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Research Article

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Improving Baffle Column Design to Enhance Its Effect on Sedimentation Inside River Intakes

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Abstract Land property is the main consideration which control choosing the location of river intakes. This leads to increase sedimentation problems inside River intakes. In this research, the baffle column design will be improved to reduce the amount of sediment entering the intake structures. The objective of this paper is studying different spacing values between baffle columns to reduce amount of sedimentation which enter river intakes as possible. The numerical model is used to simulate different flow conditions. Different spacing values will be studied and compared with base case. The base case represents the simulation without using the baffle columns. The model shows that the most suitable spacing value which achieves the least amount of sediment entering the intake is when the spacing distance is equal to column width.

Keywords Baffle Columns, Intake Structure, Spacing Distance, Numerical Model, Sedimentation

1. Introduction

Alluvial Rivers are dynamic in the sense that they have continuous morphological changes. The morphological changes, which may occur in front of the intake structure of the thermal power station are of main concern for the operation of the pump units withdrawing water from the intake structure for cooling purpose. Sedimentation may cause blockage of the suction basin or siltation inside the pump intake structure which adversely affecting the cooling water system [1]. Adequate understanding of sediment load behavior in the intake canal is required as it has both scouring and deposition characteristics [2]. It was stated that sediment transport is the set of processes that mediates between the flowing water and the channel boundary as the amount and size of sediment moving through a river channel are determined by three fundamental controls: competence, capacity and sediment supply [3]. The threshold condition which control sediment movement can be described in terms of a critical shear stress or critical velocity at which forces or moments resting motion of an individual grain are overcome [4].

The model study proved to be a useful means of evaluating the hydraulic performance of the intake structure and of improving the initial designs [5]. Mathematical models have become more suitable with the increase in computer capacity and the development of the numerical models [6]. Mathematical modeling is only possible when the equations can be transformed suitably to a useful solution form. The equations for turbulent flow are very complicated & they can be solved only by help of computers. The accuracy of mathematical modeling is limited by the accuracy of the functional mathematical relationships [7].

a lot of mitigation measures can be used to control sedimentation inside river intakes such as modifications to the area in front of the intake and the upstream riverbank, Introducing groins in the area of sediment accumulation, producing a quiescent or lentic water pool into which inflowing solids are deposited, using submerged vanes which mounted vertically on the river bed at an angle to the prevailing flow direction and using baffle column in front of intake structures [2-3, 8-12]. Several studies [3, 13-14] tried to solve Sedimentation problems in front of intake structures using different mitigation measure. A new approach was investigated to reduce the vortex activities in the vicinity of the intake structure [15]. The arrangement of baffle columns at the upstream and the offshore sides of the intake structure as a mitigation measure for flow non-uniformity at the intake was also studied [16]. Finally the baffle column technique is highly recommended for enhancing the intake withdrawal-efficiency, through eliminating undesired nonuniform flow conditions approaching the intake.

2. Materials and Methods

2.1. Field Measurements and Data Collection

To study the effect of baffle column design in reducing the amount of sediment entering the intake and for modelling purposes, field measurements are necessary. Field survey was carried out covering about 5 km from Nile River. The field measurements included topographic and bathymetric survey and hydrometric measurements. The survey was carried out by HRI during December 2015 and April 2017.Figure1 shows the detailed contour map results and measured profile.

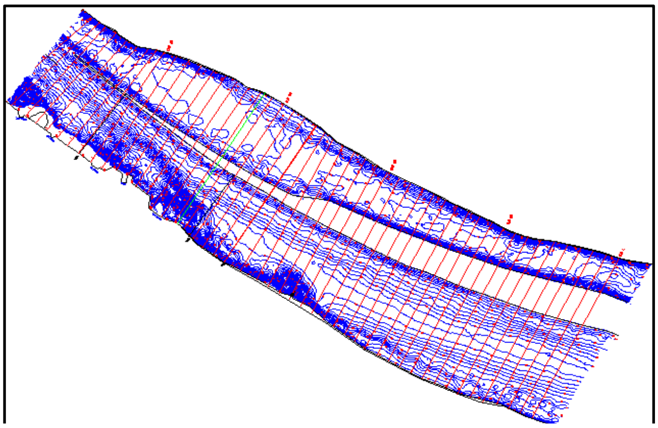


Figure 1: Detailed Contour map for modeled reach

2.2. Methodology

To release the objectives, the following methodology will be used:

1. Literature review and data collection for in hand problem.
2. Development and calibration of 3D numerical hydrodynamic flow model simulates the flow pattern in the plant vicinity using Delft3D mathematical model.
3. The morphology model will be setup.
4. Model scenarios will be proposed to be simulated in both hydrodynamic and morphology modules under different flow conditions.
5. The Power Plant will be simulated in the models before and after adding the baffle column structure.
6. Analysis of the results for different model scenarios.

