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Detect the Water Flow Characteristic of the Tigris River by Using HEC-RAS Program

Ali Dhafer Abed¹, Sumyah Maythem Jaafer²

^{1,2}Civil Engineering Department, Faculty of Engineering, AL-Mustansiriyah University, Baghdad, Iraq

Email: ali.dhafer@uomustansiriyah.edu.iq

Abstract. The Tigris River has recently suffered from a significant decrease in water levels, in addition to the scarcity of drainage and the velocity of water entering the river from Syria, Turkey and Iran. These decreases in the levels leads gradually to drying of some parts of the banks, raising the level of the riverbed, and the appearance of dry areas in the middle of the river. This led to a decrease in the width of the river and hindering the movement of river navigation. Also, the decrease in water levels leads to an impact on the water levels needed by the liquefaction plants to secure the drinking water needed by the city of Baghdad. So, it is necessary to find a technique in which the flow characteristics of the Tigris River are revealed in periods of scarcity, in order to create planning solutions that increase the water height to levels that ensure uninterrupted water supply in the liquefaction plants all over the river. Therefore, this research aims to simulate the movement of water in the Tigris River to detect flow characteristics in times of scarcity by building a one-dimensional hydraulic model (for steady flow) using the HEC-RAS program. Where the simulation will be done based on the geometric data for the shape of the river, as well as the initial and boundary conditions that represent the levels and drainages of water for the river at periods of scarcity, in addition to identifying the values of the Manning coefficient. The model will produce results that are longitudinal and cross sections, flow charts, tables and values, on the basis of which planning solutions are proposed to raise the water level to the required level, restore the natural properties of flow, and examine the compatibility of the proposed solution with the reality of the situation. It was concluded that raising the water level would be by proposing an (Ungated Inline wirs) dam. The proposed dam was tested at a minimum level in times of scarcity, ensuring its ability to raise water levels to the height required for all liquefaction plants installed along the river that required a minimum level of 28.5 m.

Keyword: HEC-RAS, hydraulic mod, Water flow, Scarcity, Tigris River.

1. Introduction

The phenomenon of scarcity and drought is one of the most important phenomena that rivers are exposed to in recent times due to many internal and external factors such as weather, silt deposits, excesses on water quotas, excessive irrigation, and other factors that affected the characteristics of water flow. The scarcity of water leads to a decrease in the water level in most parts of the river, with a slowdown in the velocity and flow of water. In order to reveal the characteristics of water flow in any river as numbers and real values of levels, flows, and velocity of water, we need to represent the behaviour of water through mathematical equations, and since the behaviour of water is complex because it is difficult to represent it through equations, so in most cases simulation programs are resorted to accurately represent the true behaviour of water and reveal its properties along the course of the river.

The situation today is that many models exist which each can solve one special problem, for example, to compute a runoff forecast, to compute flood water levels, or to compute water temperature. A real



planning situation, however, often requires many different computations performed with different models, where the output from one model is used as input to one or several others. The situation is worsened when people by different professions is involved in the planning process, e.g. hydrologists, hydropower engineers, biologists, and economists. The main obstacle for efficient integration and use of different models are differences in data storage, data input, and user interaction with the programs. To improve this situation the different models should be integrated with one common database and one common user interface. This has been the idea behind the development of the "River System Simulator". [1]

Therefore, this project will focus on using river simulation models to obtain water properties in the river of the study area. Where one of the most famous river simulation programs called HEC-RAS will be used for the purpose of simulating the movement of water within the Tigris River in scarcity periods, and to obtain shapes of longitudinal and cross-sections of the river. These sections detect the locations where the water is interruption inside the river, and the water velocity and its drainage are less. The program will reveal the sites that need to reduce their levels at the bottom of the river to obtain a permanent flow of the river water without interruption [2]. This research will propose a solution that addresses the scarcity of water in the Tigris River and raises its level, by proposing the best location in the stream of the river to construct a dam that raises the water level according to planning and design criteria. The research proposal will be tested and its effectiveness will be tested by building a simulation model using HEC-RAS 5.0.2 to simulate the water levels in the Tigris River. The simulation model will provide us with results regarding the flow characteristics of water into the river in times of scarcity before and after the proposed dam. Based on these results, the optimal planning solution will be chosen that will address the water level problem and ensure that it reaches the required level to secure water in the liquefaction plants.

2. River simulation models

There are several programs that can be used in simulating rivers as: CHARIMA, HEC- 6, MIKE II, HEC-RAS. The choice to use any of the above software depends on the following factors: 1-Cost and savings, 2-Data and output requirements. 3-Ease of use, 4-Source code, 5-Digital media interfaces.

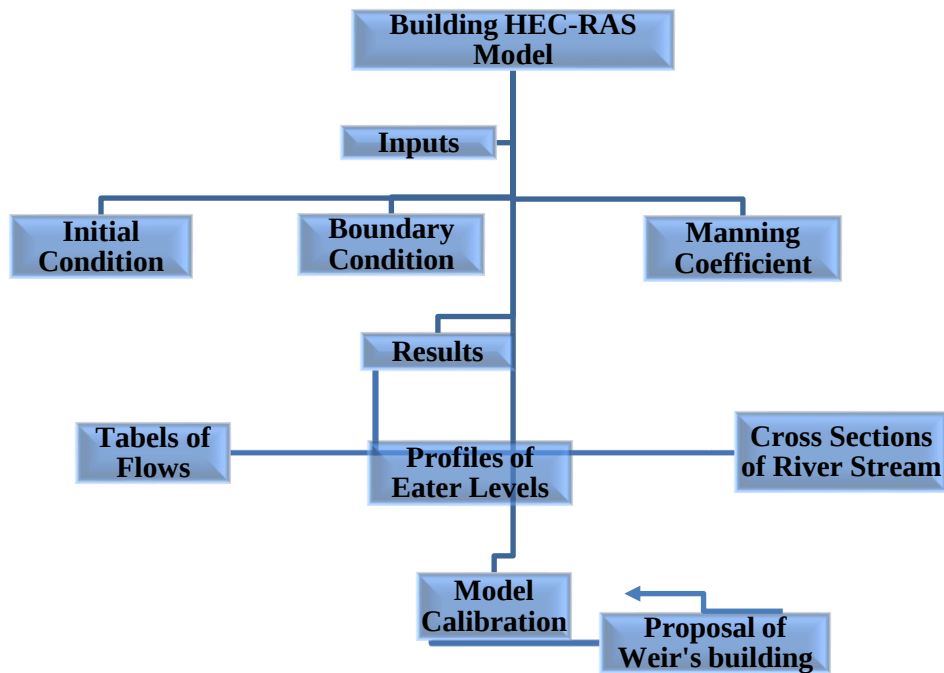
The model needs CHARIMA is a linguist programmer being written in the Fortran programming language. As for the model HEC-6 It needs additional software for the purpose of storage and operation. The model MIKE II The product from the Danish hydraulic institute is not available for further use. Buy the source code and also the limited graphical user interface [4]. So, the program was chosen (HEC-RAS) to operate the numerical model simulating the one-dimensional hydrodynamic flow in this project. The (HEC-RAS) program offers an advanced state than other software in the graphical user interface that facilitates the work because the user can see the inputs and also see local errors before starting the simulation process. Besides that, (HEC-RAS) does not need any additional software to display the results because it implicitly possesses all the software to display the results in the form of graphs or tables [5].

