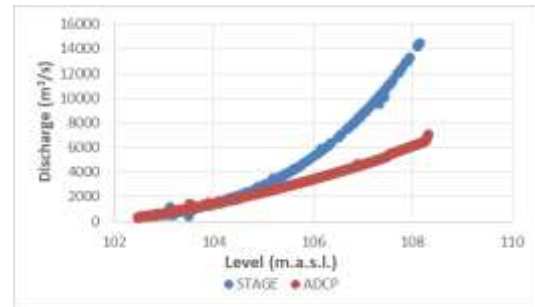


Fig. 15: Comparison of the discharges measured by traditional methods with the discharges of ADCP at Baiji station.

The same discrepancy was also observed in the observed discharges measured by the traditional methods and the ADCP method at Al-Shirqat station, but less than in Baiji station, where the minimum discharge using the traditional methods was recorded approximately ($350 \text{ m}^3/\text{sec}$) at the level (147.17 m), and the minimum discharge recorded by ADCP is about ($317 \text{ m}^3/\text{sec}$) at the level (147.17 m), and the maximum discharge that was recorded by traditional methods is about ($6000 \text{ m}^3/\text{sec}$) at the level (151.31 m), and the maximum discharge recorded using the ADCP is ($3975 \text{ m}^3/\text{sec}$) at the level (151.31 m) Figure (16).

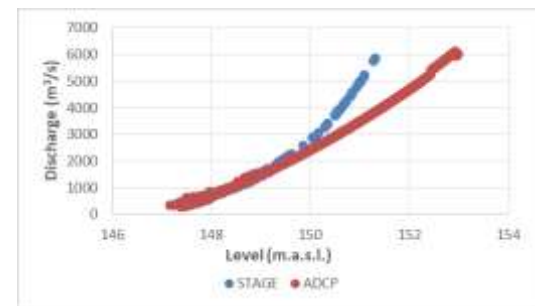


Fig. 16: Comparison of the discharges measured by traditional methods with the discharges of ADCP at Al-Shirqat station.

The maximum discharge recorded in Tikrit station ($15200 \text{ m}^3/\text{s}$), while in Al-Alam station the maximum discharge reached ($7700 \text{ m}^3/\text{s}$), although there are no additive discharges in this area and the two stations are close to each other. The discharges values of Baiji station were compared with Al-Shirqat, Al-Alam and Tikrit stations, and there was a difference in the discharge's values for the same period, especially the discharges measured by traditional methods.

4.2 Comparison of the hydrographs of Al-Shirqat, Baiji and Tikrit stations for selected flood waves.

4.2.1 Comparison of 2013 flood wave

The hydrograph observed in Baiji station which derived from the traditional equation, where the maximum discharge reached more than (12,000 m³/s), compared with the hydrograph observed in the same station and derived from the ADCP equation, where the maximum discharge reached about (6000 m³/s) figure (17), This discrepancy in the discharge's values at high levels of the same station is one of the most important reasons for re-evaluating the station.

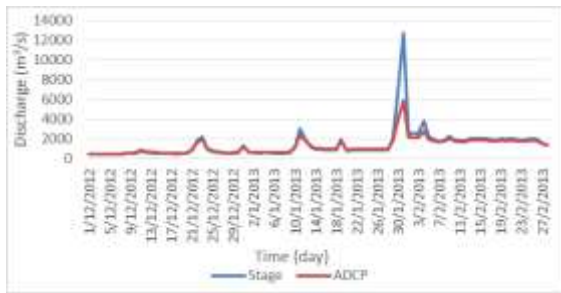


Fig.17: Comparison of the 2013 flood hydrograph observed at Baiji station using the traditional and ADCP equations.

The hydrograph of the flood in 2013 at Al-Shirqat station, which was derived from the traditional equation, where the maximum discharge reached more than (9000 m³/s), was compared with that deduced from equation of ADCP, and the maximum discharge reached (5000 m³/s) Figure (18).

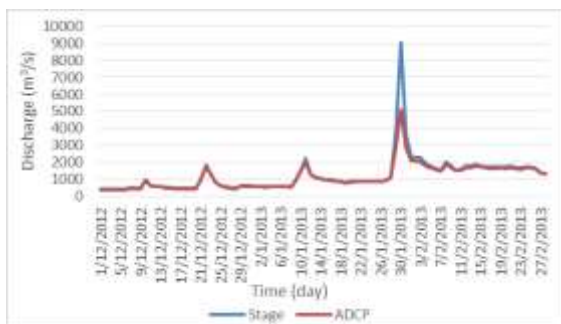


Fig. 18: Comparison of the 2013 flood hydrograph observed at Al-Shirqat station using the traditional and ADCP equations.

The hydrographs of Al-Shirqat, Baiji and Tikrit stations those deduced from the traditional equation (Fig. 19), compared with others, where the maximum discharge in Shirqat station reached (9000 m³/s), while in Baiji station, the maximum discharge was more than (12000 m³/s), while in The Tikrit station had a maximum discharge of more than (17000 m³/s). This discrepancy in the discharges for the same flood wave has no justification, due to the absence of any additives or tributaries, and the only justification is that the stations need to be re-evaluated.

