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Predicting morphological changes DS New Naga-Hammadi Barrage for extreme Nile flood flows: A Monte Carlo analysis

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A B S T R A C T

While construction of the Aswan High Dam (AHD) has stopped concurrent flooding events, River Nile is still subject to low intensity flood waves resulting from controlled release of water from the dam reservoir. Analysis of flow released from New Naga-Hammadi Barrage, which is located at 3460 km downstream AHD indicated an increase in magnitude of flood released from the barrage in the past 10 years. A 2D numerical mobile bed model is utilized to investigate the possible morphological changes in the downstream of Naga-Hammadi Barrage from possible higher flood releases. Monte Carlo simulation analyses (MCS) is applied to the deterministic results of the 2D model to account for and assess the uncertainty of sediment parameters and formulations in addition to sacristy of field measurements. Results showed that the predicted volume of erosion yielded the highest uncertainty and variation from deterministic run, while navigation velocity yielded the least uncertainty. Furthermore, the error budget method is used to rank various sediment parameters for their contribution in the total prediction uncertainty. It is found that the suspended sediment contributed to output uncertainty more than other sediment parameters followed by bed load with 10% less order of magnitude.

Introduction

The Nile drainage basin represents the longest route of sediment transport on the earth as it extends to 6671 km with more than 1500 km in Egypt. The estimate value of total sediment load carried by the river in Egypt is in the range of 10–100 kg/s. The construction of Aswan High Dam secured Egypt with an annual supply of 55.5×10^9 m^3 of water, controlled the maximum flow to 2900 m^3/s compared to 8100 m^3/s, and reduced the suspended sediment from 129 million tonnes/year to less than 2.27 million tonnes/year; both measured at Gaafra Station 34 km downstream Aswan (http://en.wikipedia.org/wiki/Nile). While building the Aswan High Dam (AHD) has stopped concurrent flooding events, River Nile is still subject to lower intensity flood waves resulting from controlled release of water from dam reservoir. This is due to increase in water

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level in Lake Nasser behind AHD and navigation requirements to increase water level in the upper delta reaches (the Delta is approximately 240 km wide and 160 km in length). Such controlled releases of flood waves are taken into consideration in design of river banks and major control structures on River Nile. However, there is insufficient data concerning the morphological changes imposed by such releases on river reaches adjacent to major control structures, such as barrages. Since water level upstream of a barrage is always maintained at a fixed level despite the flow passing, the downstream reaches are the most vulnerable to such imposed changes. Mobile bed modeling has been widely used for hydraulic and morphological assessment of real world hydraulic projects in natural rivers with high confidence. This included 2-D depth averaged models [1–10] among others. While they provide significant accuracy and CPU time saving over 3-D models, enabling simulation over significant period of prototype time and domain length, they may have limited applicability on studying mobile bed processes in river bends and around their associated training works, where secondary currents are an essential part for the process of sediment and flow interaction and hydraulics. This led to the development of various corrections for three-dimensional effects to be used in 2-D models [6,7,11]. Despite being the longest River in the world with longest route of sediment transport, River Nile has not received much amount of mobile bed hydraulic research and modeling especially in reaches at vicinity of important hydraulic structures. For instance, the morphological changes due to sediment and flow interaction in the downstream reaches of barrages are never addressed in design for new barrage despite being very important. They have shown to have profound effects on downstream bed topography, navigation, water levels and thus heading up on barrage and nearby ground water levels. While flow sediment models predict geomorphic changes in river beds, they provide no assessments of the reliability of the output. The assessment of model uncertainty is desirable to gauge the reliability and precisions in model predictions and to weigh outputs used in combination with field sample estimates [12].

One of the easiest and most efficient ways to assess model output uncertainty is the Monte Carlo technique. With the increase in computation power, the long computational time associated with this technique has diminished enabling straight forward and easy implementation. The Monte Carlo analysis was applied to assess the uncertainty of input parameters on the output decision on the rehabilitation of a sewer system based on a single computation of CSO volumes using a single storm [13]. The Monte Carlo analysis to assess the uncertainties in estimates of gully's contribution of suspended load to catchment streams [14]. Monte Carlo analysis was applied to quantify the uncertainty due to the hydraulic roughness predictor for the river bed and assess the effects on modeled water levels under design conditions [15]. To carry out the Monte Carlo analysis, the probability density function (PDF) of the input model parameters must be known. The PDF of model input parameters can be estimated by fitting experimental data, e.g. the PDF of 14 morphological parameters were estimated based on published data [16] and the PDF of 3 dam breach parameters were also estimated based on measured dam failure cases [17]. In combination with Monte Carlo simulation, the multiple linear regressions can be used to rank parameters for uncertainty. This analysis estimates the uncertainty contribution of all parameters to overall output uncertainty. This method is called the error budget [12,18,19].

This paper aims to address the uncertainty associated with using a 2D mobile model in predicting the morphological changes at the downstream reach of a major barrage in Egypt; Naga-Hammadi Barrage, due to probable releases of controlled floods from AHD. This study is intended to show the important role of uncertainty analysis associated with 2D flow and sediment modeling as a tool to help control future flood releases from AHD and in design of new barrages such as new Assuit Barrage, which will be constructed 185Km downstream Naga-Hammadi Barrage.

New Naga-Hammadi Barrage

Background

There are several hydraulic structures controlling flow along the river from Aswan to Delta Barrage. These are Old Aswan Dam, Esna Barrage, Naga-Hammadi Barrage, Assiut Barrage, Delta Barrages, Zefta Barrage, and finally near to the Mediterranean; Edifna and Damitta Barrages. They divide the River Nile from Aswan to Mediterranean Sea into four reaches, between each two consecutive structures (Fig. 1a). Naga-Hammadi Barrage is considered the biggest and most important structure on River Nile located at KM359.5 in the middle of 192 km and 167 km reaches. The old Barrage has been constructed in the early 1920s 12 km north to Naga-Hammadi city in lower Egypt. The main role of this Barrage was to raise water levels in upstream reach to efficiently deliver irrigation water to more than 52,310 km^2 through two major canals in addition to six water lifting stations, raising water levels in the upstream to improve river navigation and decrease energy required to lift water for irrigation and potable uses.

On the year 1997, Lahmeyer International was assigned by the Egyptian Government to prepare a thorough study for upgrading the old barrage to accommodate the increase in the cultivated land by 20–30% including new reclaimed lands in addition to constructing a new 64 MW power plant to make use of the discharges passing through. The Lahmeyer study found that it wouldn't be feasible to upgrade the current barrage and recommended constructing a new barrage 3.5 km downstream the old one including a navigation lock and a power plant. The study provided detailed information on the expected hydraulic, environmental and social impacts for constructing new barrage at the selected location on the upstream side of the Barrage; however no attention has been given to the downstream reach. This is despite the fact that shortly after the construction of the old barrage, erosion was experienced in the downstream leading to lowering of water levels and thus increased heading up on the barrage and a weir has been constructed as a temporary solution to this problem [20]. Within few years, the new barrages has been constructed and put to work based on the study recommendations and with no further investigations for possible morphological changes in the downstream reach. Discharge through Naga-Hammadi Barrage is annually determined and depends on the water level behind AHD and water requirements; is maximum during summer (July–August), and minimum during winter (December–February). The average discharge in the downstream is 2170 m^3/s, and 1200 m^3/s during summer and winter seasons respec-