Evaluation of water intake location suitability using hydrodynamic modeling

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ABSTRACT: The selection of a water intake location is an important issue for the life time of the intake and the running operation cost and hence it is indirectly affecting the final water unit price. Hydrodynamic properties of the location (e.g. water depth, velocity, turbulence, bed shear and sediment in suspension, are among the most important factors affecting the location selection aside to other factors related to construction techniques, planning considerations, navigation obstructions, environmental impacts and others. An existing water intake located on the River Nile West bank in Assuit is currently subjected to sedimentation problems causing operational drawbacks that require frequent dredging. In this manuscript, a hydrodynamic model for the subject location was developed and investigated through a number of alternative solutions to minimize the sedimentation problem and to provide better hydrodynamic conditions for intake operation. The main aim of this study is to develop a procedure to define the best power plant intake location based on multi-criteria analysis technique that is supported by the results of a hydrodynamic modeling developed for the power plant location. Using the RMA2 2-D hydrodynamic model, the hydraulic characteristics of the location (i.e. water depth, and velocity) were investigated for each proposed scenario and then weights were given to each of them for comparison. The selected solution is the one that gives the best hydrodynamic performance based on the proposed multi criteria procedure.

1 INTRODUCTION

This study was conducted to investigate the distribution of velocities at an existing water intake along the Nile River west bank. The intake is currently facing major problems due to low velocities now occurring close to it. There are many reasons that could have led to the reduction of flow velocities resulted in sedimentation and silting in the intake area.

Na & Park (2005) applied a 3-D hydrodynamic model to Lake Paldang, South Korea which has 3 inflows, the optimum drinking water intake location was determined from the applied model. The circulation and spreading patterns of the incoming flows in the lake, as well as their composition ratios to the drinking water intakes were determined from the model, and three alternative intake locations were proposed. The simulation results suggested that the horizontal and vertical relocations of the intake aqueduct could significantly decrease the composition ratio of the contaminated water. [2]

Michell, Ettema, & Muste (2006) controlled the sediment buildup at a large thermal-power station intake drawing water from a small alluvial river due to a chronic problem with alluvial-bed. The problem required expensive corrective dredging and adversely affected the station's fuel-consumption efficiency. They described how the sediment problem was successfully controlled by means of modifications to the area in front of the intake and the upstream riverbank. A hydraulic model was used to aid the design of the modifications. [3]

Moussa (2010) applied a 2-D model, CCHE2D to analyzes and solve the problem of sedimentation at water intake of Rowd El-Farag pump station. The study showed there is a significant morphological change in this reach due to the long study period and two hydraulic Structures (Imbaba and Rowd El-Farag Bridges). Moreover, different alternatives for sediment control were investigated such as: dikes on the western side of the river at different locations and dredging at the study area at different levels 14 and 12.5 (1 and 2.5 m respectively) below minimum water level. [1]

Mahgoub (2013) applied a movable bed model to study the new Tebbin power plant, with a scale of

1:50. A comprehensive model test program was designed to cover the different river flow conditions and operation modes of the power plant. Double rows of submerged vanes were mounted vertically at an angle of 60° to the main flow direction. These rows were set to generate a secondary circulation in the main flow in order to modify the near bed flow pattern thus re-distributing the flow and the sediment transport within the channel cross-section. The study results showed that, in case of vanes absence, sediments with rates 1–2 m3/week were stuck within the sediment trap under the winter conditions. Also, the results indicated that the submerged vanes play an important role in preventing the sediment intrusion. Also, it was clear that using groins might lead to enhancing the sediment distribution at the intake vicinity. [4]

This manuscript presents the results of the hydrodynamic model for the current situation to investigate the problem, by applying two-dimensional mathematical model (RMA2), then proposing several alternative solutions to solve this problem. Cadastral and hydrographic investigations were conducted for the site in addition to the compilation of hydrological data concerning elevations and discharges that will be used for the modeling process.

2 SITE DESCRIPTION

The intake of ‘’Nazlet Abdellah’’ water station is located km upstream of Asyut Barrage at the western side of the River Nile, Figure1a. Figures ab, and 1c show the existence of several islands in the western part of the River Nile, the most important is ‘’Al-Wasty’’ island, which extends about 4 km and relatively connected with the rest of the islands at low elevations and ends about 450 meters south of water intake. The stream width at the location of the station during the peak discharges varies around 1000 meters in front of the station intake.