3. Numerical Model

3.1. Model Description

Delft3D Software Package of Deltares developed in the Netherlands is integrated, powerful and flexible software. It can carry out simulations of two- (either in the horizontal or a vertical plane) and three-dimensional flows, sediment transports, waves, water quality, morphological developments and ecology. Delft3D encompasses a number of well-tested and validated modules, which are linked to and integrated with one-another. These modules are flow, waves, water quality, ecology, particle tracking and sediment transport

3.2. Model Construction

Delft3D Software Package was used to develop the hydrodynamic numerical flow model which simulates the flow pattern in the modelled reach. The numerical model covers an area about 700 Km^2 from Nile River (1.3

Km in the flow direction & 0.55 Km in the cross direction). The model will enable the study of cross flow and morphological changes induced by the intake discharge.

The development of a numerical flow model starts with the selection of the model limits, which gives the location of the open and closed boundaries and the overall size of the model. The second step in the schematization process is the design and generation of the computational model grid. The computational grid is a curvilinear grid to avoid the stair case problem which affects the numerical accuracy. In the design of a curvilinear grid it is important to follow the land boundaries as good as possible. To guarantee an accurate schematization for the baffle column the domain decomposition method used in grid generation. Fine grid 1.5m*1.5m used in the interested area in front of intake & coarse grid 15m*15m used in the overall model. Figure2 shows computational model grid around intake and the overall grid layout.

The water depths have been derived from the contour map obtained from the bathymetric survey. The bathymetric data has been mapped through an interpolation procedure on the computational grid of the modeled reach. In this way each co-ordinate of the computational grid of the model is given a depth value. The resulting bathymetry in the model is presented in Figure

The time step was selected for the model simulations based on the grid size and the Courant Number. Time step of 0.01 minute (0.6 second) was used in the simulations. This time step fulfils the numerical criteria and the Courant Number requirements.

