ESTIMATING THE SEDIMENT TRANSPORT CAPACITY OF TIGRIS RIVER WITHIN AL MOSUL CITY.

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ABSTRACT

The capacity of Tigris River to transport the sediment within Al Mosul City is one of the most important characteristics of the river. Establishment of islands within this reach of the river because of decreasing the discharge of Tigris River can be controlled through studying this characteristic. Establishment of these islands and increase of the sediment deposition in the river reach affect the water treatment plants and the urban and industrial activities that are located on the banks of this reach.

A steady one dimensional mathematical model for simulating the flow and estimating the sediment transport capacity of the studied reach was implemented and run by using the HEC-RAS (Version 3.1.3) software and making use of recorded field measurements for running and carrying out the calibration and verification processes.

Flow velocity and sediment transport capacity were estimated for a range of discharge from 50 to 1500m^3/sec. Locations of the low flow velocity were specified. The comparison between sediment capacity rating curves of these locations showed that the sediment transport capacity of the reach cross sections at 13000 and 4500m from the end of the reach, before and after Al Khosar River, is less than that of the other cross sections of this reach.

The comparison between the sediment transport capacity and the inflow sediment quantity into the river reach before and after Al Khosar River with discharge and sediment concentration of 425m^3/sec and 600ppm from Al Mosul Dam and 5m^3/sec and 3150ppm from Al Khosar River showed that the deposited sediment in the river reach before and after Al Khosar River was 21900 and 15000tonnes/day, respectively.

To avoid deposition of sediment before Al Khosar River and then along the studied reach the inflow discharge into the reach from Al Mosul Dam must be not less than 1500m^3/sec. While, to avoid deposition of sediment after Al Khosar River the total discharge must be not less than 780m^3/sec. The river reach cross section of low flow velocity must be developed to increase the sediment transport capacity.

Keywords: Sediment Transport Capacity, Establishment of islands, Al Khosar River

حساب طاقة الحمل الرسوبي لنهر دجلة ضمن مدينة الموصل

الخلاصة

إن قدرة نهر دجلة ضمن مدينة الموصل على حمل الرسوبيات هي واحدة من أهم خصائص النهر التي من خلال دراستها يمكن السيطرة على تكون الجزرات داخل هذا الجزء من نهر دجلة والتي بدأت بالتكون بسبب انخفاض معدلات تصاريف نهر دجلة. إن تكون هذه الجزرات وزيادة معدلات الترسيب في النهر يؤثر بشكل كبير على محطات تصفية المياه والفعاليات الصناعية والمدنية الواقعة على ضفتي هذا الجزء من النهر.

تم اعداد وتشغيل نموذج رياضي للجريان الثابت احادي البعد لمحاكاة الجريان وحساب طاقة الحمل الرسوبي في هذا الجزء من النهر بإستخدام البرنامج الجاهز(HEC-RAS (Version 3.1.3 والإستعانة بقياسات حقلية مسجلة سابقاً لغرض إعداد النموذج وإجراء عمليتي المعايرة والتحقق.

تم تشغيل النموذج وحساب سرع الجريان وطاقة الحمل الرسوبي على طول النهر لمدى من التصاريف تراوح بين 50 الى 1500 م^3/ثا. تم تحديد مواقع سرع الجريان البطيء وتبين من خلال مقارنة منحنيات علاقة طاقة الحمل الرسوبي مع التصريف لهذه الأجزاء إن طاقة الحمل الرسوبي لمقاطع النهر الواقعة على بعد 13000 م و4500م من النهاية، قبل وبعد نهر الخوصر، على التوالي، اقل من نظيراتها في المقاطع الأخرى من النهر.

تبين من خلال مقارنة طاقة الحمل الرسوبي وكمية الرسوبيات الداخلة الى النهر قبل وبعد نهر الخوصر بتصريف مطلق من سد الموصل مقداره 425 م^3/ثا وبتركيز رسوبيات 600 جزء في المليون وتصريف نهر الخوصر 5م^3/ثا وبتركيز 3150 جزء في المليون إن كمية الرسوبيات المتراكمة في مقطع النهر قبل وبعد نهر الخوصر هي 21900 طن/يوم و 15000 طن/يوم، على التوالي.

لتجنب تراكم الرسوبيات في مقطع النهر قبل نهر الخوصر وبالتالي المقاطع الأخرى من النهر في مثل هذه الظروف يجب أن لايقل االتصريف المطلق من سد الموصل عن 1500م^3/ثا. ولتجنب تراكم الرسوبيات في مقطع النهر بعد نهر الخوصر يجب ان لايقل مجموع التصريف المار في هذا المقطع عن 780م^3/ثا. ويجب كري وتعديل مقاطع النهر التي تكون فيها سرع الجريان قليلة لزيادة طاقة الحمل الرسوبي فيها.

1- Introduction

The reach of Tigris River from the north side of Al Mosul City to the southern end of this city, 21km, is important because it divides the city into two parts which are the Right bank and the Left bank, Figure 1. Most of the water treatment plants intakes are placed on this reach in addition to the existence of different industrial and urban activities.

There are two bends in this reach. The first at the beginning and the second at the end of this reach. However, it is straight through the city and contains a number of big and small islands.

Al Khosar River, which is a small seasonal tributary, discharged in this reach of Tigris River at the beginning of the last third of the reach.

The decrease in the discharge of Tigris River because of the decrease in the water resources causes a decrease in flow velocity, Establishment of islands and changing the morphological characteristics of this reach.

Capacity of the river to transport the sediment is one of the most important characteristics of the river and plays the major role in the establishment of islands and changing the morphological characteristics of this reach.

Integration of steady one dimensional mathematical model and field observation data and utilizing the HEC-RAS software (Version 3.1.3) was used to implement and run a simulation model to estimate the flow velocity and the capacity of the river to transport the sediment.

2- River Data

Seventy seven cross sections were surveyed along the studied reach, by using the Echo Sounder instrument [1]. These cross sections were selected to represent the geometry of each part of the reach, Figure 1. The distance between the surveyed cross sections ranged between 71 to 606m.

The water surface elevation was measured at 16 cross sections [2]. These measured water surface elevations are listed in Table 1.

