Modeling of Sediment Transport
In Aswan High Dam Reservoir

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ABSTRACT

Estimating sediment deposition volumes in reservoirs is one of the major problems faced by engineers involved in river regulation. The accumulated sedimentation helps in getting the effective volume of the reservoir and the life time of the project. Contour maps of the bed profile of Aswan High Dam reservoir are predicted as a function of space and time using Anew methodological approach. The life time of the Aswan High Dam reservoir is also estimated. The present approach is based on the field data analysis. It considers the temporal and spatial changes of bed density that affects the deposited and eroded depth. The present approach shows good agreement between the measured and predicted cross sections for the period from 1980 to 1995 and consequently provides reliable prediction for bed contours of Aswan High Dam reservoir. Computer runs show that the deposition will continue until year 2000 in the first 140 km of the reservoir and the bed level will rise 1.5 m in average to reach the level 160 m above mean sea level. This deposition will be followed by an erosion period until year 2010 and the bed level will reach 150 m in the same reach. The eroded sediment will move to the next.60 km towards the dam direction. The life time of dead zone of Aswan High Dam Reservoir is expected to be 311 years and 1202 years for the life zone.

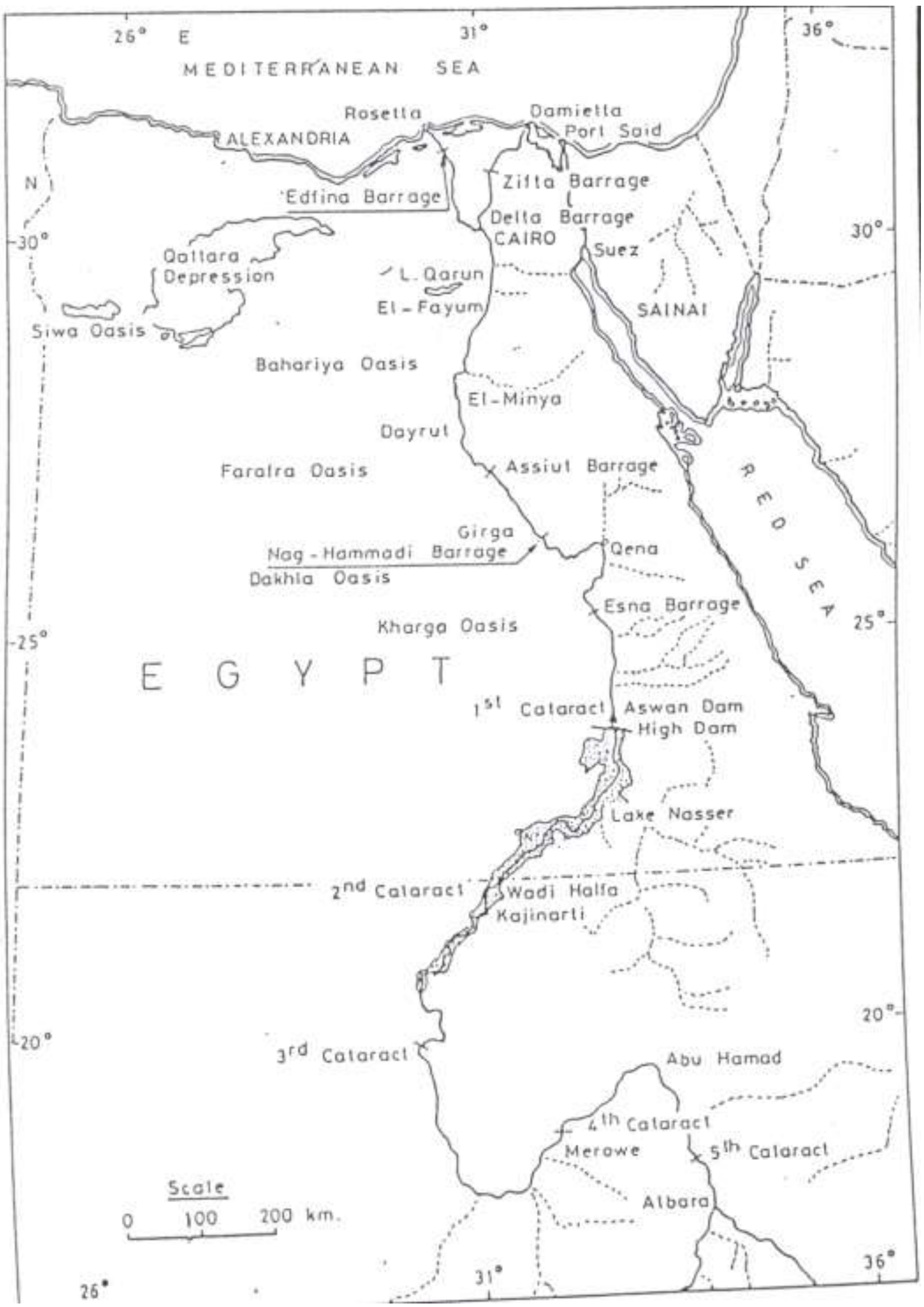
Introduction

The Aswan High Dam (AHD) is a rock fill dam, closing the Nile at a distance of 6.5 km upstream of the old Aswan Dam, about 950 km south of Cairo as shown in Figure 1. The construction of the AHD upstream of the old Aswan Dam, made it possible to have an over year water storage and thus create a reservoir upstream the dam. The length of the AHD reservoir is about 500 km at its maximum storage level, which is 182 m, with an average width of about 12 km and a surface area of 6540 km2. The storage capacity of the reservoir has a volume of 162 km3 divided into three zones: dead storage capacity of 3l.6 km2 between levels 85 m and 147 m, live storage capacity of 90.7 km3 from level 147 m to 175 m, and flood protection capacity of 39.7 km ranging between levels 175 m and 182 m that is the maximum level of the reservoir. Prior to the construction and operation of AHD, in 1964, 9-10 million tons of suspended sediment were deposited annually on the flood plains of the Nile, while about 93% of the total average annual suspended load of 124 million tons was carried out to the Mediterranean Sea. Since the full operation of AHD in 1970, the flood discharge of the Nile downstream the dam, has been greatly modified and more than 98% of the total suspended load was retained within the reservoir and the total amount of sediment transported downstream the reservoir dropped to only 2.5 million tons/year.

Problem identification

The trapped sediment transported towards the dam through moving waves of erosion and deposition. This deposition will affect the storage capacity of the reservoir. The erosion will affect the stability of the banks and in turn the planning for development of these banks. The problem of sediment transport in AHD reservoir has been tackled using One-dimensional model for example by EL-Manadely, M.S. (1991) and Abdel-Aziz, T.M. (1991). These models give a global overview and approximate values for the sediment movement in the longitudinal direction only. The One-dimensional model

Figure 1: Map showing the locations of control works in Egypt



may give good estimation of the total amount of sediment load that deposits in the reservoir, but it does not give information about the distribution of such deposits in the longitudinal and transverse directions. A typical measured cross section at distance 394 km upstream AHD and the distribution of the deposited sediment during the period (1990-1992) are indicated in Figure 2. The calculated cross section using the one-D model of Abdel-Aziz, T.M. (1991) is shown as compared to the measured ones. This figure demonstrates the limitation of information resulting from the application of the one-D models.

Research objectives

1- Develop a new methodological approach for analyzing the field data taking into consideration the limited collected data of flow velocity and suspended sediment concentration.
2- Estimate the li re time of the reservoir considering the effect of sediment consolidation and the actual shape of bed profile in the longitudinal and transverse directions.
3- Develop the bed contour maps as a function of time.

