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Evaluation of Current and Post-Development Carrying Capacity of Tigris River Reach in Mayssan Province

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Abstract

The study aims to evaluate the current flood carrying capacity and its change after some cross sections developments for the 110 km reach of Tigris River and Kmait flood escape system. This reach extends from Ali Al-Gharbi station to Amarah Barrage station. The model is calibrated by using set of data at the Ali Al-Garbi gaging station, that includes flow varied between 790 to 470 m^3/s during April 2019. Manning's n coefficient value of (0.03) is selected as it has the minimum least-squares root difference of (0.148) between the measured and estimated water levels. The results show that the current capacity of Kmait flood escape and this Tigris River reach are 280 m^3/s and 1100 m^3/s, respectively. According to the study of strategic for water and land resources in Iraq, 2014, scenarios are conducted for some cross sections development to improve the capacity of the reach to 2750 m^3/s. Results of applied development show that Tigris River can safely accommodate a flood wave of 2750 m^3/s when modifying the cross-sections in different locations, and raising the banks level in three locations, 0+00, 79+00 and 95+00km. Earthworks volume of development of the reach is 247603200 million $\mathbf{m^3}$, with the total cost of 490 billion IQD.

Keywords: Tigris River, Kmait Flood Escape, Flood Simulation and Manning's Coefficient.

تقيم وتطوير نهر دجلة بين علي الغربي وسدة العمارة وتأثير الاداء الهيدروليكي لمهرب كميت الفيضاني على النهر

ميسم قومي النعيمي ، محمد راشد الجحيشي

الخلاصة:

أجريت هذه الدراسة لتقييم وتطوير استيعابية تصريف نهر دجلة بين علي الغربي وسدة العمارة بطول ١١٠ كم. بالإضافة إلى تأثير السلوك الهيدروليكي لمهرب كميت الفيضاني على نظام نهر دجلة قيد الدراسة ، ويتضمن التحقيق محاكاة السعة الحالية لنهر دجلة ضمن منطقة الدراسة ، ومهرب كميت الفيضاني باستخدام نموذج HEC-RAS. الإصدار ٦,١. تمت معايرة النموذج ، وأجريت العملية باستخدام مجموعة من البيانات في محطة قياس علي الغربي ، تمثل البيانات مع تدفق متنوع بين ٧٩٠ و ٤٧٠ م ٣ / ثا خلال شهر نيسان ٢٠١٩. وأظهرت نتائج المعايرة أن اقل معدل للجذر التربيعي للخطأ يساوي ٠,١٤٨ عند استخدام معاملماننك n البالغ ٠,٠٣ لكل من القناة رئيسية والمجرى الفيضاني لنهر دجلة. تمت محاكاة السيناريوهات لدراسة استيعابية التصريف في ظل الظروف الحالية. وأظهرت النتائج أن القدرة الاستيعابية الحالية لمهرب كميت الفيضاني ونهر دجلة بين علي الغربي وسدة العمارة تبلغ ٢٨٠ م ٣ / ثا و ١١٠٠ م ٣ / ثا على التوالي. تم تنفيذ سيناريوهات لتطوير وتحسين استيعابية تصريف نهر دجلة بين علي الغربي وسدة العمارة الى ٢٧٥٠ م ٣ / ثا حسب دراسة الاستراتيجية في العراق ٢٠١٤ التي نفذتها وزارة الموارد المائية.
بلغ حجم الاعمال الترابية لتطوير نهر دجلة قيد الدراسة ٢٤٧٦٠٣٢٠٠ مليون م ٣ بتكلفة اجمالية ٤٩٠ مليار دينار عراقي. تظهر نتائج التطوير ان استيعابية نهر دجلة قيد الدراسة يمكن أن يستوعب بأمان موجة فيضان بتصريف ٢٧٥٠ م ٣ / ثا عند تعديل المقاطع العرضية في مواقع مختلفة ، وكذلك رفع مستوى الضفاف في ثلاثة مواقع ، ٠٠+ ٠ كم ، ٠٠ + ٧٩ و ٠٠ + ٩٥ كم.