The upstream inflow discharges into this reach were approximately constant during the period of measurements, 60 days, because they depend on the operation requirements of Al Mosul Dam. This discharge was 425m^3/sec. The maximum, average and minimum recorded discharges at Al Huriah station in Al Mosul City for the period from the year 1986 to 2009 were 3180, 500, and 41 m^3/sec, respectively[3].

The measured discharge of Al Khosar River at its outfall in Tigris River was 5m^3/sec [2], while the range of its discharges is between 5 to 150m^3/sec [4].

The velocities of flow were measured at 40 cross sections by using the Current Meter instrument [2]. The mean velocities of flow at these 40 cross sections are listed in Table 2.

The suspended and bed sediment load of Tigris River are trapped at the upstream of Al Mosul Dam. The source of the suspended and bed sediment transported in the studied reach, 60km downstream of the dam, is the catchment area of the river between Al Mosul Dam and Al Mosul City and the catchment area of Al Khosar River which transports this load into Tigris River.

The concentration and grain size distribution of the suspended sediment along this reach were measured by using the Turbidity Meter and Hydrometer instruments [2]. These measurements were carried out at different flow and rainfall conditions. Concentration of the suspended sediment when there is no rainfall, the water flows in the studied reach is only that released from Al Mosul Dam, was between 6 to 30ppm. When there is rainfall, this concentration becomes 600ppm in the reach before Al Khosar River and 3150ppm in the reach after Al Khosar River. Analysis of the collected samples shows that the grain size distribution of the suspended sediment was as shown in Figure 2.

3- Flow Routing Model

A steady one dimensional flow mathematical model was used to simulate the flow in this reach in order to obtain the water surface elevation, flow velocity, and sediment transport capacity along the reach under a set of steady flow conditions.

The HEC-RAS software (Version 3.1.3) [5] was used to accomplish this target.

3-1 Geometrical Data

The surveyed river cross sections [1], left and right banks, downstream reach length, proposed initial Manning's roughness coefficient, n, of the main channel, and other reaches' information where the geometrical data are required to run the model were input to the model through the menu of cross sectional geometrical data.

All hydraulic structures, five bridges, on the river were specified and their details were involved to the model using bridge or culvert geometrical data menu.

3-2 Upstream Boundary Condition

The HEC-RAS model deals with the boundary conditions depending on the flow regime. In a subcritical flow regime, which is the flow regime in the river under consideration, boundary condition is only necessary at the D/S end of the river system and deals with its data in a separated window.

The measured discharge, 425m^3/sec, and a range of discharges from 50 to 1500 m^3/sec, Table 3, were adopted as the upstream boundary required to run the model, one value is used at each time.

Flow-change locations, Al Khosar River outfall, were specified and the net flow through the river reaches was input to the model using the steady data menu.

3-3 Downstream Boundary conditions

A known constant stage type boundary condition was adopted to run the hydraulic model for the case of measured discharge, 425m^3/sec. This stage was 211.7 m.a.s.l at cross section no. (77). Normal flow type boundary condition was adopted for running the model for the other cases, (the discharge range listed in Table 3). The adopted normal flow slope was 0.000035. These data were input to the model through the menu of steady flow data.

3-4 Model Calibration

A calibration process was carried out using stage measurements along the reach, Table 1, and the measured discharge at the upstream end of this reach, 425m^3/sec, and the discharge of Al Khosar River into this reach, 5m^3/sec.

The calibrated Manning's n values along the main channel and its left and right banks are 0.038 and 0.05, respectively.

An acceptable agreement was achieved between the estimated stage values using the calibrated data and the measured stage values as shown in Figure 3.

3-5 Model Verification

The measured velocities at the 40 cross section, Table 2, were used for the verification process. The comparison between those estimated by using the model and measured mean velocities at these cross sections is shown in Figure 4. This comparison shows an acceptable agreement.

3-6 Sediment Transport Capacity

The sediment transport capacity computations can only be run once steady flow computations have been run. Sediment Transport Capacity for any cross section can be computed using Ackers-White, Meyer-Peter Müller, Laursen, Toffaletti, or Yang sediment transport functions.

The morphological characteristics of the studied reach are compatible with the criteria of Toffaleti (modified-Einstein) sediment-transport function [6] which are:

Toffaleti (field):
$0.062 < d < 4$ mm; $0.095 < dm < 0.76$ mm;
$0.21 < V < 2.36$ m/s; $0.021 < R < 17.18$ m;
$0.000002 < S < 0.0011$; $19.1 < W < 1103.03$ m;
$40 < T < 93$ degrees F

Toffaleti (flume):
$0.062 < d < 4$ mm; $0.45 < dm < 0.91$ mm;
$0.21 < V < 1.9$ m/s; $0.0021 < R < 0.33$ m;
$0.00014 < S < 0.019$; $0.24 < W < 2.42$ m;
$32 < T < 94$ degrees F

A modified-Einstein total load function that breaks the suspended load distribution into vertical zones, replicates two-dimensional sediment movement. Four zones are used to define the sediment distribution. They are the upper zone, the middle zone, the lower zone, and the bed zone. Sediment transport is calculated independently for each zone and summed up to arrive at total sediment transport. This method was developed using an exhaustive collection of both flume and field data. The flume experiments used sediment particles with mean diameters ranging from 0.45 to 0.91 mm; however, successful applications of the Toffaleti method suggests that mean particle diameters as low as 0.095 mm are acceptable.

The sediment transport capacity was estimated for the measured discharge, 425m^3/sec, and a range of discharges from 50 to 1500 m^3/sec, Table 3.

4- Results

Results of applying the implemented model for the adopted range of discharges revealed that the water surface elevations and velocity along the studied reach were as shown in Figures 5 and 6. The mean flow velocity at main channel distances 2000 and 4500m, after Al Khosar River outfall and 9500, 13000, and 19000 m, before Al Khosar River outfall, at cross sections number 71, 62, 40, 28 and 9, respectively, was less than 0.5 m/sec for most of the adopted discharges. These low flow velocities occured at the constituted islands at the reaches of high bed elevation and wide cross sections. These cross sections can be considered as critical sections.

The estimated sediment transport capacities, by using Toffaleti function, along the studied reach for the adopted range of discharges are shown in Figures 7 to 14.

The sediment transport capacity rating curves at the critical sections, cross sections number 71, 62, 40, 28 and 9, are shown in Figure 15. These rating curves show that the sediment transport capacity at the channel distance 4500 and 13000 m, cross sections no. 62 and 28, is less than that of other cross sections along the reach.

