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The Effect of the Geometry of the Head Race Channel of Proposed Makhoul Dam on the Velocities Distribution within the Reservoir of the Dam

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Abstract

The Makhoul Dam project is considered one of the important strategic projects that Iraq is studying the possibility of establishing. It is located on the Tigris River about 170 *km* north of Baghdad Capital Particularly on the northeastern side of Sallah Al-Din City, about 30 *km* northwest of Baji town. This research aims to investigate the effect of the Geometry of the U/S Head Race Channel of the dam (dam guides) on the distribution of velocities inside Makhoul Dam Reservoir with different operating conditions for the spillway. A mathematical model is prepared by using HEC -R AS 2D program version (5.0.7, 2016) to analyze the velocity distributions inside Makhoul Dam Lake. The two dimensional hydraulic model is calibrated using a wide range of Manning's coefficient (n) that are ranged from 0.02 to 0.03. The agreement of velocity patterns resulting from using the Mathematical model was evaluated by using a statistical index of agreement, chi-square (x^2). A good agreement was obtained when the Manning's coefficient is 0.026. The results showed the effect of the Head Race Channel on the velocities distribution is focused in the region outside the concrete part of the dam body (between the embankment guides) for all operating conditions. As there is no effect of the dam's embankment guides for the head race channel on the distribution of velocities in the area between the concrete part of the dam body. The maximum flow velocity between the embankment guides is 3 *m/sec* in the case of guides, and 2.5 *m/sec* in the absence of the dam guides.

Keywords: Hydraulic Study, Makhoul Dam, HEC-RAS, Makhoul Lake.

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دراسة تأثير القناة الرأسية لسد مكحول المقترح على توزيع السرعة داخل خزانه

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الخلاصة

يعتبر مشروع سد مكحول من المشاريع الاستراتيجية المهمة التي يدرس العراق مدى امكانية انشاؤها حيث يقع السد على نهر دجلة على بعد حوالي 170 كم شمال مدينة بغداد وتحديداً في الجزء الشمالي الشرقي من مدينة صلاح الدين ، وحوالي 30 كم شمال غرب قضاء بيجي. يهدف هذا البحث إلى معرفة تأثير للقناة الرأسية اعلى جسم السد الخرساني على توزيع السرعات داخل خزان سد مكحول مع خطط تشغيل مختلفة لبوابات المسيل السفلي. تم إعداد نموذج رياضي باستخدام الإصدار 5.0.7 لعام 2016 من برنامج HEC-RAS ثنائي الأبعاد لتحليل أنماط السرعة داخل خزان سد مكحول. تمت معايرة النموذج الهيدروليكي ثنائي الأبعاد باستخدام نطاق واسع من القيم لمعامل مانينغ (n) الذي يتراوح بين 0.02 إلى 0.03. تم تقييم توافق أنماط السرعة الناتجة عن استخدام النموذج الرياضي باستخدام مؤشر إحصائي مربع كاي (x^2). تم الحصول على توافق جيد عندما كان معامل مانينغ 0.026. أظهرت النتائج أن تأثير السداد المكونة القناة الرأسية على توزيع السرعات يتركز في المنطقة الواقعة خارج الجزء الخرساني من جسم السد لجميع السيناريوهات حيث لا يوجد تأثير لتلك القناة على توزيع السرعات في المنطقة القريبة من محور السد على مسافة حوالي 100 متر. بلغت اقصى قيمة للسرعة في المنطقة المحصورة بين السداد المكونة للقناة 3 *م/ثا* في حالة انشاء القناة و 2.5 *م/ثا* في حالة عدم انشاء القناة.

الكلمات الرئيسية: دراسة هيدروليكية, سد مكحول , هيكراس, بحيرة مكحول.

1. Introduction

The Makhoul Dam project is considered one of the strategic and important projects that the Republic of Iraq is studying the possibility of establishing. Makhoul Dam is located on the Tigris River about 170 *km* north of Baghdad Capital and 30 *km* northwest of Baji town. Makhoul Lake was designed to control the floods of the Tigris River. Its function was developed to make use of the stored excess water to compensate for water shortages during water scarcity seasons **(MoWR 2020)**. When completed this project will secure a reservoir of three billion cubic meters of water, will provide better protection for the Samarra Barrage and the city of Baghdad from the flood danger, will provide electrical energy estimated at 260-*megawatt*, and will feed millions of agricultural land with water through irrigation projects which will be constructed on it later). The dam length and the reservoir area are 3670 *m* , and 256000000 m^2 receptively. Many investigations used several software to study the different flow patterns by implementing mathematical models.

(Al- Furatt Centers four studies and designs off irrigation projects, 2002) Implemented the laboratory hydraulic model for the Makhool Dam Project at Taji Town. The scale of the physical model is 1/100r and all dam structures were represented in this study. The values of average velocity were measured at 0.60 *m* from the depths. The results of this study showed several scenarios for operating the dam according to the discharges and water surface elevations, in addition to recommending the possibility of decreasing the height of the spillway about 0.5 m to become the height of the gates 7.5 m. **(Xie et al, 2014)** studied the hydrodynamic model of Jinshan lake in Zhenjiang. They used the commercial software surface water modeling system (SMS). This study selected the Manning and eddy viscosity coefficients were 0.036 and 1500 kg/m.sec respectively, depth convergence parameter of 0.0001, and paving mesh. They compared the simulation results with the measured values obtained from the hydrological monitoring. The obtained results showed that good agreement between the values of flow velocity and water level measured with the simulated values by SMS program. **(Joshi and Shahapure, 2017.)** Prepared a two-dimensional hydraulic model of Ujjanii Dam, India, by using the HEC-RAS software to find out the flood-prone area at the downstream side of the dam. The Digital Elevation Model (DEM) was obtained from Indian Geo-platform of Indian Space Research Organization and Terrain Model was created 15 from DEM. The simulation was carried out and the results showed that the area has been covered the flooding under a discharge 41000 m^3 */sec*. (**Abed and Azzubaidi, 2020)** studied characteristics of sediment accumulation that occurred in the reservoir of Mandali dam. The SMS software was used to investigate the velocity and water depth within the reservoir and the SED 2D model is used to investigate the distributions of concentrations and bed changes variation inside the Mandali Lakes. Different values of discharge and sediment were assumed. The result explained that the concentration is very high at upstream of the reservoir and decreases gradually towards then spillway outlets. In addition, the highest concentration of sediments appeared in the middle parts of the lake due to an immediate decrease in the velocity in these parts, which leads to high sediment deposition. **(Daham and Abed, 2020)** studied the hydraulic properties of Al-Gharraf River by using HEC-RAS software 1D and 2D. Numerical models were simulated using flow rates ranging, from 1000 to 350 m^3/sec. The results showed that the average velocities varied between 0.25 and 0.44 *m/sec* for the two-dimensional model. While these, values varied between, 0.36 and 0.5 *m/sec* four the one-dimensional, models. The researchers also showed that the results obtained from the 2D models were more, accurate, than those obtained from the 1D model. (**Psomiadis et al., 2021)** studied potential dam breach and estimated the risks of flood waves using HEC-RAS Two-dimensional and remote sensing data for the Bramianos Dam, in Iran. The aims of the study are to examine the influence of the failure that possibly occurs in the dam in two states piping and overtopping, and the behavior of the flood wave that will occur from for break dam. Two different methods were used to obtain cadastral data for the study area, a DEM (digital elevation model) .and a UAS (unmanned aerial vehicle) derived DSM (detailed digital surface model). The results indicate that the influence of the dam break of Bramianos Dam is dangerous and suitable operation must be taken to decrease risks by controlling the water volume stored in the reservoir, DSM was more accurate than DEM in showing the topography and natural obstacles of the study area. **(Altawash and Al Thamiry, 2022)** studied the distribution of velocity inside the Reservoir of Makhool dam at the highest operating level by various cases to operate the bottom spillway of the dam (gates), that is different scenarios in terms of these numbers off opening gates, the sequence of open gates, or the opening height of these gates, through the representation of the dam body and its appurtenances (the concrete dam body, The bottom spillway, the emergency spillway, the body of the earthen dam, embankments guides in the reservoir) using the HEC-RAS and GIS programs according to the designs prepared by the beneficiary, then investigating the maximum velocity values for each scenario and recommending the best cases for the operation of the dam and the possibility of staying away from high-velocity cases as much as possible.

