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Impact of dredging on the Nile River downstream Isna Barrage

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ABSTRACT: The construction of the High Aswan Dam (HAD) caused a dramatic reduction in fluvial discharge leading to an obvious footprint on the morphodynamics of the Nile River in Egypt (NRE). A typical erosional phase of undercutting and bed incising took place initially post-construction. Dredge work is carried out yearly at certain hot spots along the NRE course to allow for navigation. The present study focuses on the impact of dedicated dredging in alluvial rivers as a form of human interference. Numerical modeling was used to quantify volumes of erosion and deposition both with and without dredging within a 60 km reach downstream Isna Barrage (RK 167). Morphologic changes between 2004 and 2018 indicate net erosion where most of the material lost from bed is through dredging. The results suggest that dredging is altering the dynamic equilibrium of the current HAD flow release scheme.

Keywords: anthropogenic, sediment transport, fluvial discharge, morphology, dredging, degradation Delft3d, HAD, second reach of the Nile River in Egypt

1 INTRODUCTION

Human Interference has a clear impact on the morphology of the Nile River in Egypt (NRE) through the construction of hydraulic structures, laying out a river diversion network, and dredging works. Anthropogenic pressures increased during the past two centuries, and now dominates the hydrographic system in Egypt (Stanley and Clemente, 2017). The construction of the High Aswan Dam (HAD) caused a dramatic reduction in fluvial discharge which had an obvious footprint on the morphodynamics of the Nile River in Egypt (NRE). This led to a typical erosional phase of downcutting and bank erosion especially in the first 200 km downstream HAD, followed by a quazi-equilibrium phase.

In the last two decades, local scale depositions and river shoals have developed along the whole river. Shoaling is pronounced in the navigational path of the 60 km reach downstream the Isna Barrage (RK 167). Since navigation in this same reach of the NRE is of economic importance, dredge work is performed annually in several reaches along the NRE - including the area of study - in order to achieve the design navigation depth. Given the potential future variability in water discharge in the NRE, a quantitative assessment of the anthropogenic impacts on the NRE will be useful for river management.

1.1 *Objectives*

The goal of this study is to quantitatively assess the impact of one of the anthropogenic influences – namely dredging – on the current river regime over 60 km of the second reach of NRE. The objective of this study is to perform a numerical modeling study to investigate the impact of dredging on the current NRE regime downstream of Isna Barrage (RK 167). A 2D model (Delft3D) was used to carry out the modeling exercise.

1.2 *Study area and data acquisition*

A dedicated field survey campaign was carried out to measure suspended sediment concentrations and sample the bed material along the study reach. Velocity and water discharge measurements corresponding to the same study were collected. Bathymetric surfaces between RK 167 and RK 227 were surveyed for the years 2004, 2018 by the Hydraulics Research Institute (HRI) and 2007 surveyed by Nile Research Institute (NRI). Four ADCP velocity transects were measured in June 2018 along the study area for model hydrodynamic calibration as shown in Figure 1, where discharge was provided from the ADCP accordingly.

Two suspended sediment transects were sampled across the river, where each transect was represented by 3 verticals. Three samples were collected along the water column of each vertical at 0.3, 0.5 and 0.8 of the water depths respectively. Ten (10) bed grab samples were collected at the same locations of the surveyed velocity cross-section to map the bed material sediment sizes and composition (Figure 1). A historical daily record of water discharge at Isna Barrage was obtained between years 1995 and 2007. This data was used to generate a synthetic hydrograph based on a flow duration curve method to produce a yearly hydrograph for data analysis and modeling as described below.

2 MODELING

2.1 *Model description and setup*

The 2D solver of the Delft3D was used to carry out the numerical modeling exercise. The Delft3D solver was used since it has a robust hydro-morphological module. The model solves the equations of Navier–Stokes system for incompressible free surface flow, with the

Figure 1. Velocity transects and suspended sediment sampling locations.

approximations of Boussinesq equations. For sediment transport and morphology module Delft3D supports suspended-load and bed-load transport calculations of non-cohesive material (sand) (Deltares 2011).

A curvilinear grid was built to cover 60 km downstream of Isna Barrage (RK 167), where the average cell size is 20 m x 20 m. A yearly synthetic hydrograph was generated based on a historical record of flow between 1995 and 2007 and was imposed as a boundary condition. The model was set to simulate a long-term morphological simulation at a realtime of 14 years between 2004 and 2018 using the bathymetry of 2004 as an initial condition. A spatially variable Chezy took values between 40 and 80 with an average of 65 based on depth limited algorithm. The Van Rijn (1984a, b) suspended and bedload transport formula was used since bed and suspended loads are treated separately (Gaweesh and Meselhe, 2016). The model was set using three size classes at a D_{50} of 219, 321 and 678 microns to represent fine medium and coarse sand respectively, with a bed composition of 20%, 70% and 10% respectively.

