A GIS Application for Floodplain Mapping and Hydraulic Modeling

BY
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ABSTRACT:

River hydraulics, hydrology and floodplain mapping are the key issues of interests of an organization managing a river. In this paper, we investigate an application for floodplain mapping and river hydraulic modeling in connection with GIS data. Digital terrain data of a reach of the river Nile has been modeled in a Geographic Information System (GIS) desktop software and it was hydraulically analyzed in hydraulic modeling software after completing all necessary flow data and boundary conditions. We show different steps for building geometry data for a hydraulic model in a GIS software, as well as analysis procedures that can be performed by the model.

The method explained in this research depends on interchanging GIS data between a hydraulic model and GIS software and is considered as a semi automatic method for river hydraulic modeling. The method is enabling higher accuracy for river hydraulic modeling as well as it saves time of inserting geometry data into the model. Results of this research are water surface profiles due to different water discharges and flood events.

INTRODUCTION:

River Hydraulics and floodplain mapping are the main two key issues of an organization managing a river. New methods and cost effective techniques for better management of the river are always needed. Since a few decades ago, scientists are working to develop models for modeling hydraulics and hydrology of rivers. These models were developed in a form of user interfaces and software in order to allow engineers to use them and to analyze flow data about rivers.

Since the past decade there is a tendency to automate the process of hydraulic and hydrology modeling for rivers. Accordingly, geometry data needed by models software are the key issue to ensure higher accuracy. The latest GIS technologies allow users to virtually represent earth's features and to develop attributes for these features in a form of databases. Several methods are expressing the exchange of data among hydraulic and/or hydrology models and GIS software. These methods are graduating according to the level of automation of data exchange between a GIS and the model. The integration of a GIS with floodplain computer models allows users to be more productive. Integrated models enable users to devote more time to understanding flooding problems and less time to the mechanical tasks of preparing input data and interpreting the output (Shamsi, S., 2002).

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Now a days some institutions are working to develop complete GIS solutions for their tasks. These solutions are depending mostly on geoinformation technologies and developments in the geographic information systems science. The main idea is to automatically update hydraulic models as long as the GIS have been changed.

In this research, an application of GIS for floodplain mapping and hydraulic modeling is presented. It is assumed to study all data and step procedures needed to implement hydraulic modeling using GIS data. The method implements a data exchange between a desktop ArcView GIS and a 1D hydraulic model for river analysis - Hydraulic Engineering Center- River Analysis System (HEC-RAS). HEC-GeoRAS ArcView extension has been used to develop geometry data needed for the analysis. Flow data and other boundary conditions data were completed in HEC-RAS. Furthermore, some scenarios and simulations for water surface levels according to different flood events are presented.

STUDY AREA:

For performing necessary analysis and investigations of this study, a reach of the river Nile in Cairo was chosen. The reach is located at the area between Lat: (29° 58´ – 30° 06´) N and Long: (31° 12´ – 31° 15´) E at the center of Cairo city. And it is extended south from Daheb Island to Zamalek Island at North. Figure (1) shows the area of study.

The reach was hydrographically surveyed by the Nile Research Institute during the time 09.11.2004 and 12.11.2004 and these included the bathymetric survey with echo sounders and accurate positioning with Differential Global Positioning Systems (DGPS) techniques, water discharges and flow velocity measurements during the survey mission, sediments samples for the banks and the river bed, and some spot heights measurements for the banks. The flow discharges and water levels database of the area were also available at Nile Research Institute and they were used as an input data for different simulation procedures.