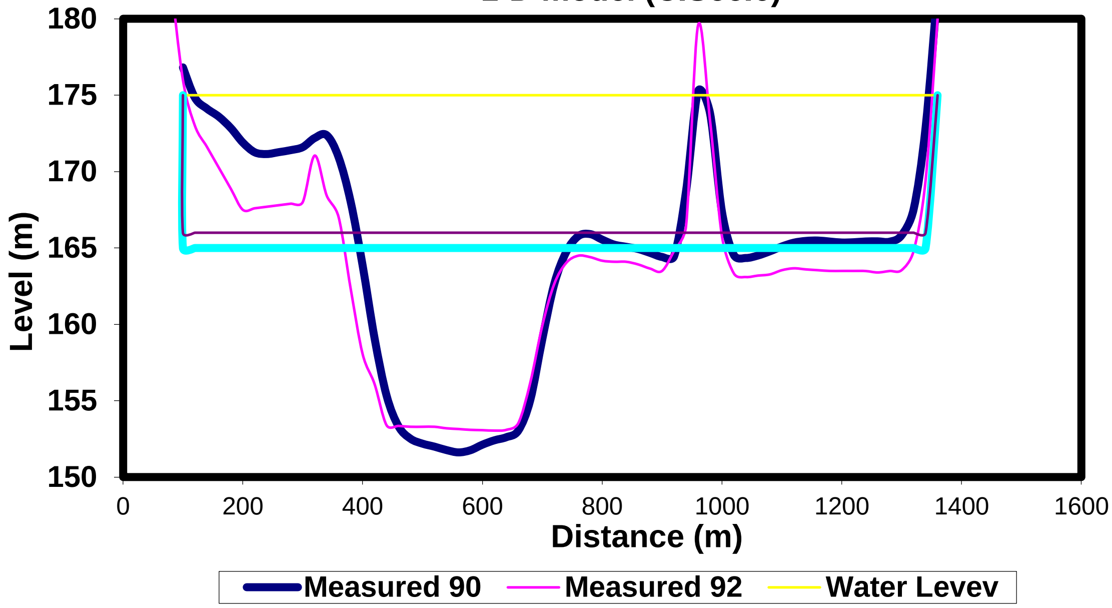
Data analysis

The different measurements of cross sections, water flow velocities, suspended sediment concentrations, and bed materials were collected and treated in a special way to help at the end to get the sediment transport in the longitudinal and the transverse directions in AHDR

Velocity distribution in the transverse direction

Since the velocity is the most important factor that affects the sediment transport either in the longitudinal or the transverse direction, it was assumed that the sediment distribution will be similar to the velocity distribution in the transverse direction. The calculated mean velocity at the

Figure 2 Comparison between measured and calculated by 1-D model (C.Sec.6)



three vertical lines for the whole cross sections during the period from 1980 to 1992. Data for years 1983, 1984, and 1985 are missing. The horizontal velocity distribution is presented using these values assuming zero values of velocities at the banks. The distribution is similar in shape for each cross section and was found to have the following characteristics:

1- Similarity of distribution for the different years and for same cross sections.
2- The distribution is almost symmetrical around an axis in the middle of section.
3- It follows a polynomial distribution of fourth degree and is given by

$$V = C_1 + C_2 X + C_3X^2 + C_4X^3 + C_5X^4 \qquad (1)$$

in which V is the velocity at the distance X, C_1, C_2, C_3, C_4 and C_5 are coefficients. Therefore, there are ten equations for each cross section; each of them corresponds to one year. This means that there are ten values for C_1, C_2, C_3, C_4 and C_5 as a function of time. From these ten values a relationship was deduced for each coefficient as function of time for each cross section. The developed relations for each cross section have the following forms,

$$C_1 = A_1 \, Ln\,(T) + B_1 \quad (2)$$

$$C_2 = A_2 \, Ln\,(T) + B_2 \quad (3)$$

$$C_3 = A_3 \, Ln\,(T) + B_3 \quad (4)$$

$$C_4 = A_4 \, Ln\,(T) + B_4 \quad (5)$$

$$C_5 = A_5 \, Ln\,(T) + B_5 \quad (6)$$

The developed curve for cross section 23 is shown in figure 3 as an example. In which T is time in years, A1, B1, A2, B2, A3, B3, A4, B4, A5 and B5 coefficients. These factors represent the irregularity and orientation of each cross section. They represent also the variation of the water surface width and water depth of the different cross sections. These coefficients for the different sections were calculated and presented in table .1

Table (1): The coefficients of the velocity distribution curve at each section

C.Sec.	***Al***	***B1***	***A2***	***B2***	***B2***
23	-2.2E-14	1.71	1.41	-10.70	-10.70
19	-0.43	3.28	1.07	-8.12	-8.12
16	-0.11	0.86	1.43	-10.86	-10.86
13	-0.94	7.12	0.20	-1.49	-1.49
10	0.14	-1.09	0.26	-2.00	-2.00
8	-1.83	13.87	-0.18	1.36	1.36
6	0.03	-0.26	0.31	-2.36	-2.36
3	2.07	*-15.74*	0.10	-0.73	-0.73
D	-0.06	0.49	-0.10	0.77	0.77
27	*0.15*	-1.13	0.02	-0.19	-0.19

Table (1) The coefficients of the velocity distribution curve at each section (continued)