2.2 *Calibration*

The model went through robust calibration of hydrodynamics and sediment transport using the data collected during the field survey campaign. Several roughness variations where used until a spatially variable roughness map where was obtained to achieve calibration. Depth average simulated velocities were compared to the observed velocity measurements at the surveyed transects as shown in Figure 2, where the average goodness of fit is at 82%. Suspended load comparison was also run using the data from the two measured transects. Several parameters where tested including using single or multiple size classes, reference height (RH) and a transport calibration multiplier.

The model performed better using three size classes as opposed to using one only. In order to calibrate for transport the Van Rijn (1984a) RH and transport multiplier both were varied between 0.1 m and 1 m, finding the calibration values at 0.7 and 0.4 respectively. The error in simulated transport relative to the observed was 2.4% and 58.9% at transects 1 and 2 respectively.

2.3 *Long term morphological simulations*

The model was set to run a 14-year real-time simulation to investigate morphological changes between two surveyed surfaces in 2004 and 2018. A flow boundary condition composed of a yearly repetitive flood cycle was imposed throughout the 14-year simulation (generated as described in the "Study area and data acquisition" section). The tail water level was set based on a rating curve that was generated at the model downstream boundary. A linear interpolated tail water boundary level was generated based on the daily stage records between 1995 and 2007 at Isna (RK 167) and Naga-Hammadi (RK 359) Barrages. The interpolated stage was then correlated with upstream discharge to form a rating curve, which was used to generate a stage time series corresponding to the 14-year synthetic hydrograph.

A morphological acceleration factor of 30 was used to speed up the morphodynamic simulation. A well-mixed bed composition was assumed for the setup of bed stratigraphy, using

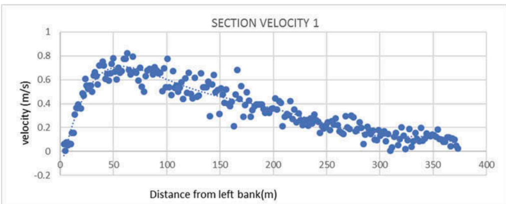

Figure 2. Example of a calibrated velocity transect, with distance from left bank in (m) vs velocity magnitude (m/s).

the sand proportions mentioned previously was used since there was no information on bed stratigraphy. An equilibrium sediment profile was used for the sediment boundaries. The dredging rule abided by authorities was imposed, which is to trigger dredging along the navigation path if water depths become less than 2.3 m. There is a great uncertainty in the actual-annual dredged volumes. Hence, the model was run with and without dredging to quantify the impact of dredging and calculate the actual net difference in volume between 2004 and 2018.

3 RESULTS

3.1 *Impact of dredging*

The observed bed surfaces of 2004 and 2018 were subtracted from each other to show a negative net difference of 5.95 million m^3 over the whole 60 km reach. The year 2004 bed surface was subtracted from the 2018 bed surface for the observed as well as the simulated surfaces for both the with and without dredging scenarios. The negative and positive difference in bed surfaces reflect erosion and deposition respectively (Figure 3).

The simulation results of the with-dredging scenario generated erosion and deposition volumes of approximately 28.055 Million m^3 and 22.77 Million m^3 respectively, with a net volume of degradation of 5.285 Million m^3. The error in the simulated volumes of erosion and deposition with respect to observed over 14 years is 21% and 32% respectively, where the model over estimating either process. Yet, the error in the simulated net difference between erosion and deposition is approximately 11% only. The simulated volume of dredging amounted to approximately 5.028 Million m3 which is 84% of the net observed volume (95% of the net simulated volume), and is 18% of the observed volume of erosion between the years 2004 and 2018 (22% of the simulated volume of erosion). The simulated total sediment volume entering and exiting the study domain in the with-dredging scenario are approximately 4.078 Million m3 and 5.338 Million m^3, respectively. This shows that the dredge volume is approximately 1.23 times greater than the incoming flux of bed material load, imposing a supply limited regime on the study reach.

3.2 *Longitudinal change in volume*

For further scrutiny, the study reach was divided into 4 straight reaches (St1 through St4), 2 bends (Bnd1 and Bnd2) and 1 bifurcation (Bfr1) as shown in Figure 4. The volumes of erosion and deposition were calculated for each sub-reach and normalized by the length in km and plotted as shown in Figure 5. The model was able to show that straight reaches 3 and 4 were sensitive to dredging activities which is observed in reality. The net difference results show that there is a general degradation pattern. Opposed to the net deposition at the first riverbend (Bnd 1) working as a sediment sink, a sharp bend such as the second riverbend (Bnd 2) showed a net erosive trend and sensitivity to dredging activities. The results reflect a supply limited river behavior of a quasi-equilibrium phase and inclined towards degradation.

