DEVELOPMENT OF DECISION SUPPORT SYSTEM (DSS) FOR HIGH ASWAN DAM RESERVOIR SEDIMENTATION

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ABSTRACT

High Aswan Dam Reservoir (knowing Lake Nasser), is the main water supply source in Egypt. Accelerated the land use and human activates in the headwater watersheds within the Nile basin; especially in Ethiopian plateau leads to increase the eroded soil and consequently increase the sedimentation in the reservoir. There is a need to identify current and future sedimentation in the reservoir. The main objective of current research is to develop a GIS-based decision support system (DSS) that can be used to analyze the effect of sediment delivery on the sustainable development of the reservoir. In addition, the decision support system (DSS) can help to evaluate present sediment deposition trends, and identify areas for future monitoring needs. The developed decision support system (DSS) is using sediment modeling techniques with geographic information systems (GIS) to create base flow and sedimentation maps in the reservoir as a function of time and space. The two dimensional hydrodynamic and sediment transport model is used to evaluate the effects of various scenarios of the natural inflow of the Nile River on the sedimentation progress in the reservoir. The decision support system (DSS) ensures faster and economic means for quantify and located the sediment deposition in the reservoir. It is also designed to help the decision makers and agencies in making watershed management planning within the Nile Basin.

Keywords: High Aswan Dam Reservoir, Geographical Information Systems (GIS), Sediment Deposition, Decision Support System (DSS), Numerical Models.

INTRODUCTION

The River Nile is the second longest river in the world, starting at its remotest headstream, the Luvirona River in Burundi, Central Africa, and to its delta on the Mediterranean Sea in northeast of Egypt. Most sediment carried by water from the watersheds within the Nile basin is received by the river during the flood season, and originates from the Ethiopian Plateau. Due to the construction of High Aswan Dam (HAD) (1964-1968), it was estimated more than 134 million tons per year [Sha-
lash, 1980] were deposited annually in the reservoir decreasing its storage capacity. From the comparison of the reservoir volume from the year 1964 (original volume) until year 2003, It was estimated that more than 5.2 Milliards tons of sediment deposit in the reservoir [NRI, 2003].

Therefore the monitoring and the prediction of deposited sediment in High Aswan Dam Reservoir (HADR) are essential to estimate the life time of the reservoir. Current trend towards a more efficient management of reservoir sedimentation using the application of numerical models and the Geographical Information system (GIS). Decision Support Systems (DSS) are a combination of advanced engineering models, analysis techniques, complex data, Geographic Information Systems (GIS), and graphical user interfaces. The DSS can combine spatial data for elevation, land-use, agriculture data, evaporation rates, climate data etc., as well as multi criteria, optimization, habitat analysis, groundwater, and/or surface water models into one system. These DSS computer systems make available to the user large quantities of current spatial data, taking a comprehensive and interdisciplinary approach to water and natural resource management.

In this research, the Decision Support System (DSS) was developed to analysis the present sedimentation in the High Aswan Dam Reservoir, quantify the deposition trends, and identify areas for future monitoring needs. The DSS was designed by incorporating a general database using MS-Excel, and other database software, two dimensional models, and has linked it to GIS software. The numerical model is used to simulate the current situation in the reservoir and predict the sedimentation deposition in the reservoir under various scenarios of floods into reservoir. Multi dimensional hydrodynamic modeling requires extensive display and analysis of spatial data. So that the Geographic Information System (GIS) is used as effective tools for sorting, managing, and displaying the types of spatial data often used in water modeling analysis. The graphical, statistical, and database capabilities of the GIS provide powerful tools for the analysis of model data and results. The GIS was used to develop a computational grid by using data topographic maps, data base digital data, and bathymetric data. The GIS also is being used to display model results, including bed elevation, water surface elevation, velocity magnitude contours, and velocity vectors. The ability to select among various combinations of data layers for display and analysis is one of the strengths of GIS application to hydrodynamic modeling. Further benefits can be gained by using the GIS as a database for water quality and biological data collected and analyzed in connect with the hydrodynamic data.

OBJECTIVES

The aims of this research are:
• Development a link between numerical model and the Geographic Information System (GIS) to develop base flow map for hydrological and morpho-
logical changes with time (velocity, water surface, water depth, bed elevation changes, and suspended sediment distribution).

♦ Formulation of the Decision Support System (DSS) to help the decision-makers in the strategic planning, operation control of sediment in the reservoir.

♦ Application of the DSS for simulation of the current and future sediment distribution in the reservoir for different scenarios of high and low floods.