This research aims to investigate the effect of the Geometry of the U/S Head Race Channel of the dam on the distribution of velocities inside the reservoir of the Makhoul Dam with different operating conditions for the spillway. Through comparison with the results of the study mentioned in **(Altawash and Al Thamiry, 2022)**.

2. Study Area and Inputs Data

The project of Makhoul Dam is considered one of the strategic and important projects which the Republic of Iraq study planning on its construction in the North of the country. The Makhoul Dam is located on the Tigris River in Salah Al-Din City, near the Baiji Town. **Figure 1** shows the location of reservoir region for Makhoul Dam Through using of HEC-RAS and GIS programs. The properties of Makhoul Region are represented in **Table 1** , and the information of steel structures is shown in **Table 2.**

The climate of the Makhoul Dam reservoir could be classified as a hot, and dry in summer, and the cold and wet in winter. To illustrate the storage capacity and submerged areas of the Makhoul Dam Lake with differences in water levels inside the reservoir, this is shown in the **Figure 2.**

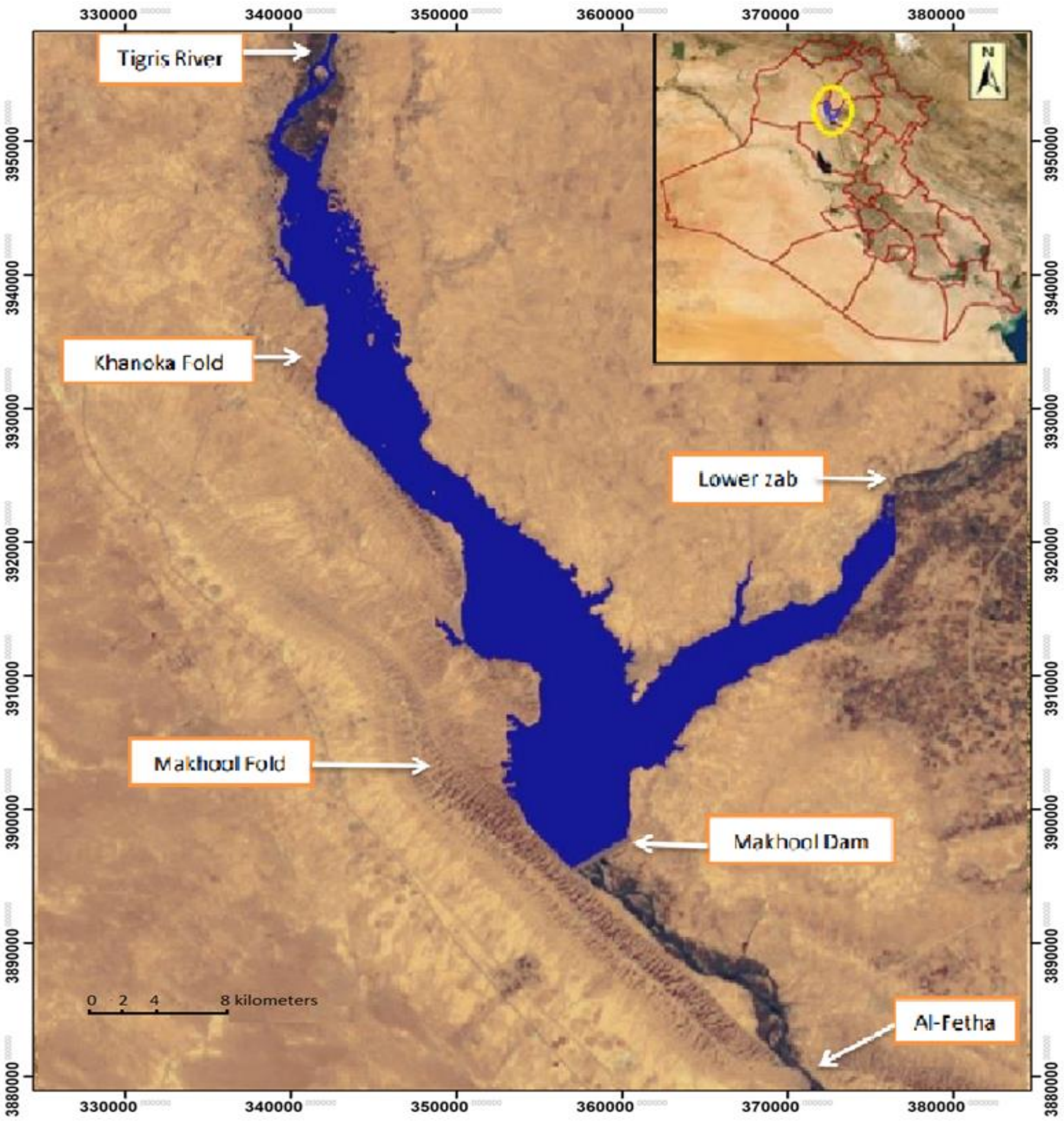


Figure (1): The locations of Makhoul Reservoir **(Altawash and Al Thamiry, 2022)**.

Table (1): General properties of Makhoul Dam **(Altawash and Al Thamiry, 2022).**

The top level of the dam	160.0 *m.a.m.s.l.*
Dam height (from the lowest point on the riverbed).	56 *m*
Top width of the dam.	12 *m*
Dam length at the top level.	3670 *m*
Maximum design flood level.	152.150 *m.a.m.s.l.*
Maximum design operating level.	150.250 *m.a.m.s.l.*
Minimum design operating level.	140 *m.a.m.s.l.*
The storage volume of makhoul reservoir at a level (150 *m.a.m.s.l.*)	2.90 $bn.\ m^3$
The storage volume of Makhoul Reservoir at a level (140 *m.a.m.s.l.*)	0.9860 $bn.m^3$
The storage volume of Makhoul Reservoir used annually	1.9140 $bn.m^3$
Bottom Spillway discharge (has gates)	22200 m^3/sec
Emergency Spillway discharge (no gates)	1303 m^3/sec
The flood discharge designed of reservoir	18000 m^3/sec

Table (2): Information about the gates of the Makhoul Dam, **(Altawash and Al Thamiry, 2022).**

Name of structure	type of gate	Gates No.	Dimensions of Gate, m
Bottom spillway	Radial gate	16.0	10.0 × 8.0
Power station	Fixed wheel gate	4.0	10.0 × 10.0
Fish ladder	sliding gate	4.0	2.0 × 2.0

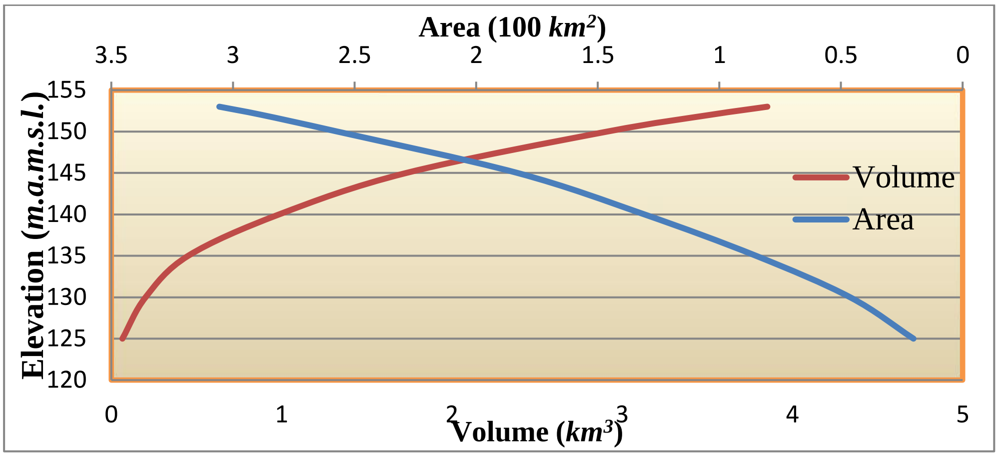


Figure (2): Curve of Elevation -Area- Volume for the Makhoul Lake. **(Engineering Consulting Bureau of Al-Anbar University, 2020).**

3. Methodology

3.1. Numerical Model

For this study, the software is utilized to developed 2D unsteady hydraulic model of Makhoul Lake with several different conditions. This software is a well-known HEC-RAS, version (5.0.7) March 2016 developed by the US Army Corps of Engineers, is capable of simulating the hydraulics properties, water quality and sediment transport in rivers, estuaries and channels. A two-dimensional HEC-RAS hydraulic model is used to simulate the flow characteristics inside Makhoul Dam Reservoir after representing and adding of Makhoul Dam structures and n required boundary conditions. The boundary condition depends on the selected data that obtained from the relevant authorities in Iraq that collected over several years. The numerical model of Makhoul Dam contains of earth embankment, guide banks and outlet structures (bottom spillway, emergency spillway, fish pass, and powerhouse). The bottom spillway of the Dam is designed as a gated outlet, while the emergency spillway is free-opening. The gated spillway consists of 4 sections as shown in **Figure 3** which shows the spillways of Makhoul Dam after representing them in the program used in this study.