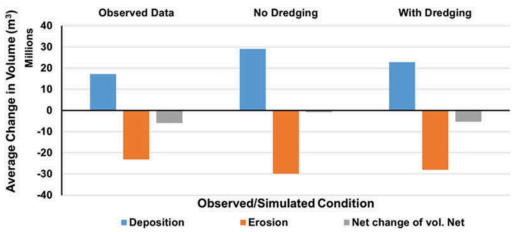

Figure 3. Erosion and deposition volumes between 2004 and 2018 for the observed and simulated.

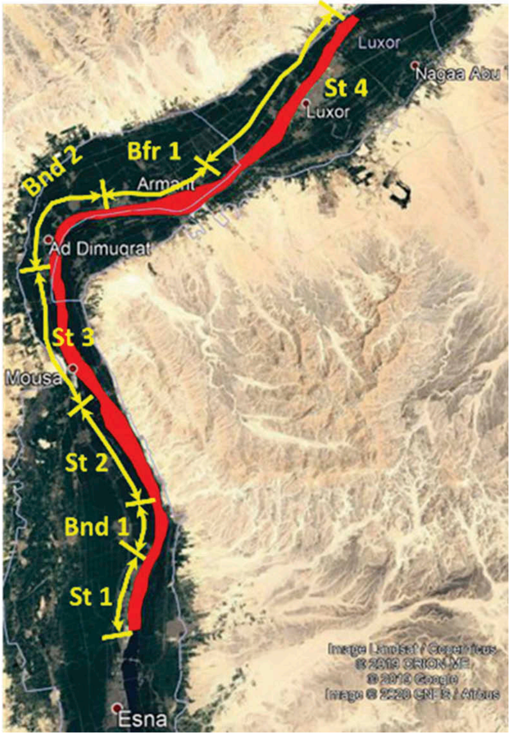

Figure 4. Study reach divided into 4 straight reaches (St1 through St4), 2 bends (Bnd1 and Bnd2) and 1 bifurcation (Bfr1), for the calculation of erosion and deposition volumes.

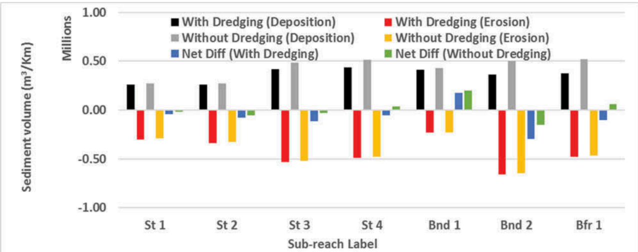

Figure 5. Reach normalized net erosion and depositional volumes and net difference between 2004 and 2018 bathymetric surfaces along straight reach, bend and bifurcation segments.

4 CONCLUSION

The model showed that dredging has a major impact on the dynamic equilibrium in the study reach, contributing to develop a net degradation between years 2004 and 2018. Erosional and depositional volumes were comparable along the various segments, with a net erosional difference both at riverbends or river crossings. Dredging is quantified approximately at 84% of the net degradation between the observed bed surfaces of the years 2004 and 2018, which is also 18% of the erosional volume of the same period. The first 60 km in the second reach of the NRE downstream Isna Barrage and between RK (167) and RK (230) is going through a degradational phase due to the lack of fluvial input and an Adhoc operation and management of dredging. The release of river flow and Dam operation scheme should take the transport of sediments and morphological changes along with the irrigation demands and navigation requirements.

REFERENCES

Deltares 2011. Delft3D–Flow, Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments, user manual, hydro-morphodynamics. Delft, Netherlands, 185.

Gaweesh, A., and Meselhe, E., 2016. Evaluation of sediment diversion design attributes and their impact on the capture efficiency. *Journal of Hydraulic Engineering*, 142(5), 04016002.

Stanley, J.D. and Clemente, P.L., 2017. Increased Land Subsidence and Sea-Level Rise are Submerging Egypt's Nile Delta Coastal Margin. *The Geological Society of America* (GSA Today) Volume No. 27, Issue No. 15.

Van Rijn, L. C. 1984a. Sediment transport. Part I: Bed load transport. *Journal of Hydraulic Engineering*, 10.1061/(ASCE)0733-9429(1984)110:10(1431), 1431–1456.

Van Rijn, L. C. 1984b. Sediment transport. Part II: Suspended load transport. *Journal of Hydraulic Engineering*, 10.1061/(ASCE)0733-9429(1984)110: 11(1613), 1613–1641.