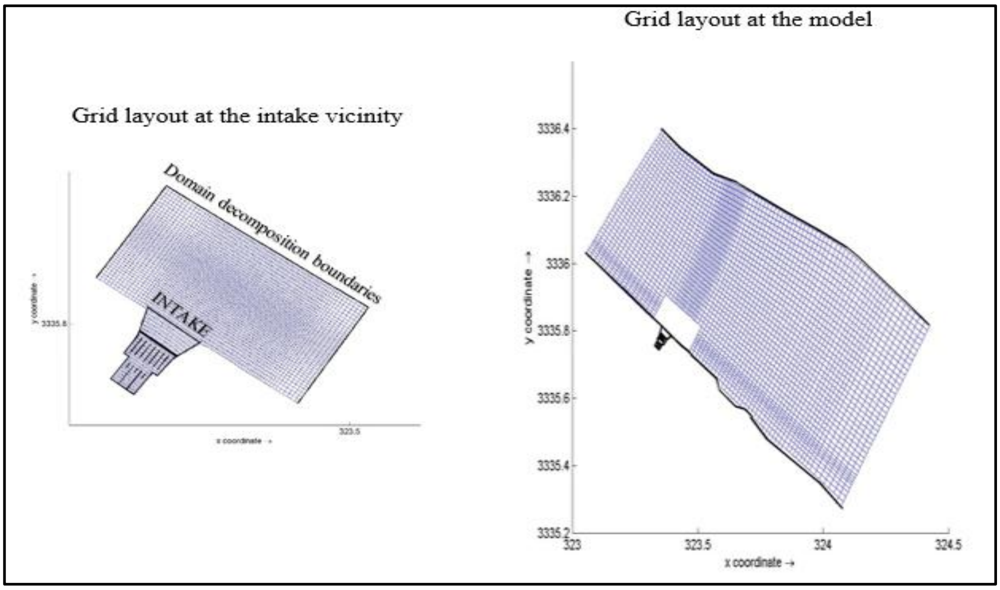


Figure 2: Layout of the overall & detailed model grid

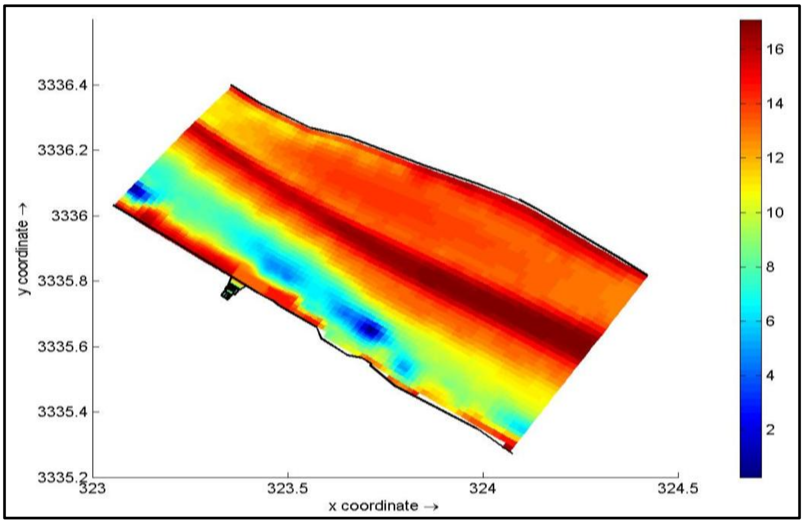


Figure 3: The model bed level schematization

3.3. Model Scenarios

In this section a detailed description for scenarios will be shown. As known the discharge of the Nile River is seasonally varied so the tests were conducted under four hydraulic conditions as showed in table 1. The total number of the tests is 20, the first four tests present the simulation of the base case and the other sixteen tests present the change of baffle column design as shown in table 3. Table 2 shows different values for the ratio between column width (b_b) & spacing between columns (Ls). Different four values of Ls will be studied as shown in the table.

Table 1: The Hydraulic Conditions for the Executed runs

	Q_1	Q_2	Q_3	Q_4
Q(m^3/s)	1883	1471.5	662	470
W.L(m)	16.69	16.69	16.5	15.5

Table 2: Different Studied Values for Spacing Distance

L_{s1}	L_{s2}	L_{s3}	L_{s4}
b_b	$1.5b_b$	$2b_b$	$3b_b$

Table 3: Model Scenarios

Test No.	Test Name	Test No.	Test Name
1	BC-Q1	11	Q3- Ls_2
2	BC-Q2	12	Q4- Ls_2
3	BC-Q3	13	Q1- Ls_3
4	BC-Q4	14	Q2- Ls_3
5	Q1- Ls_1	15	Q3- Ls_3
6	Q2- Ls_1	16	Q4- Ls_3
7	Q3- Ls_1	17	Q1- Ls_4
8	Q4- Ls_1	18	Q2- Ls_4
9	Q1- Ls_2	19	Q3- Ls_4
10	Q2- Ls_2	20	Q4- Ls_4