For the measured inflow discharge and suspended sediment concentrations from Al Mosul Dam and that from Al Khosar River, during a rainy duration, were 425m^3/sec, 600ppm, 5m^3/sec and 3150 ppm, respectively. The quantity of inflow sediment into the studied reach before Al Khosar River is 22032 and that from Al Khosar River is 3160.8 tons/day, respectively and the total sediment quantity inflow into the river reach after Al Khosar River is 25192.8 tons/day. Accordingly, the quantity of deposited sediment at cross sections no. 28 and 62, which is the difference between the inflow sediment and sediment transport capacity for the adopted discharge range, is as shown in Figure 16. This figure shows that the quantity of deposited sediment at these cross sections with total inflow discharge of 430m^3/sec, 425m^3/sec from

Al Mosul Dam, was 21900tons/day before Al Khosar River and 15000tons/day after Al Khosar River.

To avoid deposition of sediment before Al Khosar River and then along the studied reach, the inflow discharge into the reach from Al Mosul Dam must not be less than 1500 m^3/sec. While, to avoid deposition of sediment after Al Khosar River, the total discharge through this river reach must not be less than 780m^3/sec.

5- Conclusions

The following conclusions were achieved:

1- The main channel distances at which the mean flow velocity is less than 0.5m/sec are 2000 and 4500m, after Al Khosar River, and 9500, 13000, and 19000 m, before Al Khosar River, at cross sections number 71, 62, 40, 28 and 9, respectively. These low flow velocities occur at the established islands at the reaches of high bed elevation and wide cross sections.

2- Sediment Transport Capacity at the channel distance 4500 and 13000 m, cross sections no. 62 and 28, is less than that of other cross sections along the reach.

3- The quantity of inflow sediment during the rainy period from the catchment area of the reach between Al Mosul Dam and Al Mosul City was 22032 tons/day, while from that of Al Khosar River was 3160.8 tons/day.

4- The quantity of deposited sediment at main channel distances 13000 and 4500m, before and after Al Khosar River, with total inflow discharge of 430m^3/sec, 425m^3/sec from Al Mosul Dam and 5m^3/sec from Al Khosar River, was 21900 and 15000 tons/day, respectively.

5- To avoid deposition of sediment before Al Khosar River and along the studied reach the inflow discharge into the reach from Al Mosul Dam must not be less than 1500m^3/sec.

6- To avoid deposition of sediment after Al Khosar River the total discharge must be not less than 780m^3/sec.

7- The Established islands must be removed and the wide and shallow cross sections must be modified to prevent their occurrence during very low flow velocities.

8- The inflow discharges into this reach from Al Mosul Dam must be increased during the rainy period to increase the sediment transport capacity of this reach.

9- The sediment transport rating curve of Al Khosar River must be constructed and the discharges that must be released from Al Mosul Dam during the rainy period must be estimated for the whole discharges range of Al Khosar River.

6- References

1- Ministry of Water Resources, 2009; "Recorded Data of the Surveyed Cross Sections Along the Reach of Tigris River within Al Mosul City" General Directorate of Survey, Baghdad -Iraq, unpublished report.

2- Ministry of Water Resources and Mosul University - Dam and Water Resources Research Center 2009; "Records of Field Observations" International Center of Water Resources, Baghdad -Iraq, unpublished Data.

3- Ministry of Water Resources, 2009, "Recorded Discharges at Al Huriah Station in Al Mosul City for the Period from the Year 1986 to 2009" State Commission for Operation of Irrigation and Drainage Projects – DEP, Baghdad -Iraq, unpublished Data.

4- Mohammad E. Mohammad, 2005, "A Conceptual Model for Flow and Sediment Routing for A Watershed Northern Iraq" Ph. D. Thesis, Water Resources Dept. College of Engineering – Mosul University, Mosul - Iraq.

5- U.S. Army Corps of Engineers, 2005, "River Analysis System", Version 3.1.3, Hydrologic Engineering Center, Davis CA 95616.

6- Yang C. T, 1996, "Sediment Transport" Mc GRaw-Hill Series in Water Resources and Environment Engineering.

Table 1. Measured water surface elevations along the studied reach. (After Ministry of Water Resources and Mosul University – DWRRC, 2009).

Cross section No.	Water surface elevation (m.a.m.s.l)
1	221.5
5	220.6
10	220.0
15	219.6
20	218.5
25	217.8
30	217.6
35	217.0
40	216.1
45	215.5
50	215.0
55	214.4
60	213.9
65	213.5
70	212.6
75	211.9

Table 2. Average velocity along the studied reach. (*After Ministry of Water Resources and Mosul University – DWRRC, 2009*).

Cross section No.	Flow velocity (m/sec)	Cross section No.	Flow velocity (m/sec)
1	0.60	39	0.40
3	0.85	41	0.60
4	0.80	44	1.00
5	1.00	46	1.00
7	0.85	48	0.75
9	0.60	51	0.70
10	0.60	54	1.20
13	0.60	55	0.90
14	0.90	56	0.80
17	1.00	57	0.70
19	1.00	60	0.80
21	1.00	61	0.90
24	0.75	62	1.25
27	0.90	65	0.90
28	0.80	67	0.90
29	0.75	69	0.90
31	0.85	70	1.00
33	0.70	72	0.90
36	0.45	74	0.80
37	0.65	77	0.45

Table 3. Adopted inflow discharges into the studied reach.

