Two – Dimensional Mathematical Model to Study Erosion Problem of Tigris River Banks at Nu'maniyah

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ABSTRACT

The high and low water levels in Tigris River threaten the banks of the river. The study area is located on the main stream of Tigris River at Nu'maniyah City and the length of the considered reach is 5.4 *km*, especially the region from 400 *m* upstream Nu'maniyah Bridge and downstream of the bridge up to 1250 *m* which increased the risk of the problem that it heading towards the street and causing danger to nearby areas.

The aim of this research is to identify the reason of slope collapse and find proper treatments for erosion problem in the river banks with the least cost. The modeling approach consisted of several steps, the first of which is by using "mini" JET (Jet Erosion Test) device provides a simple method of measuring scour depth with the time for the riverbank and finding values of critical shear stress and erodibility factor for ten soil samples taken from right bank and bottom of Tigris River; the second of which involved setting up a static BSTEM software for two models (with and without treatment), then calculating the erosion amounts and factor of safety for the ten soil samples; the third approach involved implementing a two dimensional RMA2 to simulate four scenarios to find the velocity, water depth, and water surface elevation distributions for two models (with and without treatment). Therefore, observed erosion in other discharges in natural case near the right bank [especially at cross section that are located in Tigris River at Nu'maniyah City from 500 *m* upstream Nu'maniyah Bridge and cross section that are located from 1800 *m* downstream Nu'maniyah Bridge] is high because of high erodibility coefficient in those cross sections that causes high erosion. Also, failure occurs in natural case of Tigris River at Nu'maniyah City because of erosion near the right bank and does not occur because of slope stability failure for right bank where the range of the velocities near the right bank for the study area for most discharges is between 0.67 and 0.91 *m/s*. In addition to experimental work using "mini" JET device shows high erodibility coefficient in those cross sections and (2+900) which confirms that this device is very good indicator for the possibility of bank scour. The velocities upstream of the island and near the right bank in the study area are between 0.64 and 1.47 *m/s*, while downstream of the island is between 0.64 and 1.04 *m/s.* In addition to soil of Tigris River right bank at Nu'maniyah is silty soil, the scour velocity is higher than 0.5 *m/s*, therefore the right bank is safe against scour only when the discharges of Tigris River are less than 500 m^3/s. Thus, vegetation is unsafe treatment on right bank of Tigris River at Nu'maniyah City. The velocity causes removal of plants since treatment for river bank is 0.61 *m/s* where velocities near bank at most discharges are higher than this limit. Thus, treatment by riprap is the proper choice on the right bank of Tigris River at Nu'maniyah City because its cost with maintenance is 2 billion IQD less than gabion treatment in addition to velocity reduction

ratio along the right bank by riprap ranges from 15% to 85%, while velocity reduction ratio along the right bank by gabion ranges from 8% to 25%, respectively.
Key words: erosion, cost, SMS, riprap, gabion, vegetation.

النموذج الهيدروليكي لدراسة مشكلة النحر والمعالجات اللازمة في ضفاف نهر دجلة عند النعمانية

الخلاصة

ان مستويات المياه العالية والمنخفضة في نهر دجلة تهدد ضفاف النهر من خلال ظهور تشققات كبيرة وانهيارات في ضفاف النهر الناجمة عن تدفقات المياه المضطربة.

تقع منطقة الدراسة على نهر دجلة في مدينة النعمانية بطول 5.4 كم، خصوصا في المنطقة الممتدة من 400 متر مقدم جسر النعمانية وحتى مؤخره لمسافة تصل الى 1250 متر، ومما يزيد من خطر المشكلة أن التآكل يتجه نحو الشارع ويسبب خطرا على المناطق القريبة منها بالإضافة إلى تراكم الترسبات في النهر و على الضفة اليسرى منه وزيادة السرع في الجانب الآخر.

ان الهدف من هذا البحث هو لتحديد سبب انهيار الجوانب، والتوصل الى أفضل السبل لمعالجة مشكلة تآكل ضفة النهر بأقل كلفة . ممكنة. تم استخدام نموذج رياضي هيدروليكي لدراسة تآكل الضفاف ومقارنة سبل المعالجة المتاحة التي تلبي المتطلبات الهيدروليكية وبأقل كلفة ممكنة.

يتضمن البحث عدة خطوات، أولها استخدام جهاز الميني جت الذي يوفر طريقة بسيطة لقياس عمق التآكل مع الزمن لضفة النهر وايجاد قيمة اجهاد القص الحرج ومعامل التعرية لعشر عينات من التربة، والثانية اعداد نموذجين (احدهما بدون استخدام معالجة والآخر باستخدام نوعين من المعالجة وهما تكسية حجرية وغطاء نباتي) باستخدام برنامج استقرارية الضفة وتآكل بداية النهر وحساب كميات التآكل ومعامل الامان للعينات العشرة، والثالثة اعداد نموذجين (احدهما بدون استخدام معالجة والآخر باستخدام ثلاثة أنواع من المعالجة وهي تكسية حجرية وقفة صخرية وغطاء نباتي) باستخدام برنامج نمذجة المياه السطحية الثنائي البعد وحساب سرعة وعمق ومنسوب الماء متمثلة بأربعة سيناريوهات، ولهذا لوحظ حدوث تآكل في تصريفات اخرى في الحالة الطبيعية بالقرب من الضفة اليمنى وخصوصا في المقطعين العرضيين (2 + 600) و (4 + 000) بنسبة عالية بسبب معامل التعرية العالي في هذين المقطعين. كما يحدث الفشل في الحالة الطبيعية لنهر دجلة في مدينة النعمانية وخصوصا في المقاطع العرضية (2 + 600) و (4 + 000) بسبب تآكل بالقرب من الضفة اليمنى ولا تحدث بسبب فشل ثبات الميول للضفة اليمنى حيث أن قيم السرع بالقرب من الضفة اليمنى لمنطقة الدراسة بالنسبة لمعظم التصاريف ما بين0.67 و0.91 م / ثا.

اضافة الى أن العمل المختبري باستخدام جهاز الميني جت أظهر ارتفاع معامل التعرية للمقاطع العرضية (2+600)، (2+900) و(4+000) مما يؤكد احتمالية تآكل ضفة النهر حيث أن السرعة في مقدم الجزرة وبالقرب من الضفة اليمنى لمنطقة الدراسة تتراوح ما بين 0,64 و1,47 م / ثا، في حين تتراوح السرعة في مؤخر الجزرة ما بين 0,64 و1,04 م / ثا، بالاضافة الى أن التربة للضفة اليمنى لنهر دجلة في النعمانية هي تربة غرينية، وسرعة التآكل فيها أعلى من 0.5 م / ثا، وبالتالي فإن الضفة اليمنى سوف تكون آمنة ضد التآكلات فقط عندما يكون تصريف نهر دجلة أقل من 500 م^3 / ثا.

ان الغطاء النباتي هو من سبل المعالجة غير الآمنة على الضفة اليمنى من نهر دجلة في مدينة النعمانية حيث ان سرعة إزالة النباتات تبلغ 0.61 م / ثا بينما كانت نتائج السرع بالقرب من ضفة النهر اليمنى في معظم التصاريف هي أعلى من هذا الحد. ان علاج ضفة النهر اليمنى باستخدام التكسية الحجرية هو الخيار الافضل في مدينة النعمانية لأنه أقل كلفة بحوالي 2 مليار دينار من العلاج بواسطة القفة الصخرية بالإضافة إلى أن معدل نسبة تخفيض السرع على طول الضفة اليمنى باستخدام التكسية الحجرية يتراوح بين 15٪ الى 85 ٪، في حين أن معدل نسبة تخفيض السرع على طول الضفة اليمنى باستخدام الكابيون يتراوح بين 8 ٪ الى 25 ٪ على التوالي.

الكلمات الرئيسية: التآكل، الكلفة، نظام نمذجة المياه السطحية، التكسية الحجرية، القفة الصخرية، الغطاء النباتي.

1. INTRODUCTION

1.1 General

Erosion threatens riverbank, particularly those located in cities such as roads, residential buildings, and other facilities. During the last twenty years growing islands have become noticeable features in Tigris River within Iraq, the number of islands is increasing with time. In addition to the impact of human activities in dam building, bank lining, and dumping of debris within the channel has led to change in the geometry of the river and its ability to carry flood waters.