During the field measurements, the presence of two stone peaks on the east side of the end of ‘’Al-Wasty’’ island and separated by a distance about 150 meters south of the intake location was observed. The length of southern peak is about 60 meters while the Northern one is the longest with a length about 90 meters and is located in the south of station intake about 500 meters. It was also noticed that the sub-stream (Creek), located to the south of the intake and between the authentic western side of the Nile and the island was closed.

Figure (1a): General location

Figure (1b): Station Intake and the Western Creek

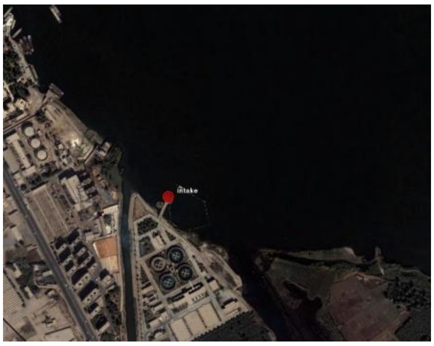

Figure (1c): Station Intake, and the stone peaks to the East

3 PROBLEM IDENTIFICATION

The causes of the problem of silting in front of intake location were a set of many morphological and hydraulic factors in addition to human interference. Taking into consideration the changes in the course of the River Nile imprisonment subject of the study-as shown in figures 1a, b, and c so it can display the various factors and the impact of each as follows:

1-Creek closure located south of intake location at western side of the stream, which is located between the Nile western bank and ‘’Al-Wasty’’ island. This closure has been randomly done to create a road linking the mainland and the island without taking into consideration the amount of discharges that usually passes through this creek.

2-Diversion of the discharge passing course of the River Nile due to the presence of two stone peaks on the eastern side of the north end of "Al-Wasty" Island. This situation has led to the collision of the water currents with the two stone peaks and created a deviation to the east, leading to reduction of the current speed and diversion of flow away from the intake location.

3-The Presence of a stone ledge at the western side of the stream and upstream of the intake location, which has a length of about 50 meters in the direction perpendicular to the stream, helped to trap the vulnerable water currents passing in front of the intake location.

4-River morphology that indicates an increase of the river width to about 1000 meters followed by a decrease of the width to about 300 m just downstream the intake location, figure 1a.

5- The main barrage located 3 km downstream of the intake location is raising the water profile and hence reducing the velocity.

4 FIELD MEASUREMENTS

During the hydrographic and hydraulic measurements, as well as the hydrological data collection of the levels and behavior course of the Nile River, it has been taken into account that a two-dimensional hydrodynamic model for the problem investigation will be implemented.

1- Hydrographic measurements representing the bottom of the River Nile as well as the course sides upstream and downstream the intake location and covering a distance of about 7.500 km.

2- Measuring the speed of water current that was used to estimate the flow through the cross section to be used later in the model as a boundary condition and to also use it in the calibration process.

3- Hydrological data was collected to identify the water levels corresponding to the minimum and the maximum discharges and the corresponding water levels upstream and downstream of intake location. The water levels ranged between 47.25 meters during 1996, and 50.65 meters during 2002 and corresponding to flow rates of 30.60 m^3/day and 222.500 m^3/day respectively.

5 MODEL SELECTION

Reliable assessment and resolution of river hydraulics issues depend on the engineer's ability to understand and describe, in both written and mathematical forms, the physical processes that govern a river system.

The choice of appropriate analytical methods to use during a river hydraulics study is predicated on many factors including the objectives, the level of detail being called for, the regime of flow expected, the availability of necessary data, and the availability of time and resources to properly address all essential issues.

A Survey was made on the 2D Hydrodynamic models. The selection and the comparison between models were based on the following points:

- Availability.
- Ability to be applied to calculate water levels and flow distribution in rivers and reservoirs.
- Easiness to learn and use.
- Availability of documentations.
- Very good visual representation of the data which helps in the interpretation of the results.

The RMA2 model under the SMS interface was selected in the case study.

5.1 *Origin of the Program*

The original RMA2 was developed by Norton, King and Orlob (1973), of Water Resources Engineers, for the Walla Walla District, USA Corps of Engineers, and delivered in 1973. Further development, particularly of the marsh porosity option, was carried out by King and Roig at the University of California, Davis. Subsequent enhancements have been made by King and Norton, of Resource Management Associates (RMA), and by the USA ERDC at the Waterways Experiment Station (WES) Coastal and Hydraulics Laboratory.