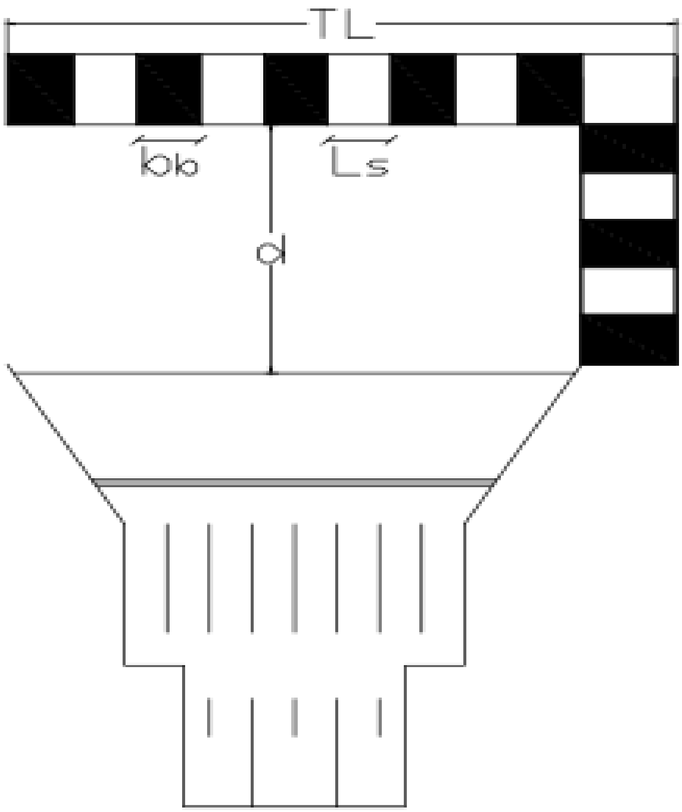


Figure 4: baffle column parameters

4. Results & Discussion

Figure 4 shows the location of sections which used in the analysis. Section-1 located inside the intake (at the intake opening), section-2 located in front of the intake and section-3 located at a distance of 25m in front of the intake. Section-4, 5 & 6 located in the vicinity of the intake in the direction perpendicular to the flow direction.

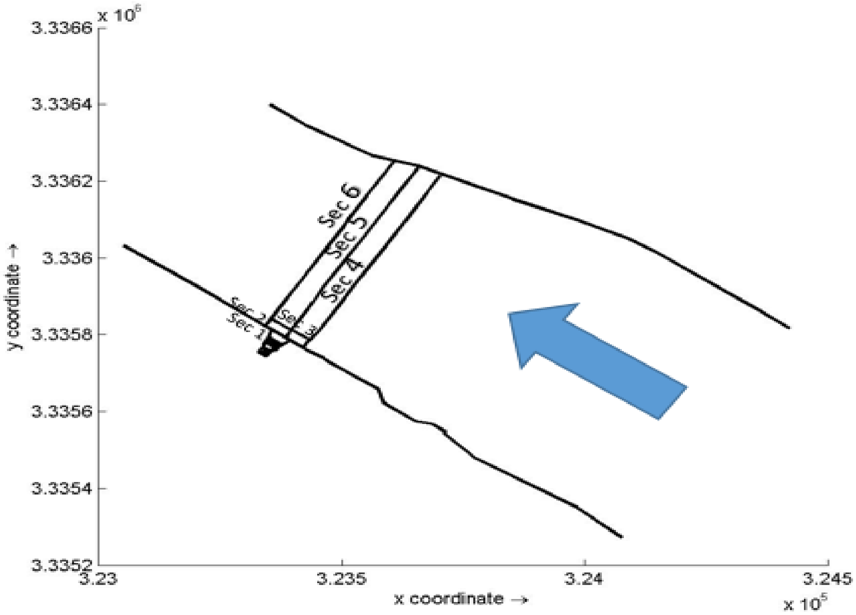


Figure 4: Result analysis cross sections

4.1. Sedimentation inside Intake

The volume of sedimentation which entering the intake in each scenario was calculated and shown in table 4 and also compared with the base case. From the table it is clear that the baffle column design has a significant effect on sedimentation inside the intake as the change of spacing distance affect the volume of sedimentation which enter the intake. Also it can be seen that percentage of reduction in volume of sedimentation which entering the intake is directly proportional to the flow discharge. Also the table shows that Ls_1 ($Ls = b_b$) is the most suitable ratio between spacing length (Ls) to column width (b_b) which lead to the least amount of sedimentation entering the intake and is suitable for all river conditions.

Figure 5 shows the deposition and erosion occurred inside the intake structure after using baffle column with Ls_1. From the figure it can be seen that there is an observed impact of the baffle column design under all flow river condition but this impact is reduced with the river flow reduction. The amount of sediment entering the intake is reduced and there is a small area of bed erosion in the intake entrance for all river conditions. But the amount of sediment entering the intake and the area of bed erosion in the intake entrance in flow discharge-3 are less than in flow discharge-4 as the flow discharge-4 is considered a critical flow discharge.