The Layer of Terrain is associated with the DEM which can be obtained from GIS software, for this research, the DEM is obtained from **(the General Authority for Surveying in Iraq).** In this study, the topography inside the reservoir and near the dam body is modified according to the designs information by the Arc-GIS software, Hence, issuing a new DEM .Created Terrain layers can be added to the HEC-RAS 2D program from RAS-Mapper Window after the projection of the project **(Manual of HEC-RAS 5.0)**, and set by using the UTM system (WGS 1984.0, ZONE 38.00).

To generate the two-dimensional flow areas, a polygon lines must draw in the window of geometry. After that s, the grid is formed by entering the value of spacing between .each grid, in this study, the finite element mesh of Makhoul Reservoir was generated with the dimension of (10.0×10.0) m To generate a grid of cells consisting of (5.491.664 cells) in the study area.

In this study, the boundary conditions are the flow hydrograph for water sources that resource Makhoul Lake, which are the Tigris River and the Lower Zab tributary as explained in **Figure 4**. For the downstream, the boundary condition is the rating curve to control outlet discharge from the reservoir as shown in **Figure 5.**

3.2. The Guide Banks

Guide Bank are earthen embankments with stone pitching in the slopes facing water, to force the river into the restricted channel, to ensure the smooth and axial flow of water near the weir site. Gide banks are constructed in upstream or downstream or both near the hydraulic structures. In Makhoul Dam, the guides were constructed at the upstream and downstream with different dimensions and angles. The u/s head race channel of the dam is represented by using the geometry window in the HEC -RAS program as explained in the **Figure 6. (Altawash and Al Thamiry, 2022)** and **Figure 7.** Show the representation of the dam and downstream guides by the geometry window in the HEC -RAS without guides of upstream head race channel.

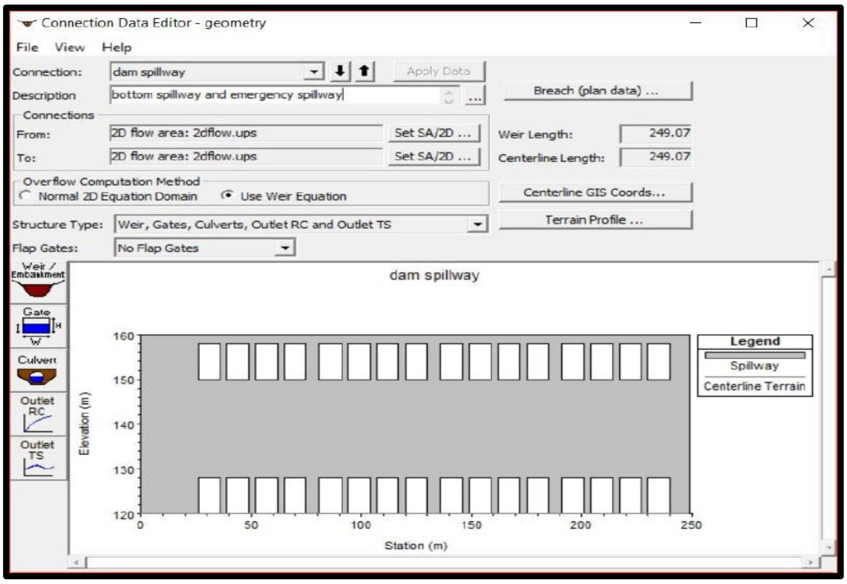


Figure (3): The spillways of Makhoul Dam (gated and emergency) that implemented in the HEC-RAS Program. **(Altawash and Al Thamiry, 2022)**

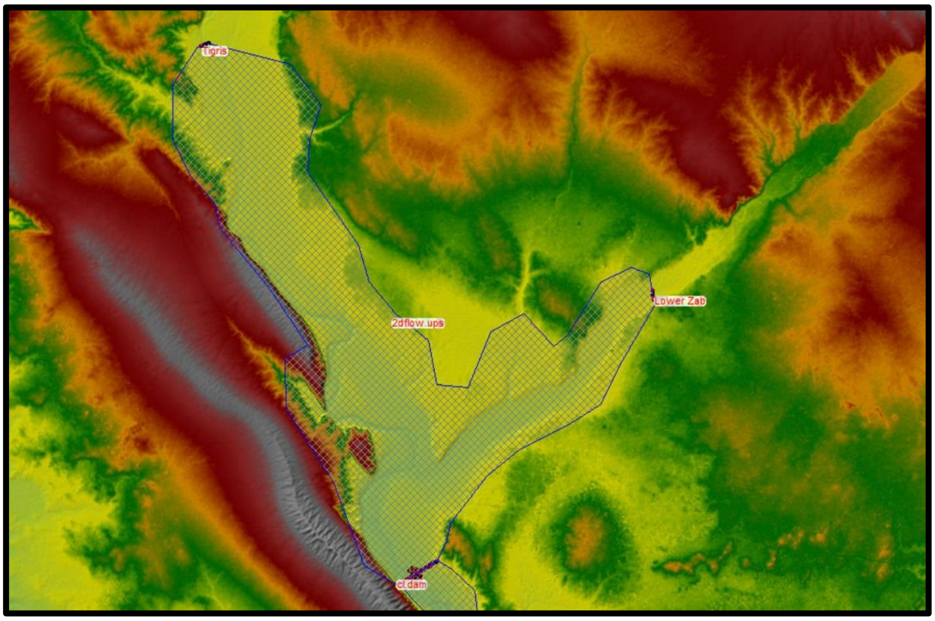


Figure (4): The upstream boundary conditions for the inlet of the Makhoul Lake. **(Altawash and Al Thamiry, 2022)**

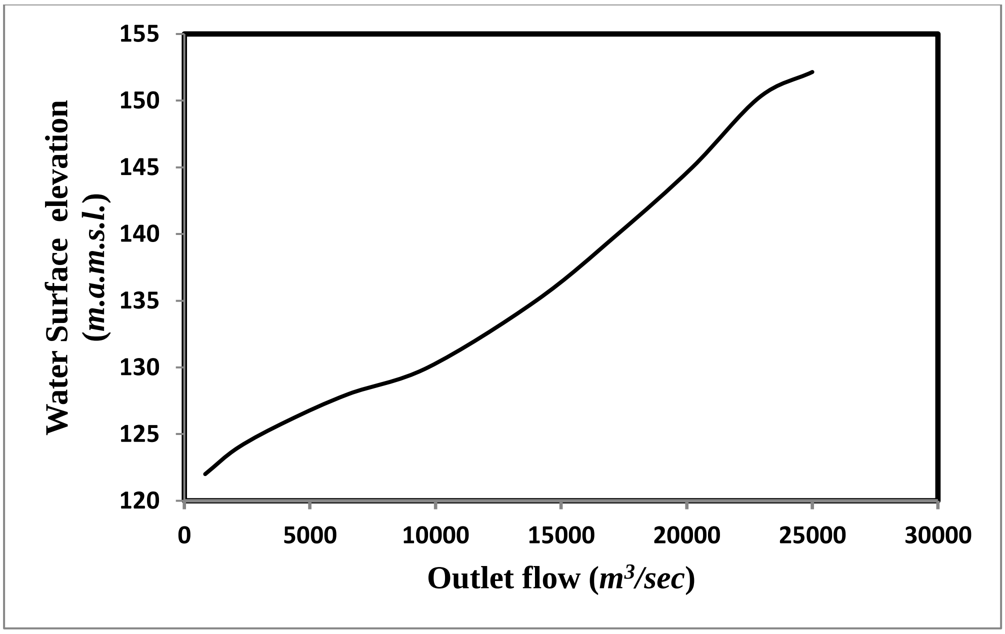


Figure (5): The boundary condition for the downstream of the Makhoul Lake, (**Al- Furat Center for Studies and Designs of Irrigation Projects, 2002**) .