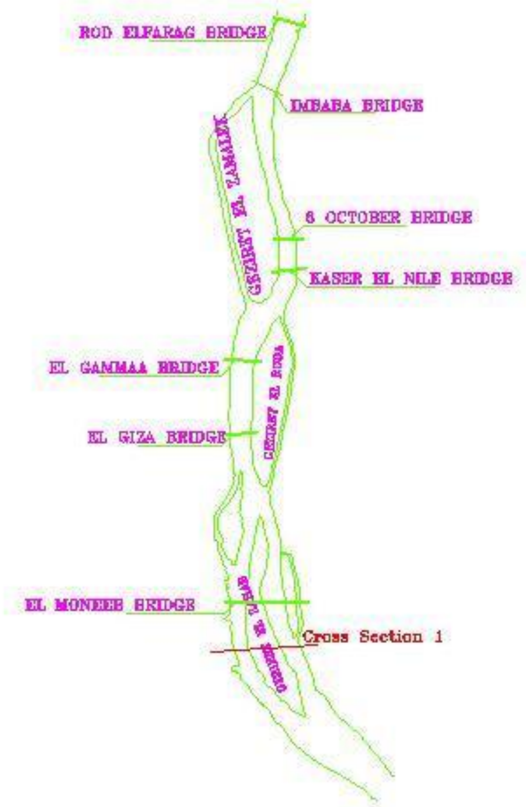

Figure 1, the Study Area in River Nile Region

GEOMETRY DATA PREPARATION:

The role of the GIS in this step was to create georeferenced geometry data that can be exported and read by the hydraulic model. This step has been implemented through an ArcView extension HEC-GeoRAS developed in the Avenue programming language. HEC-GeoRAS extension enables creating a RAS GIS import file consists of geometric attribute data necessary to perform hydraulic computations in HEC-RAS. Input geometry data needed by HEC-RAS and that can be developed in the GIS are; Digital Terrain Model for the area to be modeled, bed contours of the river, stream center line, main channel banks, flow path center lines, cross sections, land use and corresponding Manning's coefficients, ineffective flow areas, storage areas and bridges geometry.

HEC-GeoRAS requires information about topography in order to create the Triangular Irregular Network (TIN) file. These heights information have been gotten from the hydrographic survey data of the river bed at study area between Roda and Kasr El-Nile Bridge and heights for the floodplain area have been extracted from old topographic and contour maps of scales 1:10,000 and 1:5000 respectively. All other geometric data will be drawn in the 2D window of the study area and it will extract its heights and dimension attributes from the TIN file of the area that we created previously. In the next step a theme was created for the contour lines from the TIN theme. Contour lines will help visualizing the study area.

The area has been represented as a one reach by the center line theme and it was given a river name and a reach representative name. The area has been modeled in different themes and each theme is representing a geometric feature of the reach. The stream center line was drawn from upstream end to the downstream end following the channel thalweg. The tool also allows creating a river network of many reaches in case of many reaches or additional tributaries are to be modeled. The main channel banks theme draws the main channel flow in the over banks. Cross sectional bank stations were assigned based on the intersection among the cross sections and the channel banks. The Flow Paths were represented in the Flow Path centerlines theme and they are identifying the hydraulic flow path of the left overbank, main channel, and the right overbank respectively by identifying the center of mass of flow. Down stream cross sectional intervals are usually calculated along the flow path centerlines.

Cross Sections that to be exported into HEC-RAS were drawn perpendicular to the direction of the flow at some places representing the reach. There is also a possibility for cross sections to take its heights from the TIN file. Figure (2) shows a cross section plot in ArcView. The extracted cross section is marked in the plan of the area in Figure (1).

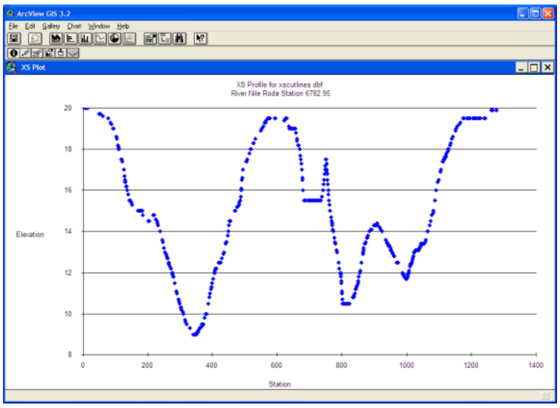

Figure 2, a Cross Section Extraction from TIN

A polygon theme was created to estimate the Manning's values along each cut line. Land use theme was created from old maps available for the area and Manning's values corresponding to different land uses were taken from HEC-RAS hydraulic reference manual. Themes data base are designed to be updated automatically once a step is being finished and they create attributes for the features they are representing. These procedures gave a clear indication for the attributes to be included in each data base for river hydraulic modeling.

