2D Hydraulic Model of Aswan High Dam Reservoir

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Abstract

The construction of the Aswan High Dam (AHD) in Upper Egypt, about 950 km South of Cairo, resulted in the formation of a reservoir that trapped almost all of the inflow and hence forms the second largest man made lake.

The water is discharged downstream the dam through 6 tunnels located at (147.00) m above sea level. Therefore, this level was considered as the critical water level for the turbines. There is a spillway on the western side used to release the water that exceeds the maximum storage capacity when the water level reaches more than (182.00) m level. Another, uncontrolled, spillway was constructed at the end of Khor Tushka (on the western side of Lake Nasser at about 256 km upstream the dam). This spillway is connected to Tushka depression by a canal by which the excess flood can be turned to the depression.

The length of AHD reservoir is about 500 km at its maximum storage level, which is (182.00) m. The reservoir has an average width of about 12 km and a surface area of 6540 km2. This reservoir is considered to be the second largest man-made lake in the world, where the storage capacity of the reservoir has a volume of 162 km^3 .

The present paper presents the results of a 2D simulation model of AHDR and the flood wave propagation through out the AHD reservoir. The modeling study aims to determine the optimal management policy for the reservoir in flood conditions by modeling the physical problem via a 2D routing model.

Introduction

Routing is a process used to predict the temporal and spatial variations of a flood hydrograph as it moves through a river reach or reservoir. The effects of storage and flow resistance within a river reach are reflected by changes in hydrograph shape and timing as the floodwave moves from upstream to downstream. In general, routing techniques may be classified into two categories: hydraulic routing, and hydrologic routing.

The hydrologic method is in general simpler but fails to give entirely satisfactory results in problems other than of determining the progress of a flood down a long river. But for example when a flood comes through a junction, backwater is usually produced and this can only be accurately evaluated by the basic hydraulic equations.

Hydraulic routing techniques are based on the solution of the partial differential equations of unsteady flow. Hydrologic routing employs the continuity equation and an analytical or an empirical relationship between storage within the reach and discharge at the outlet.

Actual transverse variations will differ so greatly from the assumed variation that stream wise values, determined from a one-dimensional study, will be in significant error. If flow velocities in floodplains are much less than that in the main channel, actual depths everywhere will be greater than those computed on the basis of uniform velocity distribution

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in the entire cross section. It is possible that the transverse variations will be of greater importance than the stream wise values. This is why a 2D model was used in this study due to the natural sophisticated lay out of the AHD reservoir.

Stanley S. Butler (1982) presented an alternate reservoir flood routing approach applicable for routing design floods determined from statistically derived design storms. The approach treated routing as an instantaneous discharge point-function process instead of an average discharge incremental time procedure, avoiding some of the difficulties and errors in the traditional methods but yet this method will lead to some errors in our case due to the lake sophisticated lay out and huge area. **Tawatchai Tingsanchali and Shyam K. Manandhar (1985)** developed an analytical diffusion model for flood routing; the basic diffusion equation is linearzed about an average depth and takes into account backwater effect and lateral flows. In our case there is no lateral inflow but rather an evaporation losses. **Francisco N. Correia et al. (1997)** used intergraph GIS as the basis for storing and overlaying information and for displaying results. Idrisi GIS, supported by a common PC, is used for running the hydrologic and the hydraulic models. The GIS was a powerful tool in our data preprocessing. **Bruno Molino, Michele Greco and John S. Rowan (2000)** applied a physically based two-dimensional model to the case-study site of Abbeystead Reservoir, U.K. The model, developed for density currents, solves the Navier-Stokes equation coupled to a general sediment transport equation. Although, this was a case study and has some limitations yet it can not be applied in our case. **Francisco N. Correia et al. (1998)** used Intergraph GIS coupled with Idrisi GIS substantially increased the flexibility of using GIS as a tool for flood studies. A lumped (XSRAIN) and a distributed (OMEGA) hydrologic models were used to simulate flood hydrographs. The well known HEC-2 Hydraulic model was used to compute flooded areas. These models were applied in the Livramento catchment with very good results. The computation of flooded areas for different flood scenarios, and its representation in GIS, can be used in the assessment of affected property and associated damages. This is a very useful GIS-based approach to floodplain management. In the study presented here a hydraulic model was used to obtain accurate result rather than hydrologic routing.

The Problem Definition

There have been several attempts to use combined simulation-optimization models to solve reservoirs operation problems efficiently. In many cases, complex simulation models are available, but direct incorporation of them into an optimization framework is computationally prohibitive.

The choice of a routing model is influenced by many factors, such as the required accuracy, the type and availability of data, the type of information desired (flow hydrographs, stages, velocities, etc.), and the familiarity and experience of the user with a given method. The modeler must take all of these factors into consideration when selecting an appropriate routing technique for a specific problem.

This study aims to develop a 2D hydraulic model to rout flood waves through the AHD reservoir, which will help the decisions makers in operating the AHD for the best benefit use of flood water in different branches of development.

Development of bathymetric charts for AHDR and building a geographical database for the reservoir were the first steps on the way of developing such model.