C.Sec.	B3	A4	B4	AS	B5
23	1.2E-Ol	6.3E-O5	-4.8E-04	-7.9E-08	6.0E-07
19	3.4E-02	l.lE-O5	-8.3E-O5	-8.4E+0l	S.7E-08
16	9.4E-02	3.6E-O5	-2.7E-04	-3.9E-08	2.9E-07
13	S.OE-03	1.1E-06	-S.IE-06	-6.SE-10	4.9E-09
10	S.7E-03	8.4E-07	-6.4E-06	-3.4E-10	2.6E-09
8	-8.6E-03	-I.6E-06	1.2E-O5	S.8E-10	-4.4E-09
6	7.3E-03	9.8E-07	-7.SE-06	-3.lE-10	2.4E-09
3	-l.SE-02	6.9E-07	-S.3E-06	-4.0E-10	3.1 E-09
D	-2.SE-03	-3.1E07	2.4E-06	8.2E-ll	-6.2E-I0
27	2.8E-04	1.4E-O5	-1.1 E-07	-1.6E-12	1.2E-ll

Suspended sediment concentrations

In the new methodological approach for prediction of sediment transport in the transverse direction, it is essential to have continuous records of sediment loads; this means that continuous records of discharge are necessary. But the only continuous records of discharges are available at Dongola (250 km upstream the entrance of AHDR). This is in addition to one measurement only for suspended sediment concentration for each year for any cross section. Therefore, it is necessary to identify the link between the suspended sediment concentration at each cross section and the corresponding discharges at Dongola. The suspended sediment concentrations at each cross section during the period (1980-1992) were collected. Using these values and the corresponding discharges at Dongola, a relationship was deduced for each cross section in the form.

$$C_{ss} = A \,.Ln\,(Q_w) + B \qquad (7)$$

In which C_{ss} is the suspended sediment concentration at cross section in ppm, Q is the corresponding discharge at Dongola in million m^3/day, and A, B are two constants. The values of these constants for each cross section are indicated in Table 2.

It was noticed that when the discharge at Dongola is high, the suspended sediment concentration is high at each cross section, and for low discharge values at Dongola, the suspended sediment concentration at each cross section is low. Therefore it is expected that similar trend for this relationship is valid at each cross section. So it is concluded that a general formula can be developed for any other cross section in the reservoir. One of these relations is indicated in figure 4 for cross section 23 where

$$C_{ss} = 161.672 * Ln\ (Q_w) - 613.13 \qquad (8)$$

Table 2 Coefficients of the discharge and suspended sediment concentration curves

C.Sec.	A	B
23	161.67	-613.13
19	151.61	-568.23
16	133.88	-495.88
13	99.24	-352.48
10	75.69	-263.94
8	64.09	-225.48
6	64.54	-221.29
3	69.77	-246.08
D	48.68	-168.00
27	62.81	-225.64

Estimation of new cross section

To estimate the deposited/ eroded sediment volumes that take place at each cross section as a result of the sediment transport associated with water flow, the following procedure will be used. The following equation may be used to get the value of sediment load

$$\mathbf{Q_s = Q_W + C_{SS} * T} \qquad \mathbf{(10)}$$

where: Q_s is sediment load in Kg, Q_w is discharge at the section in m^3/sec, C, is suspended sediment concentration in ppm (kg/m^3) as calculated in equation 7, and T is time in sec.

In the next step, the density of sediments is needed for each time step where the rate of deposition is not uniform. An approach presented by Abdel-Aziz, T.M. in 1991 was utilized. The density of deposited sediment for each cross section for same dates of the field trips during the period from 1980 to 1995 has been calculated and the density for the years 1998, 2000, and 2010 has been predicted using that approach. Knowing the sediment load and the density of sediments we get the sediment volume. To distribute that deposited/ eroded sediment volume, it is assumed that each cross section represents a certain reach considering that the section is in the mid distance of this reach. And it is assumed also that the calculated deposited volume for each cross section will be distributed uniformly along the reach represented by this section to get the deposited/ eroded area. Now to estimate the new deposited/eroded depth it is assumed that the calculated deposited area will be distributed in the transverse direction similar to the velocity distribution. Each cross section is divided into strips of equal widths of20 m. The average of the two depths at the beginning and the end of each strip is calculated and considered constant along the total width of the strip. The velocity distribution at each cross section is a function of the longitudinal distance, the transverse distance, and time as presented in equation 1.

The cross sections in 1995 have been calculated based on the measured cross sections in 1993. For all cross sections, the calculated areas are very close to the measured ones except cross sections 13 and 27 where there is a slight difference between the measured and the calculated sections.