A typical GIS for a Water Utility will have more information than is necessary for a hydraulic model. A well-built GIS system can be easily translated to a hydraulic model. The modeler however needs to give some consideration as to which features and attributes will be brought in from the GIS into the model (Moolihan, M., 2004Finally, from old maps of the area, storage areas were digitized. Storage areas are needed to perform unsteady flow analysis as in this case. At this step, all digitizing steps for the RAS geometry data were completed, but before we can export an exchange file to the model, we must attribute all data that to be included in the geometry file, such as the geometric data for each cross section and distances among cross sections heads in the stream centerline and in the over banks. Moreover, the theme setup for the input data, new 3D data for cross sections and streamline, and the output geometry data file were fixed. As a next step, HEC-GeoRAS allows an automatic attributing for the data to be exported, such as stationing, bank stations, stream/reach name, stream lengths, etc...

GIS – MODEL DATA INTERFACE:

By properly completing the geometry data and attributing them, an export output file in a special exchange format could be exported from the GIS and imported by the model.

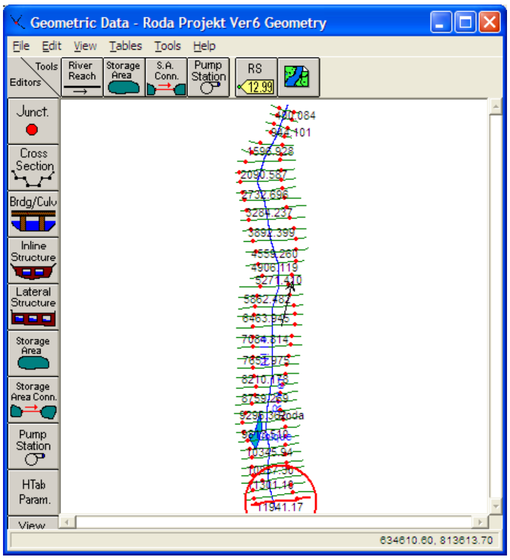

Figure (3) Geometry Schematic Diagram of the Study Area Imported from GIS

Geometric data will be extracted from the 3D files created from the RAS themes. Following this step, the geometry file for the Roda area was imported by HEC-RAS model and then necessary editing and corrections for the data were done. These corrections include filtering of unnecessary points from each cross section and minimizing the number of points of cross sections to 500 points when the number of points exceeds this number. Figure (3) shows the geometry layout of the study area and the schematic diagram of the geometry in HEC-RAS geometry editor after importing the GIS file.

In HEC-RAS and as a preparation for the unsteady flow analysis, the flow data and the boundary conditions should be completed. For the study area, flow data were the daily discharge at the upper stream cross section during the simulation period and the slope of the river bed at the down stream cross section. An initial condition for the discharge at the upper stream cross section was also inserted. Corresponding initial elevation for the storage area was inserted. HEC-RAS enables both unsteady flow analysis and steady flow analysis for a stream based on a fixed simulation time. In the HEC-RAS unsteady flow analysis window, a start date for the simulation and an end date were fixed. Other computation settings needed by the program, like a computation interval, a detailed output interval and a hydrograph output interval was also completed.

Then an unsteady flow analysis for the study reach was performed based on the actual flow data provided by the Nile Research Institute or observed by the survey mission. These flow data were actual data representing the current condition of the river Nile at this area. Results of the analysis were to be seen as water surface levels. Furthermore, an unsteady flow analysis was also performed against flood discharges, this was important in order to map floodplain due to flood discharges. Results of unsteady flow analysis could be exported from HEC-RAS as georeferenced geometry.

The interface method between the GIS and the model includes two steps; the first step is a pre-processor, which analyzes and exports the GIS data to create model input files and a post-processor, which imports the model output and displays it as a GIS layer. The interface method automates the interchange of data between the GIS and the model. This automation is accomplished within the GIS and through a user interface menu by the HEC-GeoRAS tool.

