EFFECT OF TRANSVERSE WATER VELOCITY DISTRIBUTION ON SEDIMENTATION AT ASWAN HIGH DAM RESERVOIR

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ABSTRACT

Aswan High Dam Reservoir (AHDR) is the store of Egypt water that runs down from the North of Sudan. The reservoir extends for a distance of about 500 km upstream the dam. Nearly a reach of 350 km lies within the Egyptian borders and the rest lies in Sudan. It should be kept as large and deep as possible to secure the water storage capacity required. However, the coming water always brings sediments which deposit as it runs downstream. Overtime, the amounts and distributions of such sediments in the longitudinal and transverse directions around the reservoir are found to accumulate increasingly and irregularly. Therefore, it has been realized that these sediments may largely threaten the water storage capacity, navigability, and water quality of the reservoir. Accordingly, the sediment accumulations and their distribution patterns have to be monitored and estimated annually so that their threats can be avoided or, at least, mitigated.

Previous studies showed that one of the most influencing parameters in sediment accumulation and distribution in reservoirs is the water flow velocity. (ISO, 1968) states that at least twenty verticals have to be used for measuring velocity at any cross section. This applies at large as well as small rivers and reservoirs for highly accurate measurements. In case of AHDR, only three verticals were considered for measuring water velocity (magnitude only) for all the scientific expeditions conducted by the Nile Research Institute (NRI) and High Aswan Dam Authority (HADA) from 1973 to 2001 because of time limitation. However, in the scientific expedition of 2003, it was decided to extend the measurements at each cross section for more accurate results. Water velocities (magnitude & directions) were measured at seven equally spaced vertical locations along each cross section. The components of these velocities in the longitudinal and transverse directions were also computed.

The objective of this research is to study the effect of the water velocity direction on distribution patterns of sediment deposition in AHDR based on field data analysis. A comparison between the water velocity diagrams and sediment deposition diagrams at different cross sections was held. The results revealed that the mean transverse velocity (MTV) is more representative of sediment distribution patterns than the mean velocity (MV) in all cases of flooding (low, average, and high). It is, therefore, concluded that the MV is unreliable in predicting the sediment transport distribution patterns around the reservoir. It is recommended to depend on the MTV in recognizing the deposition patterns.

Keywords: Sedimentation, Velocity distribution, AHD Reservoir

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1 INTRODUCTION

Sediment distribution within reservoirs is generally influenced by the water flow velocity and the sediment load transported by the water current. This load usually increases during flood seasons causing more sediment deposition and accumulations, specifically at the upper part of the reservoir. Sediments carried into a reservoir may deposit throughout its full length, thus gradually raising the bed elevation and causing aggradations. Also, if the flow current changes its direction, the sediment deposition distributions experience changes. This means that the flow velocity directions control the sediment movement and thus, affect the bed development.

In this research, the sediment distribution is studied within Aswan High Dam Reservoir (AHDR) at the upper part within the Sudanese borders. This is because the river bed at that part undergoes continuous sediment deposition annually. Starting in 1973, the year of the first scientific expedition to AHDR, the flow velocities used to be measured as values only. By 1998, they were measured as values and directions. It was realized that the transverse velocities have remarkable influence on sediment distribution.

2 OBJECTIVE

The research mainly aims to study the effect of the water velocity direction on distribution patterns of sediment deposition in AHDR by the analysis of measured field data over different flood years (low, average, and high).

3 DISTRIBUTION OF SEDIMENT IN RESERVOIRS

There is no analytical solution to the problem of estimating or predicting the distribution pattern of the sediment in a reservoir. The solution to the problem has, therefore, been obtained by collecting the sedimentation data from sedimentation resurveys of several reservoirs and analyzing the same with respect to their sediment deposition at their different elevations (Mutreja, 1986).

Boreland and Miller (1958) have suggested two Empirical methods in predicting the sediment distribution pattern. The first is a mathematical procedure based on the observations of sediment distribution in several reservoirs. It is called Empirical Area-Reduction Method. The second is strictly mathematical and called Area-Increment method. There are also many other methods introduced in the literature. For example, Rao et al. (1985) used a visual interpretation technique on large scale imagery of Landsat- MSS to estimate the water-spread area at different levels to evaluate the capacity of the reservoir and concluded that the results are comparable with hydrographic survey observations and similar to the curves obtained from the conventional methods. Also, Kamuju Narasayya et al (2012) has presented a method that uses Satellite Remote Sensing in assessing reservoir sedimentation. It is based on the fact that the water spread area of reservoir at various elevations keeps on decreasing due to sedimentation. Remote Sensing technique gives directly the water spread area of the reservoir at a particular elevation on the date of pass of the satellite. This helps to estimate sedimentation over a period of time.

4 STUDY AREA AND DATA COLLECTION

Aswan High Dam Reservoir (AHDR) was formed as a result of water impoundment upstream the High Dam after its completion in 1968. The water surface area of the reservoir began to expand gradually during the filling ten years between 1968 and 1978 until its average length became 500 km upstream the dam; of which about 350 km lie within the Egyptian borders and the remaining 150 km lie within the Sudanese borders. The river bed formation of the part of the reservoir lying within Sudan (the reservoir headwater area) has become deltaic due to continuous sediment deposition. Therefore, the Nile Research Institute (NRI), which took this name in 1990, was established in 1975 under the name of the Research Institute for the Side Effects of the High Dam. It was mainly established to observe and monitor the side effects of the Aswan High Dam on both the reservoir upstream and the river downstream. Of these effects are the bed morphological changes (the bed development).

This research paper is interested in investigating the sediment distribution patterns over different flood years especially at the **head area of the reservoir** since it is the only inlet of water to the reservoir. It is important to understand the deposition process quite well and recognize the way the reservoir bed is developed. This helps predict the sediment accumulation spots that may block or hurdle the water movement and cause water stage rise within the reservoir.

Many field measurements are conducted annually to collect the data necessary for study and analysis as follows:

4.1 Flow Velocity Measurements

Before 1998 during the annual scientific expeditions of the NRI and HADA to AHDR for monitoring and keeping record of its hydraulic, hydrologic, and morphological state, the flow velocity measurements used to consider no direction because of the unavailability of multi-direction measuring equipment.