2.1. HEC- RAS Software

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. Prior to the 2016 update to Version 5.0, the program was one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The release of Version 5.0 introduced two-dimensional modeling of flow as well as sediment transfer modeling capabilities. The program was developed by the United States Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995 [2]. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities [3].

3. Methodology:

The research methodology can be summarized through the following diagram:



3.1. Equations used in river simulation

This model is based on solving the continuity and momentum equations in the longitudinal direction of the river using the implicit difference method.

For Continuity Equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_I \quad (1)$$

Momentum Equation

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA \left(\frac{\partial z}{\partial x} + S_f \right) = 0 \quad (2)$$

Whereas: [2]

Q=water flowrate, A= total flow area, t= time, x= longitudinal distance, q_I =lateral inflow per unit length, g= gravity acceleration, z= water surface level, S_f = friction slope,

The value of s_f is calculated using the Manning equation as follows:

$$S_f = \frac{Q^2 n^2}{R^{4/3} A^2} \quad (3)$$

Whereas:

R= hydraulic radius, n= manning roughness coefficient

3.2. HEC-RAS Inputs

a- Geometric Data:

Geometric data include river waterway shape data and Manning coefficient values. Watercourse shape data includes cross-section shape data along each river and the distance between each two cross-sections, reach lengths and Stream junction Information [4].

b- Initial conditions

Solving unsteady flow equations requires determining the values of all variables (water levels and discharges) at zero time, which is known as the initial conditions. Program (HEC-RAS) used Back water

curve method for steady flow as a method of calculating the initial conditions using the terms of the boundary conditions at time zero and by applying the Manning equation [4].

c- Boundary conditions

Boundary conditions are necessary to establish the starting water surface at the ends of the river system (upstream and downstream). The upstream boundary condition is the discharge at the upstream end of the reach, while the downstream boundary condition is the water surface at upstream [6].

Boundary conditions are of vital importance to establish the starting water surface at the ends of the River system (upstream and downstream) prior to the program calculations [7].

d- Manning Coefficient

The Manning's roughness coefficient is used to describe the flow resistance or relative roughness of a channel and is a function of the bed material, depth of flow, discharge, cross-section geometry, channel variations obstructions to flow, type and density of vegetation, and degree of channel meandering. Manning's roughness coefficient (n) is commonly used to assign a quantitative value to represent the collective effect of these factors [6].

3.3. *Calibrate the model of HEC-RAS*

In river simulation, the most sensitive parameter is Manning's roughness coefficient. Calibration of river Manning's roughness coefficient value (overall resistance) have try along study reach through simulation of these discharges and water depths using HEC-RAS Model. Calibration is a mathematical inverse problem because it tries to determine the initial and local parameters that depict a system from a given measurement data set of particular variables. Traditionally, the calibration of hydrodynamic models has been achieved manually [5].

The calibration process minimizes the objective function by adjusting of the parameter sets; depicting the river and considering the ranges of the parameter's values for the flow condition. The root mean-squared-error RMSE between simulated and observed data is the most commonly used objective function [6].

4. **Study Area (River Tigris):**

The catchment area of the river is 473,103 km² and is distributed between Turkey, Syria, Iran and Iraq, River Tigris enters Iraq four kilometres north of Fieshkhabor, near Zakho city. The Tigris is joined by its first tributary inside Iraq, which is known as Khabur River. This tributary is 100 km long; its catchment area is 6,268 km² with an average discharge of 68 m³/s. The Tigris River runs south for about 188 km in a hilly area to reach Mosul city. The elevation of the channel bed is 22.5m above sea level, about 49 km south of Mosul toward Sharqat city, the Tigris joins its biggest tributary, the Greater Zab. Its total length is 437 km with a mean discharge of 450 m³/s [9]. It supplies 28.7% of the Tigris water. The Tigris River runs south and the Lesser Zab tributary joins the river Tigris. The total catchment area of this tributary is 22,250 km². The total length of the tributary is 456 km with a mean discharge of 227 m³/s. About 30 km downstream of this confluence, the Tigris River crosses Fatha gorge. The Adhaim tributary joins the Tigris 68 km south of Sammara Barrage [8]. The tributary drains an area of 13,000 km² lying within Iraq. Its length is 330 km. The mean daily discharge is 25.5 m³/s. The banks of the river Tigris south of its confluence with the Adhaim tributary are below the maximum flood peak level by 3 m from the left, and by 1.8 m from the right. Further to the south, the river reaches Baghdad. The slope of the channel is very low, i.e. 6.9 cm/km. It is noteworthy to mention that since 1990 the flow of the River Tigris at Baghdad is completely controlled by the regulating scheme at Sammara and the Adhaim dam. About 31 km south of Baghdad, the last main tributary "Diyala" joins the Tigris. Diyala's drainage basin is 31,896 km² with a mean daily discharge of 182 m³/s [10]. Note figure 1.