The stability of a bank primarily depends on channel and flow characteristics, and the strength of the bank materials and instability can be inherent in some channel systems as a result of the nature of the river system such as high energy braided rivers and historic or geomorphic factors such as tectonic uplift. Patterns of erosion and deposition are influenced by many factors, including: storm frequency, flow properties, bank material composition, bank geometry, bank moisture conditions, channel geometry, the local topography, vegetation and man-induced factors.

The study area is located on the main stream of Tigris River at Nu'maniyah City and the length of the considered reach is 5.4 *km*, see **Fig. 1**.

2. OBJECTIVES

The main objective of the present study is to investigate the flow process that causes scour in the river bank and the recent treatments that can be used in Iraqi rivers.

Tigris River was considered as a case study with the use of the adopted suitable bank treatments of least cost.

3. LITERATURE REVIEW

Khalaf ,1999. presented numerical models, (hydrodynamic and morphological) to predict Tigris river behavior under certain conditions. The first model was a two dimensional depth-averaged hydrodynamic model. Based on the conservation of mass and momentum equations to compute the velocity field and water depths. This model was verified by applying it to an idealized channel, a channel 10 *m* long, and a channel with 180◦ bend. The application gave good agreement between computed and analytical or published data.

Ibraheem ,2011. analyzed four cases of flow conditions for the circumferential open canal in the University of Baghdad Campus in Al-Jaderiya by using RMA2 model. The first case represented the current flow conditions; other cases represented modification of the flow within the canal. The researcher found that under the initial flow conditions, the velocities were very low along the canal. By increasing the supplied discharge the flow conditions within the canal were enchased. In the case of increasing the supplied discharge to the maximum capacity of the supply pipe, the flow along the canal was the best compared with other smaller discharges.

Holttschlag and **Koschik ,2002.** developed a two-dimensional hydrodynamic model of St. Clair–Detroit River Waterway in the Great Lakes Basin by using the generalized finite-element code RMA2 to compute flow velocities and water levels as part of a source-water assessment of public water intakes. Seven steady-state scenarios were used to calibrate the model. The researchers found an agreement between simulated and expected flows in major channels and water levels at gaging stations.

Mclean, et al, 2003. used a two – dimensional numerical model to study clear-water scour at a bridge contraction with a cohesive bed. They used flow data, variable or constant, to calculate scour and update the bed of the model. The model output (velocity, depth, and water surface), and SMS data calculator were used to calculate time –dependent scour based on the erosion function at each coordinate in the model. An ultimate scour depth, the unit flow rate, and other model parameters at a particular time step can also be calculated. Finally, their study covered the methodology and results for calculating time – dependent as well as ultimate scour using a two – dimensional finite element computer model.

Hanson and **Hunt ,2007.** used two types of soil (silty sand and lean clay) in laboratory experiments laboratory JET. The soils were air dried, sieved by using sieve #4, and then thoroughly mixed with water to achieve the desired water content. The soils were stored for a minimum of 48 hours to allow time for the soil particles to hydrate.

The soil was compacted in the standard mold with a manual rammer, then placed and compacted in the mold in three layers.

Once a test is started, scour readings were taken with a point gage. The point gage is aligned with the jet nozzle so that the point gage can pass through the nozzle to the bed to read the depth of scour. The point gage diameter is nominally equivalent to the nozzle diameter so that when the point gage rod passes through the nozzle opening, flow is effectively shut off. A deflection plate is attached to the jet tube and was used to deflect the jet, protecting the soil surface, during initial filling of the submergence tank.

They observed from the above plots of scour depth versus time that the water content had a significant effect from the driest sample to middle range water content, but it showed less effect from the middle range water content to the wettest sample for each soil and erodibility factor varies over several orders of magnitude depending on soil texture and plasticity, compaction effort, and water content.

4. CAUSES OF BANK FAILURE

Garanaik and Sholtes, 2013 stated that bank erosion is a natural process in stable rivers; however, it can become accelerated and exacerbated by direct and indirect human impacts.

Also erosion leads to failure of riverbanks by factors such as, **Talukdar, 2012**:

1. Rapid drops in water after flood.
2. Banks saturation.
3. Deflection and accelerated flow around infrastructure, barriers, and plants in the river.
4. Removal or disturbance of vegetation from riverbank because of trees that fall from bank.
5. Rainfall interval.
6. Direct erosion of the riverbank such as Livestock trampling and removal of riparian vegetation.
7. Indirect erosion of the riverbank such as channel incision, thus widening from hydrologic alteration in watershed.
8. Sloughing of saturated bank caused by rapid drawdown.
9. Liquefaction of saturated silty and sandy bank material.
10. Erosion due to seepage from banks at low river discharge.
11. Scour along waterline due to wind or wave wash of passing vessels.

5. PROCESSES OF RIVERBANK EROSION

Bank Erosion includes three main groups of processes:

1. Hydraulic instability caused by scour at the toe of a marginally stable bank, debris and vegetation, removal of bank vegetation, secondary current etc., **Islam, 2008**.

2. Gravitational mass failure processes detach sediment primarily from cohesive banks and make it available for fluvial transport, **Talukdar, 2012**.
3. Geo-technical instability caused by detachment of more coarse-grained layers in any given alluvial bank, by water flowing out of the bank face, termed as "piping" or "sapping",**Hagerty and Hamel, 1989**.

6. TIGRIS RIVER CHARACTERISTICS AT NU'MANIYAH CITY

The topographic survey department at the Center of Studies and Engineering Designs in Ministry of Water Resources (MoWR) during November 2013 snapped levels of Tigris River in Nu'maniyah Region for 5.4 *km* according to the needs of the mathematical models, including fifty-four cross-sections were measured along Nu'maniyah Reach.

The hydrological data of Tigris River during flood of 1988 in the study area were supplied by the National Center of Water Resources, MoWR, as listed in **Table. 1**.

The value of river roughness coefficients is 0.03, **Abdul-Sahib, 2014**, and bank protection such as (gabion, riprap, and vegetation) are listed in **Table. 2**.

The adopted hydraulic data include a gradient value of 7 *cm/km* for high discharges and 5 *cm/km* for low discharges, **Geohydraulique, 1977**.

Abdul-Sahib, 2014 computed the rating curve for 900 m upstream of Nu'maniyah gaging station where the river cross section is more suitable as a gaging station, see **Fig. 2**.

7. FIELD WORK

In order to measure the erosion rate at the river bank, ten soil samples were taken from right bank and toe of Tigris River during the period from 27 to 30 April 2015. Locations of the soil samples are listed in **Table 3**.

7.1 Laboratory Work and Equipment

Al-Madhhachi, 2013 manufactured "mini" JET device to measure scour depths with time for the riverbank. This device was used to find the values of critical shear stress (τ_c, Pa) and erodibility factor ($k_d, cm^3/Ns$) for ten samples, **Table 4**.

8. STATIC BSTEM SOFTWARE

BSTEM is one of the models used for bank stability that was developed by the National Sedimentation Laboratory in Oxford, Mississippi. BSTEM is used to design river channels and exists as a simple spreadsheet tool in Microsoft Excel software.

The main objective of the BSTEM software is to compute erosion rate, factor of safety, and slope stability of the bank, **Fig.3**.

The necessary data of these mathematical calculations were divided into the following groups: Bank Geometry, Flow Conditions, Bank Material, Toe Model Output, Bank Model Output, and Bank Vegetation and Protection.

9. APPLICATION OF RMA2 MODEL

RMA2 has a wide range of applications in many types of engineering problems that need to simulate it with numerical modeling and from these applications, **Militello,** and **Zundal, 1999**:

1. Calculation of the water levels and flow patterns in rivers.
2. Calculation of water levels and flow distribution around islands.
3. Investigation of the circulation and transport in water bodies with wetlands.

4. Calculation of the flow at bridges having one or more relief openings and in contracting and expanding reaches.
5. Calculation of the flow inside and outside canal hydropower plants, at rive junctions.

9.1 Governing Equations

The program computes flow depth and velocity in two dimensions by solving the depth-averaged Reynolds equations. These equations are derived from Navier-Stokes equations (1) and (2) by integrating them over depth and including a number of modifications to account for turbulent flow, external tractive forces of Coriolis effects, boundary friction, and wind stress at the free surface. The received second order partial differential equations are described in the two horizontal directions x and y by **King, 2005**. Force momentum Eq. (1) and Eq. (2).