STUDY AREA

The High Aswan Dam Reservoir is the one of the largest artificial lake in the world, extending from the southern part of Egypt to the northern part of Sudan, about 500 km length. It extends about 350 km in Egypt and almost 150 km farther upstream in Sudan as shown in figure (1). The reservoir was created after the construction of the High Aswan Dam (1964-1968) closing the Nile River at a distance of 6.5 km upstream of the old Aswan Dam, about 950 km south of Cairo. The reservoir width depends on the water levels, however the average width of the reservoir is about 12 Km. The water levels are oscillating between 152 to 182 meters over the sea level. The storage capacity of the reservoir has a volume of 162 km³ divided into three zones: dead storage capacity of 31.6 km³ between levels 85 m and 147 m, live storage capacity of 90.7 km³ from level 147 m to 175 m, and flood protection capacity of 39.7 km³ ranging between levels 175 m and 182 m, the maximum level of the reservoir.
In this research, it was chosen the reach from km 500 to km 350 upstream High Aswan Dam with a total length of 150 km which represents the area with the most intensive sediment deposition as shown in figure (2), which describes the longitudinal section of the lowest bed elevations of the reservoir from year 1964 to 2003. It is observed that the thickness of the deposition layer may be more than 60 meters within the last 40 years at the entrance of the reservoir.

**METHODOLOGY**

**Formulation of the Decision Support System DSS**

The developed decision support system (DSS) is a knowledge-based computer program that integrates and analyses data such as hydrologic, hydraulic, morphologic data and the results of using an appropriate numerical models. The motivation of Decision Support System (DSS) is helping the decision-makers to understand the natural and causes of the sedimentation problem that may occur in the reservoir. A simple classification is adopted for technical components of DSS, as follows:

1- Information system including relational database
2- Mathematical models.
3- Geographic Information System (GIS).

In particular, the information system component provides for collecting, storing, retrieving and modifying required data. Mathematical models provide for analyzing the behavior of the morphological and hydraulic changes in the reservoir and pre-
dicting the expected sedimentation behavior to giving basic support to the decisions on the preferable options. Geographic Information System GIS is used to manage databases and linking to the models visualizes input data required and the models results.

The design of the DSS requires the following mean phases:

1. Analysis of the data information, knowledge and objectives needed by the decision makers and of the scenarios to be considered;
2. Selection of the appropriate procedures to be included in the DSS (such analysis of the behavior of the sediment deposition for the assessment of the alternatives) by choosing and linking the suitable mathematical models.
3. Design of the DSS links (including the choice of the links to databases and GIS).
4. Determine the disciplines and actors that are represented within the DSS.

Figure (3) shows the main design elements for the proposed DSS, which describes the interaction between the two main components the information system and the mathematical models. Also there are links between them and the disciplines for input, update and feedback the data; and with the actors which are responsible for decision making.

Fig. 3 The Design Element for Proposed Decision Support System DSS
Development of the Decision Support System DSS

This section describes in details the procedure of developing the Decision Support System DSS for the reservoir sedimentation by processing the flow and sediment models output results into the ArcView GIS. It consists of three primary steps:

- **Data Base Management System**

  Data collection is the basic cornerstone of the developed Decision Support System. There are different types of data formats were used in the present study that is the vector, raster, and image formats. Vector coverage represents features as points, lines and areas. Raster formats be relevant to data represented as cell that contains attributes about geographic area. The topographic and the bathymetric data which describes the geometry of High Aswan Dam Reservoir (HADR) were based on data obtained from contour maps, produced from the hydrographic survey of the reservoir provided by the Nile Research institute (NRI, 1973-2003). The channel geometry presented by Easting, Northing, and Elevation (E, N, and Z).

  The coordinates of data were referenced to the WGS84 ellipsoid with Universal Transverse Mercator (UTM) Projection. It was selected the bathymetry survey of years 1999, 2001, and 2003 for the reservoir bed between the cross section number (25) at Km 352 and the cross section number (23) Km 487 upstream High Aswan Dam which contain the major sediment deposition. The satellite images LandSat for years 1987, 2000, 2001 were used for describe the areas that surround the reservoir.

  In addition to topographic data, the model requires hydrologic and hydraulic data such as stage and flow hydrographs, stream velocities, and rating curves. In this research, the records of discharges at Dongola station km 780 upstream High Aswan Dam are used as upstream boundary condition. The suspended sediment data available at Dongola Station for the period 1966-1982 were used to establish a rising and falling stage rating curves for the High Aswan Dam Reservoir allowing for seasonal effects relating to the rising and falling stages [El-Moatasem, et. al.,(1988); Makary et. al, (1982)]. In addition, the water level hydrograph upstream High Aswan Dam was used as the downstream boundary condition for the study area. Also, these data were located in the study area with referenced global coordinates systems for easy importing to the models and Geographic information System GIS.