In recent times, the Tigris River has been exposed to scarcity and drought due to many external factors, perhaps the most prominent of which are:

- 1 - Decreased water levels flowing from neighboring countries, where they reached nearly 50% compared to the previous few years, especially from neighboring Turkey [12].
- 2- Climate change witnessed by most countries in the world, and the region suffers from it in particular, and the sharp drop in rain that followed in recent years.

- 3- The increasing abuses of the water share, whether in the governorates or within the same governorate.
- 4- Poor coordination with neighboring countries that established huge water projects and the absence of appropriate agreements guaranteeing Iraqi interests, and increasing demand for water in them for agricultural and industrial purposes has exacerbated the decline in the levels flowing to Iraq [13].
- 5- The mud deposits underlying the Tigris river. in Baghdad alone, there are more than 20 million tons of mud deposits at the bottom of the Tigris River, which requires unpleasantness and transport them outside the river basin [9].
- 6- The failure of irrigation methods and the use of primitive methods to irrigate agricultural crops, which contributed to the aggravation of the water scarcity crisis in Iraq [14].



Figure 1. River of Study Area.

5. Simulate Tigris River by HEC-RAS:

For the purpose of simulating the movement of water in the Tigris river, this requires building a numerical model that simulates the scarcity of water in a part of the river [15]. Therefore, geometric data, manning roughness coefficient, initial and boundary conditions must be defined, as follows:

5.1. Geometric data of river stream

The Geometric data consisted of topographical survey coordinates for the Tigris river stream within the boundaries of the study area. These data were obtained from the Public Authority for Survey of the Ministry of Water Resources. These points and data are 3-dimensional coordinates observed by GPS-Viva GS15 for a set of cross-sections running along the river, with distances not exceeding 200 m between one cross section and another. The Diyala Bridge, north of Baghdad, was considered the upstream of the river, and the downstream represents the meeting point of the Tigris River with the Diyala River, at the far south of Baghdad.

This data was processed in Civil 3D for the purpose of constructing a 3D digital elevation model and defining the stream of the river, its cross-sections and its banks. Civil 3D data was exported to HEC-RAS after processing it, representing the geometric data of the study area river. Note the figures that start from figures 2 - 6.

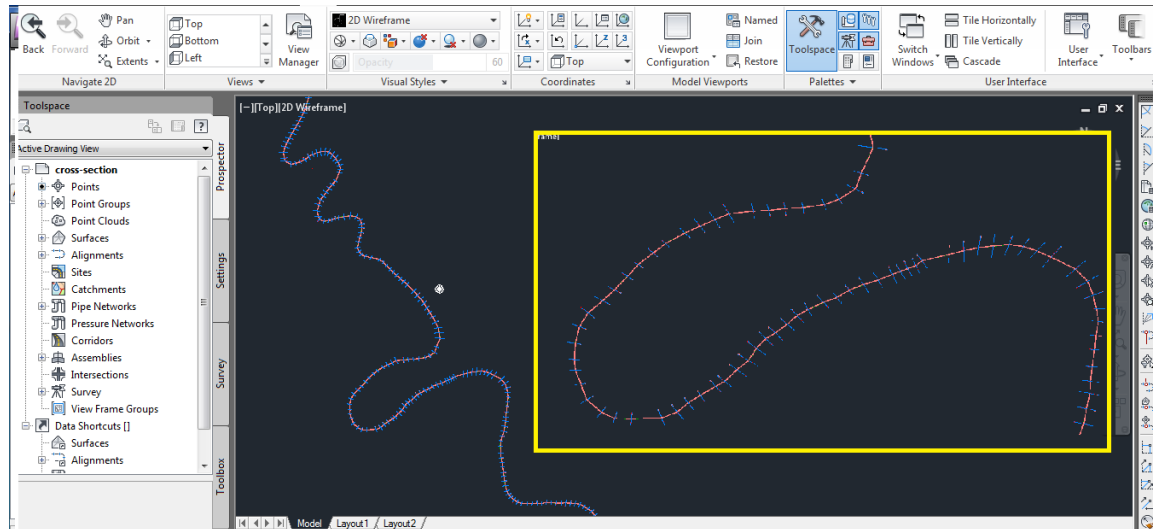


Figure 2. The path and cross-section of the river in the Autocad Civil 3D.

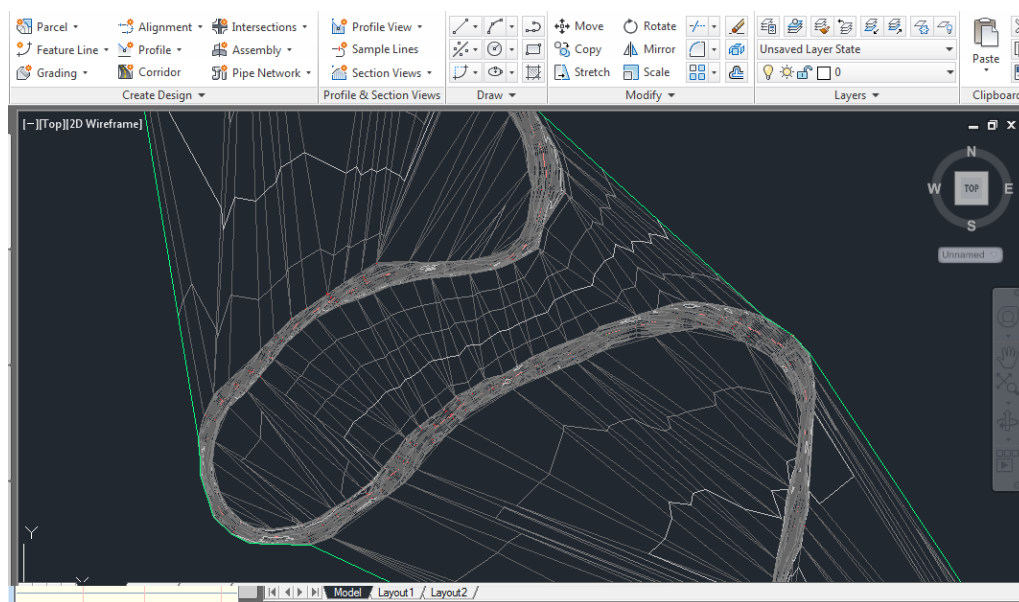


Figure 3. Building Digital Elevation Model-DEM connects the coordinates of the river sections to represent the levels of the river bed.