In this project, the Coriolis effects and wind stress at the free surfaces are neglected. Equations (1) to (3) are solved for each element in the mesh by using the Galerkin finite element method of weighted residuals. The local equations are then collected in a global matrix which is solved by using Gaussian integration. Derivates in time are substituted by a nonlinear finite differentiation approximation and variables are assumed to vary over each time step as Eq. (4) below, **King, 2005**:

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left[E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right]+gh\left[\frac{\partial \alpha}{\partial x}+\frac{\partial h}{\partial x}\right]+\frac{gun^2}{\left(1.486h^{\frac{1}{6}}\right)^2}(u^2+v^2)^{\frac{1}{2}}=0 \quad (1)$$

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left[E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right]+gh\left[\frac{\partial \alpha}{\partial y}+\frac{\partial h}{\partial y}\right]+\frac{gvn^2}{\left(1.486h^{\frac{1}{6}}\right)^2}(u^2+v^2)^{\frac{1}{2}}=0 \quad (2)$$

Continuity Eq. (3)

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0 \quad (3)$$

$$f(t)=f(t)_0+at+bt^c \qquad t_o\le t<t_o+\Delta t \quad (4)$$

The solution received is implicit and the set of equations are solved by the Newton-Raphson nonlinear iteration scheme, **King, 2005**.

9.2 Boundary Conditions

There are conditions that apply along the flow boundaries and are required to find the constants of integration that arise when the governing equations are integrated numerically to solve for u, v, and h in the interior of the solution domain.

The input parameters in this model include the upstream boundary conditions (discharge (Q) = 500, 1000, 1500, 2000, 3000 m^3/s) and the downstream boundary condition (water surface elevation at Nu’maniyah Region (W.L.) =17, 18.5, 20, 21.34, and 22.43 *m a.m.s.l.*,).

9.3 Friction Coefficient and Eddy Viscosity

The model allows assigning roughness by two methods as follows, **Abdul-Ridha, 2015**:

1. Global assignment: assignment can be made by element level or by material type.
2. Roughness by depth: The method accounts for the vegetation structural properties and flow depth.

Eddy viscosity parameters are used to control the numerical stabilization and describe energy losses related to viscosity and turbulence. A value for eddy viscosity must be assigned as well to allow the model to solve the equations. As a guideline for selecting reasonable values for the turbulent exchange coefficients for a given material is listed in **Table 5** which includes some representative ranges of eddy viscosity.

9.4 Mesh Generations

The finite element mesh was generated by using the SMS software package for the case study of AL- Nu'maniyah region. All regions in the domain were represented by two-dimensional, depth-averaged elements. The mesh was built by using an adaptive tessellation technique for triangular elements and a patch technique for rectangular ones. The finite element mesh was generated to represent the natural case as shown in **Fig. 4**, the bank protection case as shown in **Fig. 5**. **Table 6** represents the number of nodes and elements in each implemented case.

9.5 Topography

Bathymetry data for the study site was collected in the form of x, y, and z coordinates, **Center of Studies and Engineering Designs/ Ministry of Water Resources, 2013**. In order to create a numerical model, information about the topography in the study area is needed. From this survey, around 1855 scattered points were received with x-, y- and z-coordinates. For the pre-construction situation, these points were simply converted into contour lines by using the scatter module within SMS as shown in **Fig. 6**.

9.6 Input Parameters and Boundary Conditions

In order to receive reliable results from the RMA2 computations, input parameter values have to be properly assigned. The input parameters in this model include the upstream boundary conditions (discharge (Q) = 500, 1000, 1500, 2000, and 3000 m^3/s) and the downstream boundary condition (water surface elevation at Nu'maniyah Region (W.L.) =17, 18.5, 20, 21.34, and 22.43 *m.a.m.s.l.,*), the Manning's roughness coefficient (n), and the eddy viscosity (E).

These parameters and the assigned values for the simulations are listed in **Table 2**. The roughness coefficient values were chosen to be (0.03) for channel in the areas free of reeds, (0.04) for riprap, (0.027) for gabion, and (0.02) for vegetation while it was taken (0.1) in the dense reeds areas and partitioned area, **Drainage Design Manual for Maricopa County, 2013,** and **Chow, 1959**. Distribution of n in several regions according to their properties is shown in **Figs. 7** to **10**.

10. SMS MODELING

10.1 First Scenario: natural case, see Table 7.

In Scenario (1-A), the results of the velocity distribution using RMA-2 software at discharge of 500 m^3/s are presented in **Fig.11**. The range of the velocities upstream of the island in the study area is between 0.64 and 1.47 *m/s*, the velocity in the island is zero, and the range of the velocities downstream of the island is between 0.64 and 1.04 *m/s*. The maximum velocity is about 0.64 *m/s* at cross section (3+300).

In Scenario (1-B), the results of the velocity distribution at discharge of 1000 m^3/s are presented in **Fig. 11**. The range of the velocities near the right bank in the study area is between 0.60 and 0.88 *m/s*. The maximum velocity of 0.98 *m/s* occurs near cross section (3+200), and the range of the velocities at the island is between 0.77 and 0.97 *m/s*.

For Scenario (1-C), the results of the velocity distribution at discharge of 1500 m^3/s are presented in **Fig. 11**. The range of the velocities near the right bank in the study area is between 0.55 and 0.98 *m/s* and the range of the velocities in the island is between 0.92 and 1.03 *m/s*.

Fig.11 shows the velocity distribution results for a discharge of 2000 m^3/s for Scenario (1-D). It is obvious that the water depth near the right bank is between 3.25 and 4.68 *m*. The maximum velocity of 0.78 *m/s* occurs near cross section (4+000). Also the velocities ranged between 0.67 and 0.91 *m/s* near the right bank and they are between 0.82 and 0.94 *m/s* in the island.

The velocity distribution results at discharge of 3000 m^3/s for Scenario (1-E) varied between 1.13 and 1.20 *m/s* upstream the islands; the velocity in the downstream in the same section varied between 0.96 and 1.04 *m/s*; velocity near the right bank ranged between 0.96 and 1.20 *m/s*. The maximum velocity of 1.22 *m/s* occurred near cross section (4+000). The variation of velocity throughout the whole reach is shown in **Fig. 11**.

Accordingly, since the soil of the right bank is silty soil, the scour velocity is higher than 0.5 *m/s*, **Bundaberg Regional Council, 2013**; therefore when the discharge is not greater than 500 m^3/s the right bank is safe against scour. In other words, all cross sections need treatment except that previously treated by the Client.

10.2 Second Scenario: Treated right bank of Tigris River at Nu'maniyah City by riprap, see **table 7**.

Fig. 12 presents least velocity near the right bank over the area at a discharge of 500 m^3/s in Scenario (2-A). The velocity at island upstream the study area varied between 0.20 and 0.28 *m/s*, the velocity is zero in the island, the velocity downstream the island is between 0.01 and 0.1 *m/s*, and the velocity near the right bank is between 0.1 and 0.2 *m/s*. **Fig. 12** presents the velocity distribution over the area at a discharge of 1000 m^3/s in Scenario (2-B). The velocity at island upstream the study area varied between 0.98 and 1.31 *m/s*, the range of the velocities in the island is between 0.66 and 1.31 *m/s*, velocity downstream island is between 0.23 and 0.86 *m/s*, and the velocity near the right bank is in the range of 0.23 to 0.98 *m/s*. Also **Fig. 12** shows the velocity distribution over the area at a discharge of 1500 m^3/s in Scenario (2-C). The velocity at island upstream the study area varied between 0.75 and 0.93 *m/s*, the range of the velocities in the island is between 0.85 and 0.92 *m/s*, velocity downstream island is between 0.55 and 0.74 *m/s*, and the velocity near the right bank is between 0.55 and 0.93 *m/s*. Scenario (2-D) is almost like the results at a discharge of 2000 m^3/s in Scenario (2-C).

The velocity distribution results at a discharge of 3000 m^3/s for scenario (2-E) varied between (0.93-1.11) *m/s* upstream of the island; the velocity downstream in the same section varied between (0.58-0.86) *m/s*; velocity near the right bank ranged from

0.58 to 1.11 *m/s*. The maximum velocity is about 1.21 *m/s* occurs near cross section (4+000). The variation of velocity throughout the whole reach is shown in **Fig. 12**.