The mean flow velocity was measured at a number of specific cross sections along the reservoir for discharge calculation purposes. Across every section, only three verticals were chosen to measure the velocity (because of time limitation & journey hard conditions). A number of points along each vertical from surface to bottom were determined at different depths (0.50 m, 25%, 50%, 65%, 85% of the total depth, 0.750 m above the bed) to take velocity readings using a current meter as shown in Fig. (1). Then, every two consecutive readings were summed up and divided by the difference in their depths to get a mean reading. All the mean readings obtained were then summed up and divided by the total depth to get the mean flow velocity at each vertical. Finally, the mean flow velocities at the three verticals were added up and divided by three to get the mean flow velocity at the considered cross section.

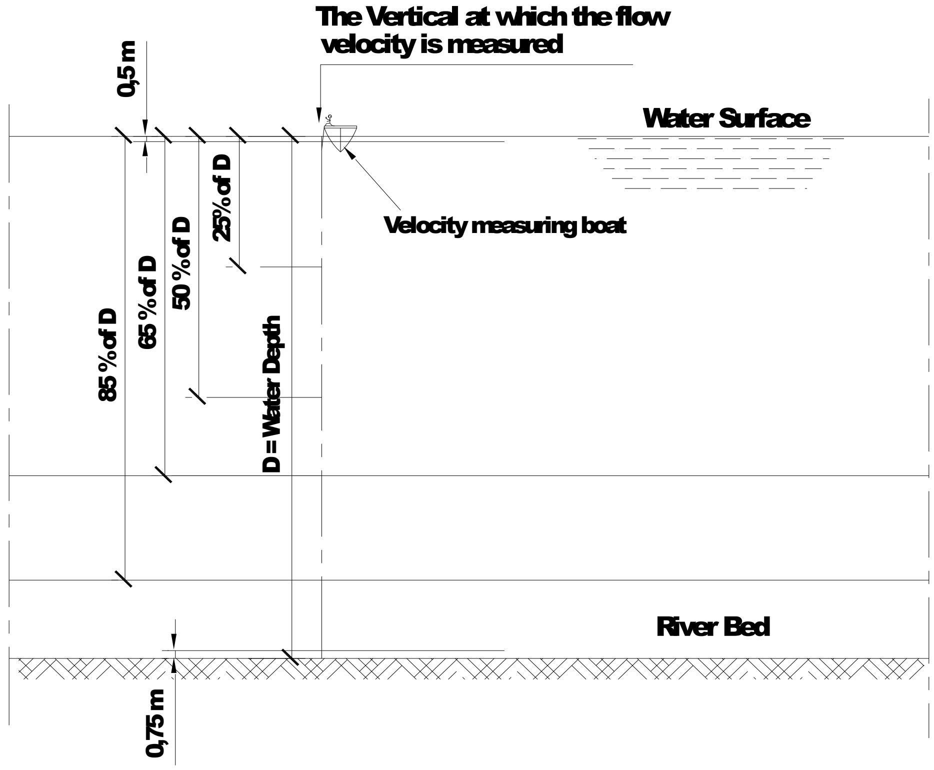

Figure 1: Depths of points along the vertical at which the flow velocity is measured.

The final flow velocity obtained in the way mentioned above was considered to be approximate due to the limited number of verticals used which should be increased to at least 20 at any cross section. The number of points within each vertical was to have little influences on the mean flow velocity. Additionally, the measurement time of 30 seconds at a point is insufficient to obtain a fair approximation of the true mean velocity at the point considered (ISO, 1968).

Accordingly, and with the advent and development of the velocity and direction measuring devices, it was decided to increase the number of verticals at each cross section to seven and measure the velocity and its direction with respect to North (because of strict time limitation) in order to get as more accurate flow velocity results as possible. It is worth mentioning that the position of each vertical is obtained from the maps in the form of UTM coordinates and then accessed in practice using a handy Global Positioning System (GPS) unit. So, all the expeditions made after that time considered the velocity and its direction with respect to North in measurements.

4.2 Morphological Changes Measurements & Sediment Estimation

In order to monitor the reservoir bed on an almost yearly basis (according to the allowed annual expedition timing, twenty fixed main cross sections across the reservoir at the head area within the Sudanese borders as shown in Fig. (2) are hydrographically surveyed using a survey boat equipped with a system of GPS and Echo sounder connected to a lab top for real time measurements. Although these sections are not equally spaced, they were chosen to represent their surrounding reaches to the most possible accuracy. Based on the advancement of the hydrographic survey equipment, the areas between them are hydrographically surveyed recently using other secondary offset cross sections spaced at distances ranging from 150 to 200 m thus, covering the 150 km area entirely (the sedimentation zone within Sudanese borders).