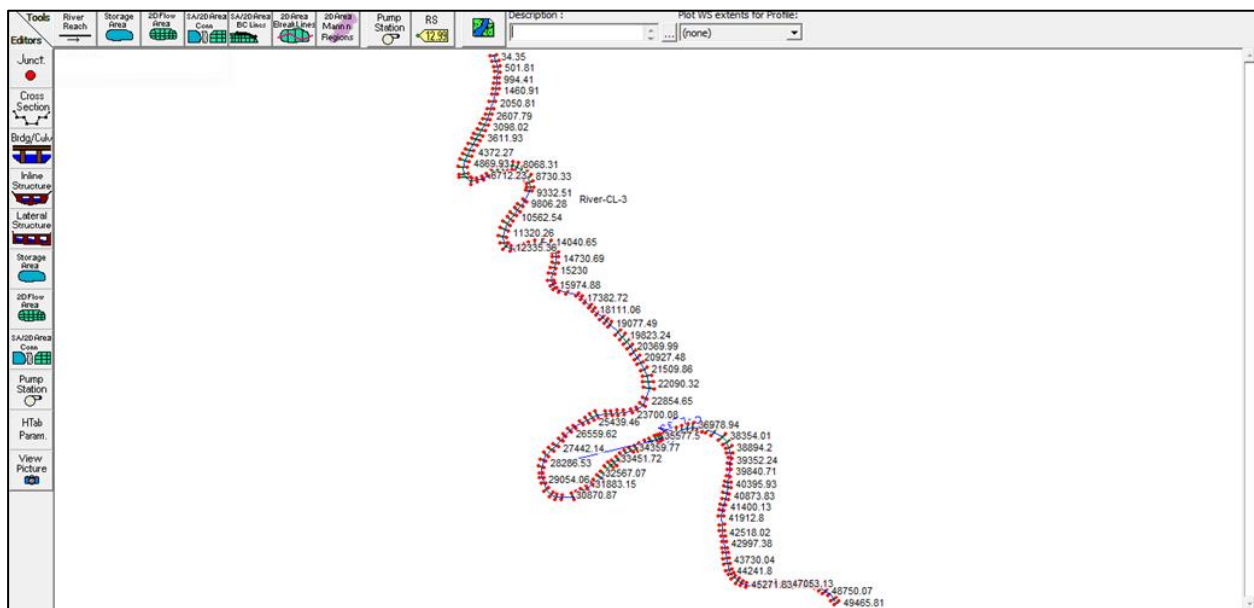


Figure 4. Geometric data within the HEC-RAS program.

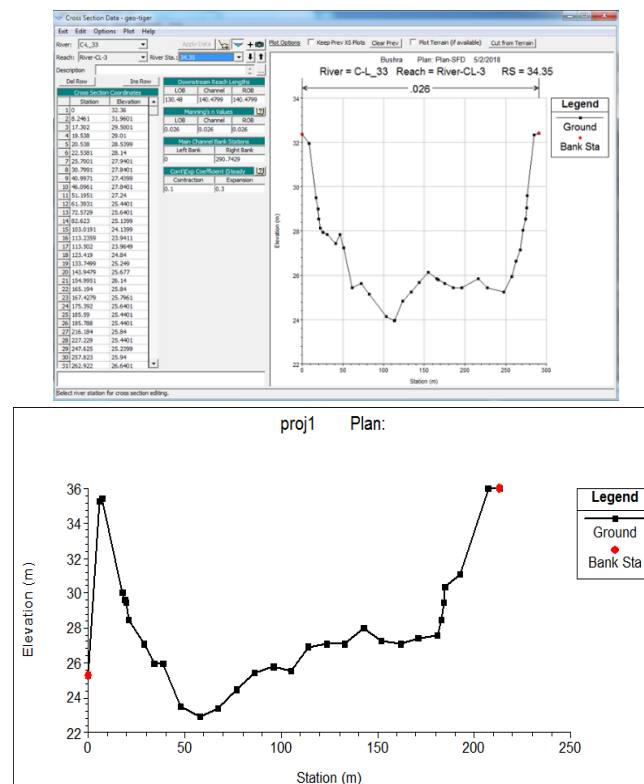


Figure 5. Shapes of some cross-sections of the river's path while defining it within the HEC-RAS program.

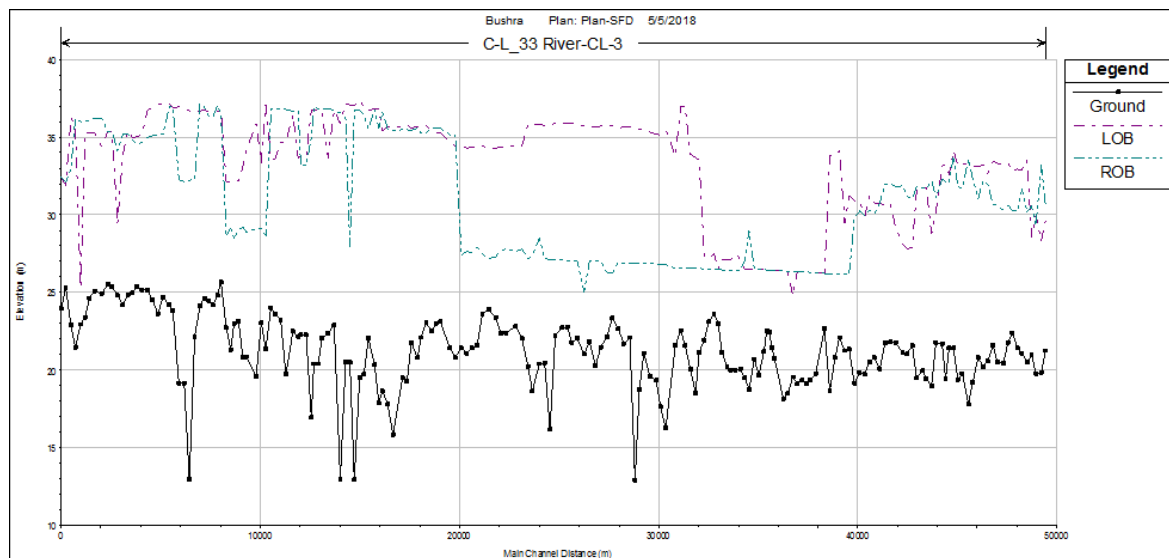


Figure 6. Longitudinal section of the river and its banks in the HEC-RAS program.