10.3 Third Scenario: Treated right bank of Tigris River at Nu'maniyah City by gabion, see **Table 7**.

Fig. 13 shows the velocity distribution over the area at a discharge of 500 m^3/s in Scenario (3-A). The velocity at the island upstream the study area varied between (0.66-0.98) *m/s*, the velocity is zero in the island, the velocity downstream the island is between (0.43-0.52) *m/s*, and the velocity near the right bank is between 0.43 to 0.98 *m/s*.

For Scenario (3-B), the velocity distribution at a discharge of 1000 m^3/s is shown in **Fig. 13**, the velocities ranged between 0.63 to 0.98 *m/s* at island's upstream, velocity downstream the island is between 0.22 to 0.78 *m/s* and the velocity near the right bank is between 0.22 to 0.63 *m/s* were a velocity of 0.60 occurs near cross section (4+000) and a velocity of 1.04 occurs near cross section (2+600).

Fig. 13 shows the velocity distribution over the area at a discharge of 1500 m^3/s in scenario (3-C). The velocity at island upstream the study area varied between 0.64 to 0.93 *m/s*, the range of the velocities in the island is between 0.64 to 0.80 *m/s*, the velocity downstream the island is between 0.54 to 0.80 *m/s*, and the velocity near the right bank is between 0.54 to 0.93 *m/s*. A discharge of 2000 m^3/s in Scenario (3-D) gives the same results as above.

The velocity distribution at a discharge of 3000 m^3/s for Scenario (3-E) varied between 0.91 to 1.11 *m/s* upstream of the island; the velocity downstream in the same section is varied between 0.58 to 0.92 *m/s*; velocity near the right bank ranges from 0.58 to 1.11 *m/s*. The maximum velocity is about 1.10 *m/s* occurs near cross section (4+000). The variation of velocity throughout the whole reach is shown in **Fig. 13**.

10.4 Fourth Scenario: Treated right bank of Tigris River at Nu'maniyah City by vegetation, see **table 7**.

Fig. 14 shows the velocity distribution over the area at discharge of 500 m^3/s in Scenario (4-A). Velocity upstream the island varied between 0.75 to 0.96 *m/s*, velocity is zero in the island, velocity downstream the island is between 0.43 to 0.47 *m/s*, and velocity near the right bank is between 0.43 to 0.96 *m/s*.

Fig. 14 shows the velocity distribution over the area at discharge of 1000 m^3/s in Scenario (4-B). Velocity upstream the island varied between 0.92 to 1.05 *m/s*, velocity downstream the island is between 0.22 to 0.92 *m/s*, and velocity near the right bank is between 0.22 to 1.05 *m/s*.

Fig. 14 shows the velocity distribution over the area at a discharge of 1500 m^3/s in Scenario (4-C). Velocity upstream the island varied between 0.89 to 0.92 *m/s*, velocity in the island is about 0.87 *m/s*. velocity downstream the island is between 0.54 to 1.1 *m/s*, and velocity near the right bank is between 0.54 to 0.92 *m/s*.

Scenario (4-D) at a discharge of 2000 m^3/s gives the same results.

The velocity distribution at a discharge of 3000 m^3/s for Scenario (4-E) varied between 0.91 to 1.12 *m/s* upstream the island; the velocity downstream in the same section varied between 0.58 to 0.89 *m/s*; velocity near the right bank ranged from 0.58 to 1.12 *m/s*. The maximum velocity is about 1.22 *m/s* occurs near cross section (4+000). The variation of velocity throughout the whole reach is shown in **Fig. 14**.

From Scenario 4, it is clear that the range of velocities is high, more than 0.7 *m/s*, in most regions for all discharges with vegetation treatment on the right bank of Tigris River at Nu'maniyah City.

Accordingly, since the maximum limit of velocities to remove plants is 0.61 *m/s*, **Varyu,** and **Fotherby, 2012**, vegetation on the right bank at all discharges in Scenario 4 will be damaged and destroyed before the occurrence of flood in the region.

Finally, vegetation is an unsafe treatment on the right bank of Tigris River at Nu’maniyah City and will be the excluded from treatment methods.

From the above Scenarios of bank protection on the riverbank by gabion treatment, the presence of a high speed at the right bank was noticed but does not mean erosion of riverbank.

Velocity reduction ratio for each type of treatments of Tigris River at Nu’maniyah City is shown in **Table 8**.

To choose the applicable type of treatment, cost of the treated reach of Tigris River at Nu’maniyah City by riprap and gabion, except cross sections (3+400) and (3+800) were calculated with an assumed maintenance cost of 10% of the total cost as shown in **Table. 9**.

Finally, riprap gives the best treatment to reduce erosion on right bank of Tigris River at Nu’maniyah City because its total cost is 2 billion IQD which is less than of the gabion treatment and riprap is the long term success in bank protection. Also riprap is required less maintenance and stayed for several decades compared with the gabion.

11. CONCLUSIONS

According to results of the present study, the following conclusions can be withdrawn:

1. Experimental work using "mini" Jet device shows high erosion coefficient of cross sections (2+600), (2+900) and (4+000) which confirms that this device is a very good indicator for the possibility of bank scour. The velocities upstream of the island and near the right bank in the study area are between 0.64 and 1.47 *m/s,* while downstream of the island is between 0.64 and 1.04 *m/s.*
2. Failure occurs in natural case of Tigris River at Nu’maniyah City especially at cross sections (2+600) and (4+000) because of erosion near the right bank and does not occur because of slope stability failure for right bank where the range of the velocities near the right bank for the study area for most discharges is between 0.67 and 0.91 *m/s.*
3. Soil of Tigris River right bank at Nu’maniyah is silty soil, the scour velocity is higher than 0.5 *m/s,* therefore the right bank is safe against scour only when the discharge of Tigris River is not greater than 500 m^3/s.
4. Vegetation is an unsafe treatment on right bank of Tigris River at Nu’maniyah City. The velocity that removes plants when used as a treatment for river bank is 0.61 *m/s* and velocities near bank at most discharges are higher than this limit.
5. Treatment by riprap is the best choice on the right bank of Tigris River at Nu’maniyah City because its cost with maintenance is 2 billion IQD which is less than that of gabion treatment; moreover, velocity reduction ratio along the right bank by riprap ranges from 15 to 85 %, while velocity reduction ratio along the right bank by gabion ranges from 8 to 25 %.

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NOMENCLATURE

a= constant, dimensionless.
b= constant, dimensionless.
BSTEM= bank stability and toe erosion model
c= constant, dimensionless.
DEM= digital elevation model
E_{xx}= eddy viscosity coefficient on x-axis, pascal.sec.
E_{yy}= eddy viscosity coefficient on y-axis, pascal.sec.
E_{xy}, E_{yx}= shear direction on each surface, pascal.sec.
F= a set of terms, dimensionless
g= acceleration due to gravity, m/sec^2
h= water depth, m.
k_d= erodibility factor, cm^3/Ns
n= manning's roughness coefficient, dimensionless.
p= pressure, pascal.
Q= discharge, m^3/sec.
SMS= surface modeling system.
t= time, sec.
u= velocity in the x direction, m/sec.
v= velocity in the y direction, m/sec.
W.L.= water level, m.
X= cartesian coordinate in x-direction.
Y= cartesian coordinate in y-direction.
Z= cartesian coordinate in z-direction.
α= bottom elevation, m
μ= viscosity, pa*s.
ρ_d= dry density, gm/cm^3.
τ_c= critical shear stress, pascal.
τ = boundary shear stress, pascal.