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1. Introduction

Tigris River is one of the most important rivers in Western Asia, it flows from the south-eastern part of Turkey, passes through the border areas of Turkish Syrian and crosses Iraq for 1430 km until it merges with the Euphrates River near Al-Qurnah to form the Shatt Al-Arab River, then it discharges its water into the Arabian Gulf. Its basin has an area of about 470 km^2 [1, 2]. Over the last few decades, some Tigris River hydraulic parameters have decreased as it passes Iraq, such as the water levels and the annual peak discharges. This decrease is due to the construction of dams along the upstream of Tigris River in Turkey and Syria. In addition to that the other well-known reasons are climate change and the global increase in water consumption [3]. The decrease in those hydraulic parameters, especially the flow velocity had caused as expected an accumulation and deposition of suspended solid during the low flow period of these last years, along the downstream part of Tigris River. This accumulation of large quantity of sediment had changed the river morphology, which resulted in an adverse impact on the hydraulic systems that use the river water. For instance, the water supply treatment plants, and the irrigation projects. In addition, in some locations the riverbanks became unstable and subject to changes. [4, 5]. Much research had been conducted for Tigris River, related to bed sediment load, calibration and validation of Manning's coefficient, water quality models and estimation of discharge capacity. However, as the river flows downstream the problems mentioned above become more evident, hence it is required to pay more attention to study the performance of the river in view of these changes [6, 7]. As the river section is reduced due to sedimentation during the low flow season, its flow carrying capacity is affected and that may be a problem during the high flow season, especially during a flood season. Accordingly, this study is conducted to evaluate the current capacity of the river and that capacity after changing some river sections by cleaning the accumulated sediment. These modifications in these sections were decided as early as 2014 The study reach is of 110 km length along the Tigris River near the Amarah City, south of Iraq. This reach extends from Ali Al-Garbi to Amarah Barrage, with an average longitudinal surface slope of the water, of 4cm/km [7]. This reach is also connected to the kmait flood escape which is constructed on the river in 1990 about 40 km to the north of Al-Amarah city.

2. The study area description

The study area extends along the Tigris River between Ali Al-Garbi to Amarah Barrage. In addition, it includes the Kmait flood escape that was constructed to protect Maysan city against flood.

2.1 Description of Tigris River Study Reach

The study area is located on the mainstream of Tigris River. This reach is 110 km long of Tigris River starting from Ali Al-Garbi and ending at Amarah Barrage.

The basin of Tigris River covers an area of about 470 km^2[1]. The study location is situated in the south-eastern sector of Iraq starting at a distance along the river of 148 km downstream of Kut Barrage, Fig.١. [7] at a station called Ali Al-Gharbi station having 658404.98 m Easting and 3591609.32 m Northing on UTM coordinate system and ends at Amarah Barrage station located at 703665.60 m Easting and 3526406.29 m Northing on UTM coordinate system. The reach under study has an average longitudinal surface slope of the water, around 4cm/km [7]. The elevation of the river's levee slightly upstream from the Ali Al-Garbi is as high as 13.64 m.a.m.s.l. This elevation progressively drops to 8.49 m.a.m.s.l. at the reach's downstream end, near the Amarah Barrage.

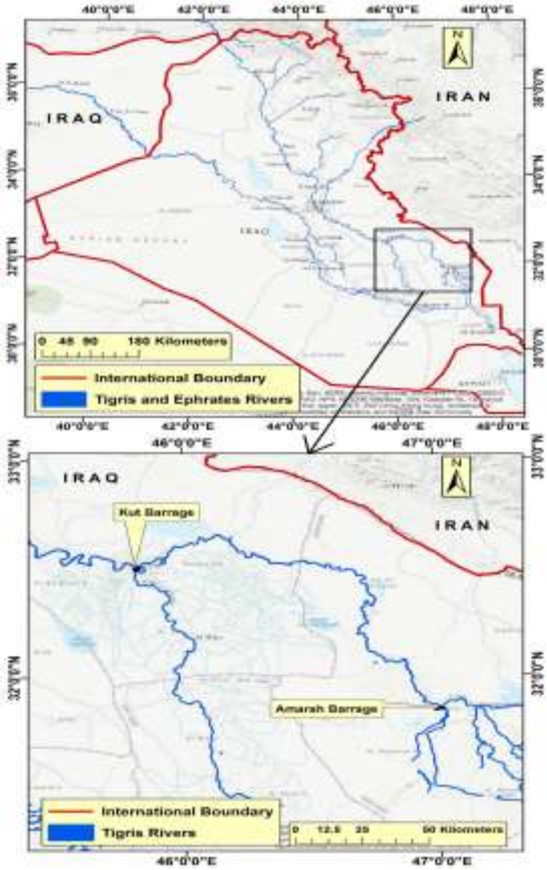

Figure (1): Map of study reach. along the Tigris River between Ali Al-Garbi and Amarah Barrage