5.2 *Model Description*

RMA2 is a two-dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface two-dimensional flow fields.

RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. The Manning's coefficient was used to define friction and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady (dynamic) problems can be analyzed.

The program has been applied to calculate water levels and flow distribution around islands, flow at bridges having one or more relief openings, in contracting and expanding reaches, into and out of off-channel hydropower plants, at river junctions, and into and out of pumping plant channels, circulation and transport in water bodies with wetlands, and general water levels and flow patterns in rivers, reservoirs, and estuaries.[5]

David et al (2004) helped protect public supplies from contaminant spills and discharges to public water intakes on the St. Clair-Detroit River Waterway using RMA2 hydrodynamic simulation and particle-tracking analyses. An existing 2D hydrodynamic model (RMA2) of the St. Clair-Detroit River Waterway was enhanced to improve estimation of local flow velocities. Improvements in simulation accuracy were achieved by computing channel roughness coefficients as a function of flow depth, and determining eddy viscosity coefficients on the basis of velocity data. The enhanced parameterization was combined with refinements in the model mesh near 13 public water intakes on the St. Clair-Detroit River Waterway to improve the resolution of flow velocities while maintaining consistency with flow and water-level data.[6]

Zindović Budo et al (2010), dealt with the analysis of the flow field around the front of buildings using the model of plane and spatial flow. It is shown that numerical models can effectively determine the hydraulic characteristics of the river and psamološke flow. Special attention was given to determining the impact of the threshold upstream from the entrance, which serves as a measure for reducing sediment feeding. For example, abstraction 'Makis' on the Sava River, illustrated the successful resolution of the problem of determining the consequences caused by the increase of its capacity.[7]

Mahatma (2013) conducted a study to model warm water (thermal) dispersion from Steam-Electric Power Plant (PLTU) at Binceta Coast (North Sulawesi) using RMA2 hydrodynamic model and RMA4 water quality model. The main objective of this study was to determine the possibility of warm water discharged from power plant outfall re-entering the power plant intake. Modelling was done with one intake and one outfall on the west and east monsoon. Result of the simulations showed that warm water plume discharged from power plant outfall will not re-entering the power plant intake both on the west and east monsoon. [8]

T. Lyubimova (2013) developed a hydrodynamic model of the Chusovskoy water intake system, supplying 1M inhabitants with potable water. Numerous field observations have shown that in the region of the Chusovskoy water intake is characterized by a higher degree of hardness and mineralization than water of the Chusovaya river. Moreover, the Chusovskoy intake system is located in the backwater zone of the dam of the Kamskay hydroelectric power station (HPS). Thus, the hydrodynamic regime of the water basin in the region of the water intake is defined by a rather complicated combination of the hydrological regimes of the Chusovaya and Sylva rivers, the water level of the Kamskiy water storage reservoir and the operating regime of the Kamskay HPS. Due to these factors and the limited possibilities of water monitoring, a numerical simulation of the above hydrological system is a matter of considerable importance for the environmental and engineering applications. Optimization of the water intake structure using the data of mathematical simulation may provide an alternative to the high-priced and time-consuming technological methods of lessening water hardness. A combination of 2D (RMA2) and 3D computational schemes. The numerical simulations in the vicinity of the water intake head and the bottom barriers were made based on the three-dimensional model, whereas the hydrodynamics of the rest of the computational domain was computed based on the two-dimensional model. [9]

6 METHODOLOGY

Geographic Information Systems (GIS) was used for data preprocessing to create a closed polygon representing the stretch of the river to be modeled. Triangular Irregular Network (TIN) has been intensified in both irregular areas and around islands, figure 2; all errors of the formed TIN were corrected to ensure model stability during calculations. The bathymetric survey data was then interpolated with the TIN to generate a surface representing the river bed and sloped sides, figure 3.

As an upstream boundary, the velocities that were measured previously at specified upstream cross sections have been used to calculate the inflow boundary conditions, and the recorded water levels upstream the downstream barrage were used as a downstream boundary.

From the previous similar studies, it has been proven that the factors affecting the process of the hydrodynamic modeling in terms of importance are as follow:

1- The bottom surface and its conformity with the reality at which a major effort has been done in this direction.
2- Coefficient of viscosity and roughness coefficient as key calibration parameters that was carried out by comparing between model results and the measured values at the monitoring stations.
3- Appropriate time intervals that have been chosen to ensure adequate representation of speed in the area under study.