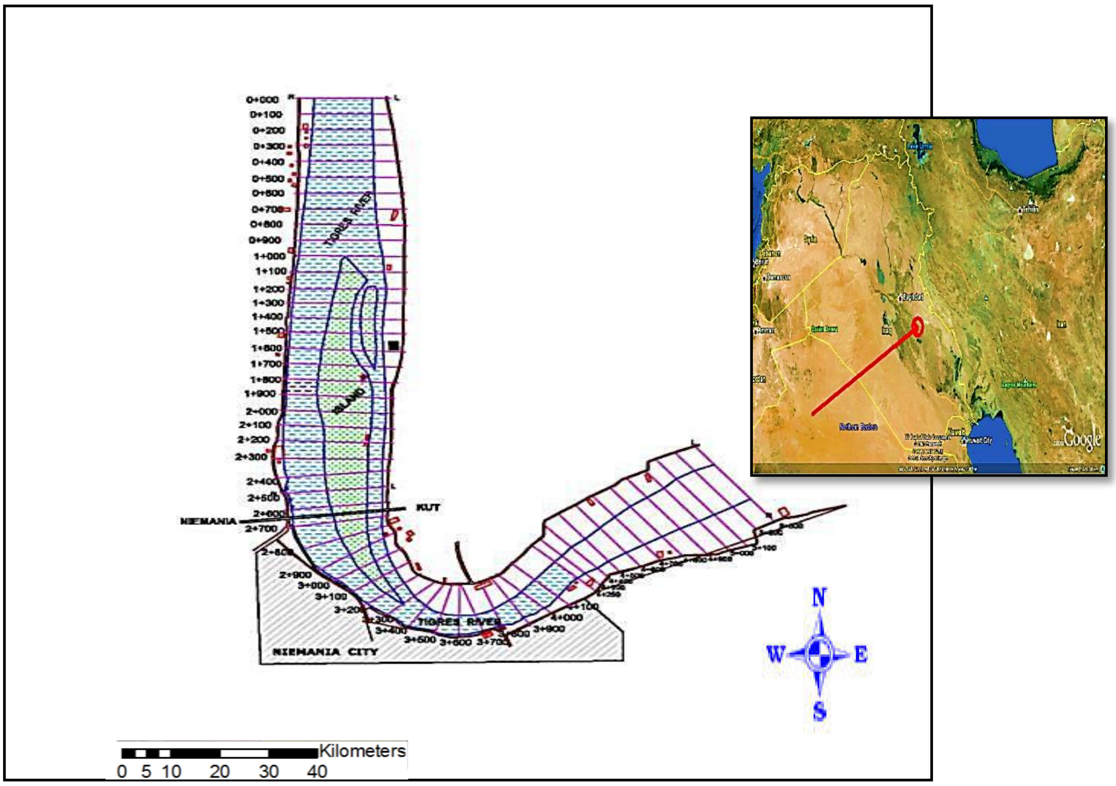

Figure. 1. Location of the study area, **Center of Studies and Engineering Designs Report, 2015**.

Table 1. Hydrological data during flood of 1988 in Nu’maniyah City, **[Abdul-Sahib, 2014]**

Discharge (Q) *(m^3/s)*	**Water Level (W.L) *(m)***
500	17
1000	18.5
1500	20
2000	21.34
3400*	22.43*

*Flood, **National Center for Management Water Resources, 1988.**

Table 2. Manning's n for bank protection such as gabion, riprap, and vegetation, [**Drainage Design Manual for Maricopa County, 2013, Chow, 1959]**.

Type of Bank Protection	Hydraulic Roughness (Manning's n)		
	Minimum	Normal	Maximum
Gabion		0.027	
Grouted Riprap	0.028	0.030	0.040
Vegetation	0.005-0.010	0.010-0.025	0.025-0.050

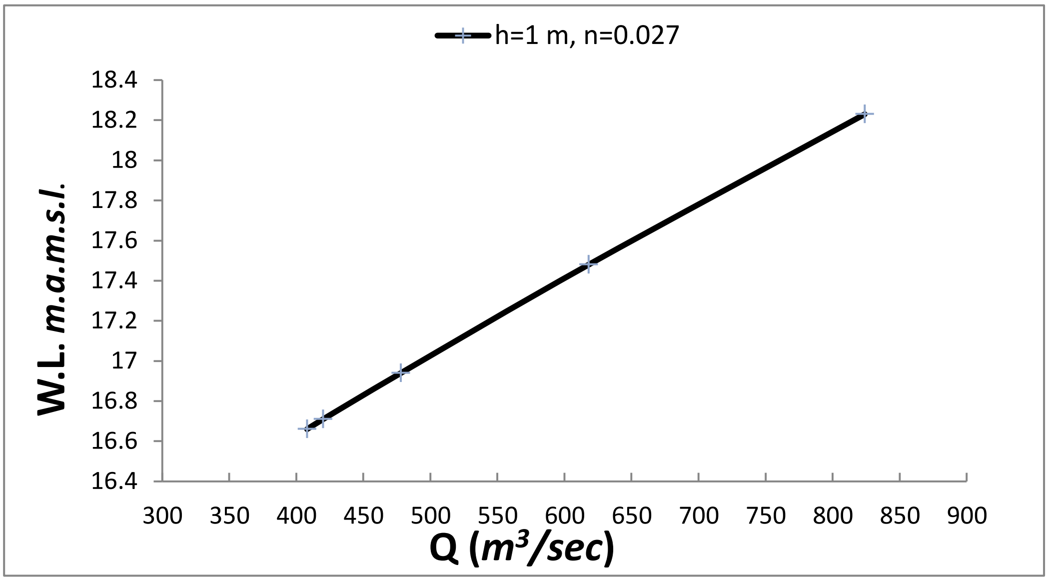

Figure. 2. Rating curve of upstream reach (C.S.22) for multigate openings for Tigris River, **Abdul-Sahib, 2014**.

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Table 3. The location of soil samples as numbered cross section on map.

Cross Section Number at Map	Riverbank	River Toe
C.S (2+600)	01B	01R
C.S (2+900)	02B	02R
C.S (3+400)	03B	03R
C.S (3+800)	04B	04R
C.S (4+000)	05B	05R

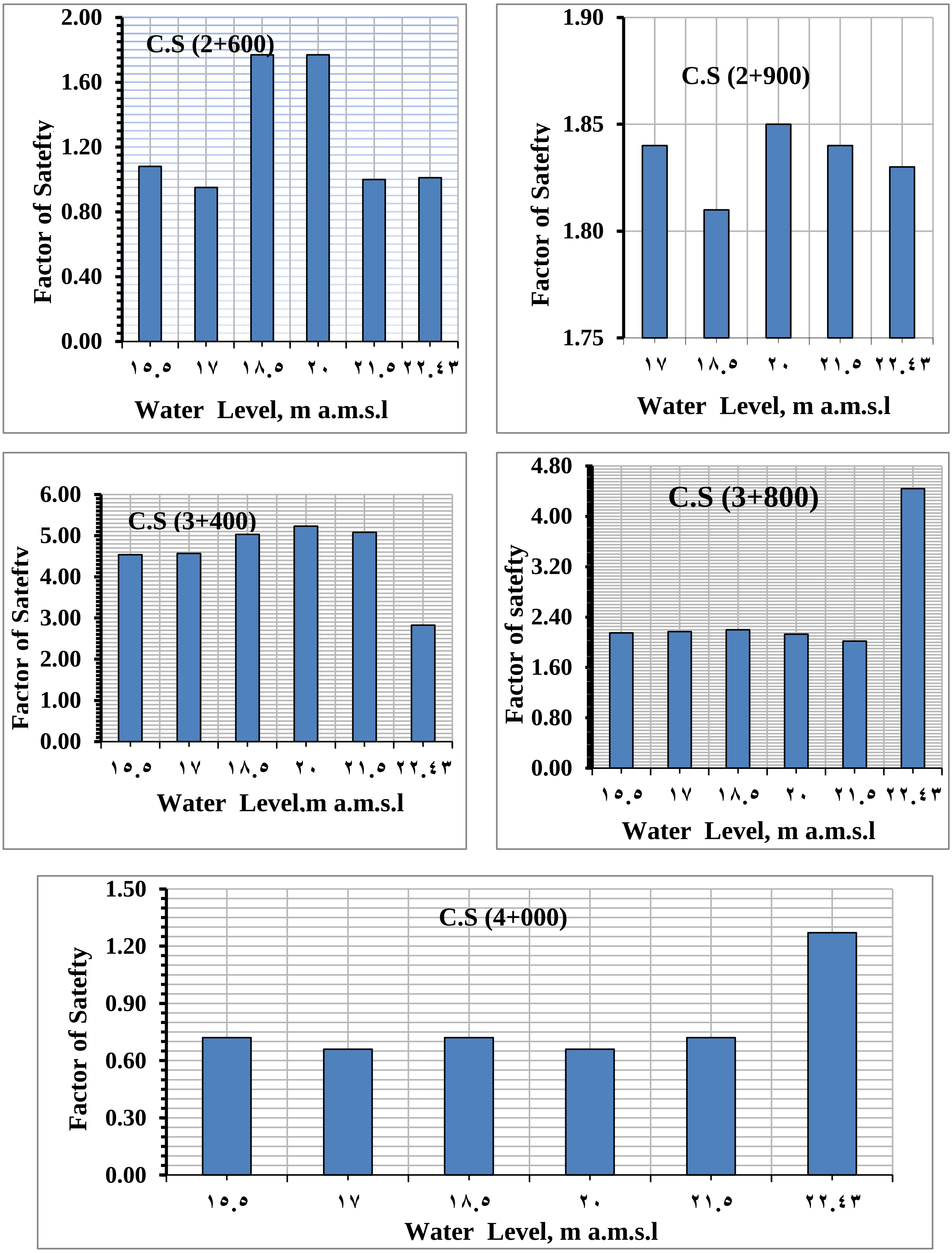

Figure. 3. Factor of safety with water level charts by using BSTEM software.

