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Flood Management of Diyala River

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ABSTRACT

Diyala Governorate was recently exposed to high flood waves discharged from Hemrin Dam. Since the dam was at its full capacity during the flood period, these waves were discharged to the Diyala River. Because of the reduction in Diyala River capacity to 750m^3/s, the cities and villages on both sides of the river banks were inundated. Thus, the study's objective is to design a flood escape out of the Diyala River, to discharge the flood wave through it. The flood escape simulation was done by using HEC- RAS software. Two hundred twenty-three cross sections for the escape and 30 cross-sections of the Diyala River were used as geometric data. Depending on the geological formation that the escape passed through, two roughness coefficients of 0.035 and 0.028 were applied. An outflow downstream Hemrin Dam varies from 1100m^3/s to 1800m^3/s was applied as boundary condition upstream Diyala River. One dimensional hydraulic model was developed for the escape and the river, the results showed that aside weir could be constructed at the escape entrance with crest level 67*m.a.m.s.l.* and 800*m* width, followed by drop structure of four rectangular steps, this case provides safe discharge to Diyala River if flood wave of 1500m^3/s released from Hemrin Dam.

Keywords: Flood, Flood Escape, weir, HEC-RAS

تخفيف الفيضانات من نهر ديالى

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مهندس اقدم
وزارة الموارد المائية

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الخلاصة

كانت محافظة ديالى عرضة لموجة فيضانات شديدة مؤخرا ، والتي اطلقت من سد حمرين لأن سد حمرين وصل للحد الاقصى للخزن خلال فترة الفيضان ، حيث تم تصريف هذه الأمواج إلى نهر ديالى ،,وبسبب انخفاض استعيابية نهر ديالى الى 750m^3/s ,مما تسبب في غرق المدن على جانبي ضفاف النهر. الهدف الرئيسي للدراسة هو تصميم مهرب فيضاني من نهر ديالى لتصريف موجة الفيضان من خلاله. تم اجراء محاكاة للمهرب الفيضاني باستخدام برنامج HEC-RAS 223 مقطعًا عرضيًا للمهرب و 30 مقطعاً عرضياً لنهر ديالى تم استخدامها كبيانات جيومترية. اعتماداً على التكوين الجيولوجي الذي يمر خلاله المهرب, تم

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تطبيق قيمتين قيمتين لمعامل الخشونة 0.035 و 0.028. وتم استخدام اطلاقات من مؤخر سد حمرين تتراوح بين 1100 م 3/ ث و 1800 م 3 / ث, حيث تم تطبيقها كشرط حدودي عند مقدم نهر ديالى. تم تطوير نموذج هيدروليكي أحادي البعد للمهرب والنهر ، وأظهرت النتائج أنه يمكن انشاء مسيل مائي جانبي عند مدخل المهرب بمستوى قمة 67 م وعرض 800 م متبوعًا بمنشأ شلالة يتكون من أربع تدرجات وبمقطع عرضي مستطيل ، وهذه الحالة توفر تصريفًا آمنًا لنهر ديالى إذا انطلقت موجة فيضان 1500 م 3 / ثانية من سد حمرين.

الكلمات الرئيسية: فيضان, مهرب فيضاني, مسيل مائي

1. INTRODUCTION

Diyala River originates in the Zagros Mountains in Iran, joins the Tigris River 15*km* south of Baghdad. It consists of three reaches, upper reach that lies upstream Hemrin Dam, middle reach, which is sited between Hemrin dam and Diyala Weir; and lower reach, which extends from downstream Diyala Weir to the confluence of Diyala River and Tigris River.

Diyala Weir is located on Diyala River. Firstly, the objectives of its construction are raising the water level upstream the weir and regulating the water distribution to the tributaries on both sides of the upstream Diyala Weir and secondly, discharging the flood wave to the lower part of Diyala River. The maximum water level upstream of the weir is 69*m.a.m.s.l.* The discharge is 2660m^3/s, while the operation water level is 67.5*m.a.m.s.l.* (**Directorate of Diyala Water Resources, DDWR.)**

Hemrin Dam lies on Diyala River, 120*km* northeast of Baghdad and 10*km* upstream Diyala Weir. The purposes of its construction are: preventing the flood of Diyala River by controlling the amount of discharge downstream Hemrin Dam, Providing irrigation water for agricultural lands of Diyala River basin, and Electric power generation.