5.2. Initial and Boundary Conditions:

In 2014, specifically in November, the Tigris River reached its lowest level, according to observations taken from the Saray Baghdad Station and the North Baghdad Station. The Saray Baghdad station, located 18112 meters from the upstream of the river, on 11/21/2014 recorded its lowest level of 27.5 m and the discharge was 320 m³/s. As for the North Baghdad station, which is 34 m from the upstream, the level of 29 m is recorded, and the discharge was 330 m³/s

These levels and discharges will be approved as initial and boundary conditions for operating the model. Note the figures that start from the figures 7 and 8.

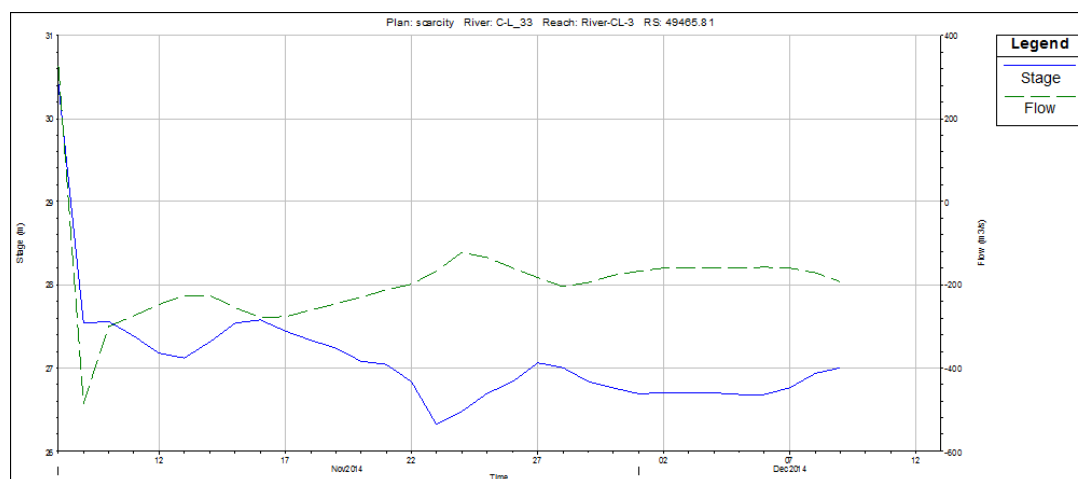


Figure 7. The levels and discharges of the Baghdad Saray station and its change over time

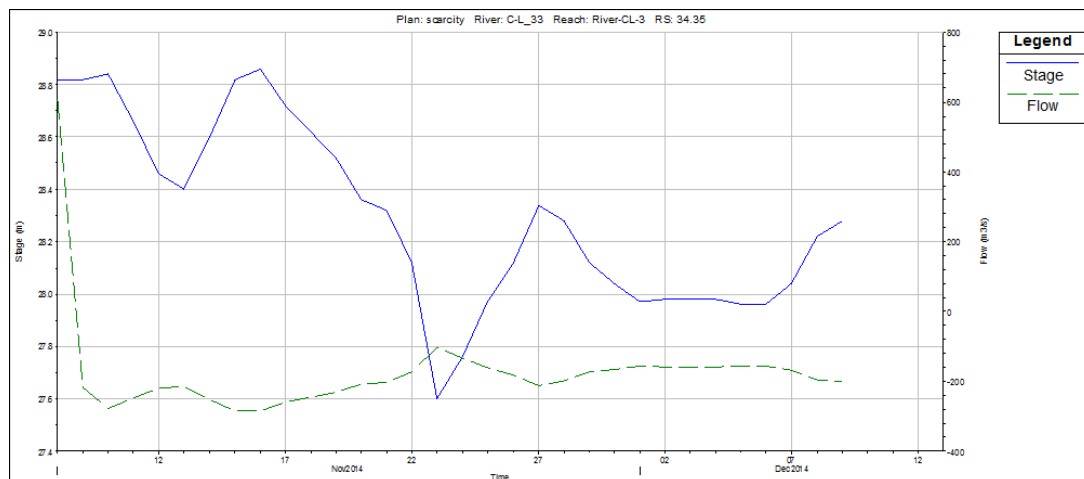


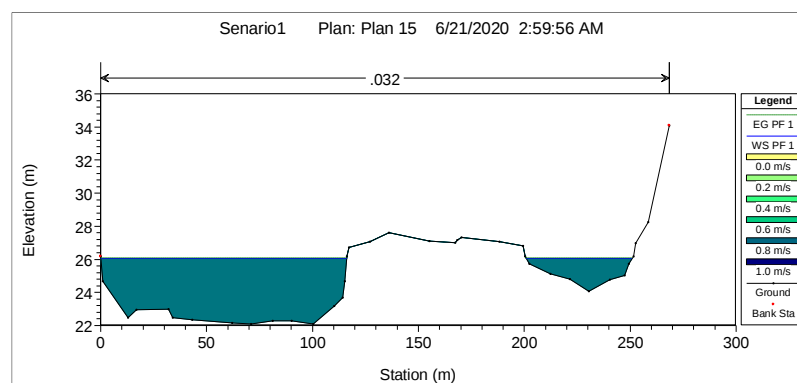
Figure 8. The levels and discharges of the North Baghdad station and its change over time.