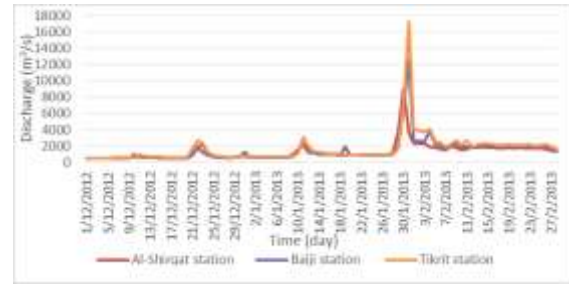


Fig. 19: Comparison of the hydrographs observed in Al-Shirqat, Baiji and Tikrit stations for the 2013 flood, which is derived from the traditional equation.

Also, the 2013 flood hydrograph observed at Al-Shirqat station, which was deduced from ADCP equation, was compared with the hydrograph observed at Baiji station and derived from same device in Figure (20), where the maximum discharge recorded at Al-Shirqat station was (5000 m³/s), while the maximum discharge recorded in Baiji station was about (5900 m³/s), when using the ADCP equation derived in the current study to find the discharges in terms of levels, it was noticed that they are more accurate and objective, and that the difference between the maximum discharges of Baiji and Al-Shirqat stations may represent the releases of Al-Debs dam.

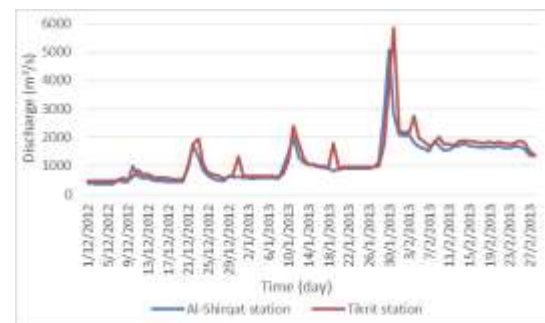


Fig. 20: Comparison of the hydrographs observed in Al-Shirqat and Baiji stations for the flood 2013, which is derived from the ADCP equation

4.2.2 Comparison of 2019 Flood Wave:

The hydrographs of this flood wave were compared for Al-Shirqat, Al-Shirqat (in addition to the releases of Al-Debs dam) and Baiji stations, in figure (21), the maximum discharge of Al-Shirqat station reached (5900 m³/s), while the maximum discharge of Al-Shirqat station (in addition to the releases of Al-Debs dam) on the Zab tributary, reached (7000 m³/s), while the maximum discharge recorded in the Baiji station reached (11000 m³/s). in this flood wave, it was noticed that Al-Shirqat station recorded realistic and somewhat accurate discharges, but the Baiji station had inaccurate and abnormal discharge values.



Fig. 21: Comparison of the hydrographs observed in Al-Shirqat, Baiji and Al-Shirqat (in addition to the releases of Al-Debs Dam) stations for the 2019 flood.

5. Conclusions

1. Floods which reach the critical level of the station, leads to a change in the shape and geometry of the river section, and thus an inaccuracy in the discharge measurement.
2. It is difficult to read the staff gauge as a result of the continuous lack of maintenance of the station and carelessness.
3. The presence of flood protection seals affects the reading of the gauge station, and lead to change the shape and geometry of the flow section and the shape of the two banks of the river and became asymmetrical.
4. The presence of dense vegetation cover in the station section, especially on the left bank of the river, led to inaccuracies in the discharge's measurement.
5. There are discrepancies between the discharges values in the same station measured by the two methods, and the discharges measured between one station to another.
6. The discharges values of Baiji station were compared with Al-Shirqat, Al-Debs, Al-Alam and

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Tikrit stations, and there was a discrepancy in the discharge's values for the same period, especially the discharges measured by traditional methods. This is due to the asymmetry of the river's cross-section, the presence of islands, dense vegetation, turbulence of flow and the velocity, and the erosion, crack, and subsidence of its concrete parts will always lead to wrong measurements of discharges, especially at high levels as a result of the very large areas that are submerged and turbulence of flow.

7. The discharges measured by traditional methods at Baiji station are much greater than the discharges received from Al-Shirqat and Al-Debs stations together, and this conflict is unjustified, since the area is free of any additional tributaries. As for the discharges recorded at the Al-Alam station, they are much less than Baiji station. Which begs the question? Where did the rest of the water come from Baiji go?

6. Recommendations

1. Adoption of the new equations to find the discharge in terms of the level that was derived during the current study and from the data measured by the ADCP device.
2. Select alternative site for the station, according to evaluation of geological, hydrological, geometric and geomorphological aspects.
3. Adopting more than one technique to measure the level, such as the recorded staff gauge and the bubble scale.
4. Installing a continuous current meter to measure the velocity of flow.
5. Re-evaluate the station and maintain it periodically, especially after the floods.

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