The reach has many lateral intakes of irrigation canals distributed along the left and right banks. Approximately 100,000 hectares of significant agricultural areas are supplied with water through these intakes downstream of Kut Barrage [7] as shown in Fig.2. Amarah Barrage regulates the water flow of the mainstream of Tigris River and Musharrah and Kahla Rivers located upstream of the barrage. Table 1. shows data of the flood escape and intakes within the study reach. These data were provided by Directorate of Water Resources of Maysan.

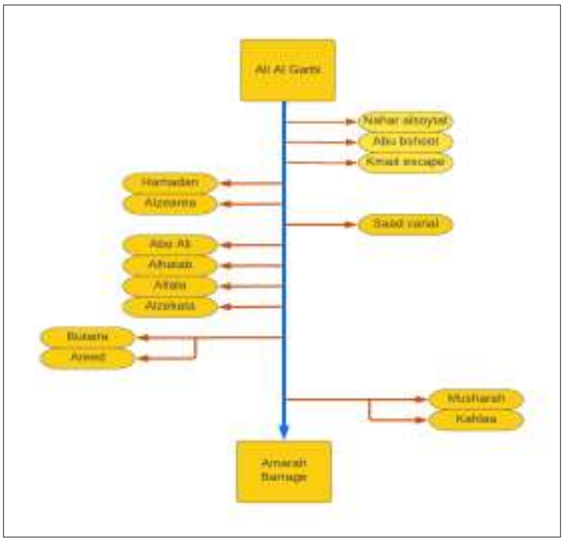

Figure (2): Schematic layout of the reach of Tigris River under study.

Table (1): Detailed data for intakes and the Escape within study reach

Name	*Type*	*Station km*	*Discharge m^3/s*	*Invert level m.a.m.s.l.*
Kmait	*Weir flood escape*	*70+000*	*350*	*7*
Buteira	*Regulated intake*	*90+000*	*700*	*2*
Areedh	*Regulated intake*	*90+000*	*700*	*2*
Musharrah	*Regulated intake*	*110+100*	*200*	*3*
Kahla	*Regulated intake*	*110+100*	*500*	*2*

2.2 Description of Kmait flood escape

Kmait flood escape is located in the Maysan Governorate, in Iraq, 40km north of Al-Amarah city, in Kmait district, which has an area of 1695km^2, through which the Tigris River crosses and divides it into two parts. Kmait flood escape was constructed to divert part of the water of Tigris River during flood season through AsSanna'f Marsh to Al-Huwayza Marsh, and then drain the water of Al-Huwayza Marsh to Tigris River through Al-Kassara River and to Shatt Al-Arab through Al-Sweib River. The total length of the escape is about 3.5km, it was constructed in the year 1990 and consisted of 27 gates each with a width of 3.5m and a height of 4m. The design capacity of this structure is 400 m^3/s. The Kmait flood escape is situated downstream of Kut Barrage, where the left bank of the Tigris River joins AsSanna'f Marsh, with an earth channel of 36 km in length [8].

According to the Study of Strategy for Water and Land Resources, 2014, the probability for the maximum flood predicted from the Tigris River to Kmait flood escape for a return period of 500 years is about 350 m^3/s. The maximum recorded discharge was 177 m^3/s at the flood in 2019.

2.3 Discharges of the Tigris River in Maysan Province

The Tigris River flow measurements in the study area were collected for years 1988 to 2019. These data were provided by (Ministry of Water Resources) MoWR. The data includes the flows recorded at Ali Al-Garbi, which is located 148 kilometers downstream of the Kut Barrage, and the Amarah Barrage gage station which are the two gage stations along the study reach where these data. The measurements also include water levels. From the provided historical data records, major flood event sets at various dates were obtained, as indicated in Table 2. On March 30, 1988, there was a flood with an 1100 m^3/s maximum discharge. By deploying flood escapes and allow flooding of some nearby agricultural regions, measures were taken to lower the flood wave, resulting in just 270 m^3/s of the wave reaching Amarah City.