Table 4. Results from special equation when using mini Jet device.

Sample Location	**Sample Number**	**Dry Density (ρ_d) *gm/cm^3***	**Erodibility Factor (k_d) *cm^3/Ns***	**Critical Shear Stress (τ_c) *Pa***	**Boundary Shear Stress (τ) *Pa***
C.S (2+600)	01B	2.03	2.16	0.08	21.52
	01R	2.05	1.11	0.38	21.52
C.S (2+900)	02B	1.88	1.19	0.18	21.52
	02R	2.04	1.13	0.33	21.52
C.S (3+400)	03B	1.89	1.72	0.13	21.52
	03R	1.78	2.41	0.06	21.52
C.S (3+800)	04B	1.93	2.56	0.04	21.52
	04R	1.73	2.09	0.07	21.52
C.S (4+000)	05B	2.01	2.20	0.09	21.52
	05R	2.00	1.20	0.40	21.52

Table 5. Model control parameters.

Description	**Value**
Iterations	4
Depth convergence	0.05 meters
Dry depth	0.05meters
Wet depth	0.09 meters
Latitude	Neglected
Wind speed	Neglected
Rainfall/Evaporation	Neglected

Table 6. Number of nodes and elements in the mathematical model of the study area.

Details	**Number of Nodes**	**Number of Elements**
Natural case	6023	2874
Bank protection case	5628	2697

Table 7. Some representative ranges of eddy viscosity, [**Donnell,** and **King, 2003]**.

Type of Problem	**E , Pa. s**
Homogenous horizontal flow around an island	500-5000
Homogenous horizontal flow at a confluence	1100 -5000
Steady-State flow for thermal discharge to a slow moving river	1000-50000
Tidal flow in a marshy estuary	2500-10000
Slow flow through shallow pond	10-50

Table 8. Description of the adopted Scenarios for the study area.

S	**Description**	**A**	**B**	**C**	**D**	**E**
First (1)	Natural case	Q=500 m^3/s at U/S and W.L.=17m at D/S	Q=1000 m^3/s at U/S and W.L.=18.5 m at D/S	Q=1500 m^3/s at U/S and W.L.=20 m at D/S	Q=2000 m^3/s at U/S and W.L.=21.34 m at D/S	Q=3000 m^3/s at U/S and W.L.=22.43 m at D/S
Second (2)	Riprap case					
Third (3)	Gabion case					
Forth (4)	Vegetation case					

Figure. 4. The finite element mesh with bank protection case.

Figure. 5. The finite element mesh in the natural case.

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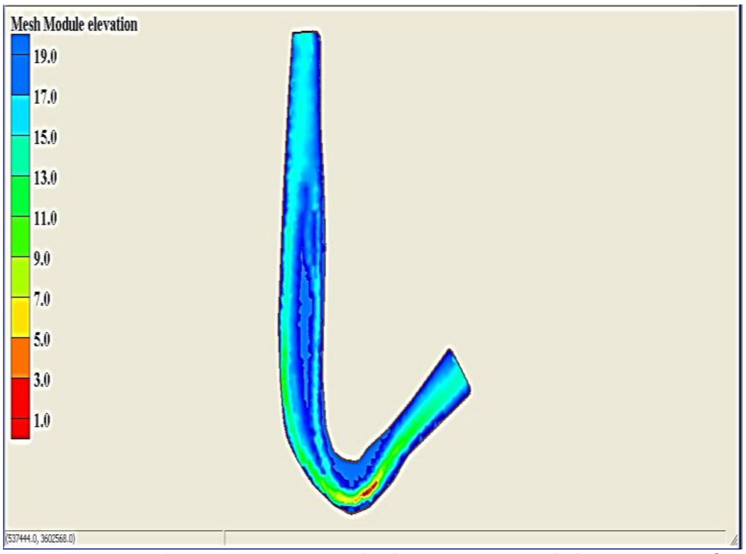


Figure. 6. Digital elevation model (DEM) of Tigris River at Nu’maniyah City.

Figure.7. Manning's n in natural case at Q=500 m^3/s.

Figure. 8. Manning's n in natural case at Q= (1000, 1500 and 2000) m^3/s.

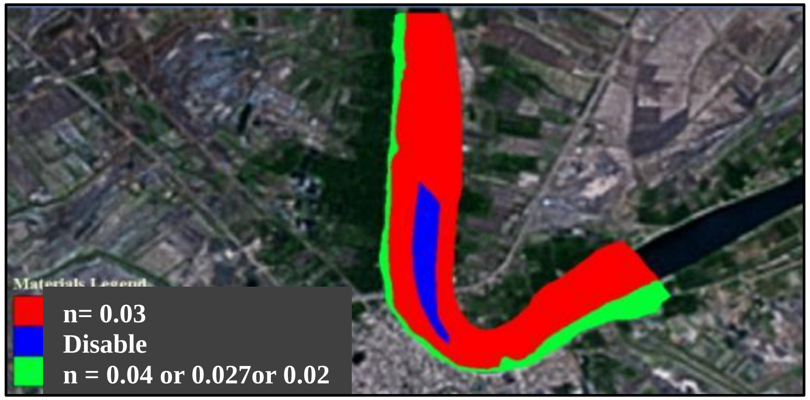


Figure. 9. Manning's n with bank protection by (riprap, gabion, and vegetation) at Q=500 m^3/s.