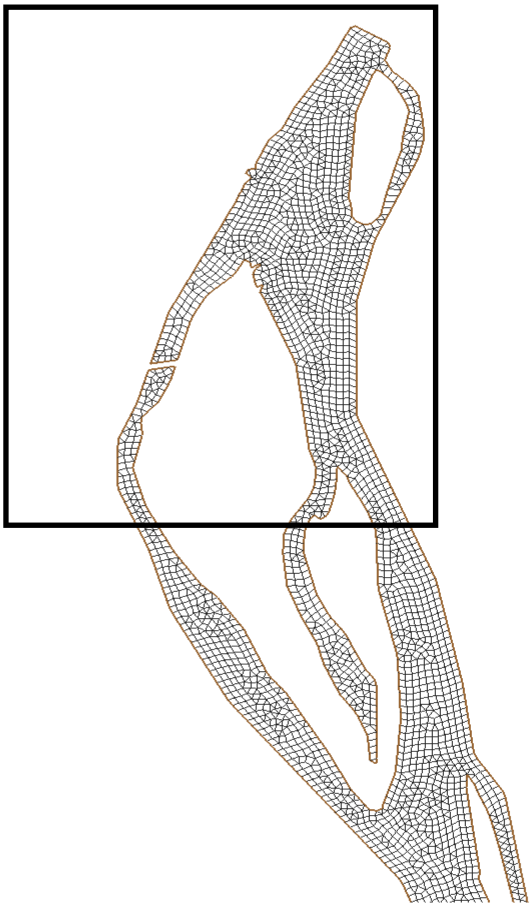

Figure (2): TIN grid for the region used in the hydrodynamic model

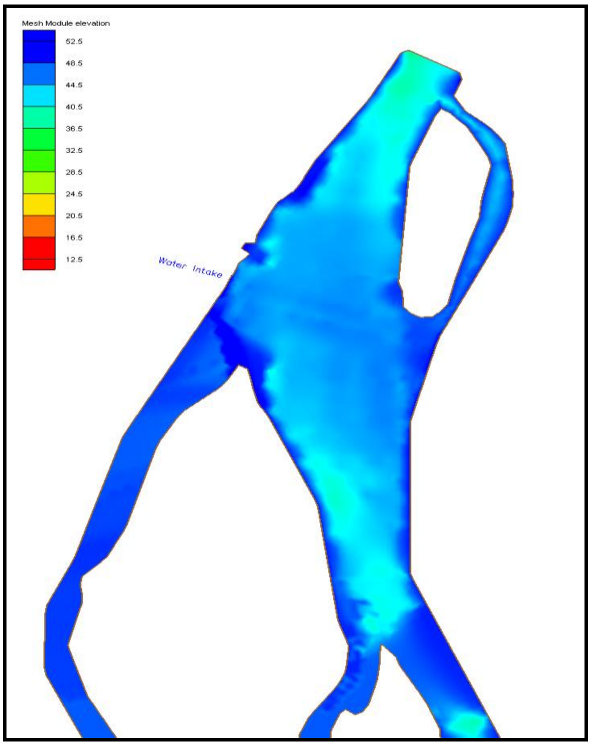

Figure (3): The surface of a river bed for the study area

6.1 *The present situation*

A 2D hydrodynamic model was built to assess the current situation of the area under study. From the clear decline in flow velocity recorded at the intake location during the survey period, despite the fact that it is one of the periods of high flow rate (during summer), and comparing these data with other historical records. Figure (4) shows the present velocities magnitudes in the study region; it is clear from the figure that the average speed at the intake is 0.10 m/s. While and figure (5) illustrates the velocity vectors.

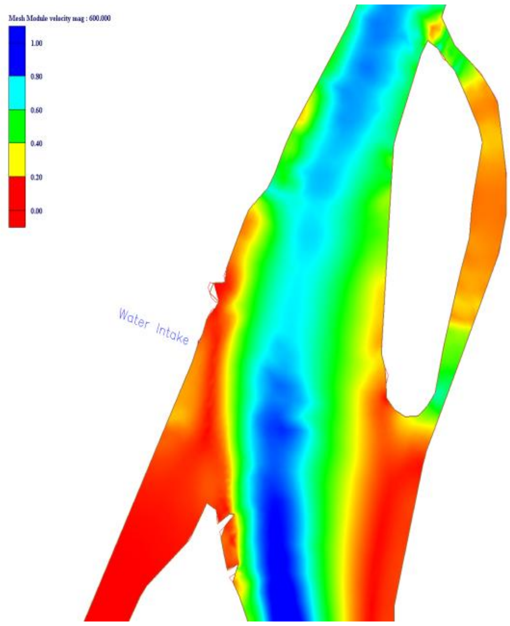

Figure (4): The values of velocities at the water intake (current situation)