Table (2): Historical flood discharges details

Data set number	**Station Name**	**Discharge m^3/s**	**Stage m.a.m.s.l.**	**Data**
1	Ali Al Garbi	1100	13.02	30/3/1988
	Upstream Amarah barrage	270	8.22	30/3/1988
2	Ali Al Garbi	800	11.78	02/01/1995
	Upstream Amarah barrage	260	8.21	02/01/1995
3	Ali Al Garbi	450	11	01/06/1995
	Upstream Amarah barrage	275	8.17	01/06/1995
4	Ali Al Garbi	300	9.55	05/02/2013
	Upstream Amarah barrage	150	6.63	05/02/2013
5	Ali Al Garbi	290	9.5	01/05/2017
	Upstream Amarah barrage	145	7.4	01/05/2017
6	Ali Al Garbi	800	11.60	12/04/2019
	Upstream Amarah barrage	145	7.98	12/04/2019

3.HEC-RAS Hydraulic One-dimensional Model

A free software established by the US army (HEC--RAS) 6.1 was used in this research, which is widely applied to perform one-dimensional steady-state gradually varied flow of the study area under different conditions. Fig.3. shows a schematic diagram of the reach of Tigris River and Kmait flood escape that is adopted in the HEC-RAS 6.1 software[9]. The reach of the Tigris River extends between Ali Al-Garbi and

Amarah Barrage with 110km length. Kmait flood escape extends 40***km*** north of Al-Amarah city with 3.5km length.

Figure (3): The scheme of the reach under study in the geometric data window of HEC-RAS software**.**

3.1 Data for hydraulic model

440 major cross-sections were measured along a length of roughly 110 km each spaced at 250 m distance. Those sections are used to construct the geometric data for the HEC-RAS model. Data were provided by MoWR**.** Fig.4. shows different cross-sections along the Tigris River: The first section is located at Ali Al-Gharbi station, the second section is located just before confluence with Kmait flood escape, third section is located after the confluence with the escape and the last cross-section is located at Amarah Barrage station. [10-13]**.**

The data of these cross-sections include information such as reach lengths, coordinates, Manning coefficient, contraction/expansion and channel overbanks and right and left banks. [14-16]**.**

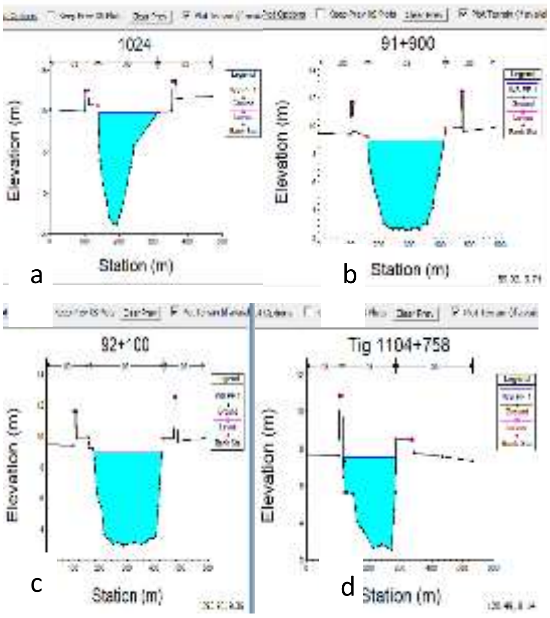

Figure (4): differents cross-sections: (a) The first cross-section at Tigris River at Ali Al-Gharbi station, (b) just before the confluence with Kmait escape, (c) just after the confluence with Kmait escape, (d) The final cross-section at Tigris River at Amarah Barrage

3.2 Hydraulic data for Kmait flood escape

The model's geometric data for the Kmait flood escape was created using 35 cross-sections, with 100 m separating each section along a 3.5 km length. Data were provided by MoWR**.** In order to ensure accuracy in the calculation of friction losses, a number of parameters were also assigned to the cross-sections, including water level elevation information, downstream reach lengths, Manning's n roughness coefficient of the mainstream, banks, main channel expansion, contraction coefficients and levees. The first and final cross-section at Kmait flood escape was shown in Fig.5.