According to the data that was provided by (**Engineering Studies and Design Center, Ministry of Water Resources)**, it is supplied with five radial gates spillway; the gates are 70*m* total width and 12.5*m* height, the maximum discharge of the spillway is 6800m^3/s at maximum reservoir level which is 107.5*m.a.m.s.l.* The operational water level of the dam is 104*m.a.m.s.l.* with discharge 4000m^3/s.

Hemrin Dam and Diyala Weir form an integrated hydraulic system to make use of Diyala River, which plays a vital role in two aspects, firstly, disposing of the flood wave, secondly, thriving the cities and agricultural lands situated on both sides of the river.

Recently, Diyala Governorate has been at the real risk of high floods because the storage capacity of Hemrin Dam reached its maximum limit during the flood. Therefore, the flood wave was discharged from Hemrin Dam to Diyala River. Due to the absence of maintenance works on Diyala River cross-sections, in addition to the overtaking along Diyala River. Thus, the capacity of the river was reduced to 750m^3/s, **(DDWR, Flood Report,2019),** which led to overtopping the river banks; as a result, large areas were flooded in Ba'quba City. The Directorate of Water Resources in Diyala Governorate prepared a detailed report about the floods in 1988 and 2019. In 1988 and 2019, Hemrin Dam water levels were 105.7*m.a.m.s.l.* and 105.3 *m.a.m.s.l.*, respectively, while the normal water level dam is 104*m.a.m.s.l.* Also, the water levels of Diyala River were 44*m.a.m.s.l.* and 42.43*m.a.m.s.l.* in 1988 and 2019, in turn, as compared to the banks level, which is 41*m.a.m.s.l.* in Ba'quba City, at Al- Jumhuriya Bridge.

After the flood of 1988, a flood escape was constructed as a precautionary action, which is Salahdin Escape, and it was not used since its construction because it was not needed to. But during the flood of 2019, it was not possible to use Salahdin Escape because the areas around its banks, from the upstream side, transformed into residential and agricultural areas, which makes it risky to use it as a flood escape, in addition to the difficulty of its modification because of lands transformation. Therefore, the necessity to construct an alternative flood escape emerged.

This study aims to suggest and design a flood escape directly from Diyala River and within the reach that lies between Hemrin Dam and Diyala Weir, which would be an alternative to the old Salahdin Escape, in order to discharge the flood wave through it.

Fig.1 shows a layout of the study area. The reach of the Diyala River understudy is about 10*km* which extends from Hemrin Dam to Diyala Weir. Two main tributaries branched from Diyala Weir, Al-Sadr Al-Mushtarak and Al-Khalis. The discharge of Al-Sadr Al-Mushtarak is $126 m^3/s$ and diverted from the right side of the weir. Al-Khalis, whose discharge is $75 m^3/s$ and diverted from the left side of the weir. These tributaries distribute discharge to sub-branches in order to supply water to the governorate for multi-purpose use (**DDWR).**
Many irrigation projects in the governorate discharge their drainage water into Ashweicha Marsh in the southern part of Diyala Governorate. The marsh lies within Wasit and Diyala Governorates; the largest area of it lies in Wasit Governorate. The natural extension is $1337 km^2$ (**Center for the Restoration of Iraqi Marshlands and Wetlands).**

Figure 1. The general layout of the study area, by Arc GIS 10.7.1, ESRI.

2. LAYOUT OF THE SUGGESTED FLOOD ESCAPE

Fig.2 shows a general layout of the proposed flood escape that branches from Diyala River and discharges into Ashweicha Marsh, with a length of 94.3*km* and located at 1.6*km* upstream Diyala Weir.
This escape was proposed as an alternative to Salahdin Escape that constructed in 1988. According to the map provided by (**the General Authority for Surveying of the Ministry of Water Resources),** which indicates the inhabited and non-inhabited areas around the old Salahdin Escape, the new alternative escape path was selected. The path selection was conducted in a way

that the first 26.5*km* of the escape from the upstream side passed through the non-inhabited areas, which is located parallel to the old escape, then, this parallel part joined the remaining length of the old escape, because this length of the old escape located within the non- inhabited areas. **Fig.3** shows a layout of both Salahdin Escape and the alternative flood escape from Diyala River.