Methodology

Modeling a flood wave through out a huge reservoir with a sophisticated lay out such as the AHDR **(figure 1)** requires a finite element mesh of the bathymetry and the use of the finite difference form of the St. Venant equations in the hydraulic routing process to obtain acceptable results.

Figure 1: The Aswan High Dam Reservoir along with Toshka Depression

The cross sections profiles obtained from the Aswan High Dam Authority (AHDA) and the Nile Research Institute (NRI), **(figure 2),** were used along with the GPS coordinates of the sections head points in a Microsoft Excel spreadsheet to transform all the points into (E,N) coordinates with a known elevation Z.

The Geographic Information System (GIS) application has been recognised as a powerful tool to integrate and analyse data from various sources. In this work a digitized WGS84 geographical map for the area of Nasser Lake were used then projected along with the section points into the Universal Transverse Mercator grid Zone (36) (UTM36) using the Geographic Information System (GIS) software. These points were used to form a scatter mesh with defined projected coordinate system.

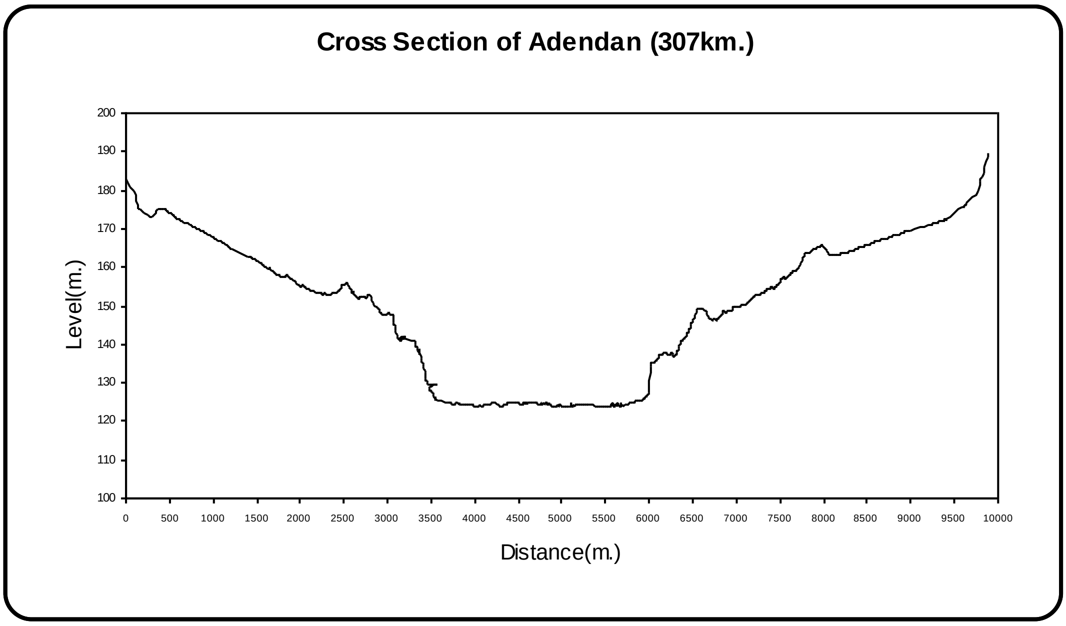

Figure 2: Cross section at Adenean (307 km US AHD)

With the aid RMA2 model under the SMS interface a TIN mesh, of the bathymetry, could be built using the data transferred from the GIS by means of interpolation using the cross sections profiles obtained from the NRI and the AHDA. The Longitudinal section of the reservoir **(figure 3)** was very useful to obtain a better result of the generated mesh.