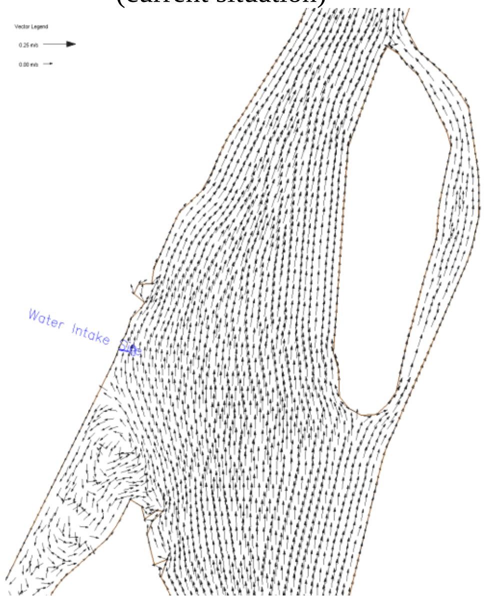

Figure (5): Directions of velocities at the water intake (current situation)

7 RESULTS OF MODELING DIFFERENT ALTERNATIVES

Alternative I: Demolishing of stone peaks from the central island. The following figures 6 and 7 show the effect of this alternative on velocity magnitude and directions. It shows an increase of the velocities magnitudes. The average velocity at the intake reached a value of 0.20 m/s which is equal to almost twice the current velocities at the intake area and no change of the water velocity in the western creek.

However, there was no significant change in the velocities directions.

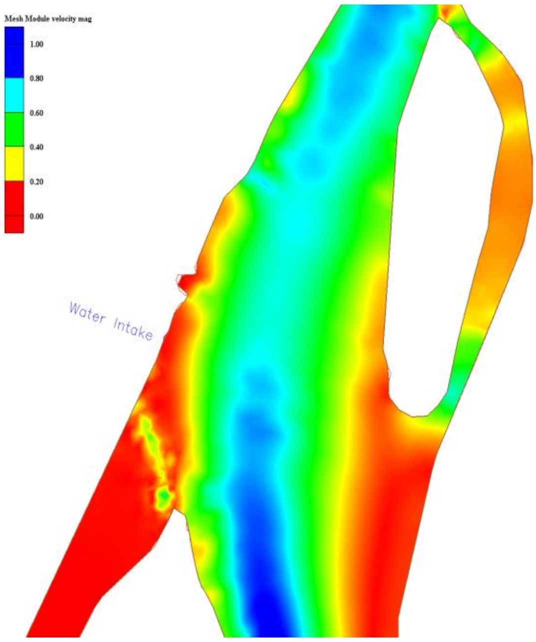

Figure (6): Velocities magnitudes at the intake (1st alternative)

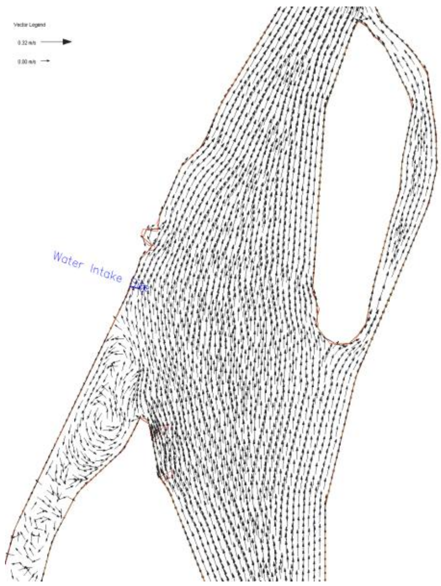

Figure (7): Directions of velocities at the water intake (1st alternative)

Alternative II: The reopening of the western creek. The following figures 8 and 9 show the effect of this alternative on velocity magnitude and directions. It clearly shows a significant increase of the values of velocities. The average velocity at the intake reached a value of 0.29 m/s which is equal to almost 3 times the current velocities at the intake area and also shows a significant increase of the water velocity in the western creek and change in the flow directions, especially from West Creek, which will help in decreasing the sedimentation rate in the area.