Figure 2. Schematic layout of the flood escape from Diyala River, by HEC-RAS 5.0.7.

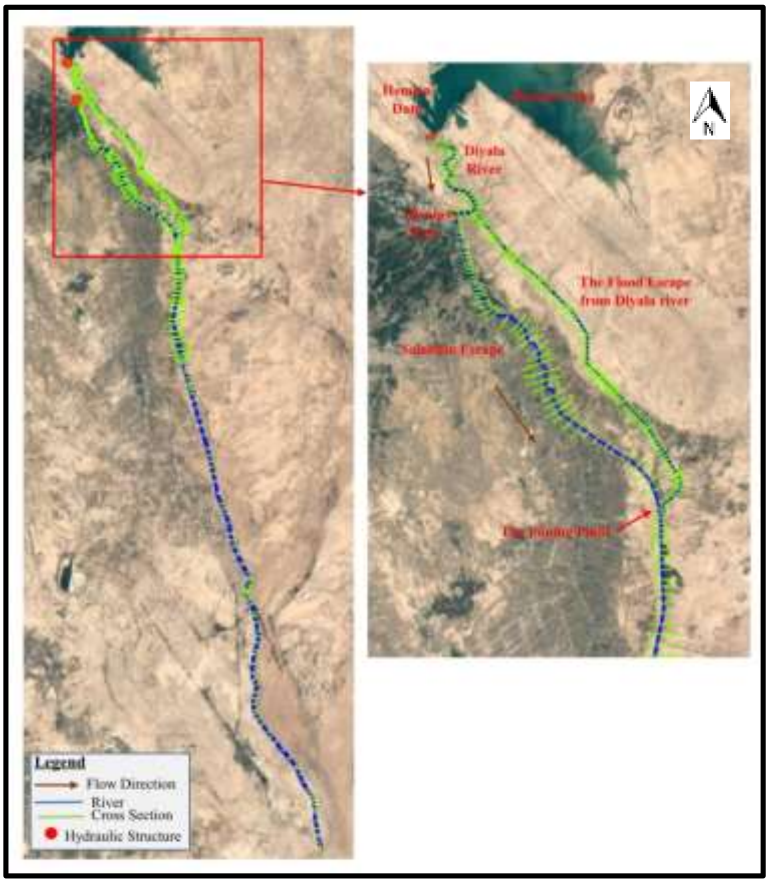

Figure 3. Schematic layout of Salahdin Escape and the flood escape from Diyala River, by HEC-RAS 5.0.7

3. ONE DIMENSIONAL HYDRAULIC MODEL

One dimensional hydraulic model was developed with the aid of HEC-RAS 5.0.7 software under unsteady state conditions. HEC-RAS is software designed by the US Corporation Engineers, Hydraulic Engineering Centre, in order to simulate and analyze steady and unsteady flow in rivers. The software solves the fundamental equations of flow in open channels, including energy equation, momentum equation, and 1D Saint Venant Equation using an iterative solution method. The hydraulic modeling was done by using geometric data and hydrological data. For the geometric data, two hundred and twenty-three cross-sections were extracted from the digital elevation model for the escape simulation. Besides, thirty cross-sections for the middle reach of the Diyala River were obtained from (**the Study of Strategy for Water and Land Resources in Iraq, SWLRI, 2014**).

Considering the coefficient of roughness and due to the lack of data about the area under study, the roughness coefficient was evaluated as follows; the first value is 0.035 **(Chaudhry, 2008)** was applied for the first 19.4*km* of the flood escape, which is a rocky area. Since the rest of the escape is located within the Diyala River basin, the second value was used depending on the roughness coefficient of the Diyala River that was determined in (**SWLRI, 2014)**, which is 0.028.