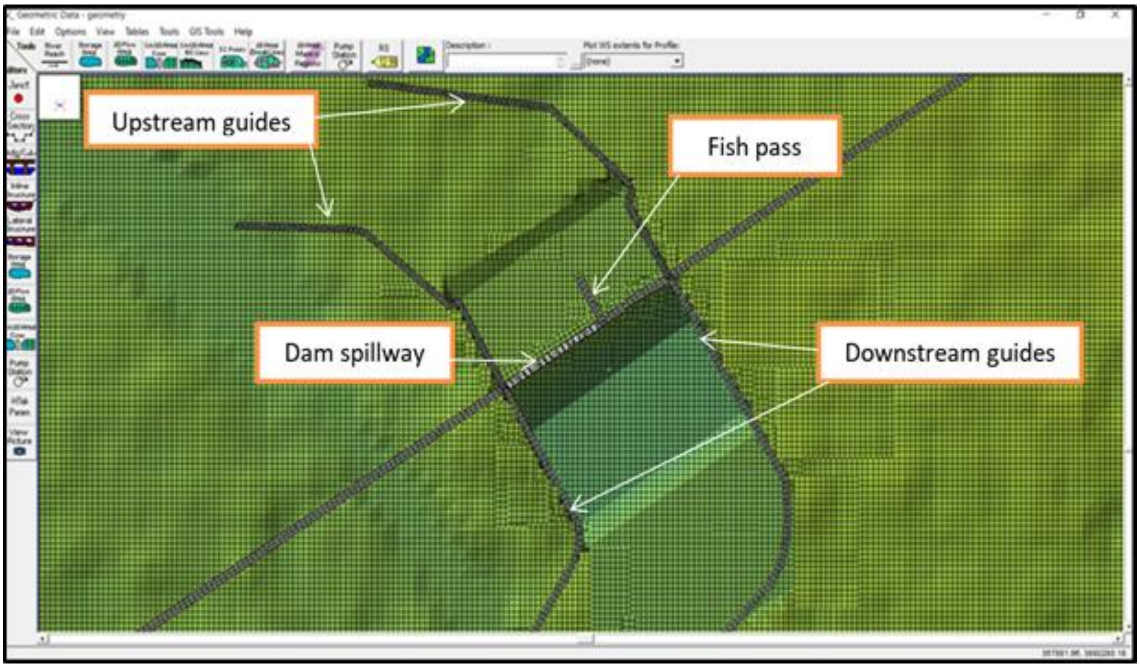


Figure (6): The representation of the Dam and Head Race Channel by the geometry window in the HEC -RAS Software as designed.

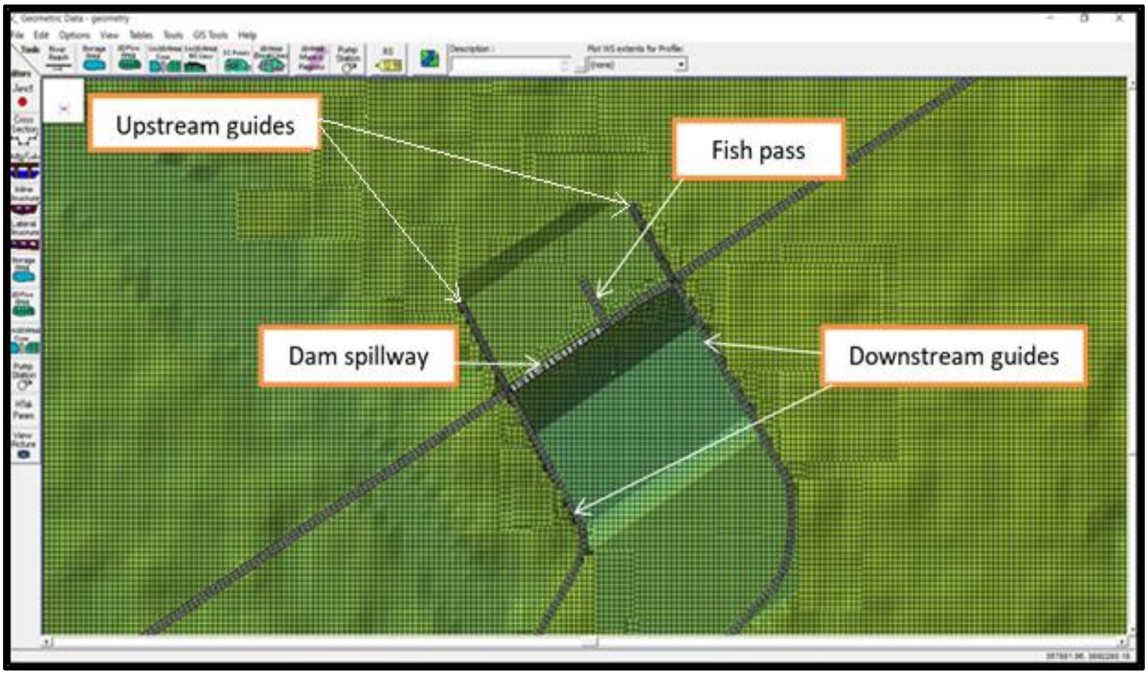


Figure (7): The representation of the dam and downstream guides by the geometry windows in the HEC--RAS without Head Race Channel.

4. Theory and Calculation

4.1. Basic Equation That Governing 2-D Flow Modeling

The Hydraulic properties that include distributions of velocity , water depths and the water surface elevations were simulated by using the numerical model developed through the HEC-RAS two-dimension program. The two-dimensional unsteady state was used to develop the numerical hydraulic model of the Lake of Makhoul Dam. The HEC-RAS Tow-Dimension is based on the numerical solutions that describing by the conservation of the mass and momentum equations in the two horizontal dimensions that could be shown as follows : **(Karim K. A., 2018)**:

Continuity equation

$$\frac{\partial H}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} + Q = 0 \tag{1}$$

Momentum equation (differential form)

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial H}{\partial x} - v_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + C_f u - fv = 0 \tag{2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial H}{\partial y} - v_t\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + C_f v - fu = 0 \tag{3}$$

Where ; u and v = velocities component , g = the gravity acceleration , v_t= the coefficient of eddy viscosity, C_f= friction coefficient fo r channel bed , and f = Coriolis parameter . x, y =horizontal and vertical directions, t= the time , and H= the water surface elevation.

4.2. Criteria of Model Evaluation

The calibration process's purpose is to determine the accuracy of the numerical simulation model implemented by the program. The calibration is done by testing several Manning's n and comparing the simulated velocity by the numerical model with the measured velocities in the laboratory hydraulic model under the same conditions. The physical hydraulic model is conducted by (**The Center for Studies and Designs, 2002)** of Iraqi Ministry of Water Resources. The two dimensional hydraulic model is calibrated using a wide range of Manning’s coefficient (n) that are ranged from 0.02 to 0.03. The agreement of velocity patterns resulting that obtained from HEC-RAS is evaluated by using a statistical index of agreement, chi-square (x^2). A good agreement was obtained when the Manning's coefficient is 0.026 as shown in **Figure 8.** This criterion is calculated as follows:

$$X^2 = \sum \frac{(M_i - O_i)^2}{O_i} \tag{4}$$

Where:

n = number of values,

Oi = values predicted by using HEC -RAS 2 D, (m/sec),

Mi = values predicted from the hydraulic physical model, (m/sec),

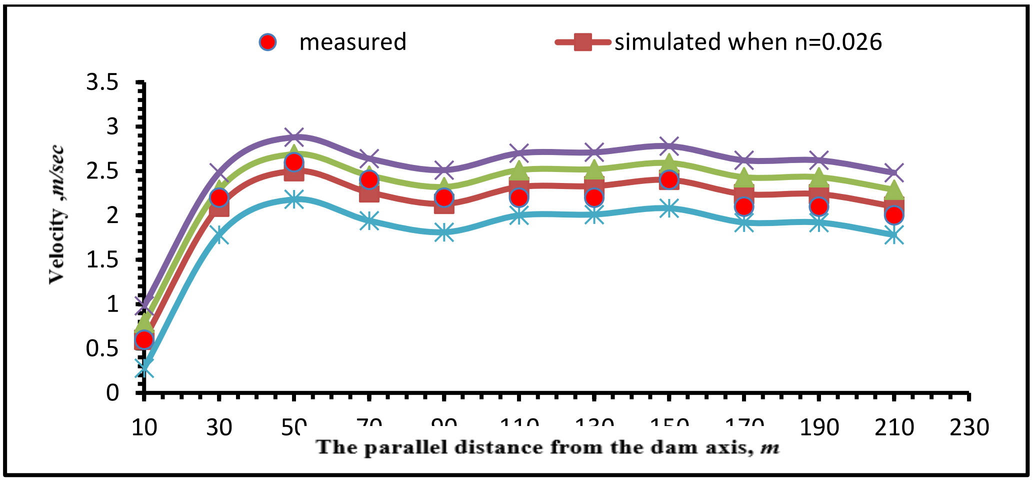


Figure (8): Calibration of the measured and simulated velocities along the dam axis at the location of spillway gates with the discharge of 20224.0 m^3/sec, the reservoirs W.SE of 150.2500 *m.a.a.m.s.ll.* .