Case No.	Discharge (m^3/sec)
1	50
2	100
3	250
4	425
5	500
6	750
7	1000
8	1500

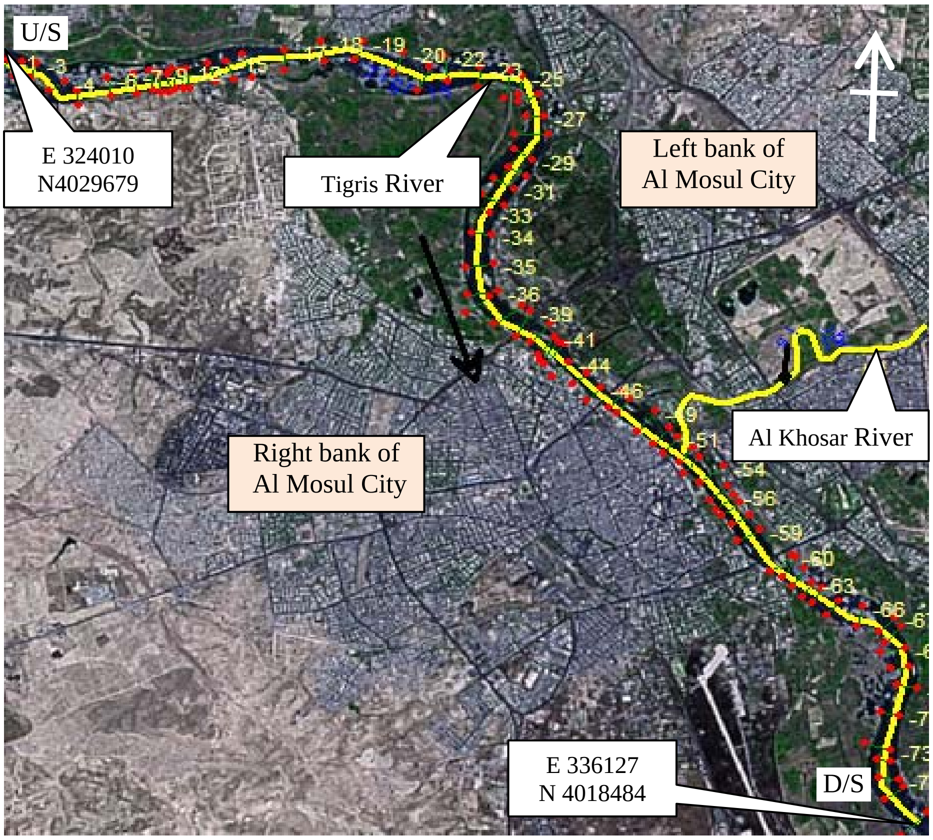

Figure 1. Layout of the studied reach and Al Mosul City.

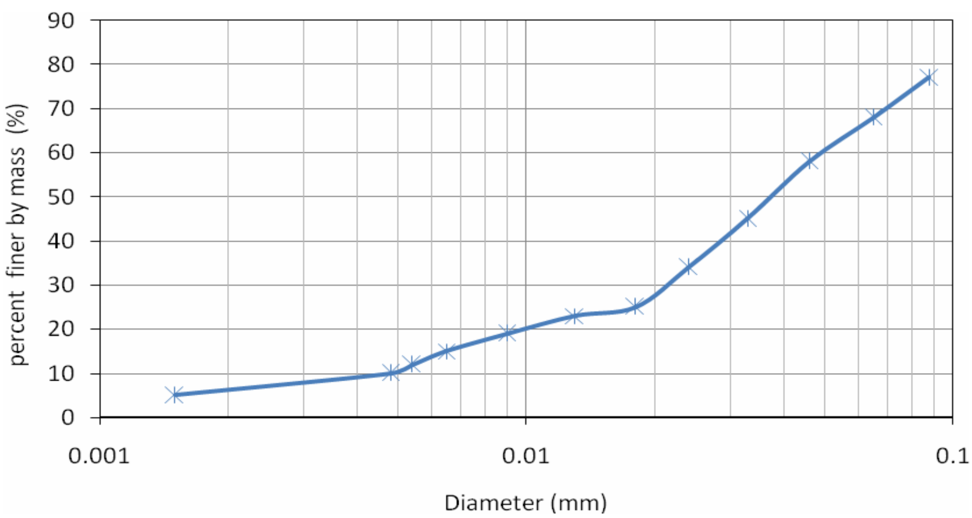

Figure 2. Grain size distribution of the suspended sediment.

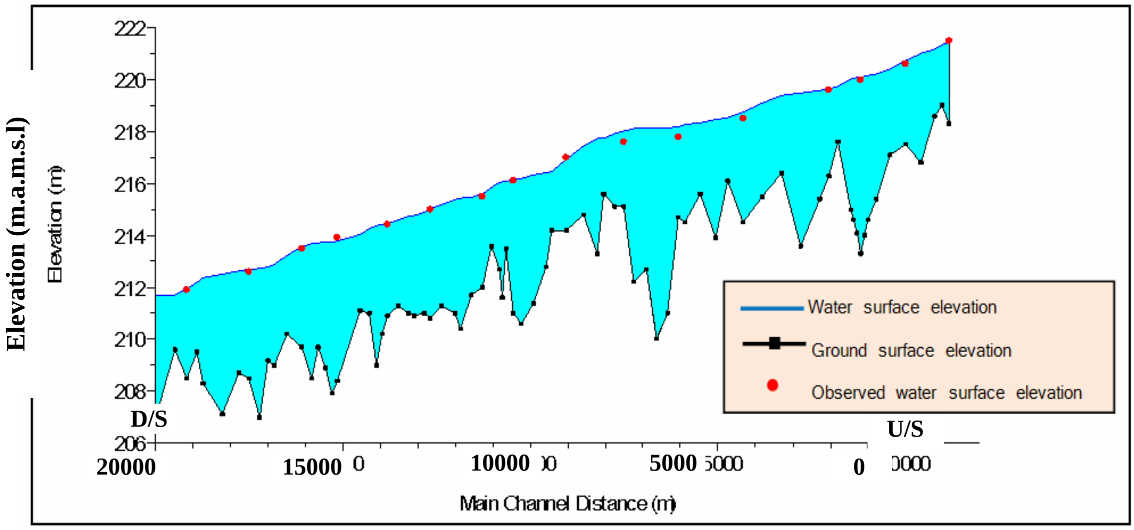

Figure 3. Comparison between estimated stage values using the calibrated data and the measured stage values.