The hydrological data includes a discharge range that varies between 1100m^3/s and 1800 m^3/s out of Hemrin Dam were utilized as a boundary condition upstream of Diyala River reach under study (downstream Hemrin Dam). This range was selected based on the inflow to Hemrin Dam during the flood of 2019 (**DDWR, Flood Report, 2019).** A normal depth was adopted as a boundary condition at the downstream end of the escape and Diyala River and computed with a slope of 0.00077 and 0.00033, respectively. These values were calculated from the longitudinal profile of the river and the downstream side of the escape.

To carry out the computation of one-dimensional, unsteady-state flow within the suggested escape, the following data were defined by using HEC-RAS 5.0.7 software:

- Schematic layout of the flood escape and Diyala River was sketched, the escape and the river was sketched in the positive direction of flow, the river sketch started from downstream Hemrin Dam at upstream of Diyala River reach under study, and to the upstream of Diyala Weir at downstream of Diyala River reach under study. At the same time, the escape was sketched from the upstream at Diyala River towards the downstream direction, until Ashweicha Marsh. As shown in **Fig.2.**

- Cross-section data: 223 cross-sections for the escape were extracted from the digital elevation model of the study area that was generated with the aid of Arc GIS 10.7.1 software, and by using the feature of HEC- GeoRAS, the extracted cross-sections data exported to HEC-RAS. The data of cross-sections include station along with the cross-section and elevation data, in addition to downstream reach lengths. On the other hand, 30 cross-section data of Diyala River reach were located, and their data were defined. The data of these cross-sections include station along with the cross-section and elevation data, banks, and lengths of downstream reach. In addition to the two values of Manning coefficient 0.035 and 0.028.

- The boundary conditions that are used for running the model are: flood wave range from 1100m^3/s to 1800m^3/s were applied at upstream Diyala River reach, with a normal depth as a boundary condition at the downstream that computed with slope 0.00077. Regarding the escape, a normal depth at the downstream side was used as a boundary condition, computed with slop with slope 0.00033.

The Diyala River and the escape models were run simultaneously under unsteady state conditions, with a proposed flood period of 72hrs, which is the duration of maximum inflow to Diyala River during the flood of 2019 is enough to reach the steady-state.

Fig. 4 shows a longitudinal profile of the simulated flood escape with natural ground level.

The ground level at station 1+570*km* to 10+520*km*, varies between 105*m.a.m.s.l.* and 80*m.a.m.s.l.*, Then, the ground level falls rapidly to 47.17*m.a.m.s.l.* throughout 9.95*km*, a gradual decrease in ground level with a slope of 0.00033 takes place, reaching Ashweicha Marsh with ground level 20.44*m.a.m.s.l.*

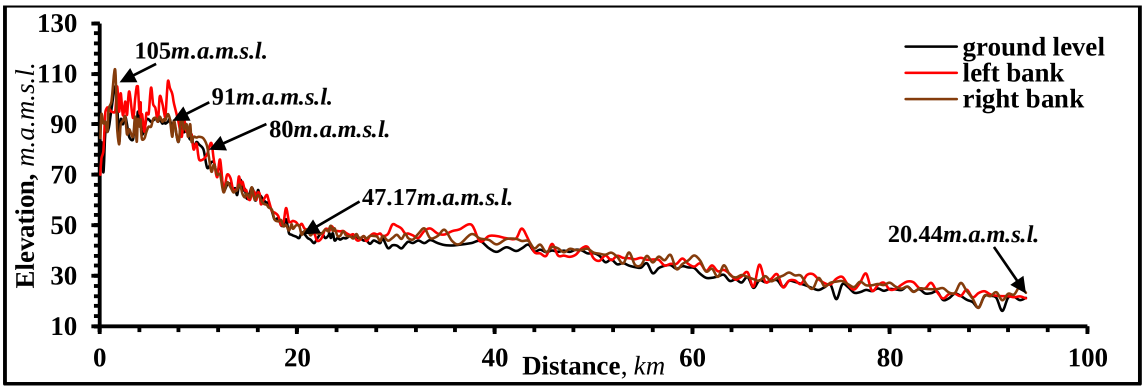

Figure 4. Longitudinal profile of the Diyala River Flood Escape with natural ground level.