5. Analyze and Results

Unsteady 2D hydraulic numerical models are simulated for several scenarios at the reservoir water level of 150.250 *m.a.m.s.l.* with different operating conditions for the spillway. These scenarios are the same as those implemented in **(Altawash and Al Thamiry, 2022)** to facilitate a comparison between cases of evidence that were studied in **(Altawash and Al Thamiry, 2022)** research and cases without guides of u/s headrace channel that were studied in this research. The inlet discharge to Makhoul Lake is 3034 m^3/s (2640 m^3/s for Tigris River, 394 m^3/s for lower Zab Rivir). The flow simulation on the upstream side of the Makhoul Dam (near the dam body and guide zones) indicated the velocity distributions in this area. These process scenarios are coded as: for example **(S-16G-2H-5691)** which means the operation spillway scenarios of sixteen gates with opening height of 2 m, and the outlet discharge is 5691 *m^3/sec*, It is to be noticed that each scenario will be simulated two times, with the embankment guides and without embankment guides under the same conditions. **Figure 9 to Figure 13** show velocities distribution and the effect of the embankment guides on the velocities in the scenarios of spillway operation when the reservoir WSE is 150.250 *m.a.m.s.l.*.

Figure 9 and 10 show the effect of the dam guides on the distribution of velocities in the Makhoul Reservoir (near the dam) for scenarios (**S-16G-2H-5691**) and **(S-16G-4H-11520)**, respectively. In scenario **(S-16G-2H-5691)** that has the outflow of 5691 *m^3/sec*. The velocity in the case of the presence of the guides in the region outside the concrete body of the dam (between the embankment guides) is ranged from 0.2 to 1.6 *m/sec*, and the high velocity is concentrated at the beginning of embankment guides, while in the absence of guides, the velocity is distributed in the same region between 0.2 and 1.05 *m/sec*, and the high velocity is concentrated near the concrete dam body. For scenario **(S-16G-4H-11520)** that has the outflow of 11520 *m^3/sec*. The velocity in the case of the presence of the guides between the embankment guides is ranged from 0.2 to 2.5 *m/sec*, and the high velocity is concentrated at the beginning of embankment guides, while in the absence of guides, the velocity values are distributed in the same region between 0.2 and 2 *m/sec*, and the maximum velocity is concentrated near the concrete dam body.

In **Figure 11 and 12** the results of scenarios **(S-16G-6H-16793)** and **(S-12G-8H-16793)** are shown that have the outflow of 16793 *m^3/sec* but with a difference in gates operation plan, the effect of the embankment guides on the velocities distribution in the Makhool Reservoir in the region outside the concrete part of the dam body (between the embankment guides) is same for both scenarios. The velocity in the case of the presence of the guides in this region is ranged from 0.5 to 3 *m/sec*, while in the absence of guides are distributed in the same region with values between 0.2 and 2.5 *m/sec*.

For scenario **(S-16G-8H-22200)**, clarified the effect of the dam guides on the velocities distribution in the Makhoul Reservoir when the outflow is maximum as 22200 *m^3/sec*, the results of the velocity distribution with the embankment guides in the region outside the concrete part of the dam (between the embankment guides) is ranged between 0.5 to 3 *m/sec*, the high velocity is concentrated at the beginning of embankment guides, while without these guides, the distribution in the same region is ranged between 0.5 and 2.5 *m/sec* and the high velocity is concentrated near the concrete dam body, as shown in **Figure 13.**

In addition, other scenarios were simulated, the results of which are listed in **Table 3** which explains the all simulation results for the velocities range obtained in this research (without guides of u/s head race channel) and comparative results (with u/s head race channel).

Figure14. Show the water depths within the Makhoul Lake at a WSE of 150.250 *m.a.m.s.l.*, **(Altawash and Al Thamiry, 2022)**

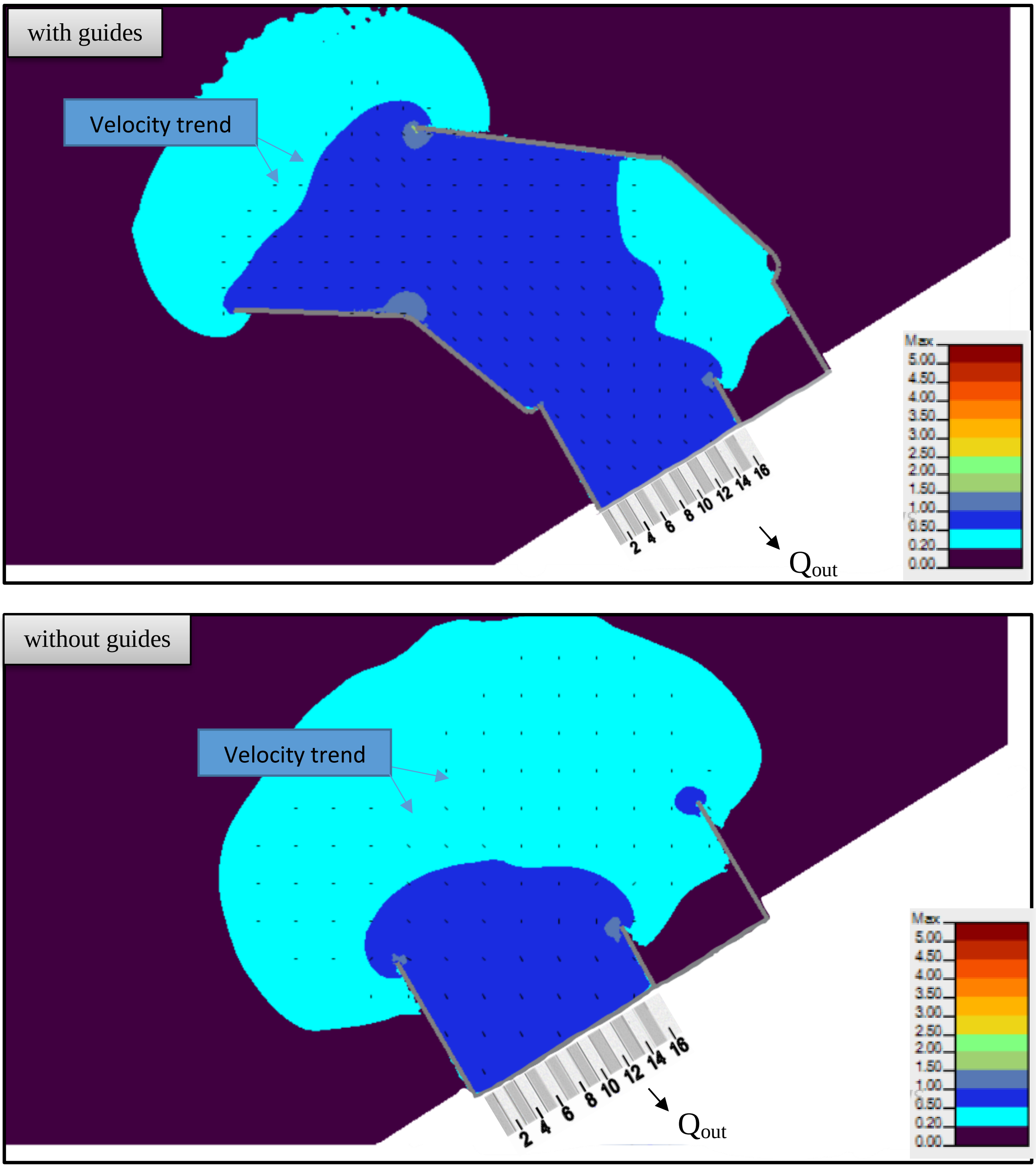


Figure (9): The effect of the U/S Head Race Channel on the distribution of velocities in the Makhoul Reservoir for scenario **(S-16G-2H-5691).**