- **Mathematical Models**

  The developed DSS is using two-dimensional hydraulic and sediment modeling techniques along with geographic information systems (GIS) to simulate flow and sediment transport in the reservoir. In this study, it was used two-dimensional hydraulic modeling (TABS-MD model) is due to the model’s ability to run on a desktop with the Surface-Water Modeling System (SMS) software (BYUEMRL, 2002). The SMS software provides valuable tools for mesh generation, data interpolation, and
graphical visualization. The SMS program was developed by Brigham Young University (BYU) in cooperation with USACE-WES. The modules (RMA2 and SED2D) of the TABS-MD were used in this study as shown in figure (4). The RMA2 hydrodynamic model solves the depth averaged two-dimensional equations of continuity and momentum transport (Donnell et al., 2000) As a result of the simulation, RMA2 produces water depth and velocity at each time step. Water depths and velocity fields produced by the RMA2 were then used by the SED2D model. The models were used for calculating water depths, water surface elevations, bed changes, erosion and deposition rates and averaged water velocities within the area of interest and under different scenarios of flow conditions chosen for the present and for future.

In order to move into the GIS environment, the model run results must be extracted as a text files. These files contains input data describing the geometry of the reservoir within the area of study, water level and flow rates, the output data describing computed water surface elevations, velocity vectors, bed changes and erosion and deposition rates in the modeled reach. These files transform from text file format into a tabular format readable and stored by ArcView GIS environment.

![Flowchart of the Numerical models](image-url)
Geographic Information Systems (GIS)

ArcView software GIS were used in development of Decision Support System, ArcView is a widely used commercial software product that contains modules for interfacing models. The GIS was used to develop a computational grid for the studying area of the reservoir using bathometric data as shown in figure (5a). After importing the model output data into ArcView, it is necessary to link these data to digital representation of the reservoir in ArcView. It is easy to perform and usually puts the data directly into a format that the GIS software package being used can process with little or no conversion. The approach is based on assigning map coordinates to stream bed elevations and computed water surface profile, velocity vector and erosion and deposition rates data stored in the model coordinates to achieve the final mapping production for the decision makers needs. The ability to select among various combinations of data layers for display and analysis is one of the strengths of GIS application to hydrodynamic and sediment modeling.

APPLICATIONS OF DECISION SUPPORT SYSTEM (DSS)

The DSS procedures for the automation of mapping based on hydraulic and sediment modeling outputs with the associated of menu items in ArcView. The DSS was used to create the bed elevation map for the reservoir as shown in figure (5b) which used as input for the numerical model. Also, it was used to predict the distribution of the suspended sediment within the area of study during the high flood period as shown in figure (5c).
The DSS user also can map water surfaces, velocity vectors, bed changes, and erosion and deposition rates as a function of time and space. In this research, the DSS applied for prediction the velocity, the suspend sediment concentration, water depths, and bed changes rates as a function of time and space for the different 12 locations along the area of study in the High Aswan Dam Reservoir (HADR) as shown in figure 6, for the complete water year for the Nile River (start from August 2000 to July 2001).

In addition, the DSS for the High Aswan Dam reservoir was applied for prediction the sediment deposition thickness for two different scenarios of floods. The first scenario supposes that there are 7 years of high floods will go into the reservoir, and the second scenario assumes that there are another 5 years of low water floods enter the reservoir. The DSS for the reservoir estimate the water discharges, and corre-
sponding suspended sediment concentration for the two scenarios as shown in figure (7).

The hydraulic and sediment models were applied to predict the sediment deposition for the two scenarios. The model results were imported to the GIS, and then the sediment deposition thickness was predicted for the 12 locations along the reservoir as shown in figure (8).

![Typical Discharge and Sediment Concentration at Dongola Station for Low and High Flood](image)

Fig. 7 Typical of the discharge and suspend sediment concentration curves for proposed high and low floods.

![Deposition Thickness for the Prediction Period in the High Aswan Dam Reservoir (HADR)](image)

Fig. 8 Predicted the Sediment Deposition Thickness for the 12 locations in Reservoir for proposed high and low floods.
CONCLUSIONS

The Decision Support System (DSS) has been developed for the simulation and prediction the sediment deposition in the High Aswan Dam Reservoir (HADR) by developed a link between two dimensional hydraulic and sediment model and the Geographic Information System (GIS) to create base flow map for hydrological and morphological changes with time in the reservoir. The DSS was used the spatial data that are being "mapped" such as bed surface elevations, physical features, bathymetry and temporal data depicting seasonal changes with time such as (velocity, water surface elevations, water depth, bed elevation changes, suspended sediment concentration, and the deposition thickness) using GIS tools. The potential applications for the DSS were presented. The DSS was used to simulate of the current and future sediment deposition distribution in the reservoir for different scenarios of high and low floods.

By building a DSS framework for this research, it will meet many needs of policy-makers and resource managers by providing mapping capability using common digital database for information, a suite of spatial analysis tools, display of predictive models results, and basis for sedimentation management alternatives. The system would provide and display the integration of hydraulic and morphological changes, within the area of interest into themes so that decisions could be made on the best available information. The DSS will provide a variety of digital and paper products. Application of the DSS reduces the analysis time and improves accuracy by integrating spatial stream geometry with hydraulic analysis.

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