4. RESULT AND DISSCUSION

Refinement was carried out on the escape from the station from 0+500*km* until 20+000*km*. This refinement includes lowering the high elevations that lie within the first 20*km* of the escape, aside weir at the upstream beginning of the escape, to work as a control structure, followed by a drop structure with a rectangular cross-section. **Fig. 5** shows the longitudinal profile of the escape after the refinement of the ground level. The crest level of the side weir was set to 67*m.a.m.s.l.*, followed by a drop structure that consists of four steps that lie between 61*m.a.m.s.l.* and 47 *m.a.m.s.l.*, the first three steps is of 4*m* height, the last step is of 2*m* height, the steps is 3*km* to 4*km* length depending on the ground level difference, the drop is within about 20+000*km*.

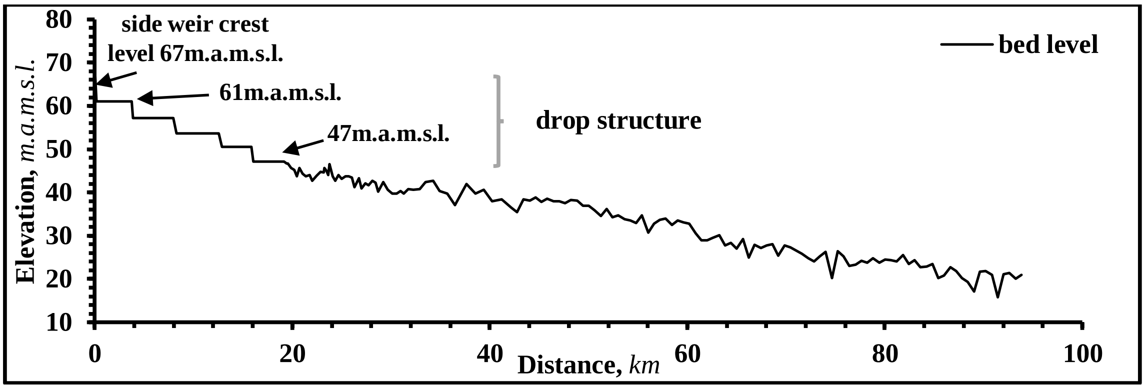

Figure 5. Longitudinal profile of the Diyala River Flood Escape, after modification.

In order to obtain the best side weir width, six values of side weir widths were conducted, with multiple drop structure widths and multiple cases of outflow from Hemrin Dam. The flow along the escape was simulated with a discharge range that varies between 1100m^3/s and1800m^3/s out of Hemrin Dam. This range was selected based on the inflow to Hemrin Dam during the flood of 2019 (**DDWR, Flood Report, 2019).** Different values of side weir width were assumed based on the discharge, and these width values were 200*m*, 300*m*, 400*m*, 500*m*, 600*m*, and 800*m*. Also, the drop width was 200*m* for side weir width of 200*m*, and 220*m* for side weir width of 300*m*, 400*m*, 500*m*, 600*m*, and when the side weir width was 800*m*, the drop width was set at 420*m*.

Table 1 summarizes the simulation results, including water level and discharge upstream Diyala Weir and the flood escape. The best side weir width selection depends on the conditions that the maximum discharge passes through Diyala Weir does not exceed 750m^3/s and the water level upstream Diyala Weir does not raise more than the maximum water level of Diyala Weir, which is 69*m.a.m.s.l.*, knowing that the design (operational) water level of the weir is 67.5*m.a.m.s.l.*

Table 1. Summary of the resulted water level and discharge upstream Diyala Weir and the flood escape