Contour maps for 1995 and 2000

The measured cross sections in 1995 were used to develop the contour map using computer software called "surfer". The software assumes that the cross sections are parallel; therefore it was necessary to develop a computer program to consider the actual inclination angles of the cross sections. The developed computer program is called CONTOUR. FOR. After using this program the contour map of the actual cross sections was developed to simulate the river bed morphology. The same procedure has been used to develop the contour map for the year 2000 using the predicted cross sections as indicated in Figure 5. The comparison between the contour maps in 1995 and 2000 indicates the expected change in the river bed morphology during this period. The deposition is expected to concentrate on the left side of the reservoir between km 460 and km 420 u1s AHD while it will settle in the middle of AHDR in the reach between km 390 and km 365 u1s AHD. The length of the sedimentation zone is about 150 km while the average width of the above mentioned cross sections is about 1.5 km except cross section 27, i.e. the length of the contour map is about 100 times of its width which is not suitable for presentation. In order to overcome this problem a distorted scale has been used, where the horizontal scale is 1: 5000 while the vertical scale of the contour map is 1: 500.

Conclusions

A new methodological approach is developed to simulate the change of the deposition and the scour locations with time and space to predict the sediment front in the longitudinal and the transverse directions of AHDR. By means of this new approach the contour maps of the bed profile are predicted as a function of space and time and the life time of the reservoir is also predicted. Finally the following conclusions are reached:

1- The present study identifies locations of scour and deposition across each section in the transverse direction.

2- A contour map of bed profile can be produced for any year to define the change of the river bed morphology.

3- The sediment deposition will continue until year 2000 in the first 140 km and the bed level will rise 1.5 m in the average to reach level 160 m. This deposition will be followed by an erosion period until year 2010 and the bed level will reach level 150 m. The eroded sediment will move to the next 60 km in the dam direction.

4- The life time of the dead zone of AHDR is expected to be 311 years and for the live zone is expected to be 1202 years.

<u>Recommendations</u>

In order to assess the ability of the developed approach and to modify the proposed coefficients it is recommended that:-

1- Continuous measurements of suspended sediment concentration are to be carried out at Dongola station together with the discharge to get more precise estimation of the input sediment load.

2- Construction of a new control station at Shalal Dal (500 km upstream AHD) which is very near to the sedimentation zone and suitable for installation of measuring devices for discharge and sediment load is needed to give reliable values of the input variables to the AHDR.

3- Measurements of variables for new cross sections in the dam direction to investigate the nature of the deposition in the vicinity of the dam are necessary for the follow up of the results of the proposed methodology.

4- Complete hydrographic survey for AHDR every 10 years using GPS (Global Positioning System) to have a global overview for the movement of the deposited sediment and to check the results obtained by the proposed approach may be carried out.

5- Automatic recording for the water level at the locations of the existing cross sections and any other new cross section using telemetry system to have a complete control for the water level measurements is needed. This will help in accurately calculating the discharge at each cross section and consequently comparing the results with the present study for any modifications in the future.

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Figure 3 Relative distribution of currents in transverse direction (C.Sec. 23 km 487.5 u/s AHD)