Table 4: Comparison between volumes of Sedimentation Entering the Intake in Each Scenario

Scenario	**Volume of sediment (m^3)**	**Percentage of reduction**	**Scenario**	**Volume of sediment (m^3)**	**Percentage of reduction**
B.C-Q1	3720		B.C-Q3	262	
Ls_1-Q1	895	76%	Ls_1-Q3	157	40%
Ls_2-Q1	655	82%	Ls_2-Q3	162	38%
Ls_3-Q1	642	83%	Ls_3-Q3	161	39%
Ls_4-Q1	961	74%	Ls_4-Q3	173	34%
B.C-Q2	660		B.C-Q4	747	
Ls_1-Q2	287	66%	Ls_1-Q4	614	18%
Ls_2-Q2	334	49%	Ls_2-Q4	655	12%
Ls_3-Q2	333	50%	Ls_3-Q4	646	14%
Ls_4-Q2	403	39%	Ls_4-Q4	656	12%

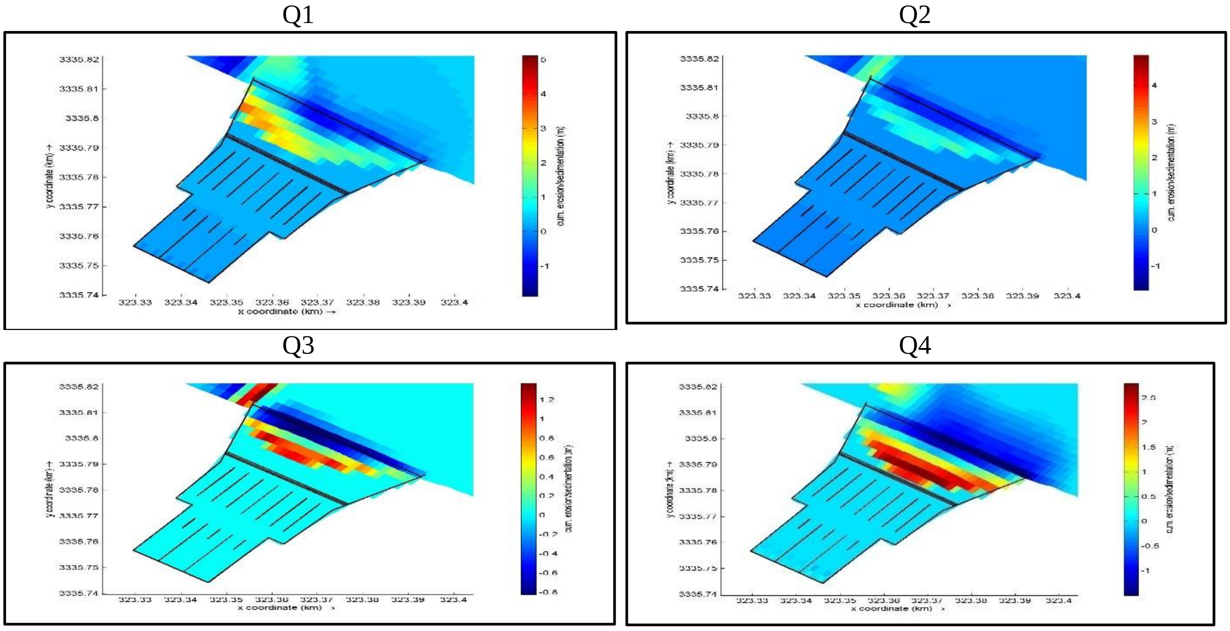


Figure 5: The Accumulative Sediment Deposition and Bed Erosion for Ls_1 under All Flow Conditions

4.2. Morphological Changes

Figure 6 shows the overall map for the study area and figure 7 shows the detailed map, from the figures it can be seen that In maximum flow discharge (Q1) there is a large amount of sediment deposition in the vicinity of the intake structure but the amount of sediment entering the intake is reduced and there is a small area of bed erosion in the intake entrance.