Width of side weir *m*	Discharge of Hemrin Dam m^3/s	Time *hrs.*	Diyala Weir: Maximum during unsteady state		Diyala Weir: Steady State		Time *hrs.*	The suggested escape: Maximum during unsteady state		The suggested escape: Steady State	
			Water level *m.a.m.s.l.*	Discharge m^3/s	Water level *m.a.m.s.l.*	Discharge m^3/s		Water level *m.a.m.s.l.*	Discharge m^3/s	Water level *m.a.m.s.l.*	Discharge m^3/s
200	1200	5	68.00	785.4	67.64	682	1	67.82	600	67.77	518
							5	68.14	414.6		
	1100	5	67.85	736.6	67.54	652	1	67.76	550	67.67	448
							5	67.98	363.4		
300	1300	5	68.00	789	67.62	675	1	67.51	683.1	67.75	625
							5	68.15	511		
	1200	5	67.91	752.5	67.54	653	1	67.72	600	67.68	547
							5	68.00	447.5		
400	1300	5	67.98	774	67.54	653	1	67.43	710.7	67.67	647
							5	68.11	526		
500	1500	5	68.00	787	67.57	660	1	67.48	912	67.7	840
							5	68.14	713		
	1300	5	67.95	768	67.48	639	1	67.36	727.7	67.62	661
							5	68.00	532		
600	1500	5	67.98	779	67.51	647	1	67.43	926	67.64	853
							5	68.10	721		
800	1800	4	68.27	960	67.64	678	1	67.43	1231	67.76	1122
							4	68.41	840		
	1500	4	67.88	750	67.42	620	1	67.35	936	67.55	880
							4	68.00	750		

All the examined widths of the side weir complied with the criteria of the maximum water level but not all of them comply with the criteria of the maximum discharge passes through Diyala Weir. Consequently, the selection of side weir width depended on the discharge that was delivered to downstream Diyala Weir.

For a side weir width of 200m, when 1200m3/s discharged downstream Hemrin Dam, the discharge at just upstream Diyala Weir during the unsteady state was 785.4m3/s 68*m.a.m.s.l.*, and this discharge does not comply with the criteria. Moreover, the water level throughout the steady-state of the proposed flood period was more than the weir design water level by 0.14*m*. At the same time, the width of 200*m* and outflow of 1100m^3/s gave a discharge of 736.6m^3/s throughout the unsteady state, which was considered safe. Additionally, the water level during steady-state 67.54*m.a.m.s.l.* upstream the weir, which is nearly equal to the design water level.

Regarding a side weir width of 300*m*, with an outflow of 1300m^3/s, resulted in a discharge of the unsteady state was 789m^3/s at just upstream Diyala Weir, which is considerably higher than the maximum discharge of Diyala River. While, the steady-state gave a discharge less than the maximum discharge, but the water level exceeds the design water level by 0.12*m*. Although the steady-state water level and discharge are safe when the width of 300*m* and outflow of 1200m^3/s, but the discharge during the unsteady state was 752.5m^3/s, which is higher than the maximum discharge.

For a width of 400*m* and an outflow of 1300m^3/s, the discharge just upstream Diyala Weir was remarkably more than the safe limit during the unsteady state.

Despite the acceptable results of the steady-state for a width 500*m* and outflow values of 1500m^3/s and 1300m^3/s, but for the unsteady state, the resulted discharges upstream Diyala Weir were 787m^3/s and 768m^3/s for the two outflows of 1500m^3/s and 1300m^3/s, respectively. These discharges are noticeably higher than the safe discharge of Diyala River.

The results of 600*m* side weir width and an outflow of 1500m^3/s showed that a discharge of 779m^3/s delivered to Diyala Weir at 67.98*m.a.m.s.l.* during the unsteady state, this could not be considered as secure as compared to the allowable discharge limit.

Regarding a side weir width of 800*m* and outflow of 1800m^3/s, even though this case passed the highest amount of discharge through the escape, it resulted in discharge at Diyala Weir extremely higher than the safe limit. Nevertheless, if an outflow of 1500m^3/s discharged downstream Hemrin Dam using a side weir of 800m width, the delivered discharge to Diyala Weir would be 750m3/s, equal to the maximum discharge value, and at a water level of 67.88*m.a.m.s.l.*

Accordingly, a side weir width of 200*m* with an outflow of 1100m^3/s, and a side weir width of 800*m* with an outflow of 1500m^3/s, these two cases gave discharges to downstream Diyala Weir of 736.6m^3/s and 750m^3/s, which were the least among all width cases, which are safe discharge to Diyala River. Therefore, choosing the side weir with a higher flood discharge to the escape would be most beneficial for safety. In addition to select the side weir case that allowed to make use of the full capacity of Diyala River to get rid of the flood wave as fast as possible.

A side weir width of 800*m* that is in line with an outflow of 1500m3/s is the most acceptable case, which delivered discharge of 750m3/s and 880m3/s to Diyala River escape, respectively. On the other hand, for a side weir 800*m*, the critical case of unsteady-state lasted for four hours. Whereas, for 200*m*, the unsteady state lasted for five hours.