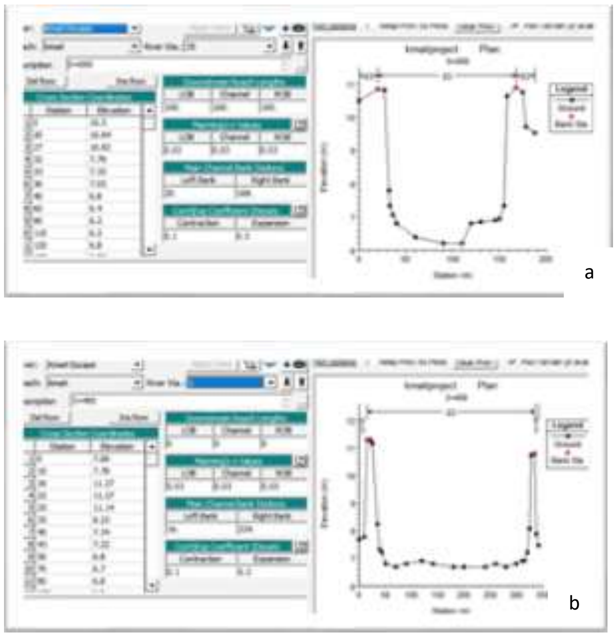

Figure (5): Cross-sections: (a) The initial cross-section at Kmait flood escape, (b) The last cross-section at at Kmait flood escape

3.3 Boundary conditions

In this case study, the discharge at the upstream and normal depth was adopted at the downstream end as a boundary condition of Kmait flood escape. The discharge at the upstream reach under study at Ali Al-Gharbi station, the rating curve at the downstream section of the Tigris River at Amarah Barrage station were used as boundary conditions in the model, Fig. 6. The formula of the equation of the rating curve was computed depending on the data from MoWR for the year 2019, the formula of the equation of the rating curve was computed, R^2 = 0.9616, that is eq. (1):

$$WL = -5E - 06Q^2 + 0.0151Q + 4.8887 \quad ....(1)$$

Where:
WL: is water level, m, and *Q* :is discharge, m^3/s.

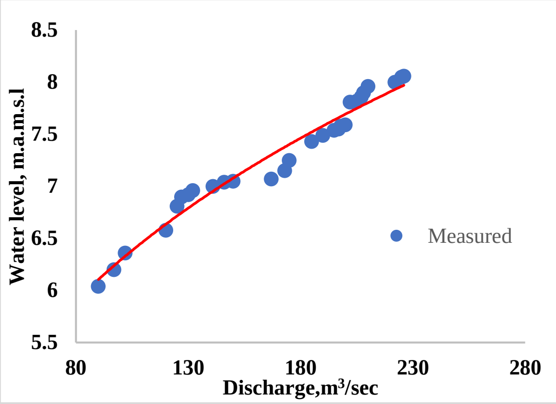

Figure (6): The rating curve at upstream of Amarah Barrage

4. Result and Discussion

The results of the hydraulic model for the flow capacity of Tigris River and Kmait flood escape will be presented and analyzed. The analysis includes the calibration and verification of the Manning's n for Tigris River under study and the current discharge capacity of Tigris River and Kmait flood and modified discharge capacity of Tigris River under study.

4.1 Calibration and validation of HEC-RAS model

The calibration process is necessary to determine the most appropriate Manning's coefficient n value for the mainstream (Tigris River reach) for the reach under study. Depending on the state of the river section and its flood plain, a specific Manning's n value should be assigned for proper simulation accordingly[17-20].

This value depends on river section irregularity, vegetation, stage,discharge and surface roughness. If the banks are rough and grassy, Manning's n may be significantly high. In general, this coefficient reduced as discharges gradually increased [21- 23].

For estimating the water levels and defining Manning's coefficient n, the HEC-RAS model for the reach under study is calibrated. To validate the model, an observed data other than the ones used in the calibration process will be used to see how well it can predict the water levels for various river flows. For Kmait flood escape, the roughness coefficient n values selected from earlier studies for equivalent stream conditions were evaluated due to the difficulty in getting the data of the water level and discharge to be used for the calibration of the value of the Manning coefficient n. One of the experts who carried out a hydraulic analysis of the Kmait River was reference length[8].

As a result of this study, the n's chosen range is (0.03-0.045). The results indicate that a roughness coefficient value of 0.03 provides the greatest consistency between measured and calculated water surface levels. Therefore, this n value was chosen for this research.