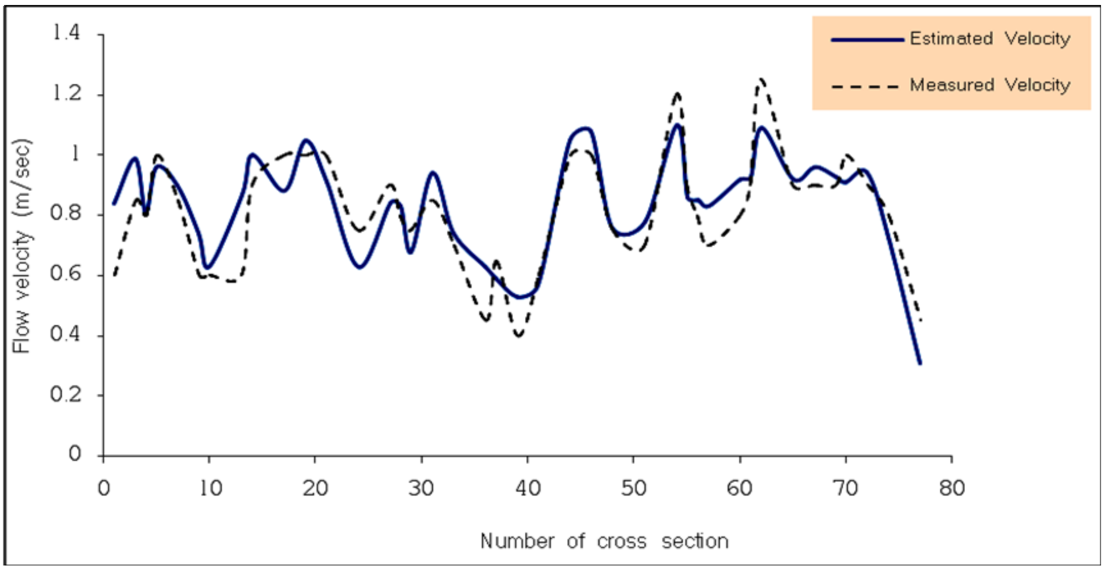

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Figure 4. Comparison between estimated and measured mean velocities.

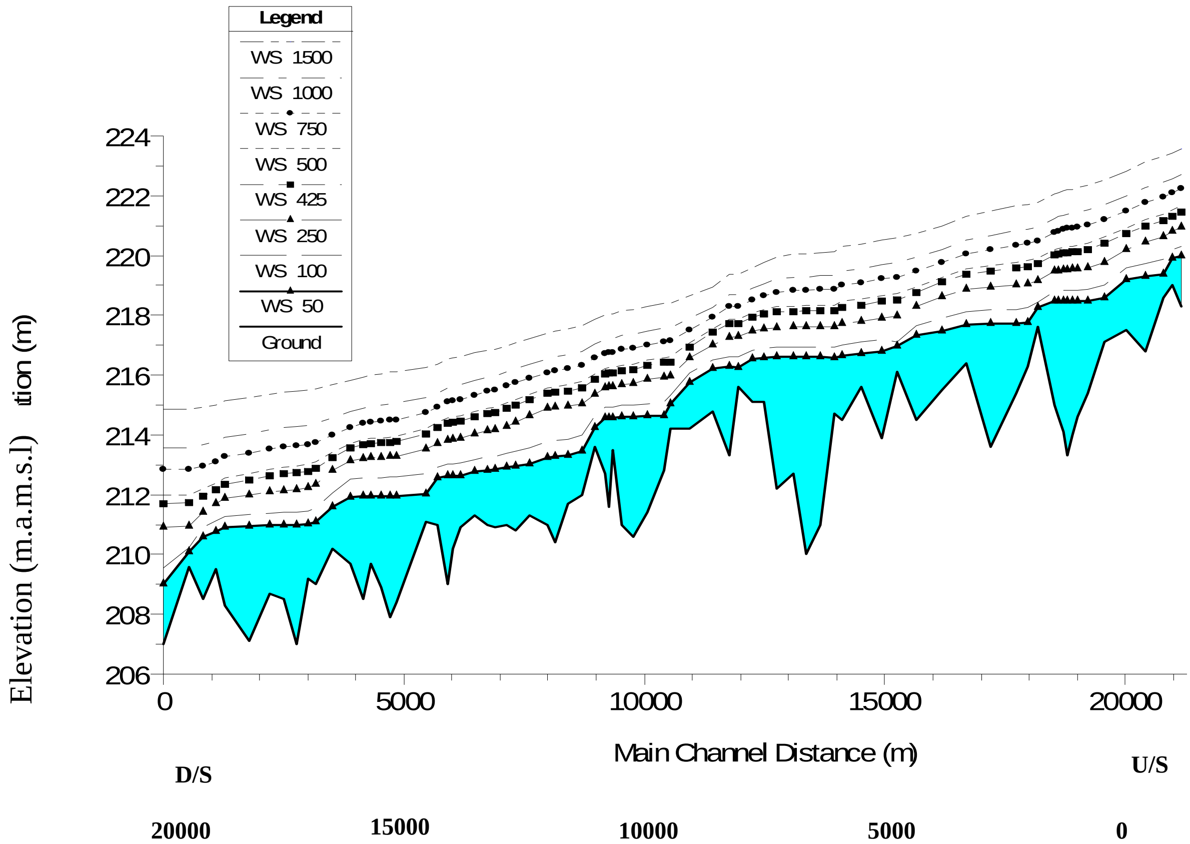

Figure 5. Estimated water surface elevation along the studied reach.