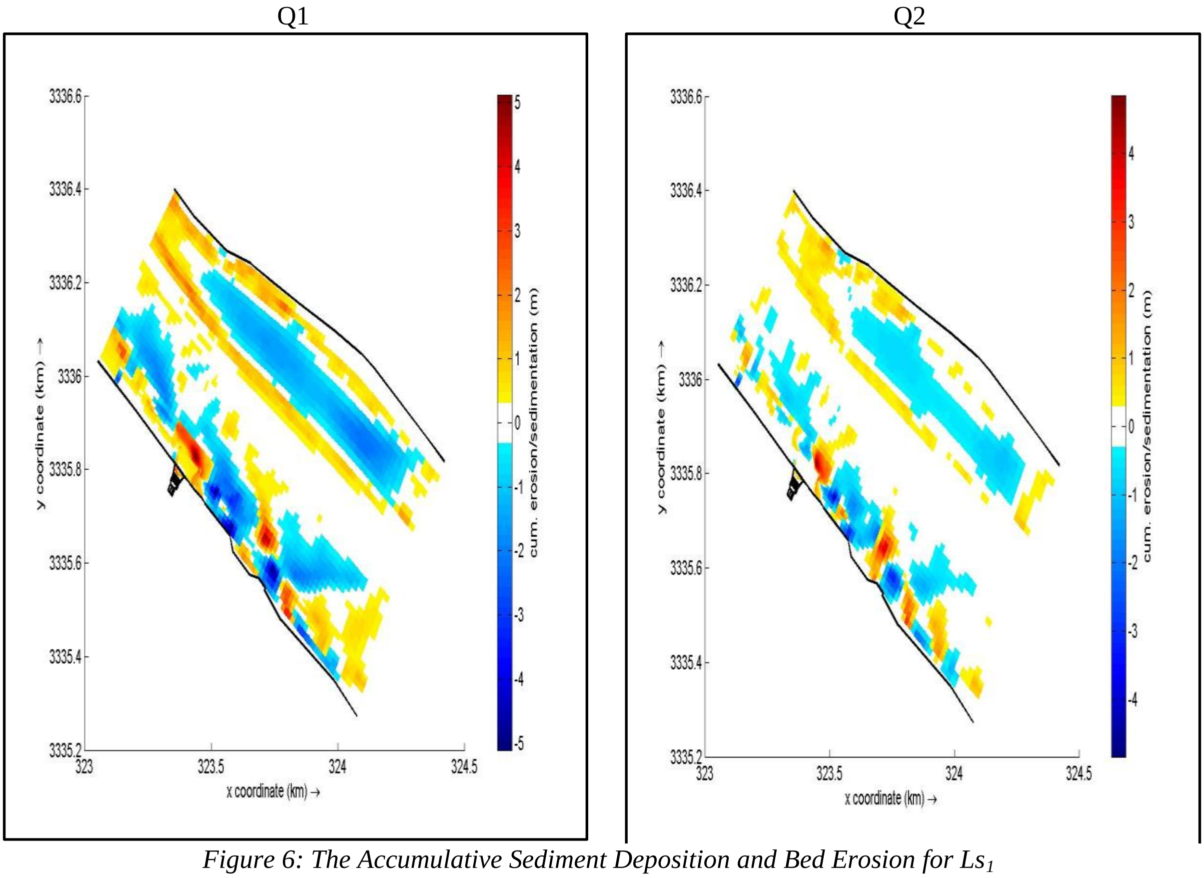


Figure 6: The Accumulative Sediment Deposition and Bed Erosion for Ls_1

On other hand in flow discharge-2 there is a small amount of sediment deposition in the vicinity of the intake structure also the amount of sediment entering the intake is reduced and there is a small area of bed erosion in the intake entrance. In minimum flow discharges (Q3 & Q4) there is almost no sediment deposition or bed level erosion in the vicinity of the intake structure but the amount of sediment entering the intake is reduced and there is a small area of bed erosion in the intake entrance.