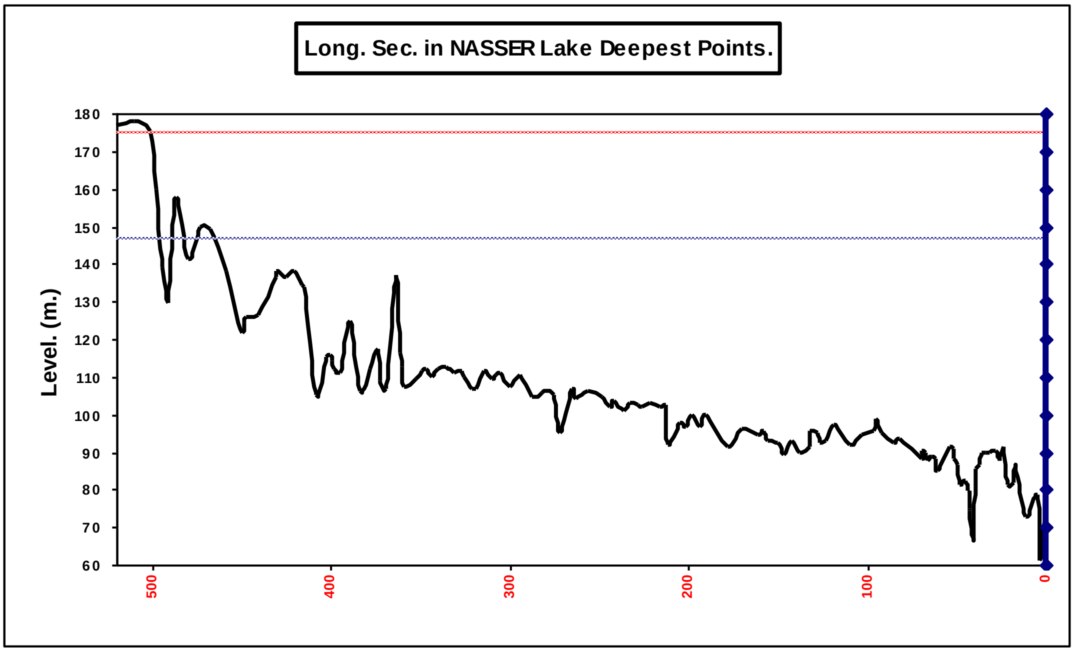

Figure 3: Longitudinal section of the AHD Reservoir

The system constraints are basically the dynamic conservation of mass within the 2D reservoir system, and the minimum and the maximum allowable limits for the water release and the reservoir level.

RMA2 is a general purpose model designed for far-field problems in which vertical accelerations are negligible and velocity vectors generally point in the same direction over the entire depth of the water column at any instant of time. It expects a vertically homogeneous fluid with a free surface. The program has been applied to calculate water levels and flow distribution in contracting and expanding reaches, circulation and transport in water bodies with wetlands; and general water levels and flow patterns in rivers, reservoirs, and estuaries.

The generalized computer program RMA2 solves the depth-integrated equations of fluid mass and momentum conservation in two horizontal directions by the finite element method using the Galerkin method of weighted residuals.

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left[E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right]+gh\left[\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right]+\frac{gun^2}{h^{1/3}}$$
$$+\sqrt{(u^2+v^2)}-\zeta V_a^2\cos\psi-2h\omega v\sin\phi=0$$

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left[E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right]+gh\left[\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right]+\frac{gvn^2}{h^{1/3}}$$
$$+\sqrt{(u^2+v^2)}-\zeta V_a^2\sin\psi+2h\omega v\cos\phi=0$$

Where;

h = Depth
u,v = Velocities in the Cartesian directions
x,y,t = Cartesian coordinates and time
ρ = Density of fluid
E = Eddy viscosity coefficient,
for xx = normal direction on x axis surface
for yy = normal direction on y axis surface
for xy and yx = shear direction on each surface
g = Acceleration due to gravity
a = Elevation of bottom
n = Manning's roughness n-value
z = Empirical wind shear coefficient
Va = Wind speed
ψ = Wind direction
ω = Rate of earth's angular rotation
φ = Local latitude

The shape functions are quadratic for velocity and linear for depth. Integration in space is performed by Gaussian integration. Derivatives in time are replaced by a nonlinear finite difference approximation.

The solution is fully implicit and the set of simultaneous equations is solved by Newton-Raphson non linear iteration. The computer code executes the solution by means of a front-type solver, which assembles a portion of the matrix and solves it before assembling the next portion of the matrix.

Discussion

In the beginning, the flow reaching AHD is greater than the released from AHD. By the end of September the water level will reach (178.00) m and the water begins discharging over Toshka spillway into the depression on the west side of the reservoir through Toshka canal.By the mid of October the water level in Aswan high dam reservoir will reach the level of (182.00) m. at this stage the discharge reaching AHD is greater than the flow releases from the dam.

There must be an increase in the current geometric dimensions of Toshka spillway to increase the discharge over it to keep the water level in AHD reservoir at (182.00) m **Soliman, Ali and El-Moustafa (2002)**.

The Obtained bathymetry mesh is a powerful tool needed in the modeling of the AHD reservoir, so it will be used in further work for the purpose of flood routing to obtain a solution for the reservoir management and the operation plans of the dam.

The results of the 2D hydraulic model shows the flood wave propagation in the reservoir. For an example a factitious flood pulse **(figure 4)** was used at the inlet and **figures (5 to 9)** show the changes to such wave in the downstream sections also **(figure 10)** shows the velocity vectors for such flood pulse near Khor Toshka.