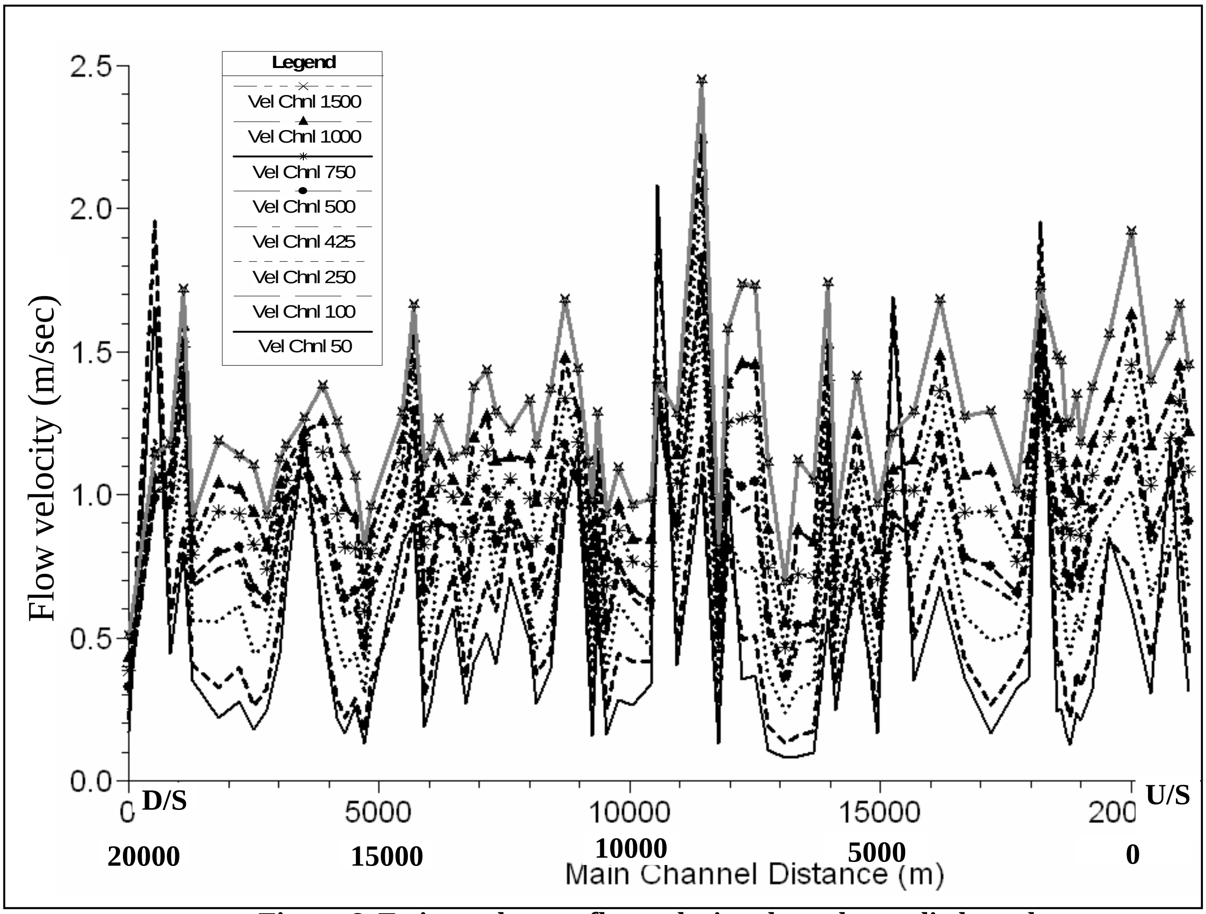

Figure 6. Estimated mean flow velocity along the studied reach.

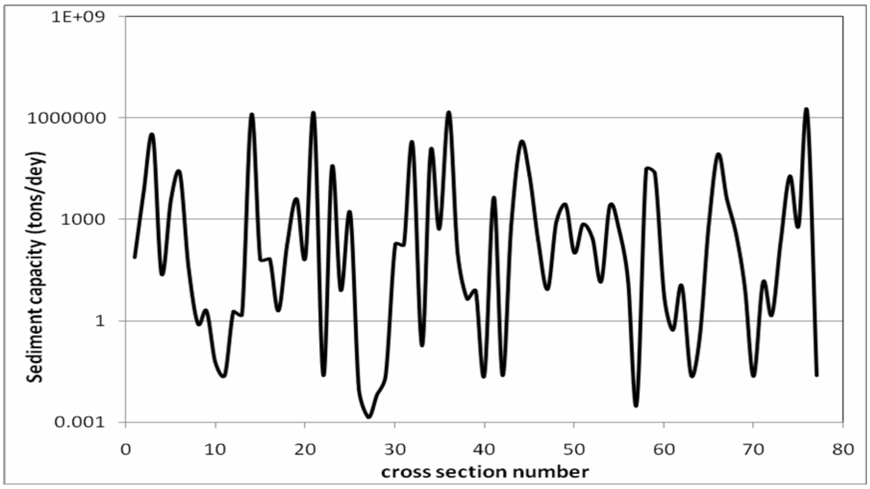

Figure 7. Estimated Sediment Transport Capacity along the studied reach with a discharge of 50 m^3/sec.

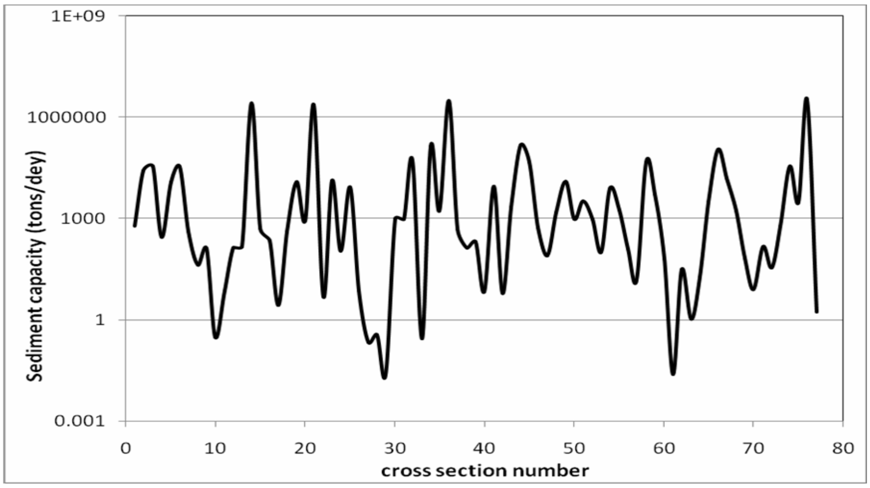

Figure 8. Estimated Sediment Transport Capacity along the studied reach with a discharge of 100 m^3/sec.

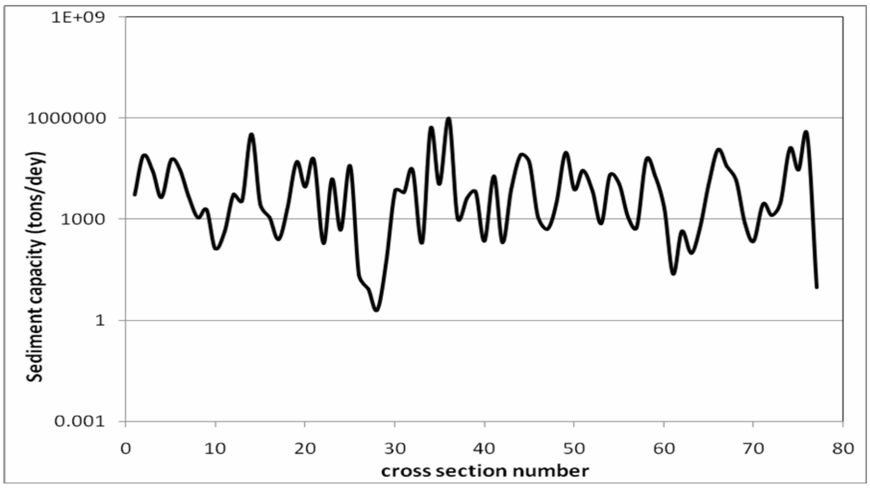

Figure 9. Estimated Sediment Transport Capacity along the studied reach with a discharge of 250 m^3/sec.