5.3. Manning Coefficient and Calibrate the Model

The values of the Manning coefficient were adopted (0.026 - 0.032) for the bottom of the river, and the values (0.040 - 0.048) for the banks. The model was calibrated by comparing the levels calculated by the program with real values for the same stations observed by the Saray Baghdad and North Baghdad Stations. After calibration, the value of the manning coefficient was 0.032 at times of scarcity.

6. Results of HEC-RAS simulation depending on the Inputs:

The results of the model are longitudinal and cross-sections of levels, discharge and velocity that change along the river, as well as tables that show the values of change as in figures that start with figure 9 and end with figure 12.



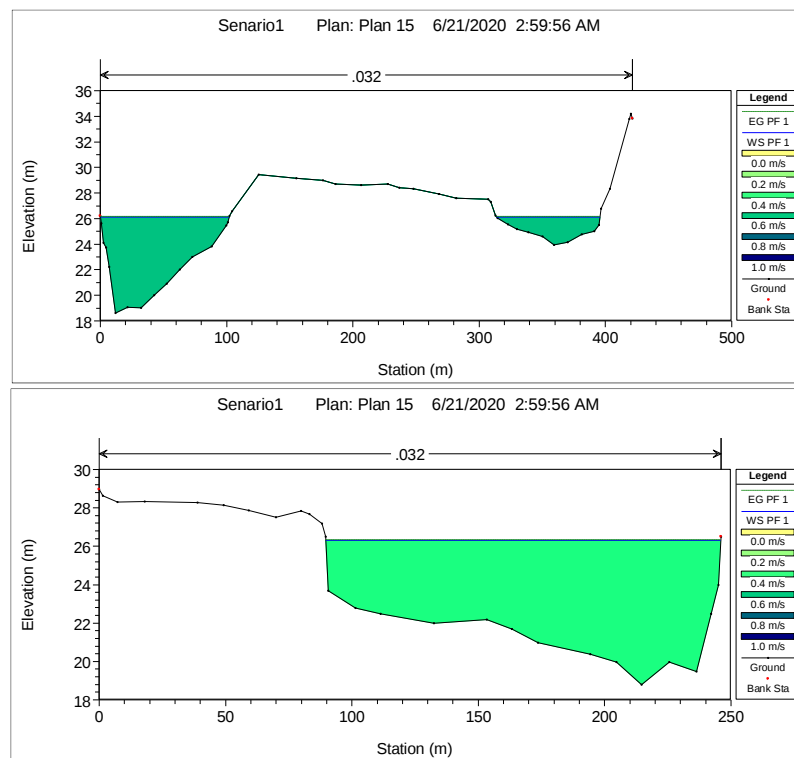


Figure 9. Some cross sections of water scarcity during the scarcity period.

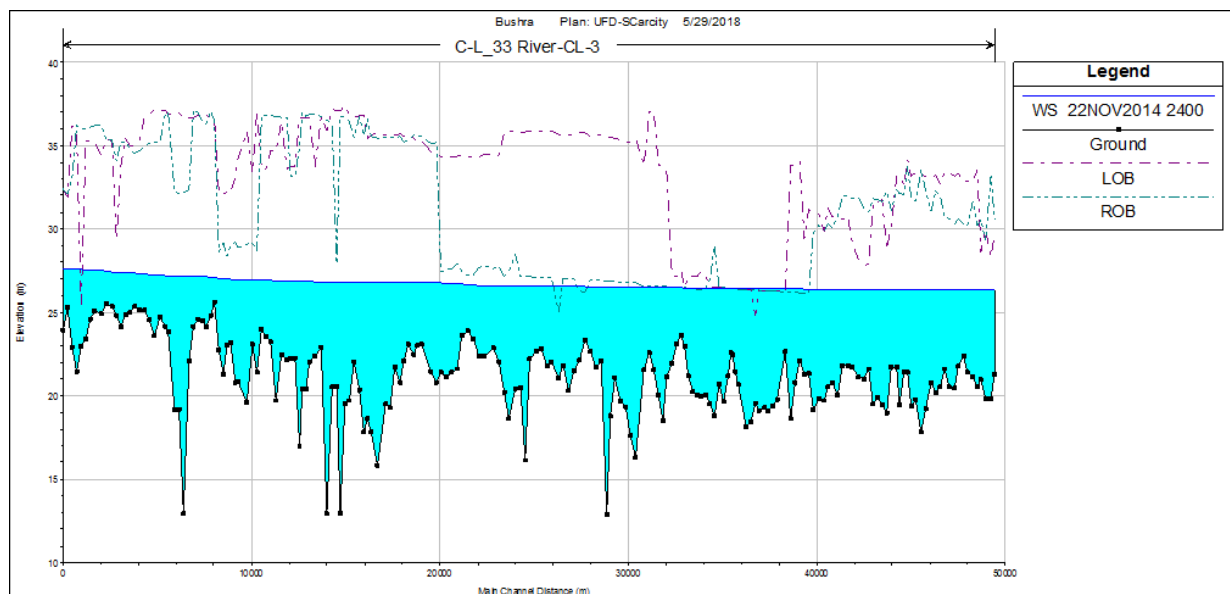


Figure 10. The longitudinal section of the water surface during the scarcity period.