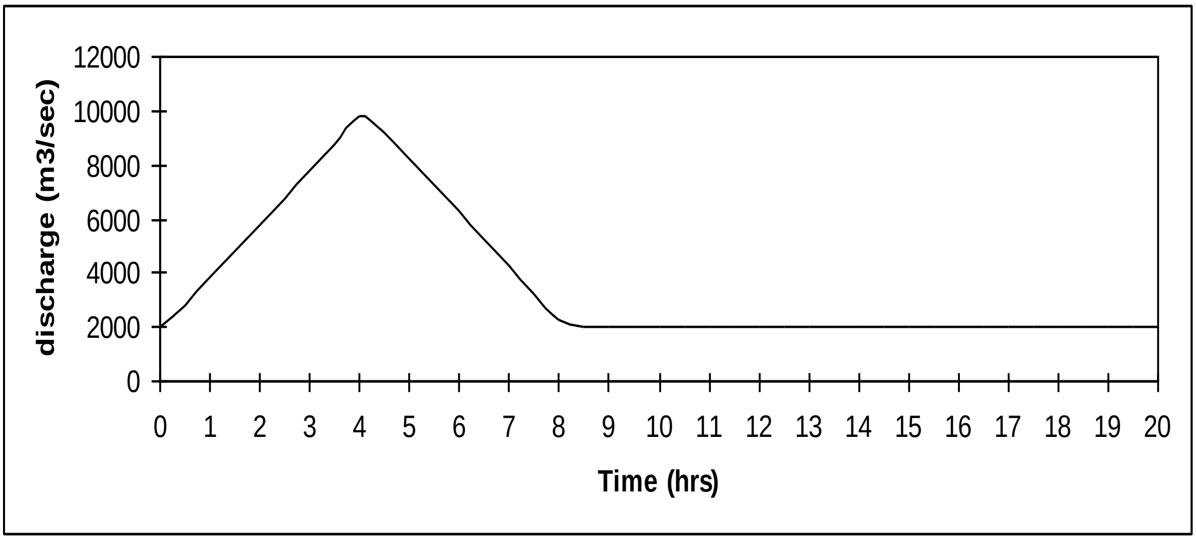

Figure 4: An Input Flood wave Pulse

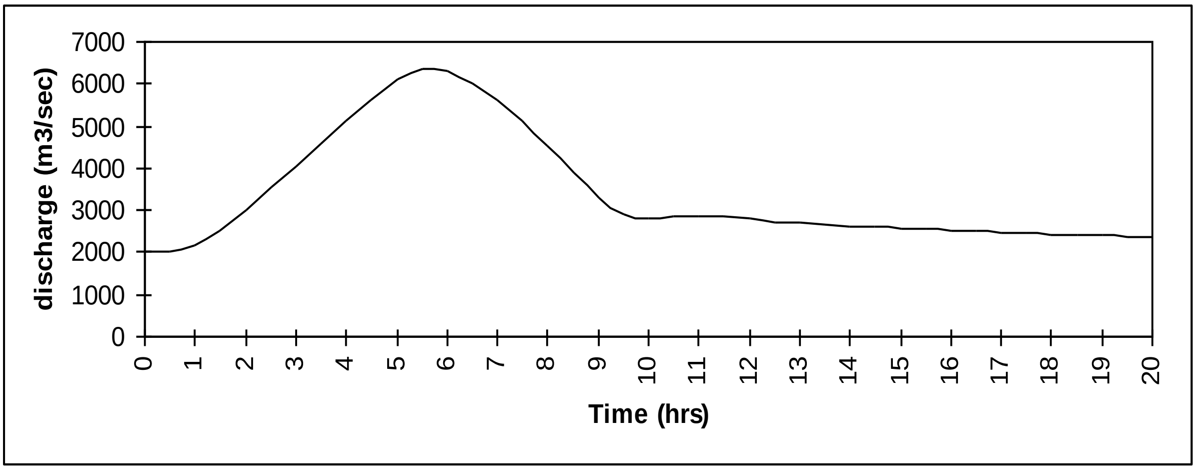

Figure 5: Hydrograph at section 5

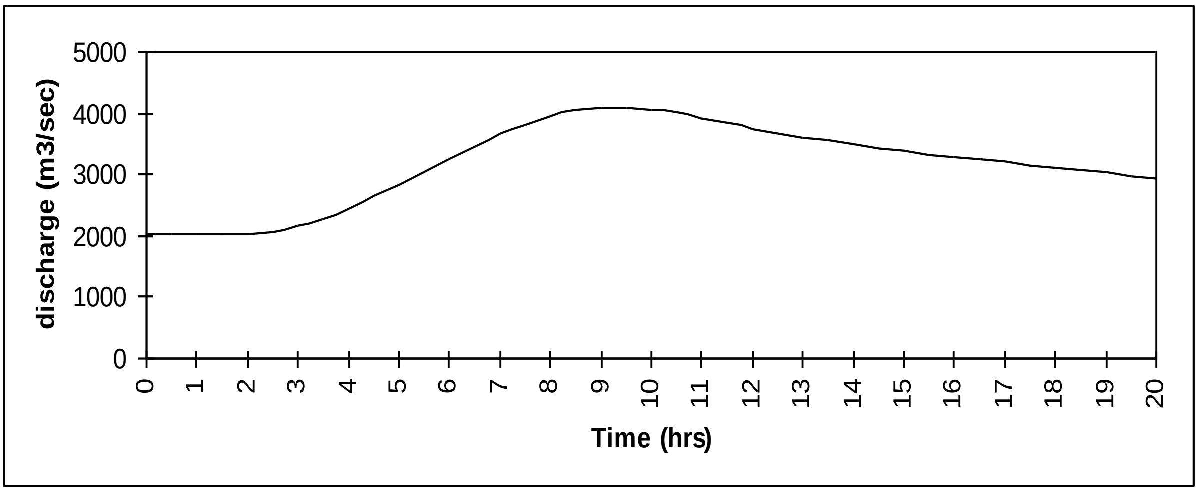

Figure 6: Hydrograph at sec 8

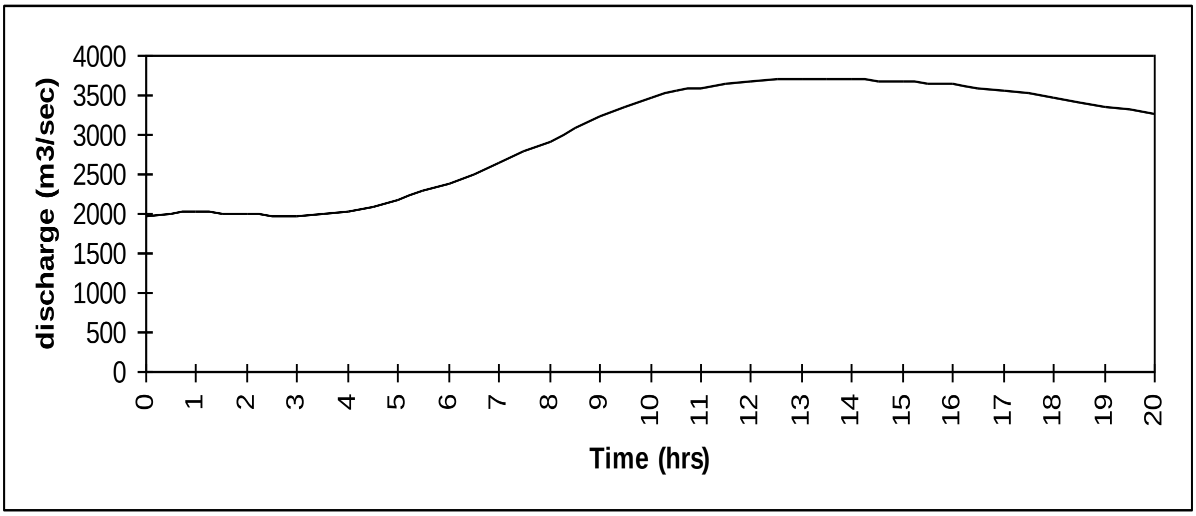

Figure 7: Hydrograph at section 10