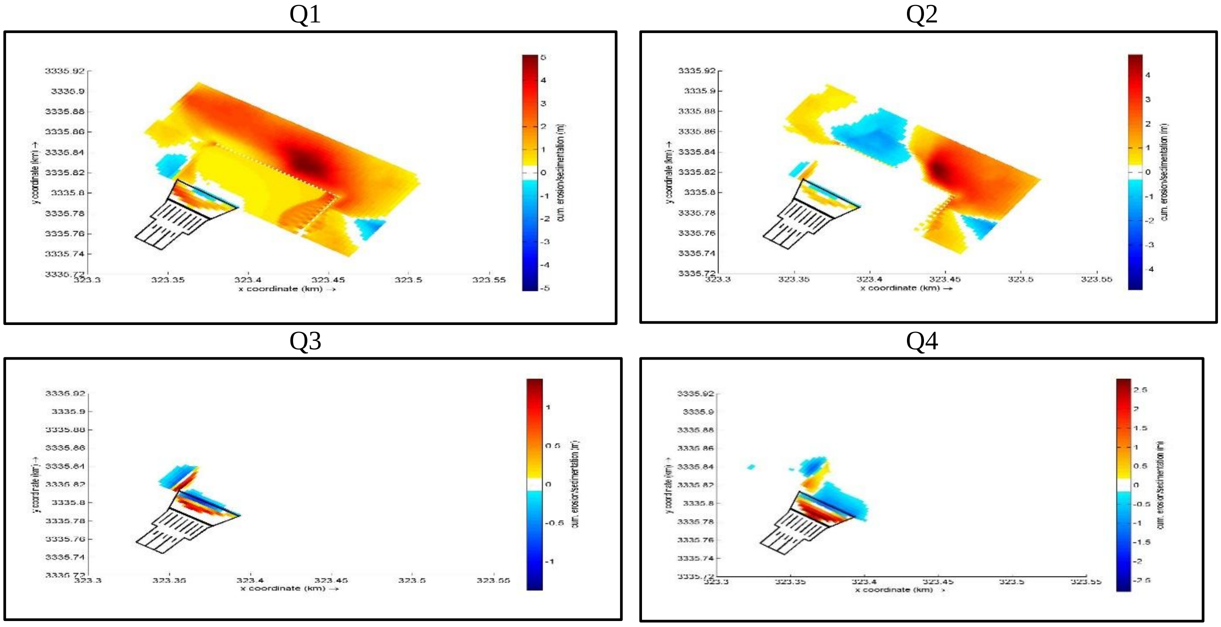
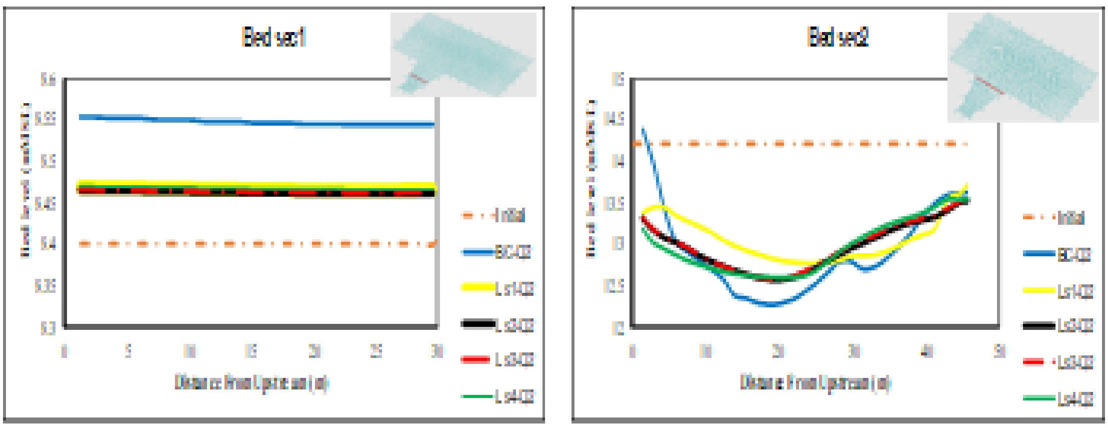


Figure 7: The Accumulative Sediment Deposition and Bed Erosion for Ls_1in the Vicinity of Intake under All Flow Conditions

4.3. Bed Level Changes

Figure 8 shows the changes in the bed level at different sections under flow discharge 2 as it considered the dominant flow all over the year. The figure shows that at section one inside the intake, there was a significant reduction in the amount of sediment deposited after using the baffle columns compared with the base case (without using the baffle column) and this occur in all spacing lengths. It also can be seen that at the intake entrance, the bed erosion was decreased in all spacing lengths compared with the base case especially in case of Ls_1 which achieve the least bed erosion. Regards to cross section-3 on the longitudinal direction within the intake, after using the baffle columns there was a significant reduction in amount of sediment which deposited in this section compared with the base case, the sections become almost identical with the initial bed levels. On other hand, it is clear that there is no observed morphological changes occurred in the three sections across the river width except in the distance from 50 to 100 in section-4 (upstream the intake) there is a little amount of sedimentation.