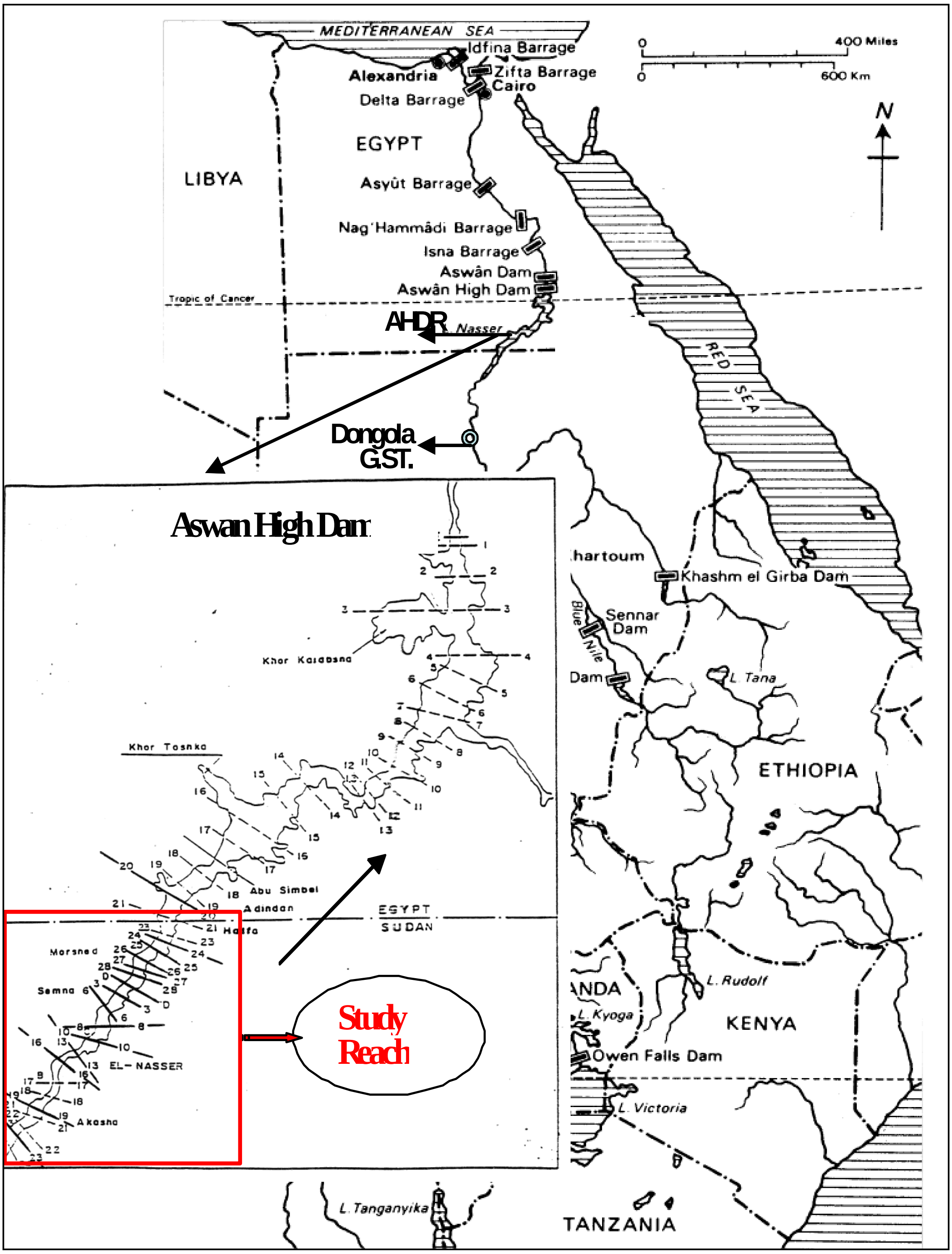

Figure 2: Positions of the Twenty Cross Sections at the Sedimentation Zone of AHDR within the Sudanese Borders

The data collected come out in the form of points of X, Y, Z coordinates after computer post processing in the office. Previously, the data were used to plot the main cross sections and compare them with those of the previous years to estimate the volume of sediment deposition using the mean area method. Recently, a contour map for the whole area within the Sudanese border could be developed due to the intensive data collected and the newly developed computer software. Such a map is compared with the map of the previous years. A good and more accurate estimation of the sediment deposition volumes could be obtained.

5 DATA ANALYSIS

In order to examine if there is a relation between the flow velocity distribution patterns and the morphological changes of the reservoir bed (whether sediment deposition or bed scour) at the deposition area of the reservoir within the Sudanese borders, 3 successive time periods were chosen; the first one was year 2003 where the natural flow was 70 billion cubic meters (bcm) and it was lower than the average flow, which is 84 bcm. As for the second period, it was year 2008 where the flood was 100 bcm and it was classified as a high flood year. The third period was year 2012 where the flood was 80 bcm which was classified as almost an average flood year. These 3 different periods represent the different cases of floods (low, average, and high) as shown in Fig. (3). This figure indicates the natural flow at the entrance of the reservoir from 1870 till 2014.

The velocity direction measurements were taken during these flood periods. Of the above 20 cross sections, 3 x-sections were selected for comparison. They are sections 23, 3, and 24. These sections were chosen on purpose since they are believed to be the most representative of the reservoir reach topography within Sudan where sediment deposition occurs. Section (23) represents the narrowest and shallowest segment of the reservoir reach. This segment ranges from 400 to 700 m in width and from 5 to 20 m in depth. It extends for about 100 km downstream the reservoir inlet. As for section (3), it represents the reservoir segment where it ranges from 700 to 1200 m in width and from 20 to 50 m in depth. It extends for about 30 km. Section (24) represents the last segment of the reservoir reach within Sudan. This segment ranges from 3000 to 5500 m in width and from 50 to 70 m in depth and it represents the remaining 20 km.

The choice of the above 3 sections as well as the three time periods of the different flood cases can help study properly the effect of the flow velocity distribution on sediment deposition in different widths and depths along the deposition area of the AHDR. Accordingly, a sound judgment could be reached and good predictions could be made on the deposition status in the reservoir.

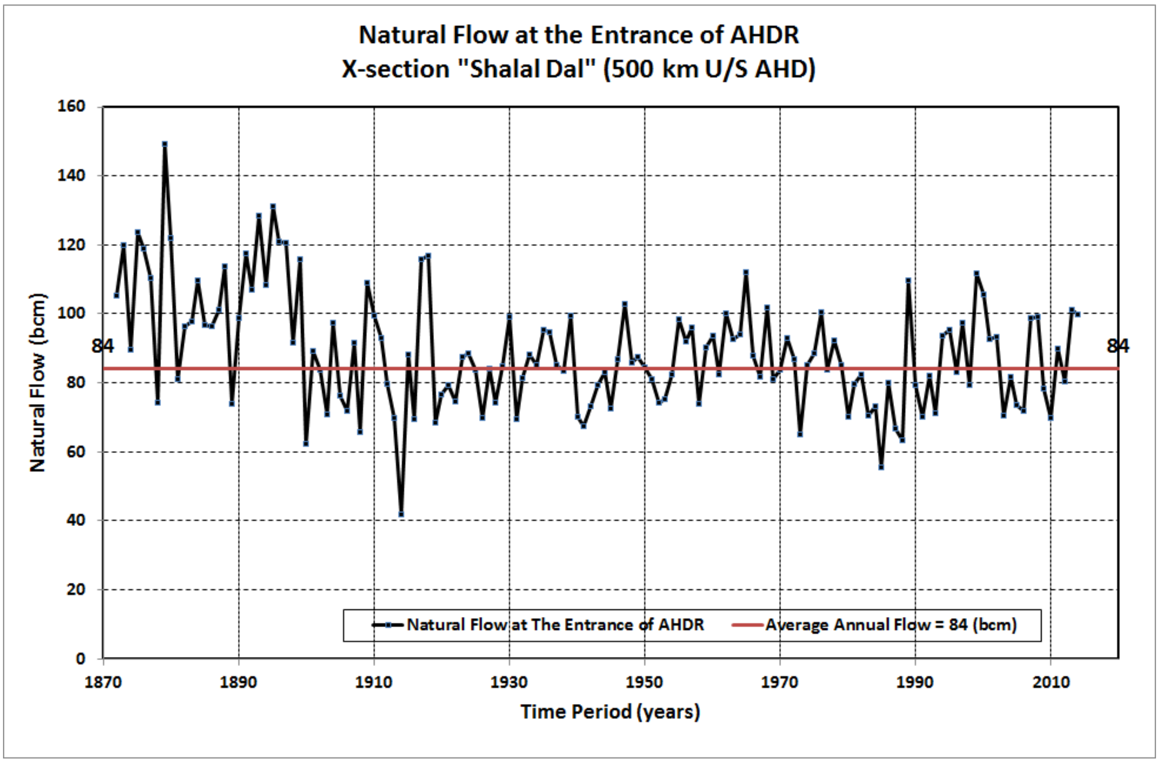

Figure 3. Natural Flow at the entrance of Shalal Dal from 1870 to 2014.