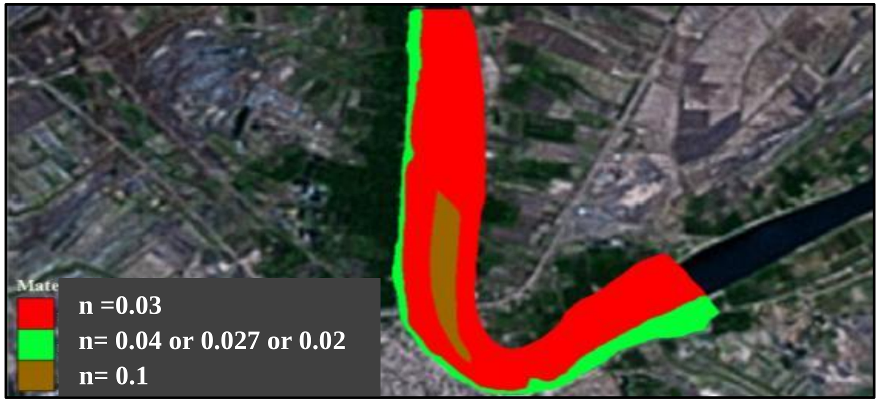
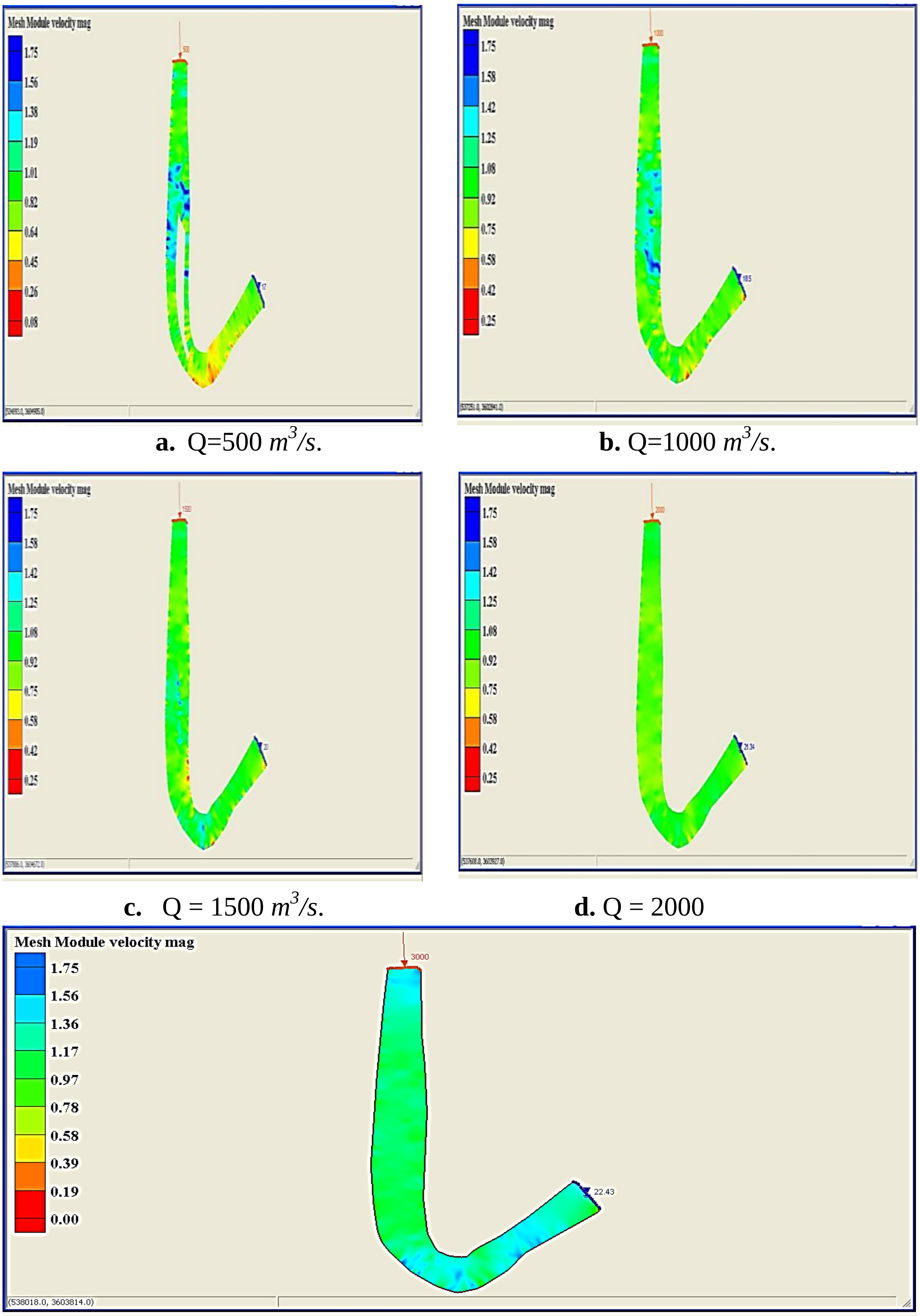


Figure. 10. Manning's n with Bank Protection (riprap, gabion, and vegetation) at Q= (1000, 1500 and 2000) m^3/s.



a. Q=500 m^3/s.

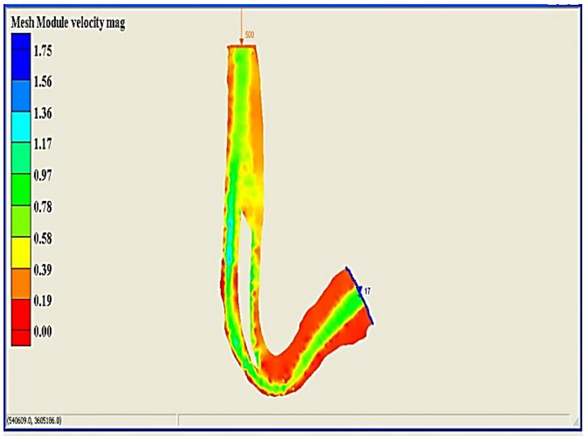
b. Q=1000 m^3/s.

c. Q = 1500 m^3/s.

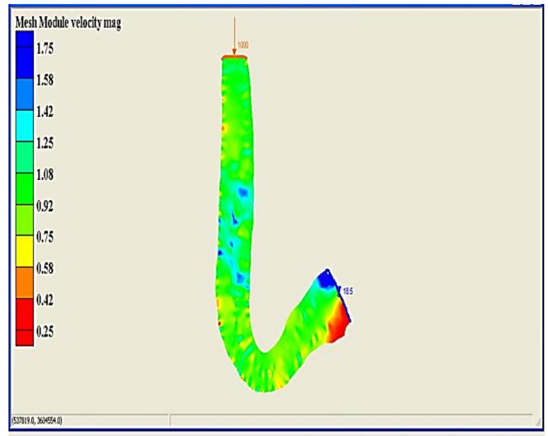
d. Q = 2000 m^3/s.

e. Q = 3000 m^3/s.

Figure. 11. Velocity distribution for Scenario 1 of Tigris River at Nu'maniyah City for natural case with discharges of (500, 1000, 1500, 2000 and 3000) m^3/s and D/S water levels of (17, 18.5, 20, 21.5 and 22.43) *m a.m.s.l.* ,respectively.

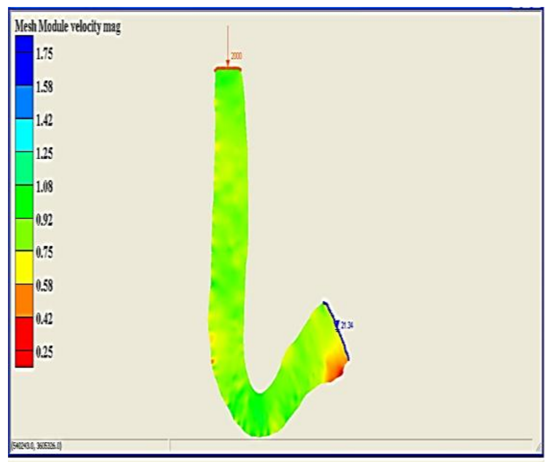


a. Q=500 m^3/s.

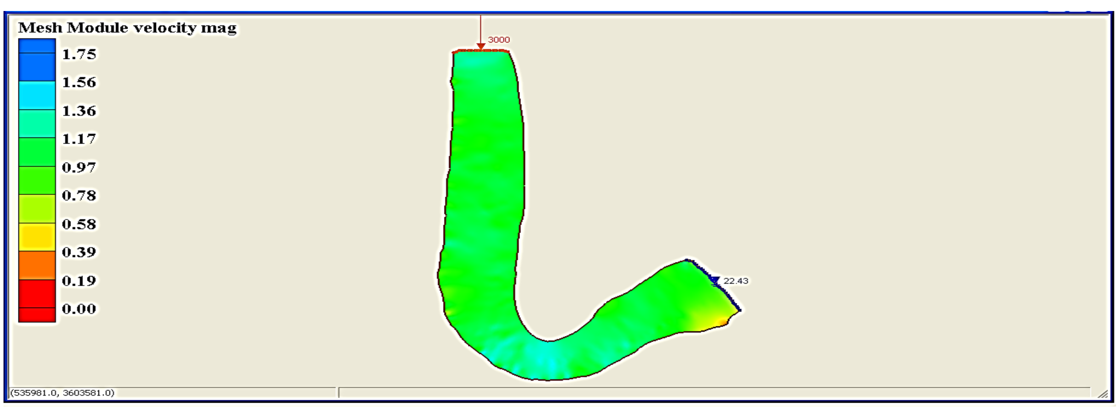


b. Q=1000 m^3/s.

c. Q=1500 m^3/s.

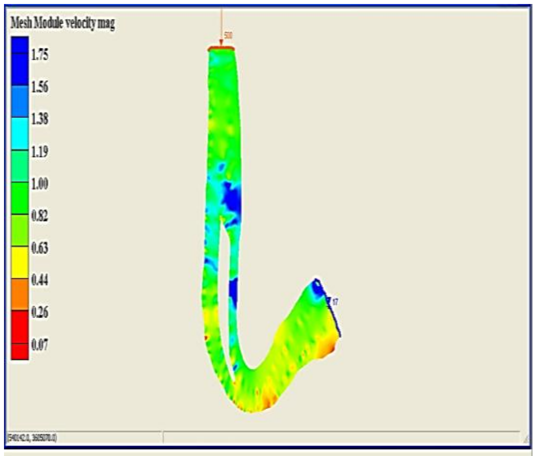


d. Q=2000 m^3/s.