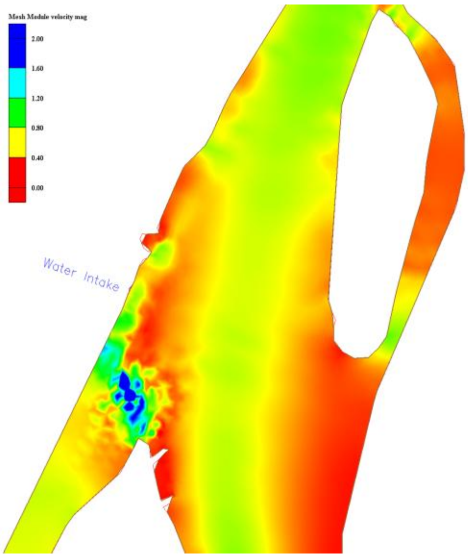

Figure (8): Velocities magnitudes at the intake (2nd alternative)

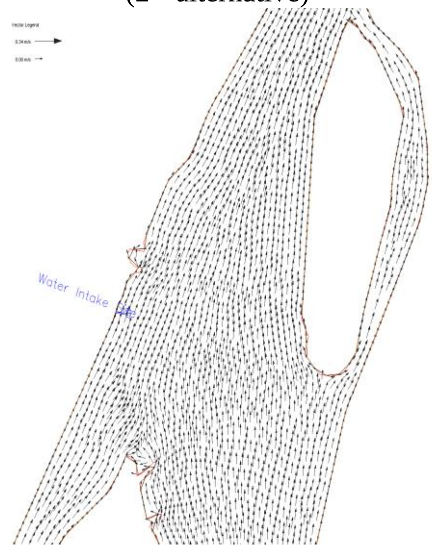

Figure (9): Directions of velocities at the water intake (2nd alternative)

8 COMPARING BETWEEN ALTERNATIVES

The results should be analysed to come up with the best alternative with the most suitable hydraulic conditions. The main hydraulic parameters, that may affect the selection of an intake location, and could be calculated from the hydrodynamic model results, include the velocity, water depth, and water level. The increase in velocity, water depth and water level are signs for the enhancement in the hydraulic conditions at the intake location. However, for the same discharge the increase in velocity will results in depth and water level reduction.

The model results (velocity magnitude, water depth and water level for each alternative) were transferred into raster files using Geographic Information System (GIS) software. Figure 10, shows sample for the raster files of the 1st alternative.

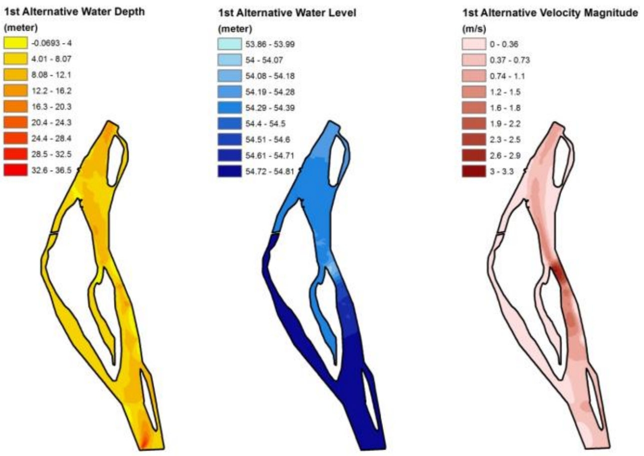

Figure (10): Raster grid for the hydrodynamic model results, 1st alternative

To compare between any alternative from one side and the original case on the other side, an area of 325 m from the intake location, representing almost half of the river width at this location, was selected to do the comparison between them. The ratios between velocity magnitude, water depth, and water level of each alternative and those of the original case were calculated for the area of comparison. Figure 11, shows sample for the resulted ratio grids for the 1st alternative.