5.1 Velocity Analysis

Using the measured flow velocities and directions, the resultant and transverse component mean velocities could be computed at the 7 verticals along each cross section (23, 3, and 24). Then, they were plotted on a chart to investigate their trend.

5.2 Morphological Changes

To identify the morphological changes that the cross sections (23, 3, and 24) of the years 2003, 2008, and 2012 experienced, they were compared with those of the directly previous years (where the expeditions took place) 2001, 2007, and 2009 respectively. Then, they were plotted on the same velocity chart.

6 RESULT DISCUSSION

After plotting the sections and velocities, 3 charts were developed for cross sections 23, 3, and 24 for each year of the 3 selected periods (2003, 2008, and 2012). On each chart, the x-section of the year under study is plotted on the primary axis and compared with that of the previous year. Also, the mean velocity and the mean transverse velocity are both plotted on the secondary axis. For example, cross section 23 of year 2003 is plotted on the primary axis and compared with that of the previous year (2001). Besides, the mean velocity and its transverse component measured in 2003 are plotted on the secondary axis. Finally, 9 charts are produced having the velocity trend patterns and the morphological changes occurred. It is worth mentioning that only the part of the cross section along which the velocity was measured is plotted to clarify the comparisons.

By examining the 3 charts (Figures 4 thru 6) for x-section 23 at the three time periods, it has been found that:
In Fig. (4), on comparing the bed profile of sec 23 in 2003 with that of 2001, it has been noted that the deposition took place from year 2001 to year 2003 along the whole width of the section. Also, comparing the mean velocity and the mean transverse component velocity with the deposition, it could be noticed that the value of the mean velocity is high at the west side and low at the rest of the x-section width which does not represent the deposition. While the value of the mean transverse component is found to be low at the west side, it is of middle values at the rest of the x-section width; which represents the occurrence of deposition along the width of the x-section more accurately.

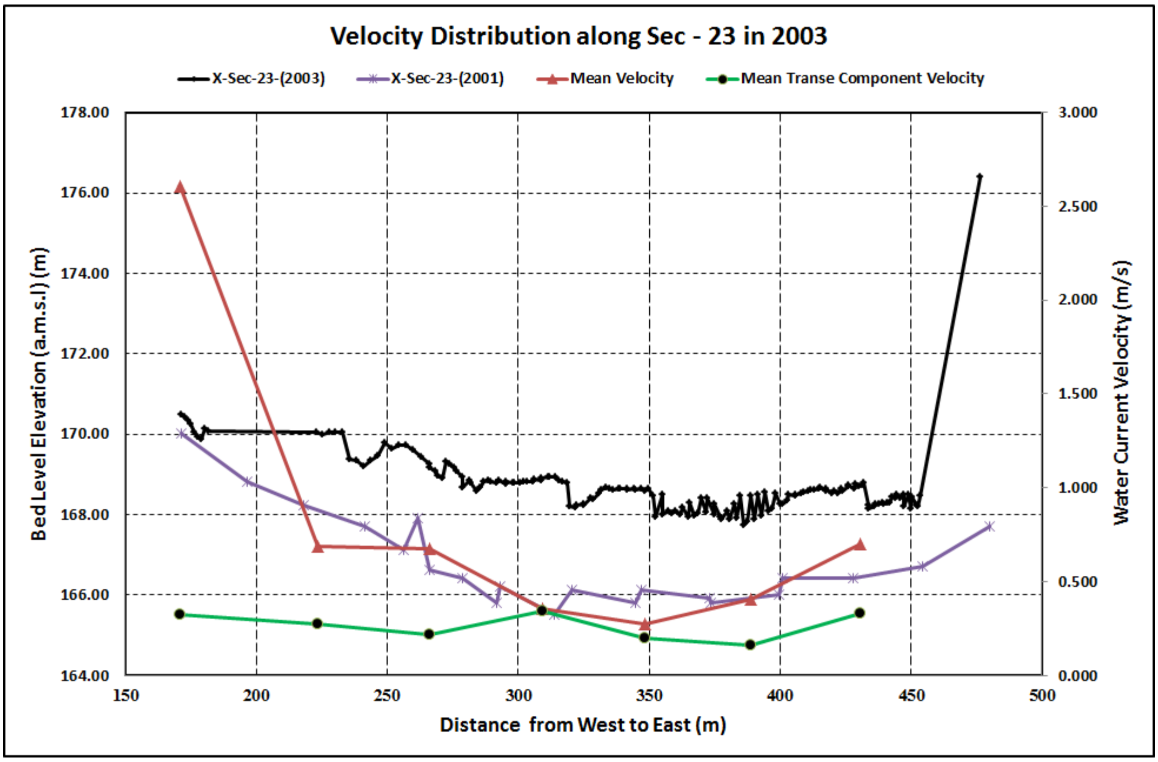

Figure 4. Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 23 in 2003.

In Fig. (5), on comparing the bed profile of sec 23 in 2008 with that of 2007, it has been noticed that a deposition ranging from 2 m to 0.5 m took place along the west side of the x-section for a distance of about 150 m. whilst for the rest of the x-section width, the difference between them was found to be very little. Since the deposition occurred in the west side, it was expected that the velocity values would be small at this part of the section while it would be high at the rest of the x-section width. This was the case in the mean transverse component but it was the opposite in the mean velocity. This means that the transverse component is more representative of the deposition distribution than the mean velocity.