4.1.1 Model calibration for Tigris River

Until the differences between the observed and simulated water levels are within the allowed ranges, coefficient "n" is continuously changed. Generally water levels observations should be used to calibrate the empirical equation's parameters such as Manning's coefficient n; therefore, different Manning's n values are suggested for both the main channel and the flood plain to examine and evaluate their effect on water surface elevation. For the reach under study along the Tigris River, the range of these values examined are (0.025 - 0.031) that are specified in the main channel with step +0.001. The Root Mean Square Error (RMSE) is used to compare the results for Tigris River between Ali Al-Garbi and Amarah Barrages. The process is conducted by using set of data at the Ali Al-Garbi gaging station, represent the data with daily measured on April 01, 2019 to April 30, 2019 a flow varied between 790 and 470m³/s, Table 3.

Table (3): Comparison between measured and simulated water surface profiles

Discharge m³/s	Water surface elevation, m.	
	Observed	Simulated
790	11.90	11.74
776	11.85	11.69
776	11.84	11.68
770	11.82	11.66
770	11.82	11.66
762	11.79	11.63
762	11.79	11.63
761	11.79	11.63
752	11.75	11.59
751	11.73	11.57
746	11.72	11.56
736	11.68	11.52
735	11.67	11.51
733	11.66	11.5
700	11.50	11.35
684	11.44	11.29
682	11.43	11.29
660	11.33	11.18
640	11.22	11.08
630	11.19	11.04
630	11.18	11.04
620	11.14	10.99
610	11.08	10.94
605	11.07	10.93
602	11.06	10.91
585	10.95	10.81
570	10.87	10.73
545	10.67	10.6
470	10.21	10.17

The results of the calibration indicate that the root mean square error between the measured and estimated water levels is 0.148 when using Manning's n coefficient of 0.03 for each of main channel and its flood plain for Tigris River, Table 4. as shown in Fig.7. The hydraulic model is employed by using the selected hydrological data that were collected on April 01, 2019 to April 30, 2019, eq. (2):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(c_i - o_i)^2} \quad \text{....(2)}$$

where:
n: is number of data,
ci: is the computed water surface, m,

and oi: is the observed water surface, m.

Table (4): RMSE values for different suggested n values of the calibration process

Cases No.	Manning's n		RMSE
	Main channel	Flood plain	
Case 1	0.03	0.03	0.1479
Case 2	0.25	0.03	0.427
Case 3	0.026	0.03	0.351
Case 4	0.027	0.031	0.297
Case 5	0.028	0.031	0.278
Case 6	0.029	0.03	0.294
Case 7	0.031	0.03	0.342

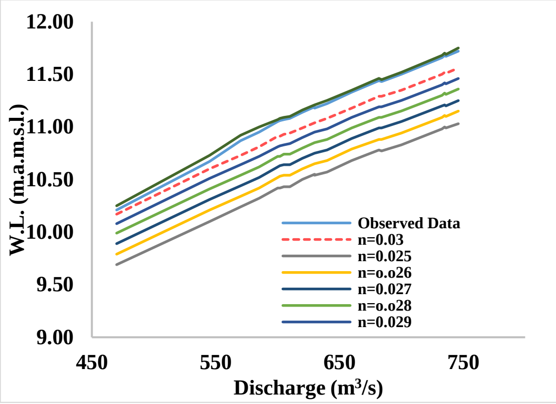

Figure (7): The comparison of simulated and observed flow water elevation along Tigris River between Ali AlGarbi and Amarah Barrages for different values of Manning's n.(calibration process)

4.1.2 Model validation for Tigris River

The calibrated Manning's values are verified using another set of measured water levels and corresponding discharge conducted in February 2019 and May 2019. Table 5. Shows the profile of water surface for the verification process. Table.3 presents an assessment between the measured water surface and that simulated by using the model. The results of the verification process showed good match between measured and simulated water surfaces with RMSE of 0.0959. Fig.8. shows the water surface profile of the simulated and observed water level verification set.