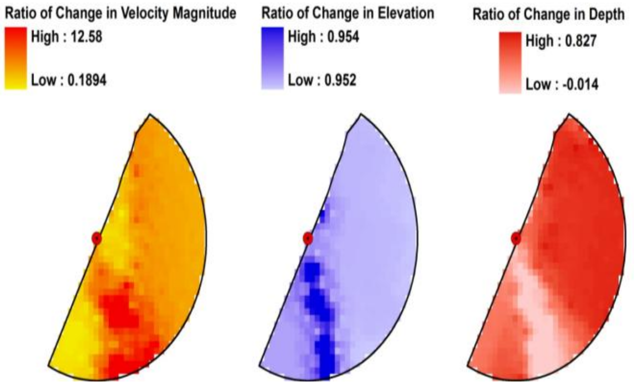

Figure (11): Raster grid for the hydrodynamic parameters ratios, 1st alternative to the original case

These ratios are to be added up all together for each alternative to present one final grid indicating the change of hydraulic conditions at the intake location, thus facilitating the comparison between them. However, as the different parameters do not have the same effect on enhancing the hydraulic conditions at the intake location, each ratio grid will need to be assigned to a weight<1 before adding them all up, equation 1.

$$\text{Weighted grid} = \Sigma\,(W_i \times RG_i) \qquad (1)$$

Where;

W_i represents the weight assigned ($\Sigma\, W_i=1$)

RG_i represents each of the ratios grids (velocity ratios' grid, depth ratios' grid, and water levels ratios' grid)

All of the suggested alternatives were proposed to increase the flow velocity which in turn will affect the water depth and water elevation and most properly will reduce them, therefore, the change in velocity is considered the most important parameter and the highest weight was assigned to its ratios' grid while the ratios' grids for the changes in water depth and water level were given equal weights. Applying equation 1 to each alternative's grid, weighted grids for each alternative resulted and will be then used for comparison, figure 12.

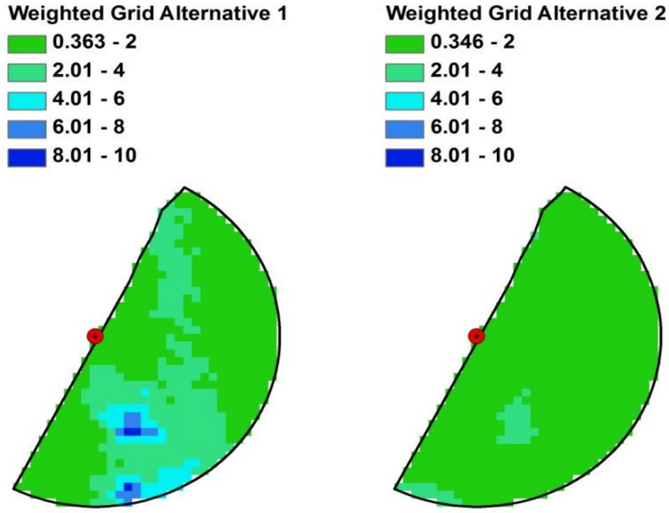

Figure (12): Weighted grids for all alternatives

The statistics of the resulted grids, table 1, will help in understanding and interpreting of the results. Both alternative 1 and 2 have almost equaled minimum ratios, however, alternative 1 has a higher maximum ratio of change, however, it may be missing the uniformity as it has the highest standard deviation and Kurtosis[1] values. Looking at the mean value and standard deviation, it is clear that alternative 2 has the lowest mean ratio value, despite, having the lowest standard deviation.

Table 1: Weighted grids' statistics

	Minimum	Maximum	Mean	Standard deviation	Kurtosis
Alternative (1)	0.362	8.95	2.164	1.25	5.84
Alternative (2)	0.346	3.72	0.929	0.569	1.72

9 CONCLUSIONS

The two-dimensional hydrodynamic model could successfully simulate the temporal and spatial mix-

[1] Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. A uniform distribution would be the extreme case

ing patterns of incoming flows through a river cross section and become a useful tool in determining the optimum water intake location in main rivers.

After studying the different alternatives proposed to solve the sedimentation problem, and according to the 2D hydrodynamic model results, and when focusing locally on the intake location, it will be recommended to apply alternative 1 (that is completely remove the encroachment and the filling of the western creek of the stream, which connects between ''Al-Wasti'' Island and the original western side of the stream), thus passing of the discharges through that creek then the demolishing of the entire length of the stone peaks located at the northern end of ''Al-Wasty'' island from the east side of the island (alternative 2) will then have a minor effect.

However when applying the proposed comparison technique to the area surrounding the intake location it can be seen that alternative 1 will have the more extended effect to the area surrounding the intake than that of alternative 2.

This technique could be adopted when selecting the most suitable locations for water intake location along rivers and water ways. However, extended work may be made to add other hydraulic parameters (i.e. shear bed stress, and velocity directions).

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