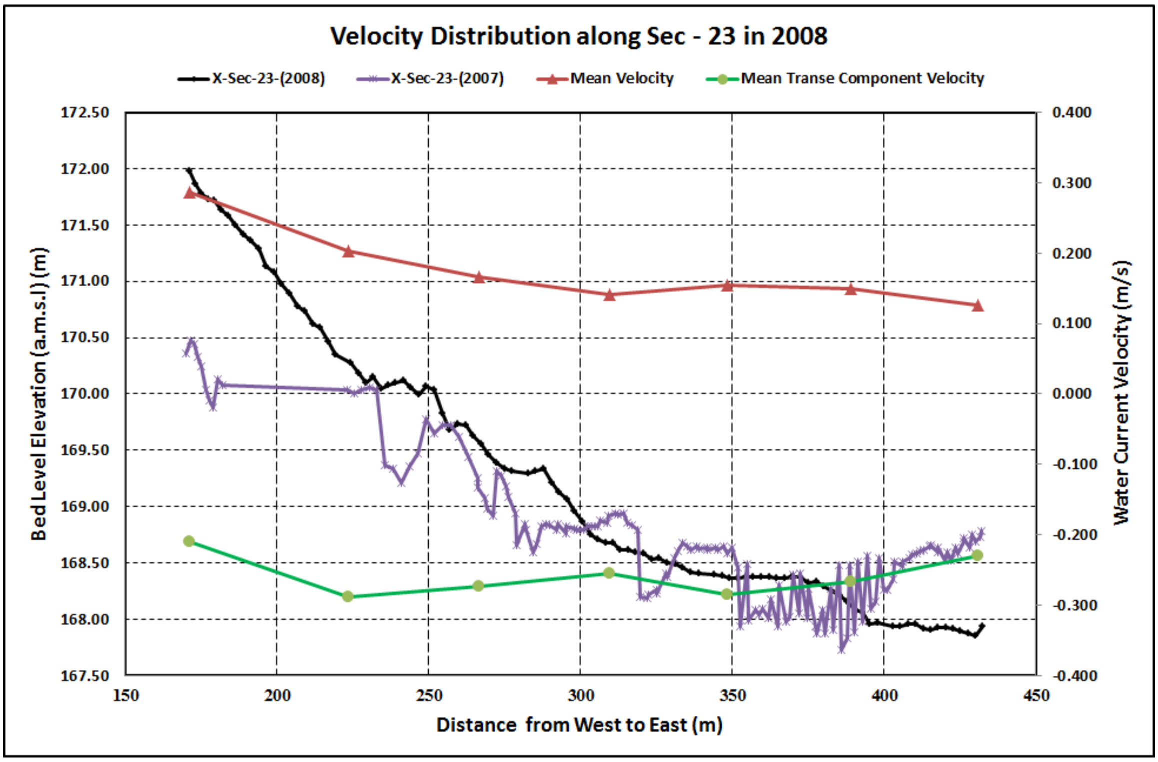

Figure 5 . Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 23 in 2008.

In Fig. (6), it has been found that the deposition occurred from year 2009 to year 2012 along the width of the x-section 23 in very small values at the west side and considerable values at the rest of the width. The mean velocity is found more representative than the mean transverse component. This result is different from that obtained from figures (4 & 5). This may be due to the long period between year 2009 and 2012 where the annual scientific expedition could not take place in 2010 and 2011. This period experienced a low flood year 2009/2010 of 70 (bcm) and a slightly high flood year 2010/2011 of 89 (bcm) and almost an average flood year 2011/2012 of 80 (bcm).

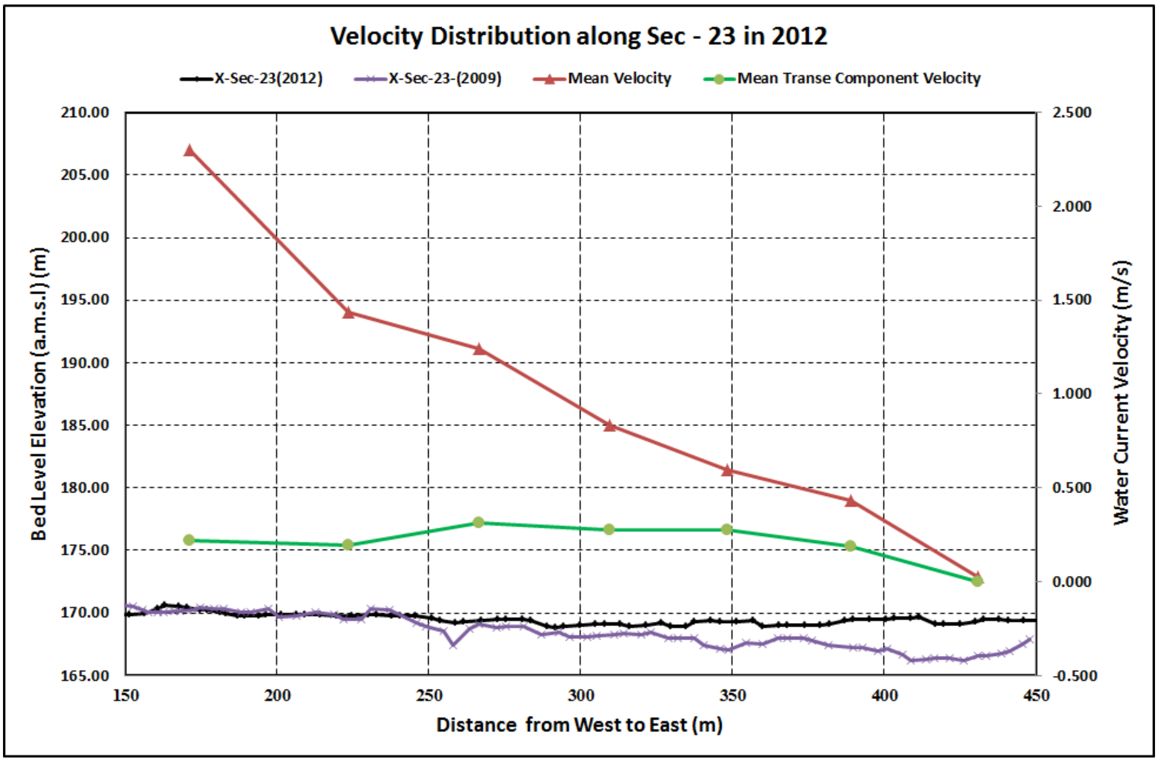

Figure 6 . Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 23 in 2012.