Table (5): Comparison between measured and simulated water level for verification of the calibrated Manning's coefficients

Discharge m^3/s	Water surface elevation, m.	
	Observed	Simulated
581	10.71	10.65
570	10.59	10.41
560	10.4	10.32
551	10.38	10.25
525	10.1	10.2
520	10	9.95
505	9.88	9.8
493	9.84	9.76
485	9.76	9.69
480	9.64	9.59

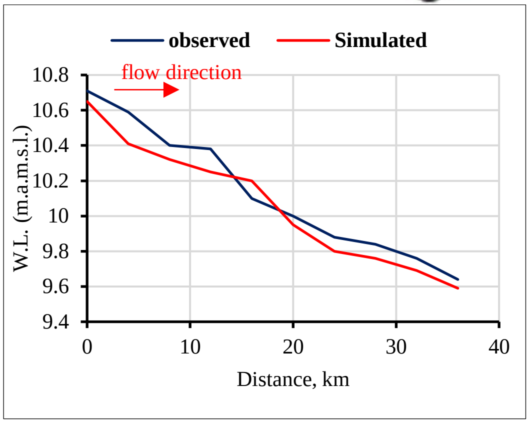

Figure (8): The comparison of simulated and observed flow water elevation along Tigris River between Ali Al-Garbi and Amarah Barrage verification set.

4.2 Current capacity of Tigris River

The current capacity analysis is implemented for Tigris River between Ali Al-Garbi and Amarah Barrage**.** Three values of discharges 1100, 1200 and 1300 m^3/s are adopted. Fig.9. show the water levels profile, the sides' levees levels and the river bed level, for these three values of discharges. At discharge 1300 m^3/s, the water level along the reach of Tigris River is lower than both the right and left levees elevation except at stations 0+00 and 80+00km where the water levels are close to the banks level. Similar observations are obtained for the discharge of 1200 m^3/s. For the discharge of 1100 m^3/s the longitudinal levees elevations of Tigris River are found higher than the water levels along the reach hence it is consideredsafe. As a result, the maximum discharge capacity in the Tigris River at this reach is 1100m^3/s.

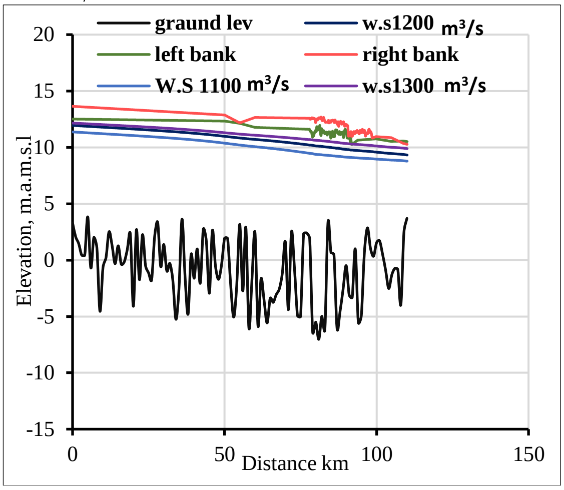

Figure (9): Water surface elevation along the Tigris River between Ali Al-Garbi and Amarah Barrage

4.3 Current capacity of Kmait flood escape

HEC-RAC software is used to prepare a steady one-dimensional flow routing hydraulic model. This model is used to simulate the flow and examine the hydraulic performance along Kmait flood escape under various flow rates. Different values of discharges have been imposed, these discharges range from 170 m^3/s up to the maximum design discharge of 400 m³/s. The resulting longitudinal water surface profiles for these discharges are shown in Fig. 10. It was found that the maximum discharge that can be accommodated within Kmait flood escape under current condition is 280 m³/s at 1m freeboard.

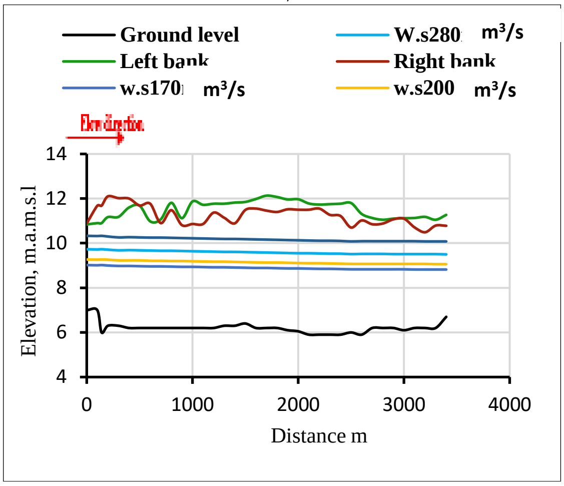

Figure (10): Water surface elevation along Kmait flood escape under current condition