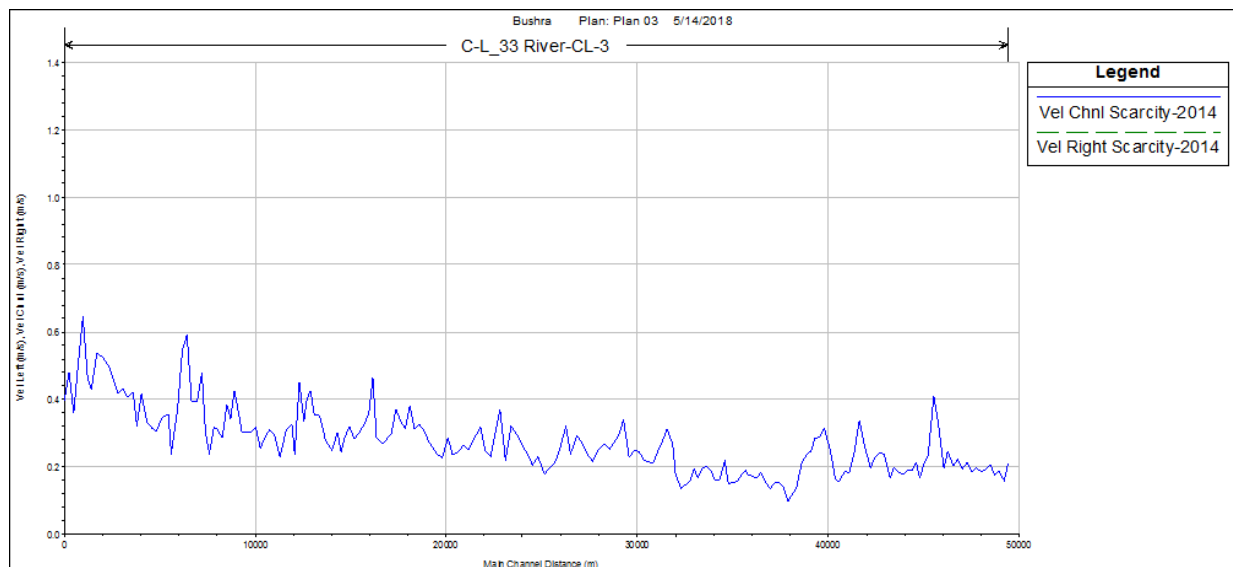


Figure 11. The longitudinal section of the water velocity during the scarcity period, which represents the velocity change along the river.



Figure 12. Some parts of the river and banks dry up.

7. A proposal to build a Weir that raises the water level and its discharges:

The Tigris River water needs to be raised to ensure the level of drinking water required by the liquefaction stations. The highest level required by the liquefaction stations is 28.5, which is the level of the drinking water station called (East Tigris Water Project), which is 5460 meters from the upstream of the river. This means that the lowest level at the time of scarcity must be at least 28.5 in order to secure to all liquefaction stations the level of water they need. Therefore, a weir must be designed to raise the water levels along the river to secure a level of not less than 28.5, and the drainage after the dam must be at least 145 m³/s to maintain the required water levels in times of scarcity.

A dam (weir) has been proposed for construction near the confluence of the Tigris River with the Diyala River at Station 48977. With regard to weir parameters: the weir type was (Ungated Inline weirs) and the shape (Ogee Spillway Crest), weir coefficient (weir coefficient) was calculated through the HEC-RAS program according to the (weir equation) and was defined for the program as in Figure 13:

- Weir Station = 48977.
- Width of Weir = 20 m.
- Spillway Approach Height = elevation of spillway crest – mean elevation of the ground (just upstream of the spillway) = $28.5 - 22.7 = 5.8$ m.
- Design Energy Head = energy grade line elevation (at the design discharge) - elevation of spillway crest = $28.5 - 23.17 = 5.33$ m.
- Weir Coefficient = Calculated by the program = 1.99

The height of the weir was chosen to be (5.8 m) from the level of the bottom level (the average level of the bottom in the station 48977 is 22.7 m), and its elevation is 23.17 m). This height was calculated according to the difference between the water level needed by the liquefaction station and the lowest water level calculated by HEC-RAS according to the different discharges.

The weir was tested for a proposal in the HEC-RAS program at a minimum discharge period (145 m³ / sec) at times of scarcity. The test was done through the constant change in the level of (Spillway Crest Elevation) until it achieved the required elevation.

The model was run before and after the construction of the weir according to different discharges at the downstream (150, 300, 450 m³/s) to cover all periods from scarcity to normal, as in Table 1. Where the program gave water, levels calculated at the station (48977) each time in which the discharge was changed.

The discharges that the program calculated were compared with the discharges calculated according to the Weir equation (Weir Equation $Q = CLH^{3/2}$), and it became clear that all the discharges were clearly increased after the Weir was placed, and all of them provide a water level of no less than (28.5 m) in this station.

The results of operating the HEC-RAS model after the definition of the weir can be observed through figures 14 and 15.

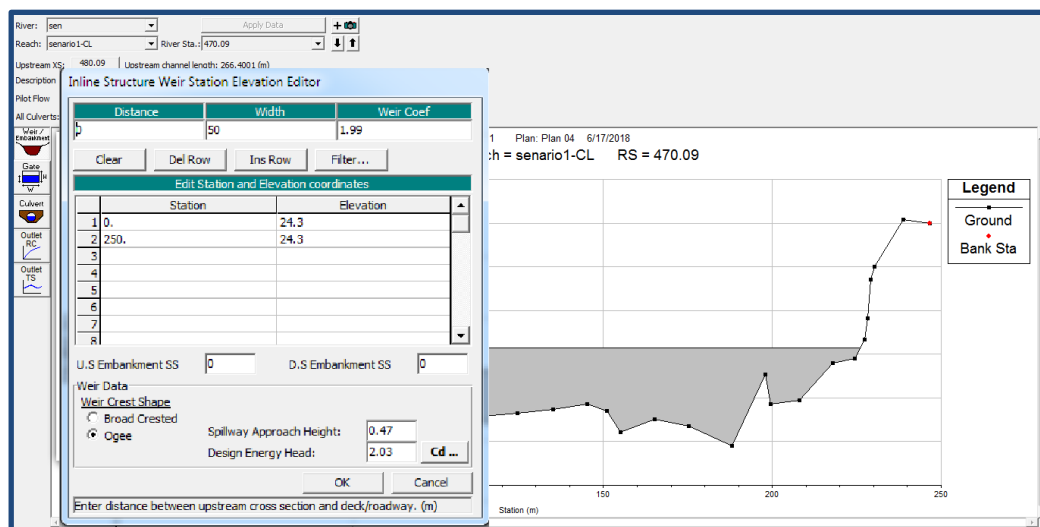


Figure 13. identify weir parameters.