Also, on comparing the results of figures (7 thru 9) for x-section 3 in the middle of the sedimentation zone of AHDR within the Sudanese borders and those of figures (10 thru 12) for x-section 24 at the end of the same zone in the same way as section 23, it has been found that the same trend exists. This trend is that the mean transverse component is mostly representative of the deposition distribution in AHDR in all cases of flooding (low, average, and high). It is also concluded that the mean velocity is deceiving in predicting the sediment distribution.

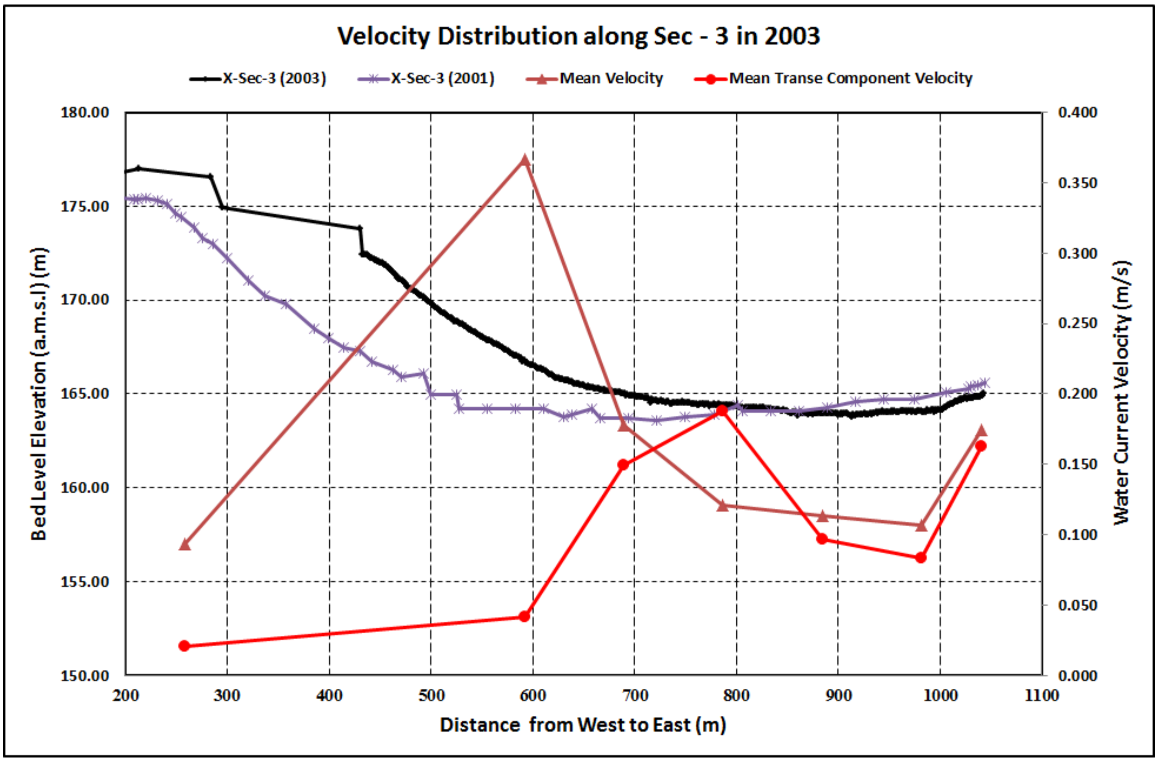

Figure 7. Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 3 in 2003.

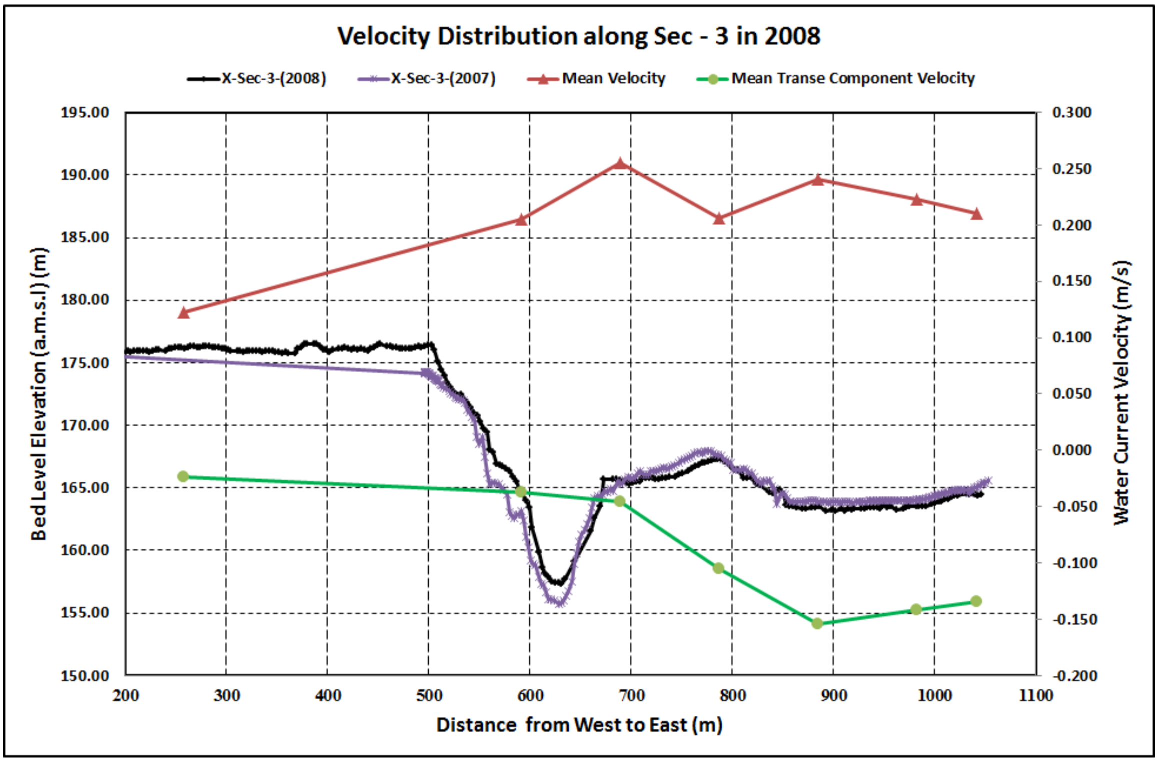

Figure 8 . Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 3 in 2008.