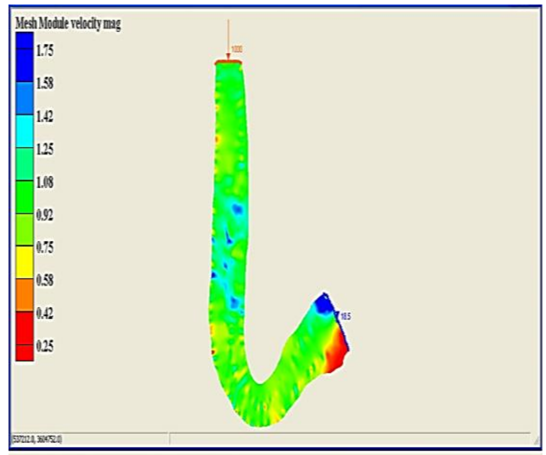


e. Q=3000 m^3/s.

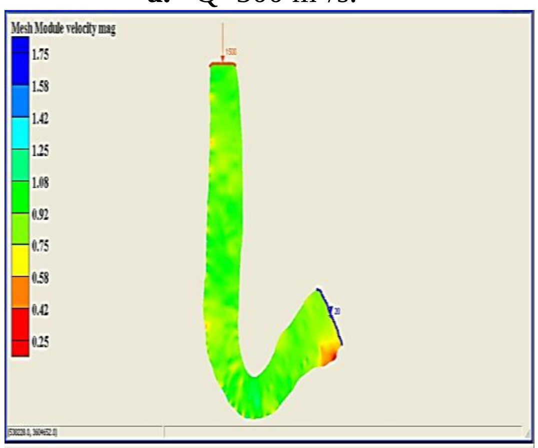
Figure. 12. Velocity distribution for Scenario 2 of Tigris River at Nu'maniyah City for treated banks by riprap with discharges of (500, 1000, 1500, 2000 and 3000) m^3/s and D/S water level of (17, 18.5, 20, 21.34 and 22.43) *m a.m.s.l.*, respectively.



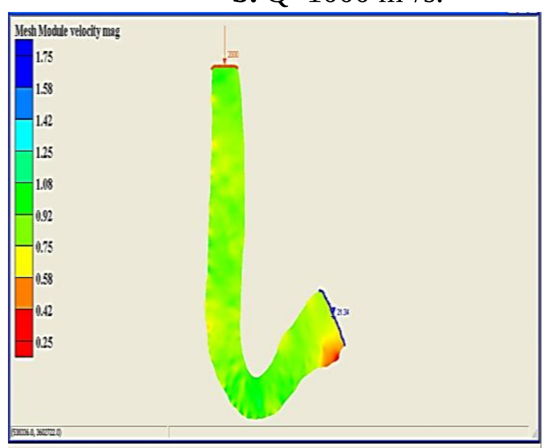
a. Q=500 m^3/s.



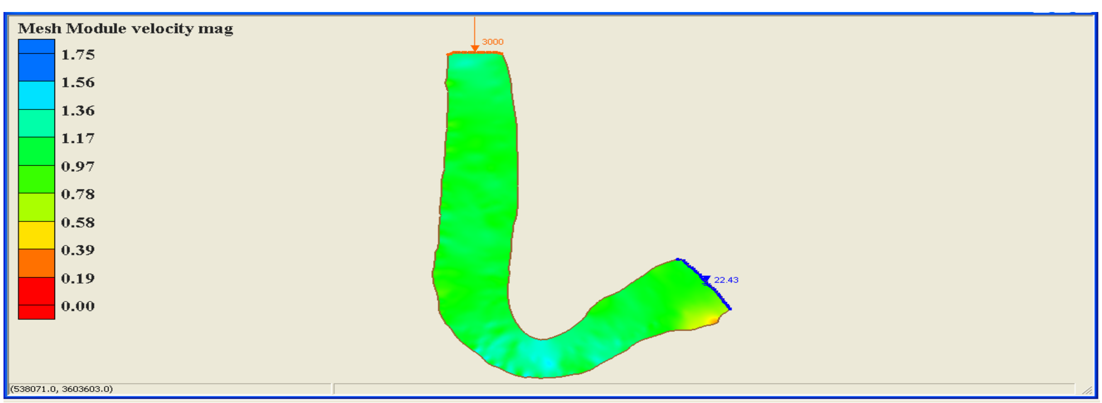
b. Q=1000 m^3/s.



c.Q=1500 m^3/s.

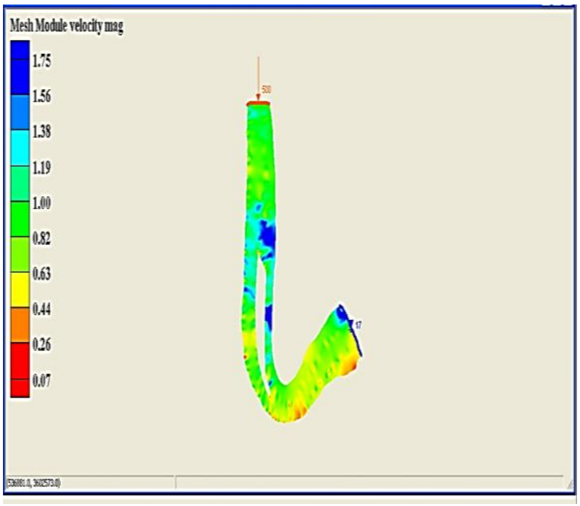


d. Q=2000 m^3/s.

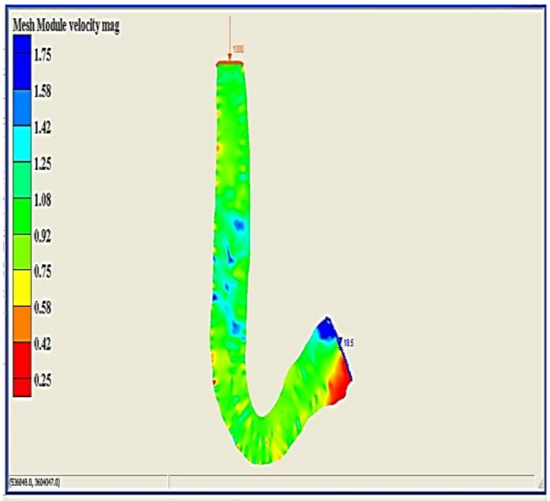


e. Q=3000 m^3/s.

Figure. 13. Velocity distribution for Scenario 3 of Tigris River at Nu'maniyah city for treated banks by gabion with discharges of (500, 1000, 1500, 2000 and 3000) m^3/s and D/S water level of (17, 18.5, 20, 21.34 and 22.43) *m a.m.s.l.*, respectively.



a. Q=500 m^3/s.



b. Q=1000

c. Q=1500 m^3/s.

d. Q=2000 m^3/s

d. Q=3000 m^3/s.

Figure. 14. Velocity distribution for Scenario 4 of Tigris River at Nu'maniyah City for treated banks by vegetation with discharges of (500, 1000, 1500, 2000 and 3000) *m^3/s* and D/S water level of (17, 18.5, 20, 21.34 and 22.43) *m a.m.s.l.*, respectively.

Table 8. Average velocity reduction ratio along the right bank of Tigris River at Nu'maniyah City for each good treatment.

Treatment Type	**Discharge *(m^3/s)***	**Average Velocity Reduction Ratio %**
Riprap	500	85
	1000	35
	1500	15
	2000	15
	3000	8
Gabion	500	25
	1000	35
	1500	10
	2000	10
	3000	8

Table 9. Cost of the treated reach of right bank of Tigris River at Nu'maniyah City with riprap and gabion bank protections for 30 years each with maintenance as 10% from the total cost.

Treatment Type	**Implementation Cost (ID)**	**Maintenance of Construction (Year)**	**Design Life (Year)**	**Maintenance Cost (IQD)**	**Total (IQD) in 30 years**
Riprap	7,464,666,300	15	30	1492933260	8,957,599,560
Gabion	4,222,865,338	5	15	1266859601	10,979,449,879