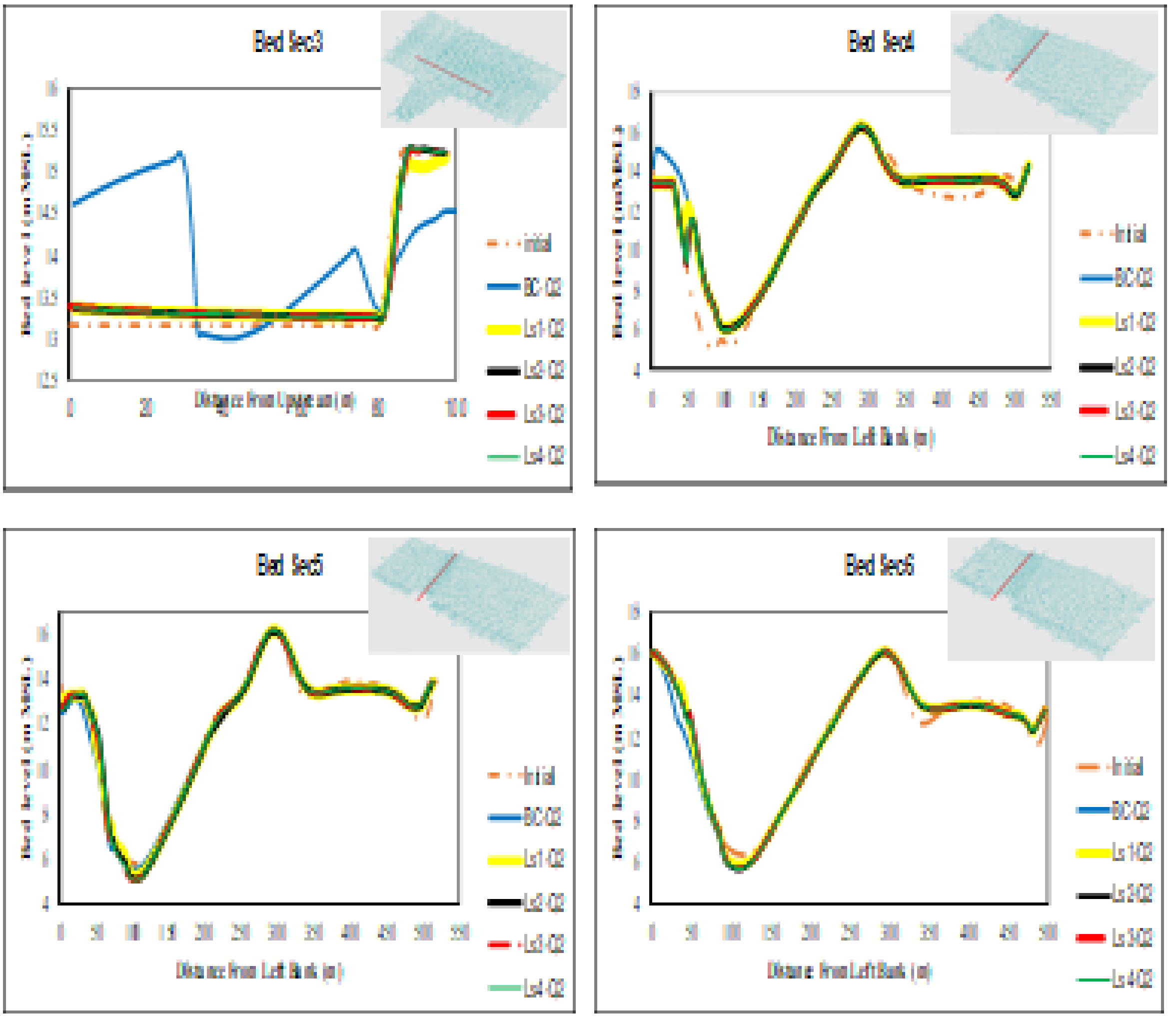


Figure 8: The Bed Level Changes for Different Sections under Flow Discharge-2

5. Conclusion

The present research studied the effect of changing the baffle column design on sedimentation inside river intakes under different flow conditions. The numerical model is applied to simulate the flow pattern and bed topography under different flow conditions. Based on the results of different scenarios, it can be conclude that using baffle columns in front of intake structures has significant effect in making the flow pattern uniform distributed inside the intake and in reducing the amount of sedimentation which entering the intake. Also it is clear that the baffle column design effect the volume of sedimentation which entering the intake and the most suitable Ls which achieve the least amount of sediment entering the intake was Ls_1. As Ls_1 reduce the sediment volume inside the intake more than other studied values of Ls. It is clear that the percentage of reduction in volume of sedimentation which entering the intake increased in maximum flow discharges.

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