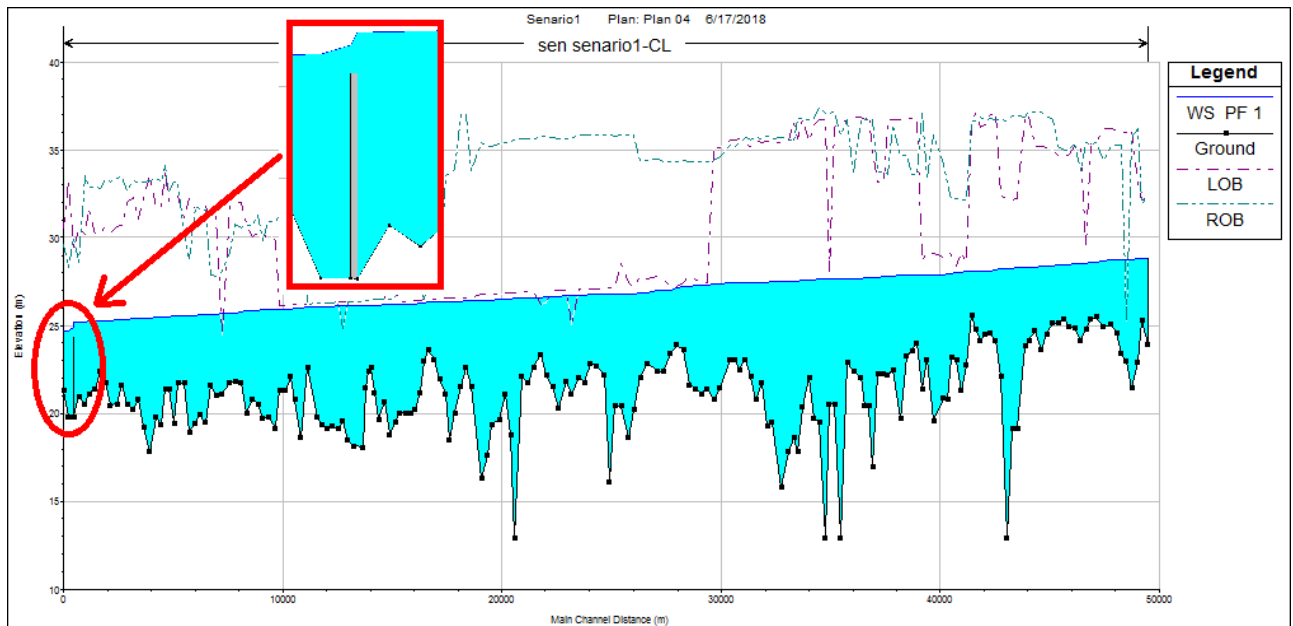


Figure 14. The longitudinal section of the water level change along the river during the scarcity period after the weir is proposed.

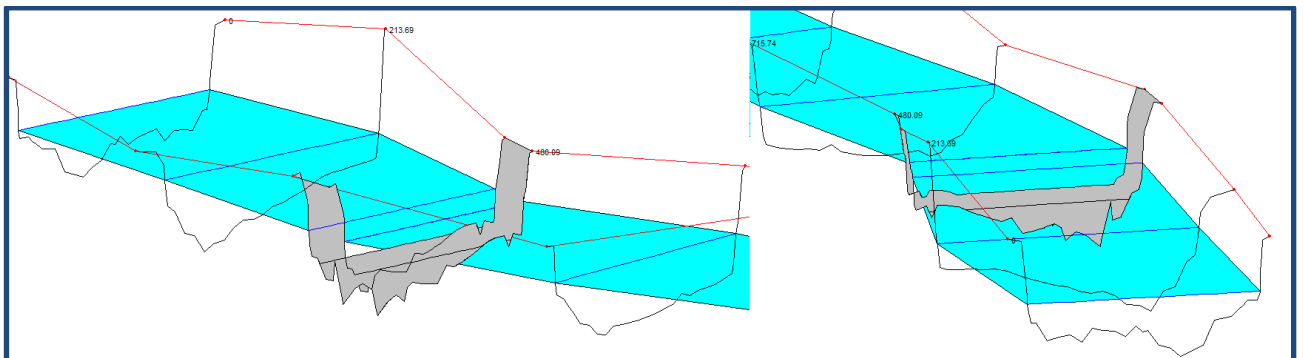


Figure 15. Cross section of the proposed weir from two different sides.

Table 1. The discharges and water levels calculated at the station (48977) before and after the weir proposal.

Discharges m^3/s	Elevations before the suggestion of the weir (m)	Elevations after the suggestion of the weir (m)	Discharges calculated according to the weir equation m^3/s
150	27.73	29.2	369.59
300	27.92	29.70	717.04
450	28.28	30.34	1261.24

8. Conclusions:

- 1- After the dam was proposed, the water level at the lowest discharge ($150 \text{ m}^3/\text{s}$) increased by 1.47 m. As for the highest drainage ($450 \text{ m}^3/\text{s}$), it increased to 2.06 m. This indicates that the water level is increasing all over the river in times of scarcity.
- 2- The lowest elevation reached by the Tigris River was recorded in 2014 by the Saray Baghdad Station and North Baghdad Station, and they were 27.5 and 29 m, respectively, and their discharges were 320 and $330 \text{ m}^3/\text{s}$ respectively.

- 3- After calibrating the simulation model by comparing with realistic values of levels, the value of the Manning coefficient was 0.032 at times of scarcity.
- 4- The locations where the water cycle was interrupted were determined at times of scarcity by specifying the cross section number (the distance from the upstream), and the most prominent of these sections that cause the appearance of dry areas in the middle of the river are (34, 2137, 4194, 6949, 7198, 7555, 7818, 10573, 10830, 12011, 12242, 12714, 12957, 27102, 27652, 40540, 40966).
- 5- The weir elevation has been proposed to provide the lowest water level with a value of 28.5 m, because this value is considered the highest elevation among all elevations of liquefaction stations that extend along the Tigris River (East Baghdad Water Project Station).
- 6- A weir was chosen near the estuary of the Tigris River, south of Baghdad, at station 48977, with height of 5.8 m above the river bed and 20 m wide, to secure a level of at least 28.5 m along the river in times of scarcity.

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