After the four critical hours ending, the steady-state was reached with a discharge of 620m^3/s at 67.42*m.a.m.s.l.* at just upstream Diyala Weir, which considered secure as compared to the safe limit.

Fig.6 shows the longitudinal profile for the escape, maximum water level, levee level, and natural banks level. From station 16+600*km* to the end of the escape, a levee was used to raise the bank level to accommodate the resulting water level. Since the bank level differs at each location, **Fig.4**, the levee rise varied from 1*m* to 4*m* along with the escape, giving freeboard value 1.5*m* to 2*m*. But the distance between 0+000*km* and 16+600*km* is naturally high, and no levee is required. Knowing that the freeboard differs at each location throughout the escape because the levee was raised with a different value at each location to keep it in regular slope, systematic and uniform profile to provide a practical implementation.

Each levee level was simulated in HEC-RAS as geometry data through the 'levee' feature. This feature allows rising the bank level with a specified levee value in each cross-section of the escape.

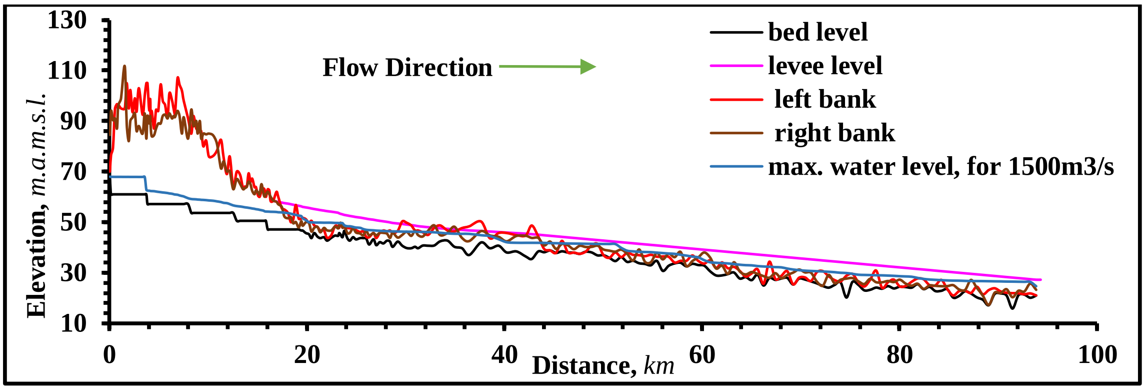

Figure 6. Longitudinal profile of the Diyala River Flood Escape, Maximum Water Level, Bank and Levee Levels.

5. CONCLUSIONS

It is necessary to construct a flood escape from the Diyala River to avoid flooding the cities and villages along the river, as happened in 1988 and 2019. The well-known HEC-RAS 5.0.7 was used to develop one dimensional hydraulic model for the flood escape to discharge the flood wave through it. The escape branched from Diyala River, with a length of 94.3*km*, and passes to the south of Diyala Governorate until Ashweicha Marsh.

According to the analysis of the results, the following conclusions are made:

- An alternative flood escape was proposed, branching from Diyala River, at 1.6*km* upstream Diyala Weir.
- A side weir was simulated at the escape entrance, with 800*m* width and 67*m.a.m.s.l.* crest level. This side weir was followed by a drop structure with four steps to eliminate the steep slope of the natural ground level.
- From station 16+600*km* to the end of the escape, the bank level was raised by 1*m* to 4*m* along with the escape to provide a sufficient freeboard value of 1.5*m* to 2*m*.
- Adopting flood escape from Diyala River with side weir of 800*m* width and 67*m.a.m.s.l.* crest level, this case would be effective in supplying safe discharge through Diyala Weir if it in line with releasing 1500m^3/s from Hemrin Dam or less.
- Lowering the crest level of the side weir of the flood escape from Diyala River (in order to increase the inflow to the escape) less than 67*m.a.m.s.l.* would affect the operational water level of Diyala Weir, which is 67.5*m.a.m.s.l.*, also, it would reduce the river discharge in natural conditions, especially at low flowrates.

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