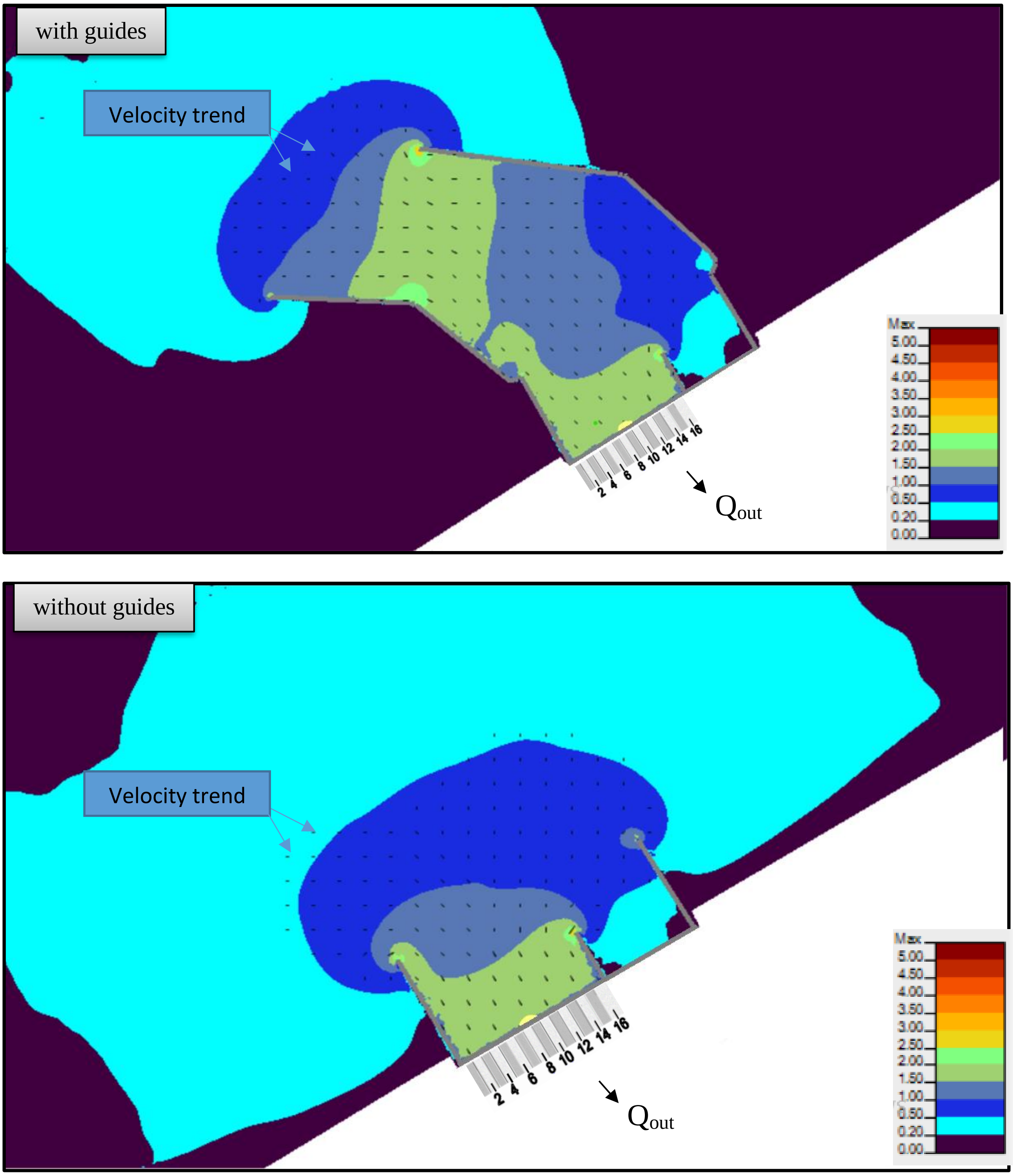


Figure (10): The effect of the U/S Head Race Channel on the distribution of velocities in the Makhoul Reservoir for scenario **(S-16G-4H-11520).**

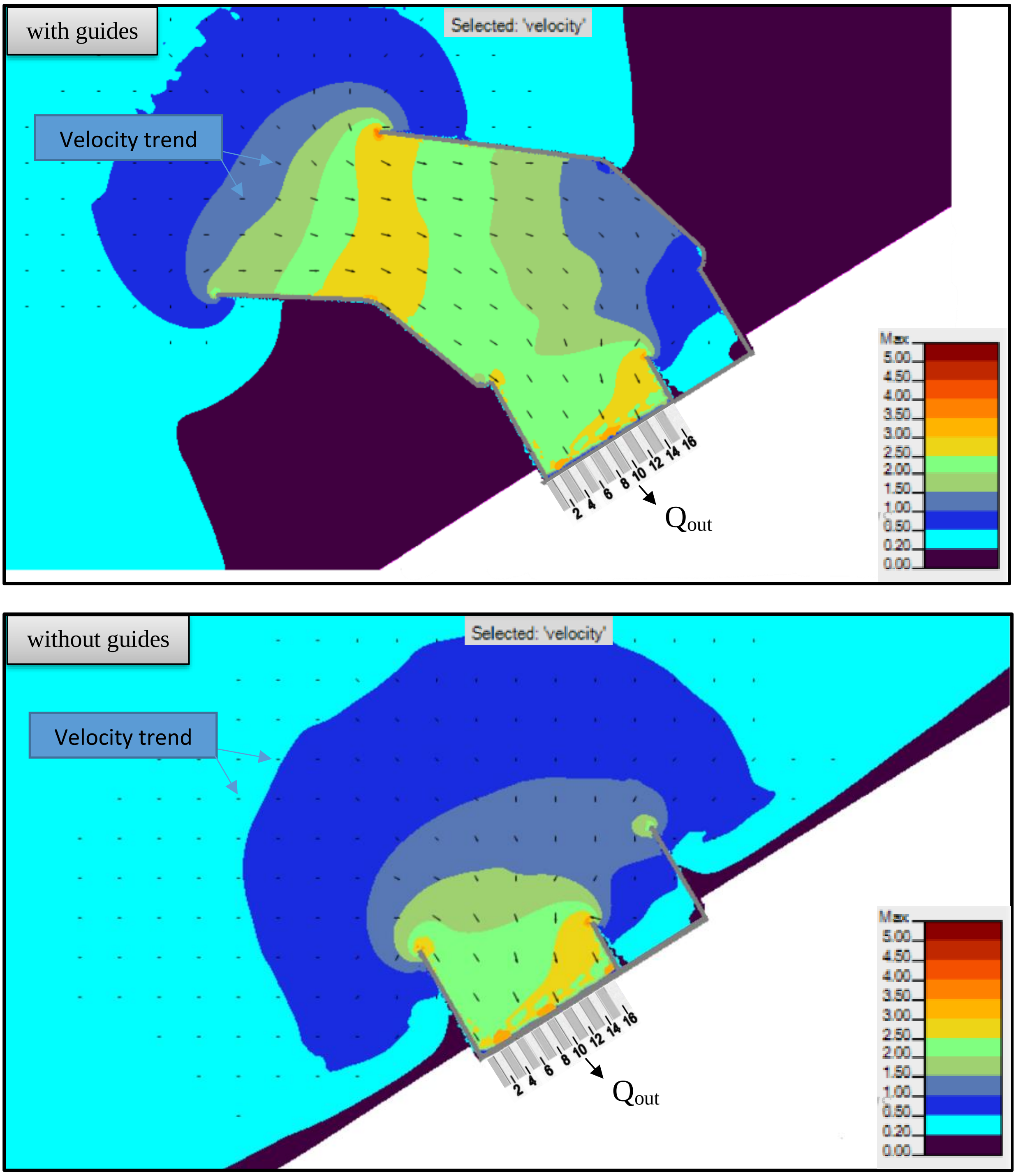


Figure (11): The effect of the U/S Head Race Channel on the distribution of velocities in the Makhoul Reservoir for scenario **(S-16G-6H-16793).**