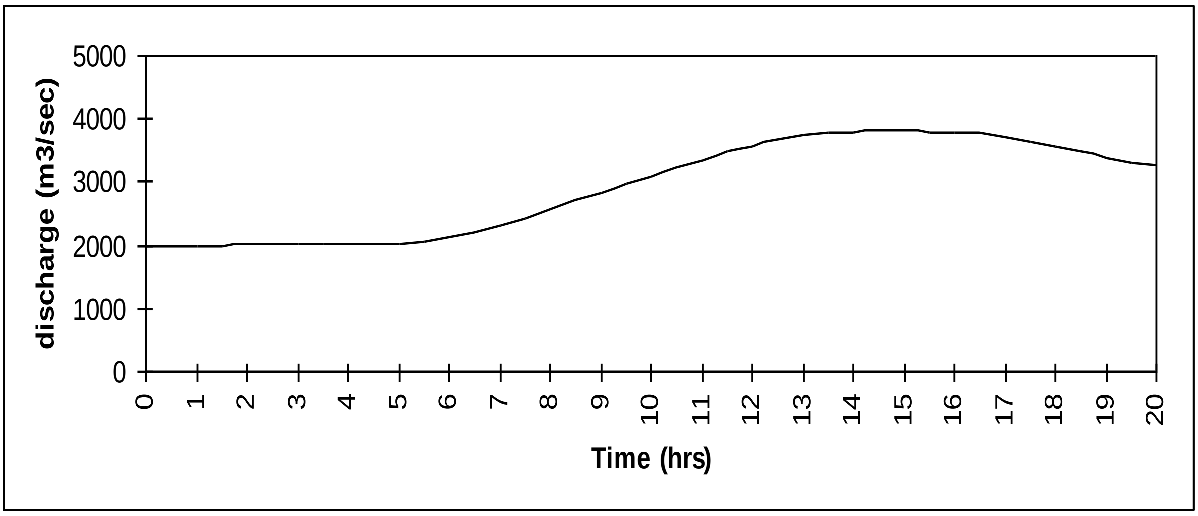

Figure 8: Hydrograph at section 11

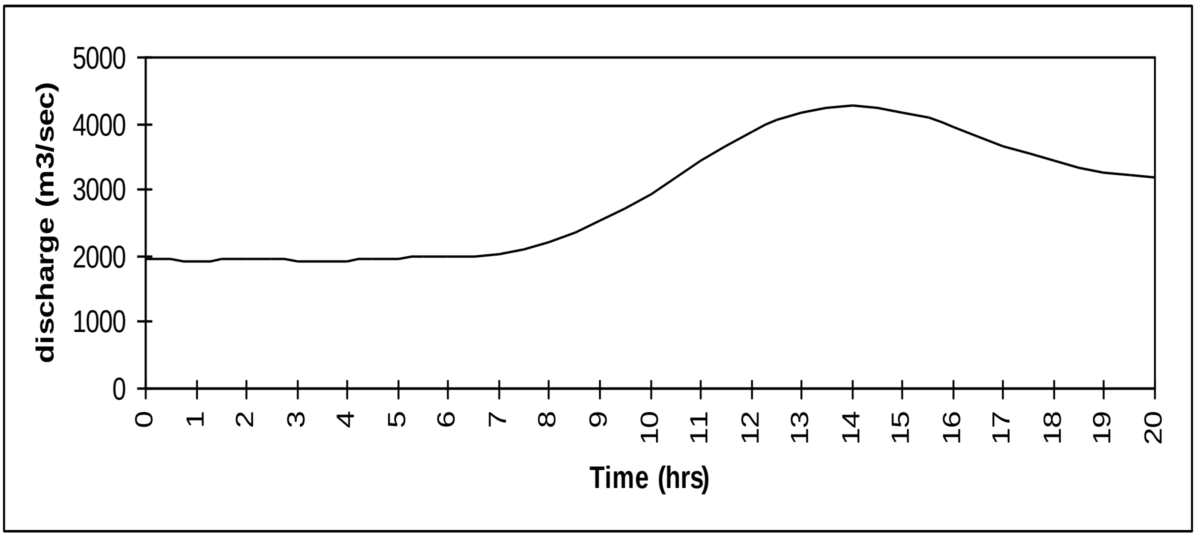

Figure 9: Hydrograph at AHD

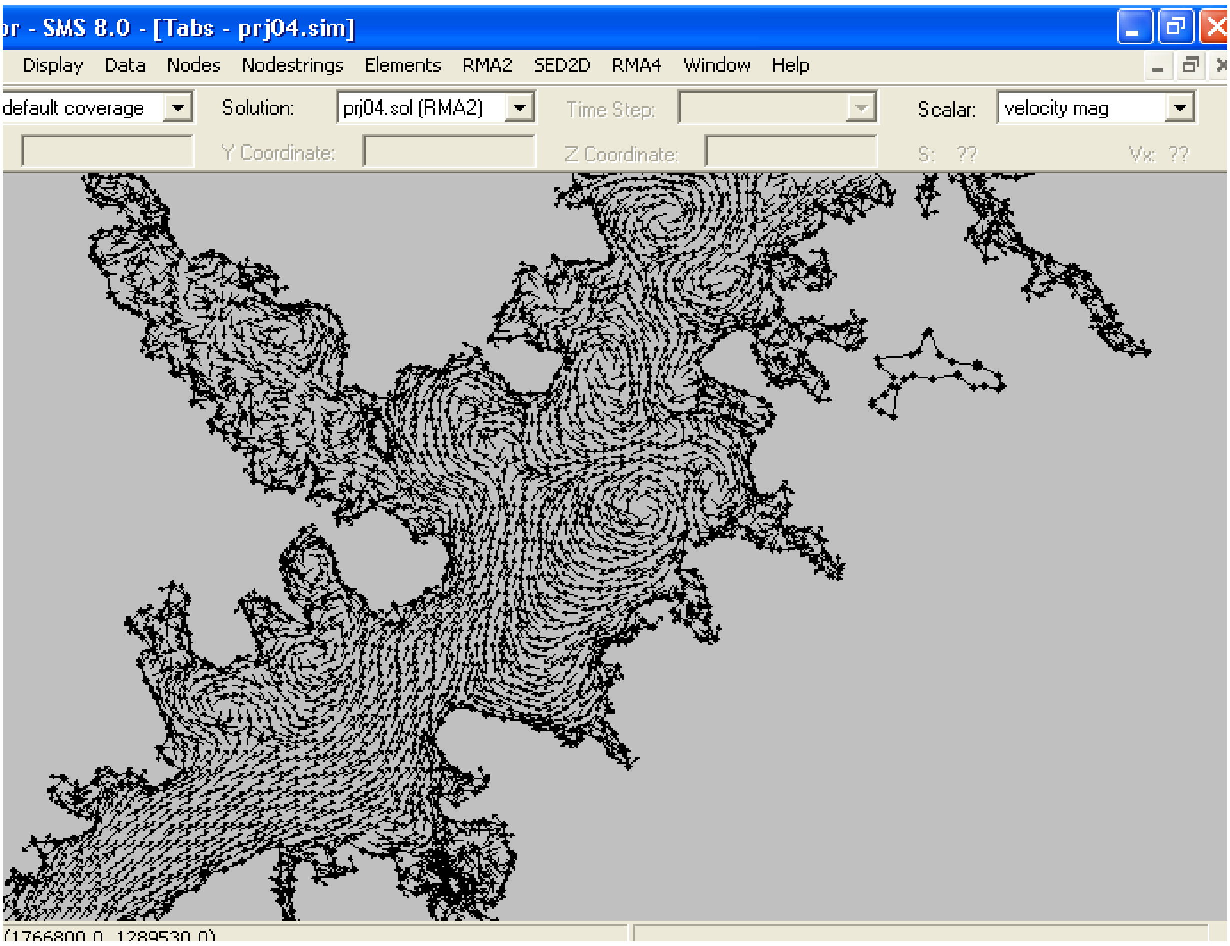

Figure 10: Resulted velocity vectors

Model verification and real case study results

When applying the maximum expected hydrograph from the first of July till the end of November at Dongola station **(figure 11)** on the model and taking into consideration the evaporation losses as calculated by the ministry of Irrigation **(figure 12)**, the results shown on **figures 13 and 14** were obtained.