4.4 Development of Tigris River within the study area

The development has been performed to increase the discharge capacity of the Tigris River under study to 2750 m³/s and discharge crosses into Kmait flood escape with a discharge of 350 m³/s according to the study of Strategy for Water and Land Resources in Iraq, 2014. As noted later in this section that the 1100m³/s represented the full current capacity of the reach of Tigris River between Ali Al-Garbi and Amarah Barrage, it is logical that that under the current conditions of the cross section, the reach of Tigris River can't accommodate the discharge of 2750 m³/s. The elevations of the water surface obtained with conditions of lateral outflows are higher that the levees of the river reach, as shown in Fig. 11.

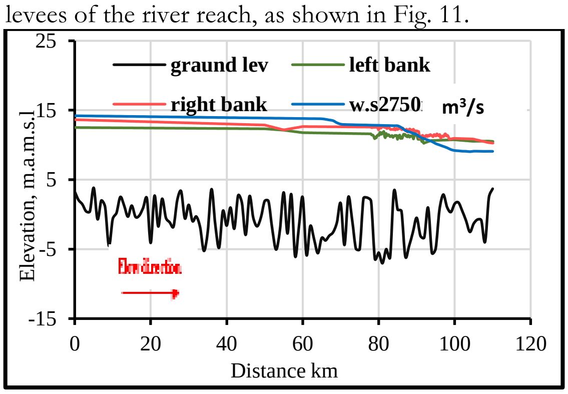

Figure (11): Water surface elevation along Tigris River under study with discharge of 2750 m³/s without modifications

Therefore, it is a very important issue that should be given utmost attention to recover the capacity of the river to accommodate expected flood discharges. The development process included modification of the cross-sections in different locations, also and raising the banks level in three locations, 0+00km, 79+00 and 95+00km. This development aims to modify the cross sections of the mainstream of Tigris River. Results of the model runs with modified cross-sections showed that the water levels along Tigris River reach are lower than the levees level which is not the case before modification. A flow of 2750m³/s can be discharged safely at Ali Al-Garbi with lateral outflow from the tributaries. Fig.12. show the water level along Tigris River under study after modifying the cross sections at different locations and raising the banks level in three locations. Water level along the reach is kept at 1m below the level of levees. The unit cost of the cut and fill volumes for the earthworks was provided by the Ministry of Water Resources. Every 1 m³ of cut and fill volumes with a cost of 2000 IQD. The Earthworks volume of these cross-sections is about 247603200 million m³, and its cost is 490 billion IQD.

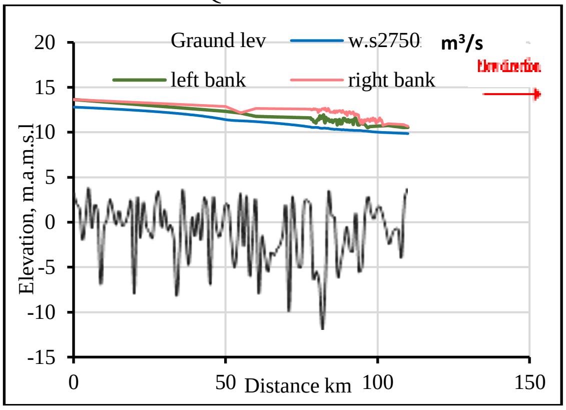

Figure (12): Water surface elevation along Tigris River under study with discharge of 2750 m³/s after modifications

5. Conclusion

Steady flow HEC-RAS model is developed for a reach of Tigris River from Ali Al-Gharbi to Amarah Barrage stations to develop the capacity of this reach. The effect of hydraulic behavior of Kmait flood escape on the Tigris River which was constructed in 1990 to protect Mayssan city is also included. The appropriate value of Manning's (n) is found to be (0.03), since it gives minimum difference between the measured and estimated water levels. It is found that the discharge capacity of Kmait flood escape under current condition is 280 m³/s while for the Tigris reach is 1100 m³/s. After the proposed modification was made, the current capacity of the reach increased from 1100 m³/s to 2750 m³/s and this has been done by modifying the cross-sections from station 0+00 km to 110+00 km. In such case, the cost cut and filling are calculated of 490 billion IQD for the volumes 247603200 million m³.

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