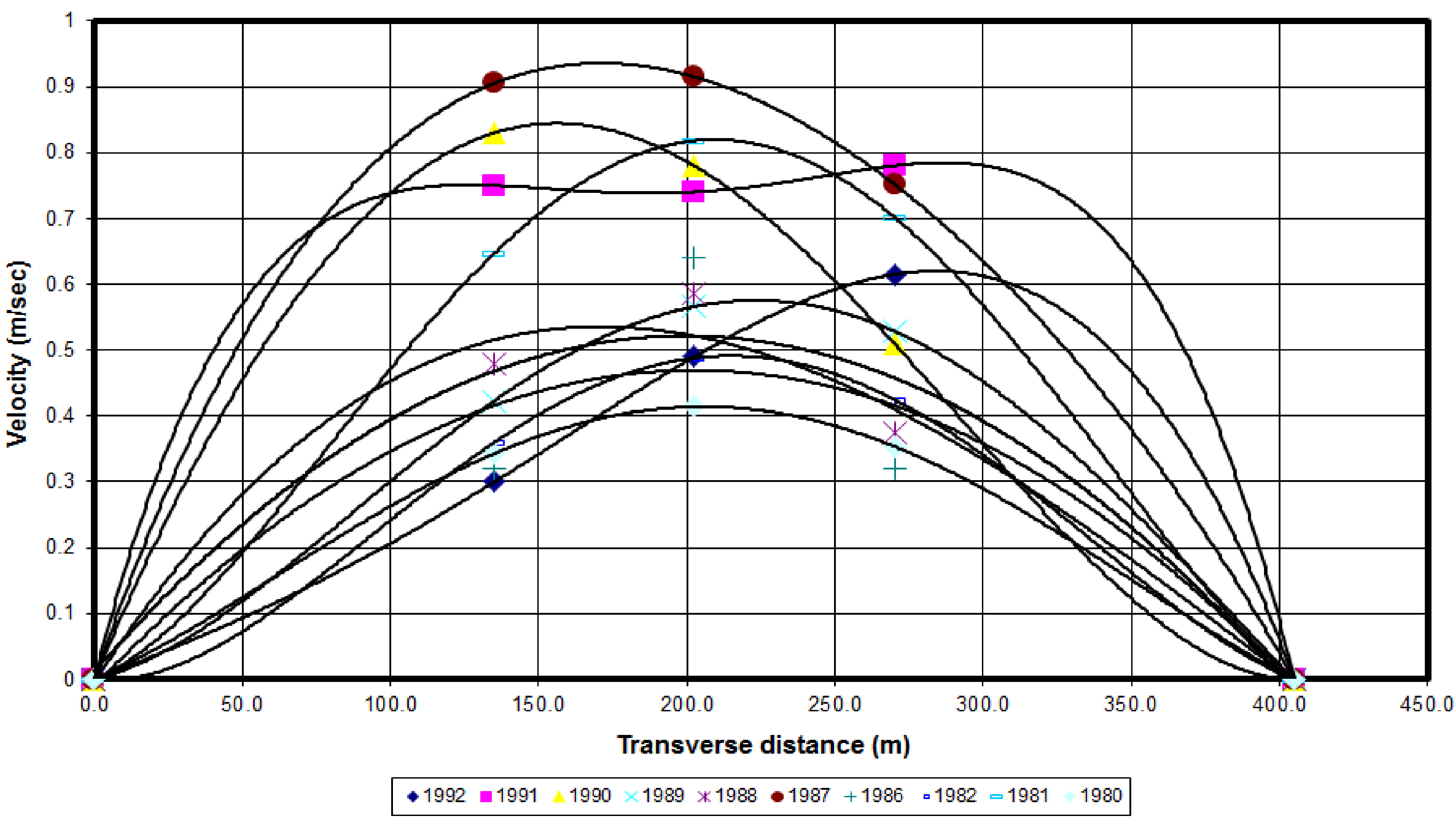