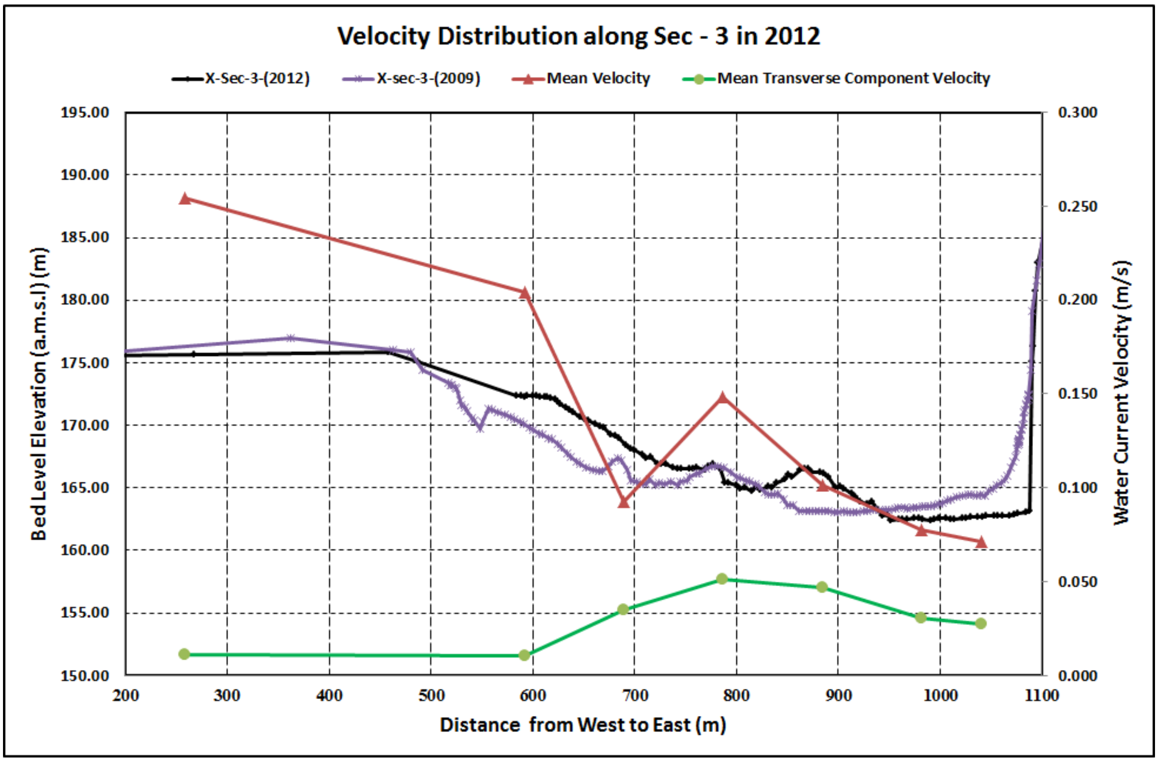

Figure 9 . Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 3 in 2012.

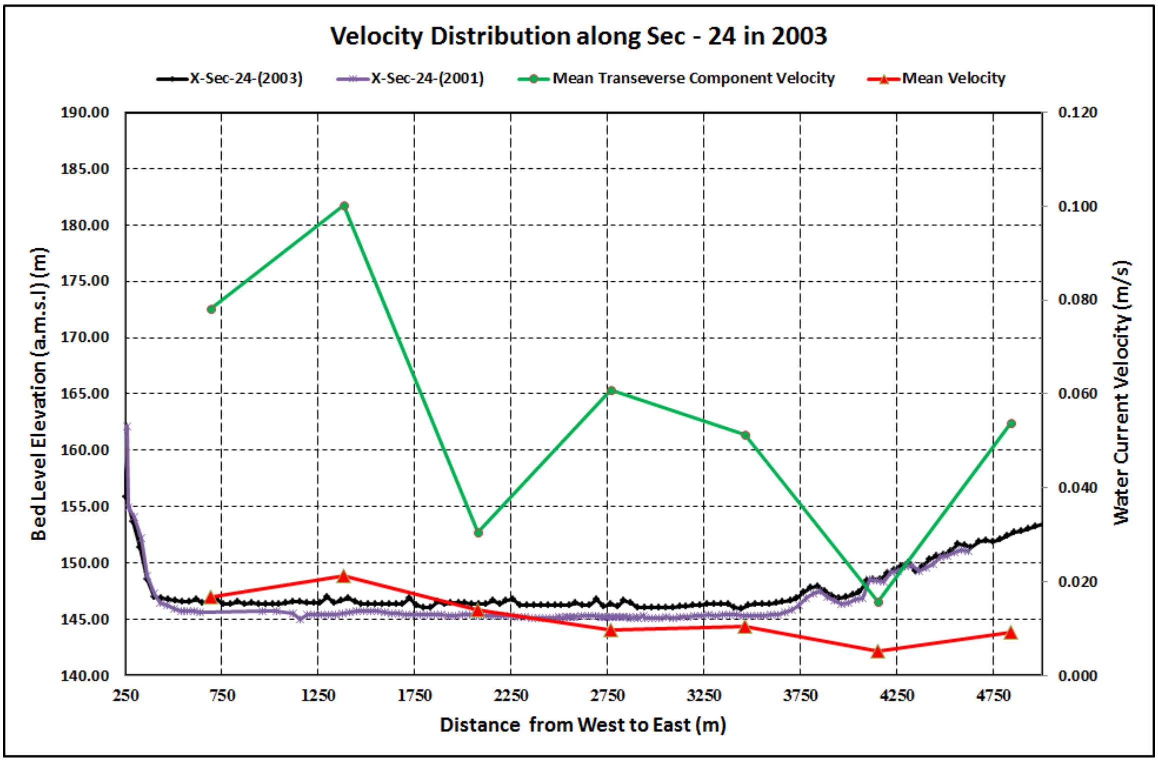

Figure 10 . Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 24 in 2003.