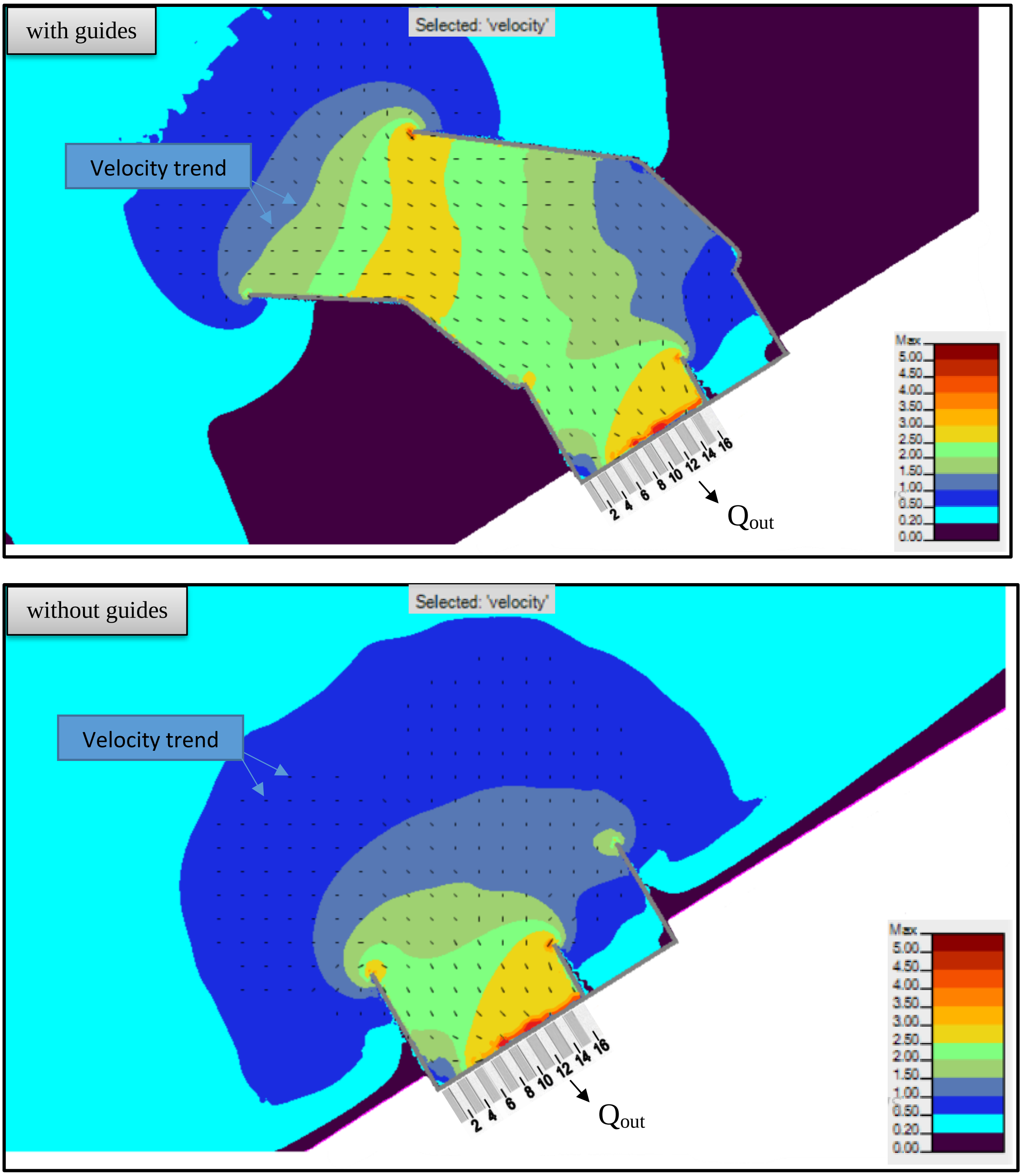
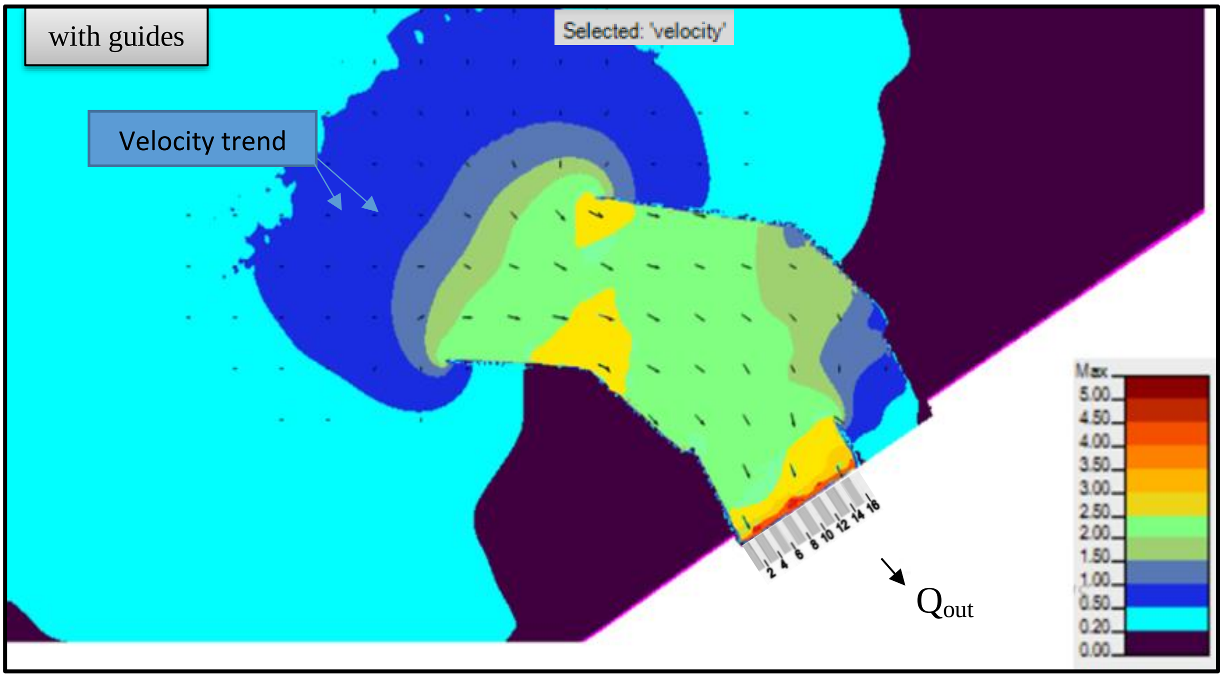


Figure (12): The effect of the U/S Head Race Channel on the distribution of velocities in the Makhoul Reservoir for scenario **(S-12G-8H-16793).**