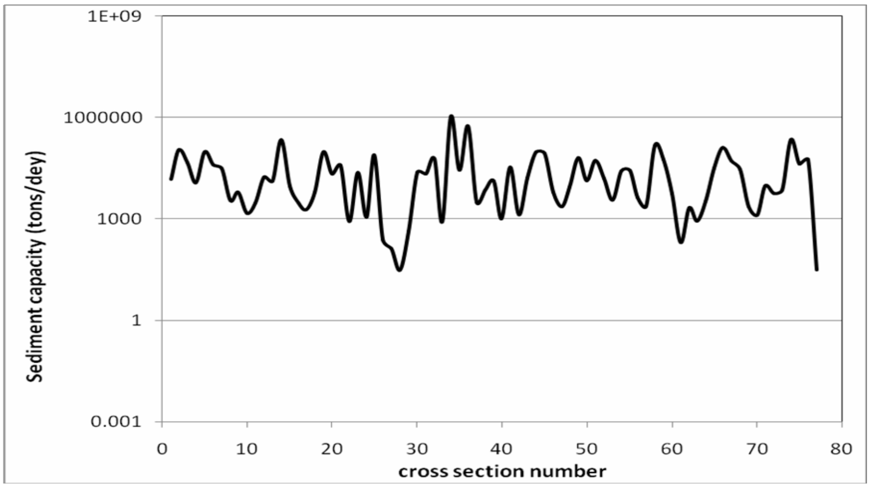

Figure 10. Estimated Sediment Transport Capacity along the studied reach with a discharge of 425 m^3/sec.

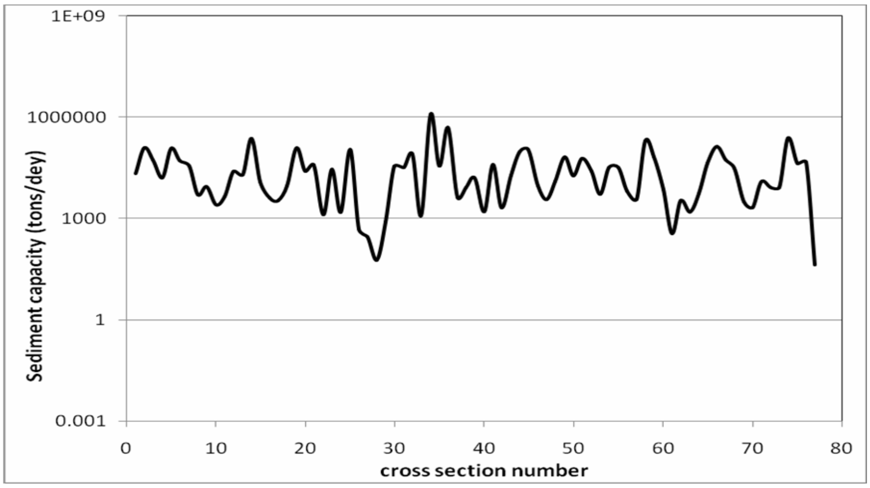

Figure 11. Estimated Sediment Transport Capacity along the studied reach with a discharge of 500 m^3/sec.

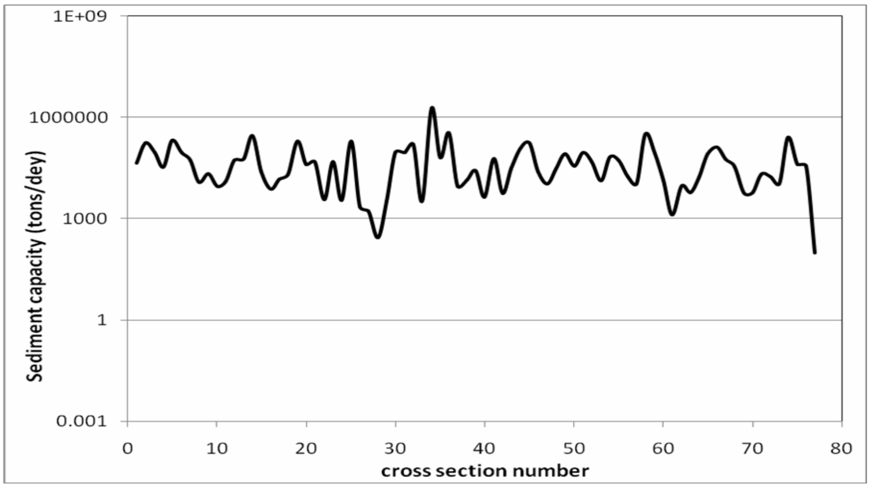

Figure 12. Estimated Sediment Transport Capacity along the studied reach with a discharge of 750 m^3/sec.

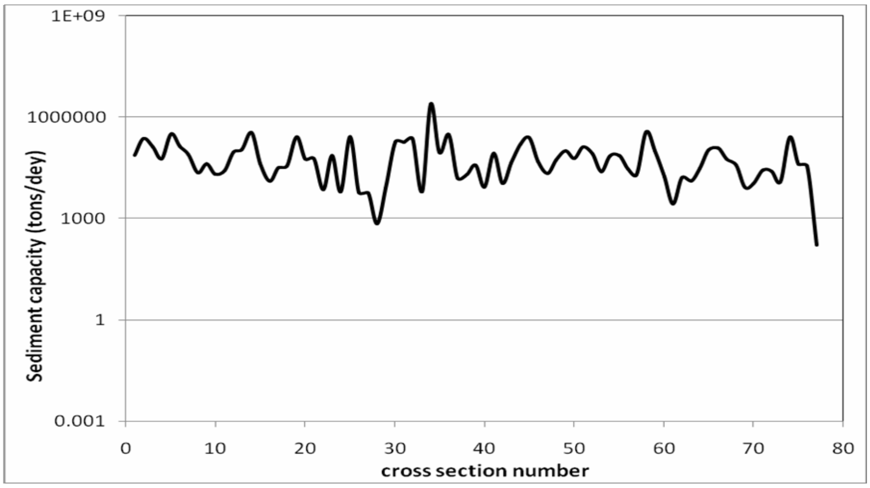

Figure 13. Estimated Sediment Transport Capacity along the studied reach with a discharge of 1000 m^3/sec.