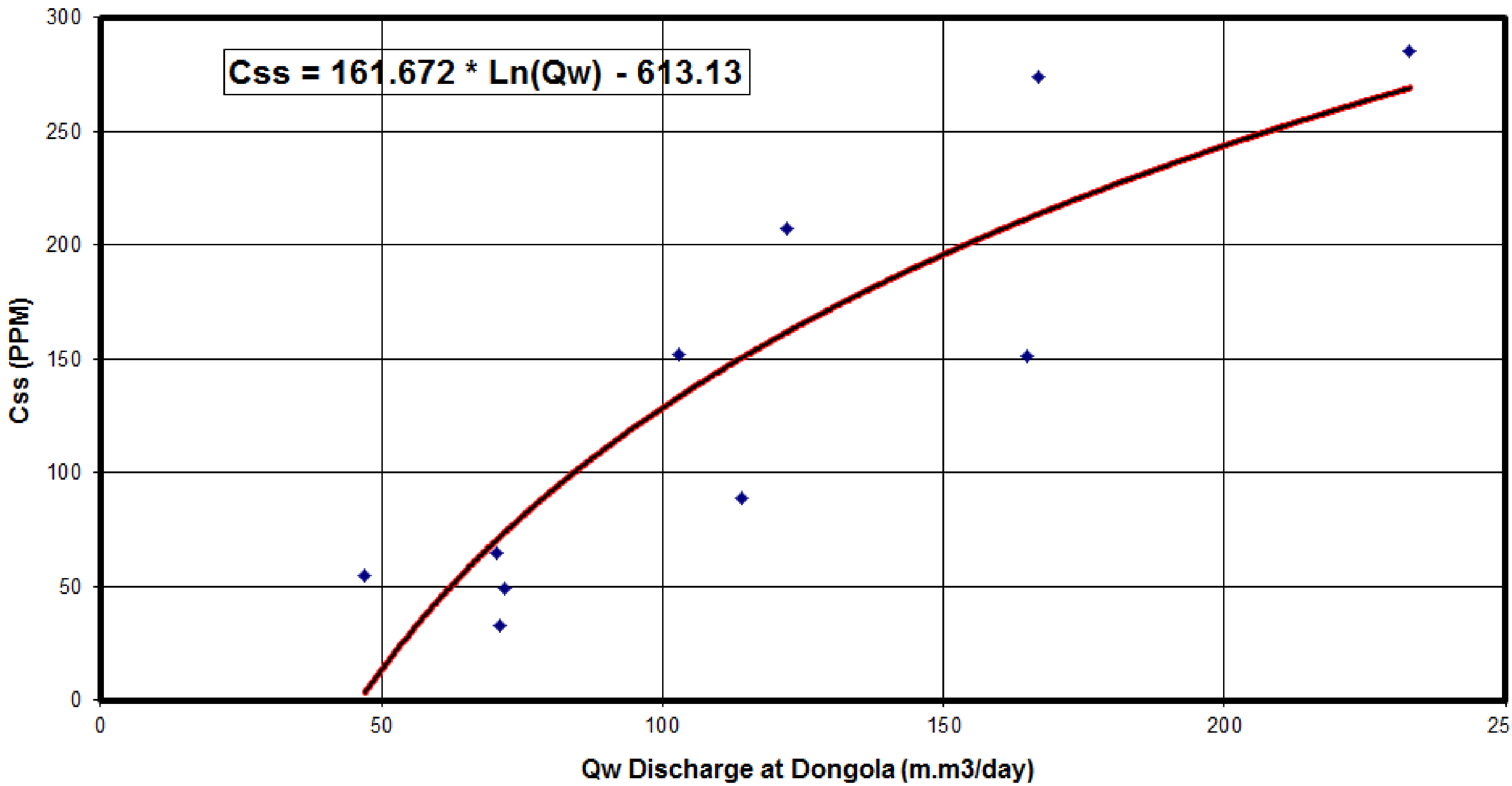