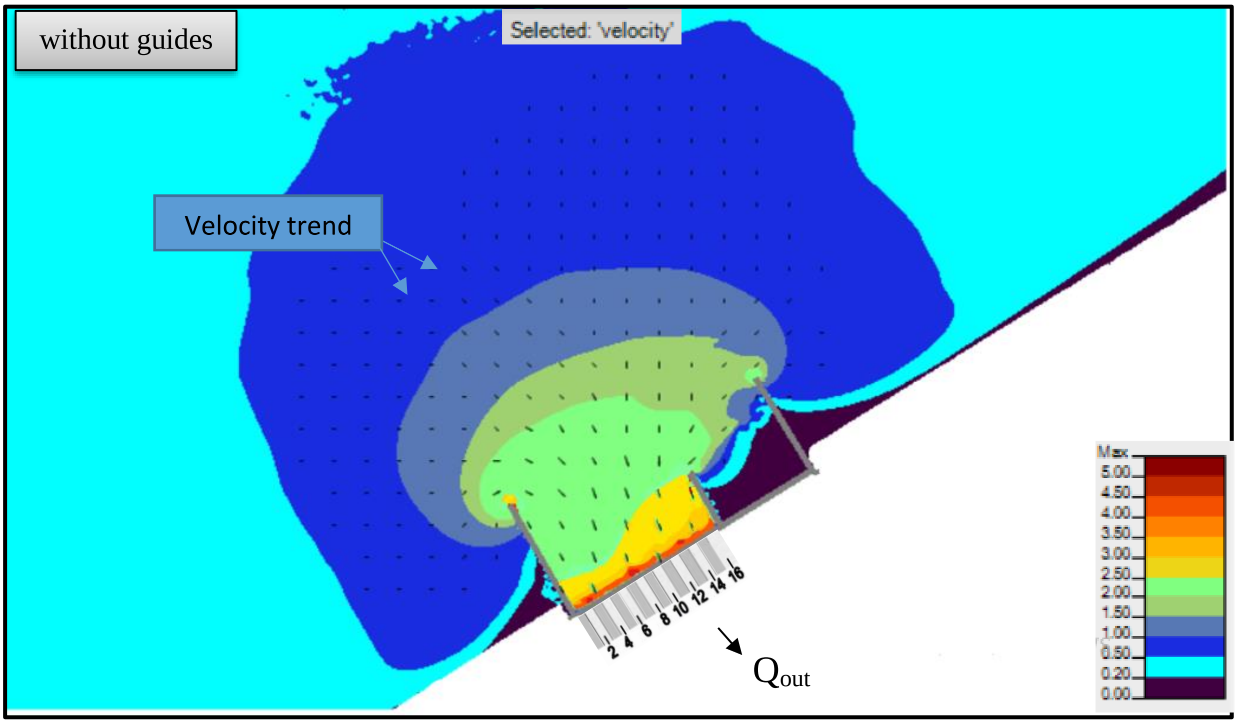


Figure (13): The effect of the U/S Head Race Channel on the distribution of velocities in the Makhoul Reservoir for scenario **(S-16G-8H-22200).**

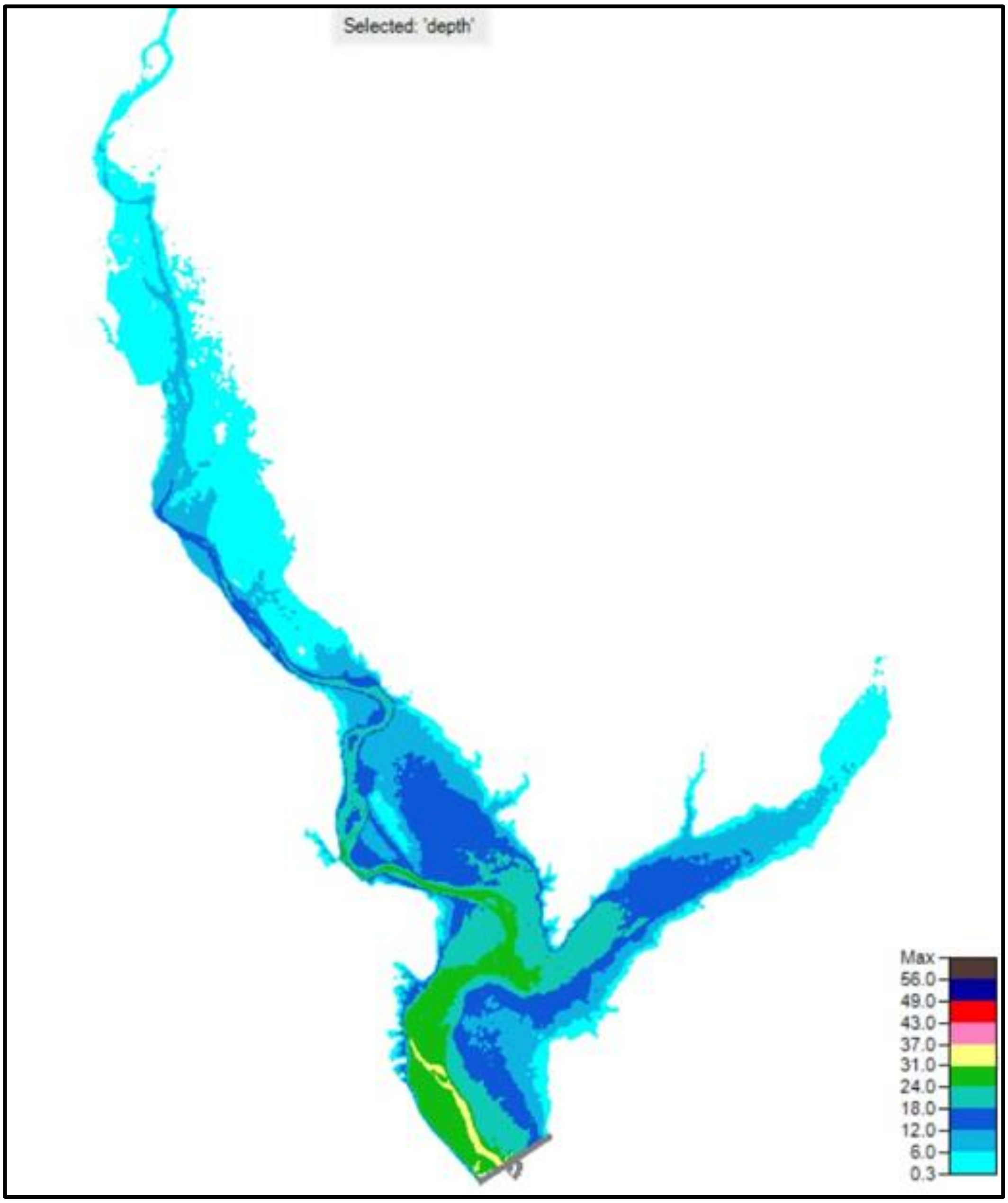


Figure (14): The distribution of water depths for the Lake of Makhoul Dam at the highest operating level of 150.250 *m.a.m.s.l.*

Table (3): Summary of velocity simulation results with operation different cases for the Makhoul Dam.

Scenarios	Outflow (m^3/sec)	Number of gates opening (*number*)	Opening height (*m*)	Velocity range within head race channel (*m/sec*)	Velocity range without head race channel (*m/sec*)
S-16G-2H-5691	5691	16	2	(0.2 to 1.5)	(0.2 to 1.0)
S-16G-3H-8431	8431	16	3	(0.2 to 1.9)	(0.2 to 1.4)
S-16G-4H-11520	11520	16	4	(0.2 to 2.5)	(0.2 to 2.0)
S-16G-5H-14375	14375	16	5	(0.4 to 2.8)	(0.2 to 2.3)
S-16G-6H-16793	16793	16	6	(0.5 to 3.0)	(0.2 to 2.5)
S-12G-8H-16793	16793	12	fully	(0.5 to 3.0)	(0.2 to 2.5)
S-12G-7H-14520	14520	12	7	(0.4 to 2.8)	(0.2 to 2.3)
S-16G-8H-22200	22200	16	fully	(0.5 to 3.0)	(0.5 to 2.5)

6. Conclusions

This part of the research will illustrate the conclusion that obtained in this study.

1- According to the numerical model, the appropriate value of Manning's coefficient n is 0.026 that achieved good agreement between the simulated velocity in this study with the values of measured velocity by the physical model.

2- The effect of the dam guides on the velocities distribution have significant effect in the region outside the concrete part of the dam body (between the embankment guides) for all scenarios. As there is no effect of the dam's embankment guides on the distribution of velocities in the area near the spillway at a distance of about 100 m. It is clear that the presence of embankment guides has two effects on the flow inside the reservoir, the first is

- They enhance the direction of the flow towards the concrete dam body with a distance of more than 500 m from the dam axis, and the second is
- Increase the velocity in the area between the guides and this may reduce the sedimentation near the dam outlet. It is very important to protect the embankment guides against scour.

3- The maximum flow velocity between the embankment guides is 3 *m/sec* in the case of guides, and 2.5 *m/sec* without them, these values are noticed when the discharges are 22200 m^3/s and 16793 m^3/sec from the bottom spillway.

7. Recommendations

After obtaining model results, discussions and conclusions as mentioned in this research, we recommend studying sediment accumulations within Makhoul Dam Lake in the future.

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Nomenclatures

HEC-RAS	Hydrologic Engineering Center -River Analysis System
SMS	Surface-water Modeling System
1D	One Dimension
2D	Two Dimension
C_F	The friction coefficient for channel bed, dimensionless
m.a.m.s.l.	Meter above sea level
bn	Billion
WSE	Water Surface Elevation
DEM	Digital Elevation Model
UTM	Universal Transverse Mercator
U/S	Upstream