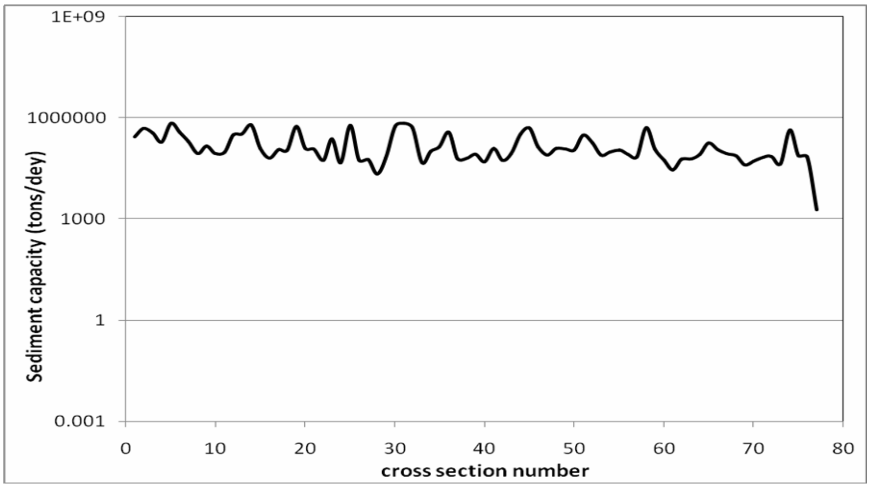

Figure 14. Estimated Sediment Transport Capacity along the studied reach with a discharge of 1500 m^3/sec.

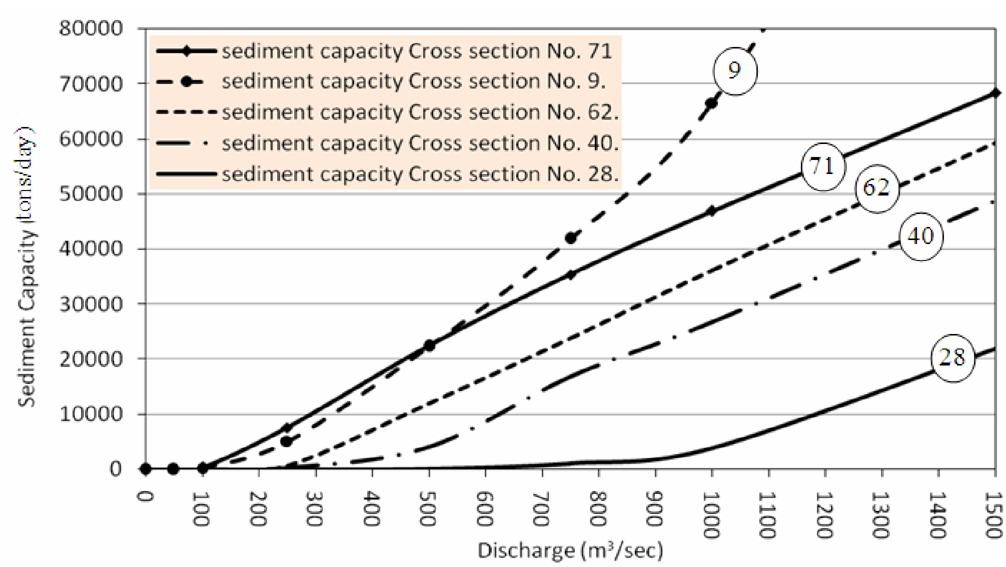

Figure 15. Estimated sediment rating curves at the critical cross sections, cross sections no. 71, 62, 40, 28, and 9.

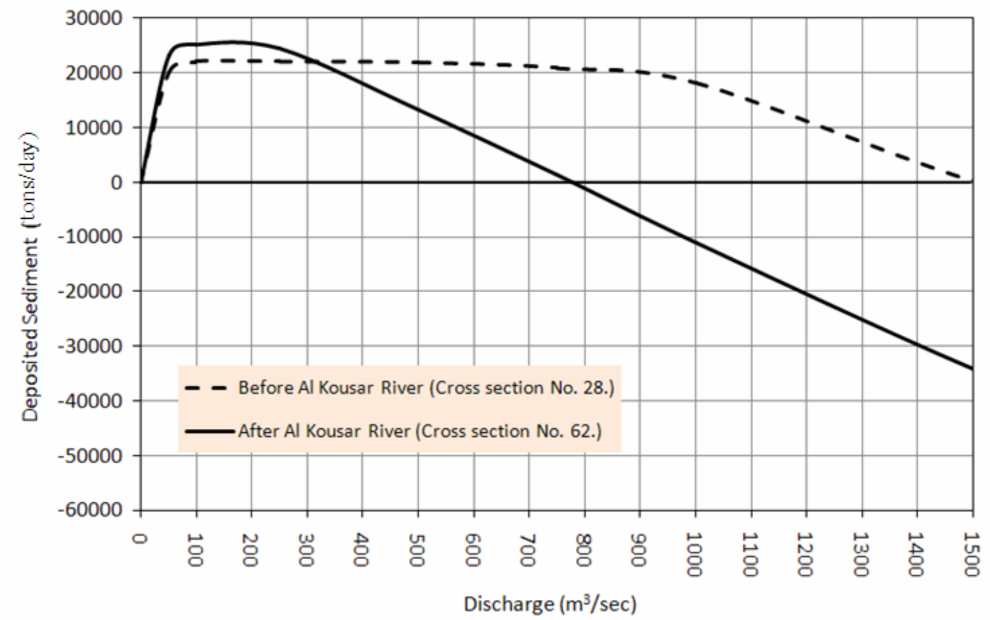

Figure 15. Quantity of deposited sediment before and after Al Khosar River for the adopted discharge range.