Figure 4 Correlation between discharge at Dongola and suspended sediment concentration at C.Sec.23



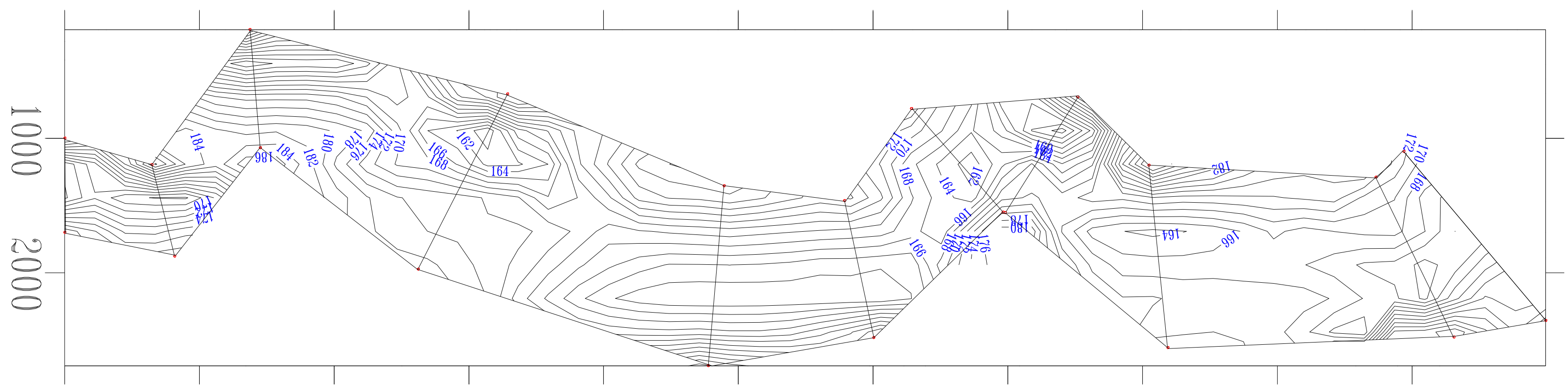


Figure 5 Contour map of AHDR (Year 2010)

and studied cross sections (depths in m)