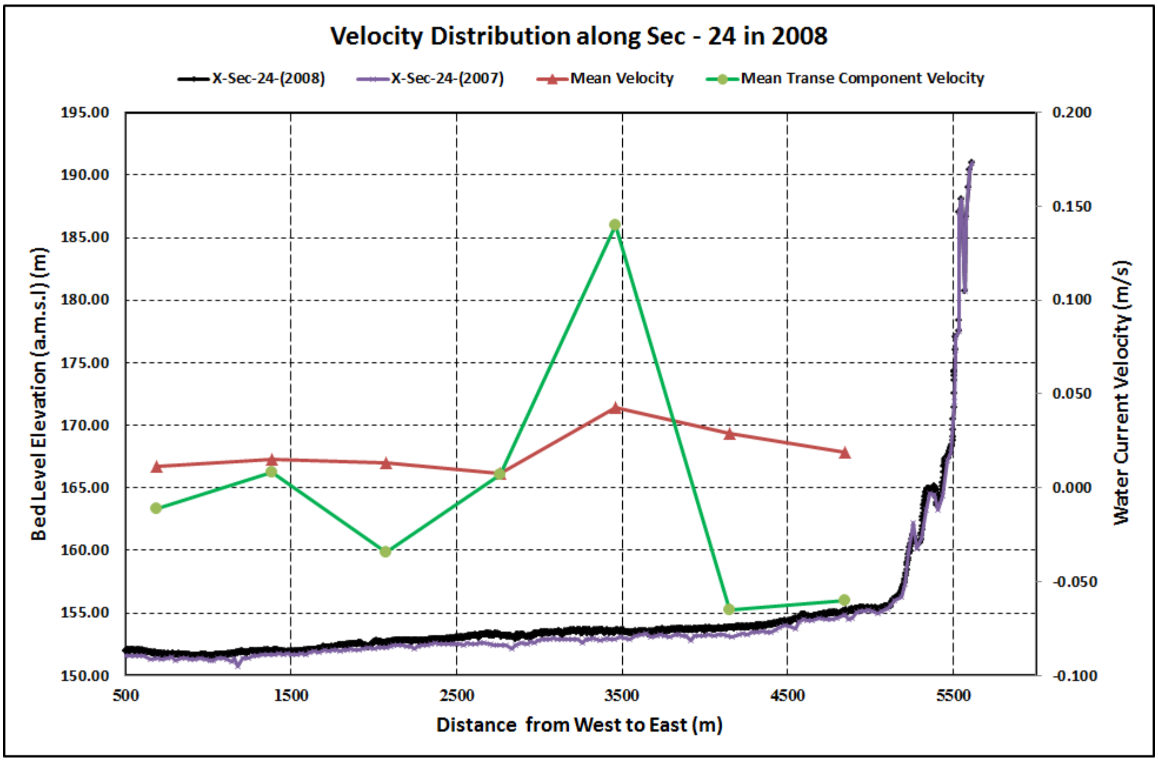

Figure 11 . Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 24 in 2008.

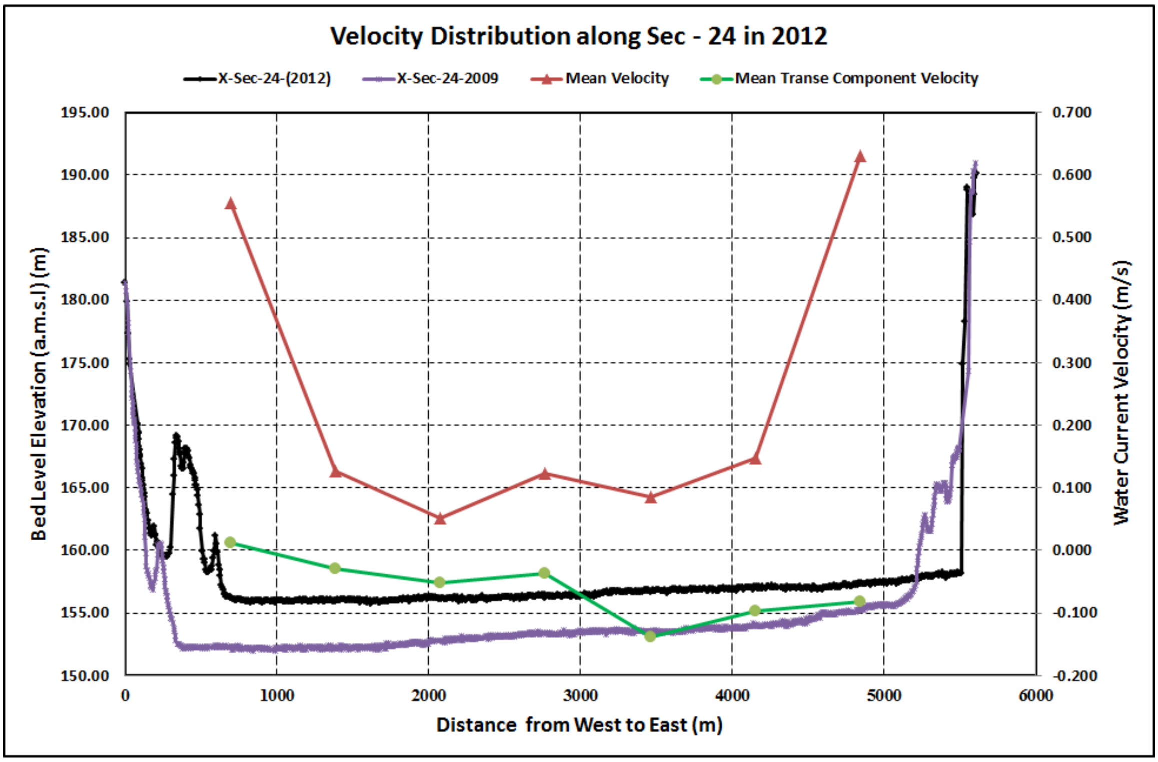

Figure 12 . Comparison of Mean Transverse Velocity with Channel Bed Morpholgical Changes at Sec - 24 in 2012.

7 CONCLUSION

Based on the above mentioned analysis, it could be concluded that:

1. The morphological changes occurring are mostly sediment depositions which mean that the sediments accumulate continuously along the head part of the reservoir;
2. The mean transverse component is mostly representative of the deposition distribution in the transverse direction along the total length of the sedimentation zone in all cases of flood (low, average, and high flood years);
3. The mean velocity trend pattern was found to be in a direct proportion to the deposition, which is not correct. This means that the mean velocity is unreliable in case of predicting the deposition distribution in the transverse direction of AHDR; and
4. The mean transverse component is more accurate than the mean velocity in expecting and predicting the distribution patterns of sediment deposition in AHDR.

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