RESULTS ANALYSIS:

Results of the unsteady flow analysis can be seen directly in HEC-RAS through water surface profiles. Figures (4a) and (4b) show an example of longitudinal water surface profiles corresponding to the actual water level of discharge 103 million m^3/day at the day of survey and a flood water surface level of discharge 200 million m^3/day respectively.

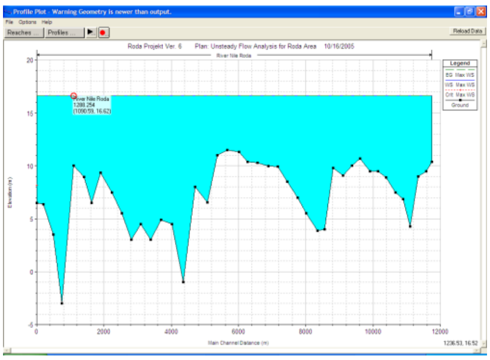

Figure (4a) A Longitudinal Cross Section after Unsteady Flow Simulation. (Discharge Q = 103 million m^3/day)

Water surface levels can be exported from HEC-RAS in a TIN format that can be read by the GIS software and accordingly we can map the floodplain in the GIS tool.

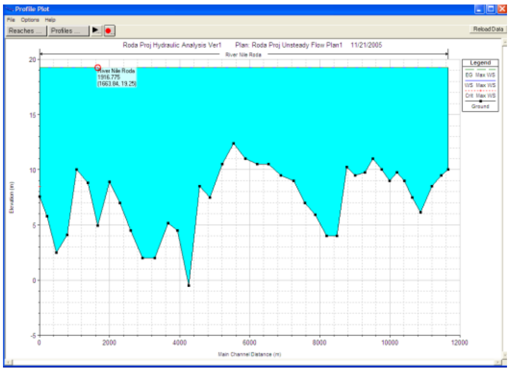

Figure (4b) A Longitudinal Cross Section after Unsteady Flow Simulation. (Discharge Q = 200 million m^3/day)

In figure (5) we can see the water surface levels corresponding to a discharge of 103 million m^3/day and 200 million m^3/day. A topographic map is set on the background in order to show the flooded area on the floodplain map. It can be seen that the banks of the river are covered by the water surface and accordingly we can estimate areas to be flooded due to different discharges.

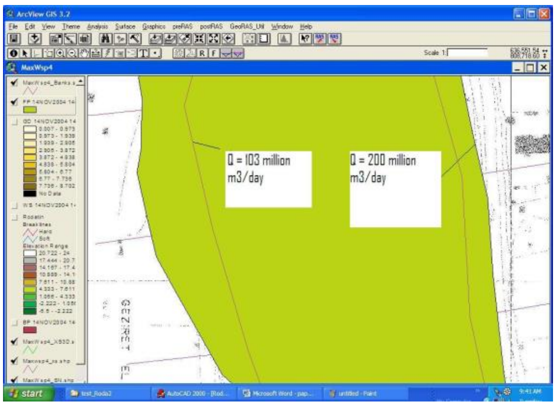

Figure (5) Water Surfaces TIN corresponding to Different Flood Events

CONCLUSIONS:

The method explained in this paper is a GIS based method in order to map floodplain and to perform river hydraulic modeling. The method interfaces between a GIS and a hydraulic model. It represents a semi automatic method to perform hydraulic modeling and at the same time it allows mapping of the results in a geographic information system. The method saves a lot of needed time for geometry data entry into a hydraulic model and it ensures better accuracy and automation for the process.

Throughout the work of this research we got an experience of necessary attributes needed by any database to be built for a river. This experience will be much useful when starting to build a geodatabase for the river as well as when others wants to access this database within the same institution or from outside. Through different steps of this research, a need for a complete automation of floodplain mapping and hydraulic modeling of the river Nile has been raised. This would not only enable fast and cost effective methods for the procedures that are currently used to perform these tasks, but also will enable an accurate performance for the river management, as well as wider spatial visibility for projects to be performed on the river Nile.

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