The storage in the reservoir was calculated from the model results using the following equation:

Storage = (Inflow – Demand releases – Toshka spillway overflow – Evaporation Losses) Δt

Then a comparison between the calculated storage from the model results and the storage calculated using the bathymetry Digital Elevation Model (DEM) **(figure 15)** showed a good results with maximum error of 4.47 % .

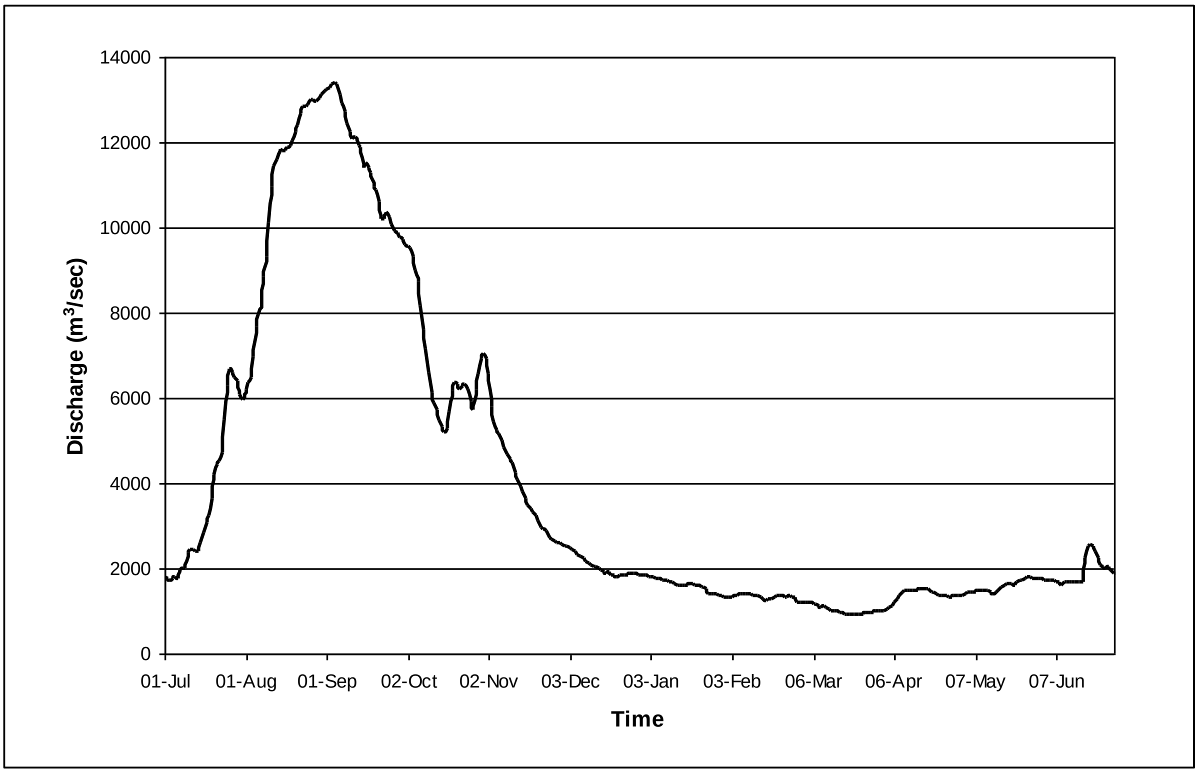

Figure 11: Maximum expected hydrograph at Dongola station

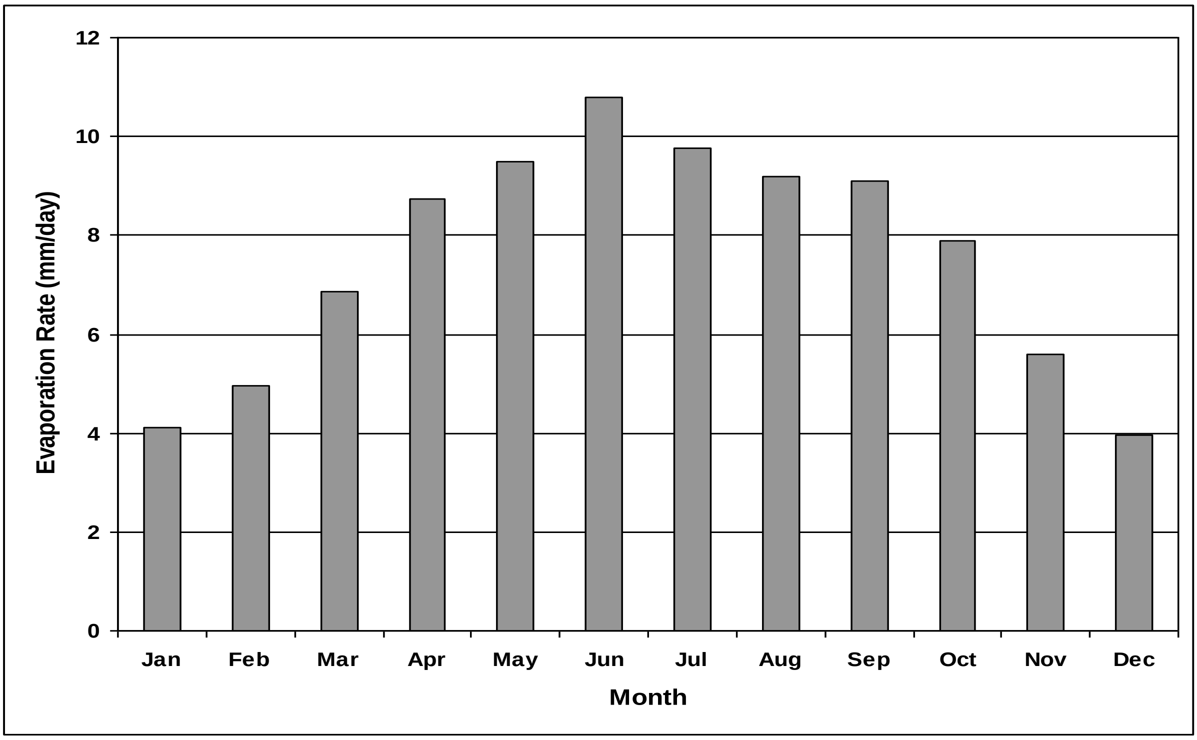

Figure 12: Estimates of Monthly Evaporation Rates From (AHDR)
Source: Omar, M.H. and El-Bakry (1970)

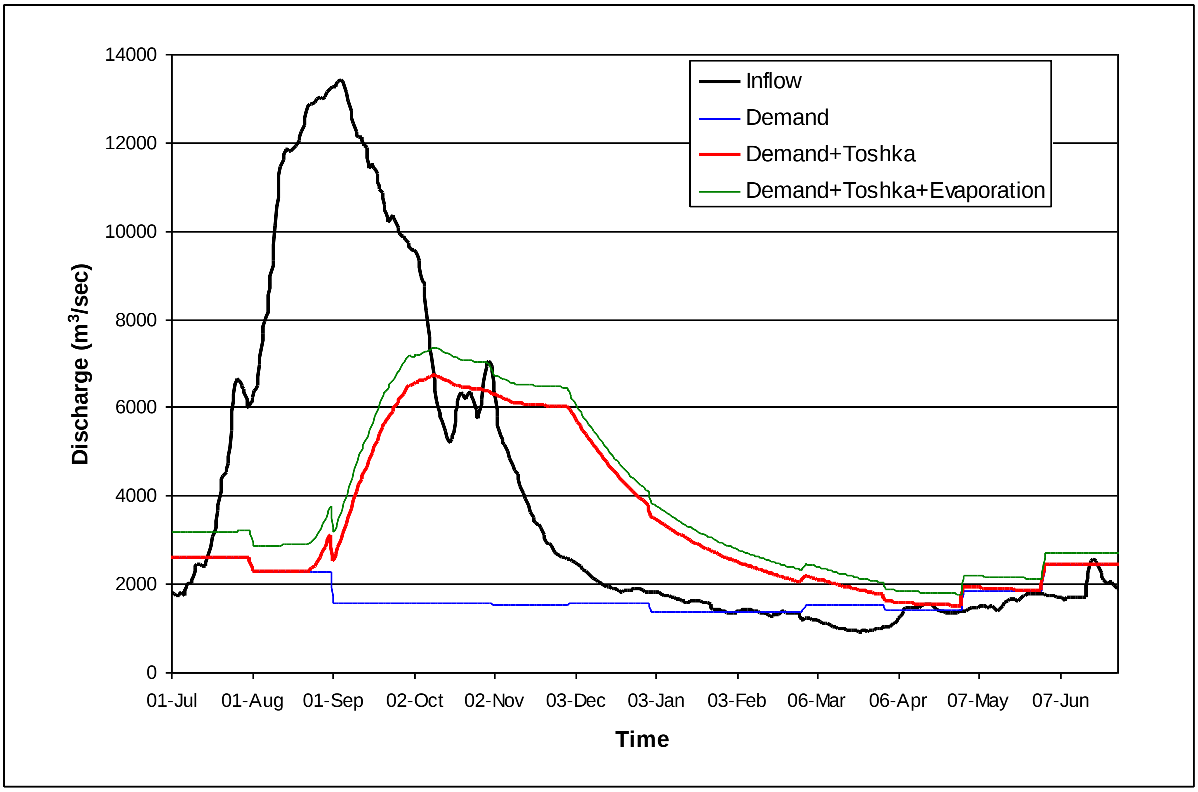

Figure 13: Inflow, Demand withdrawals, Toshka spillway outflow and Evaporation losses Vs. Time

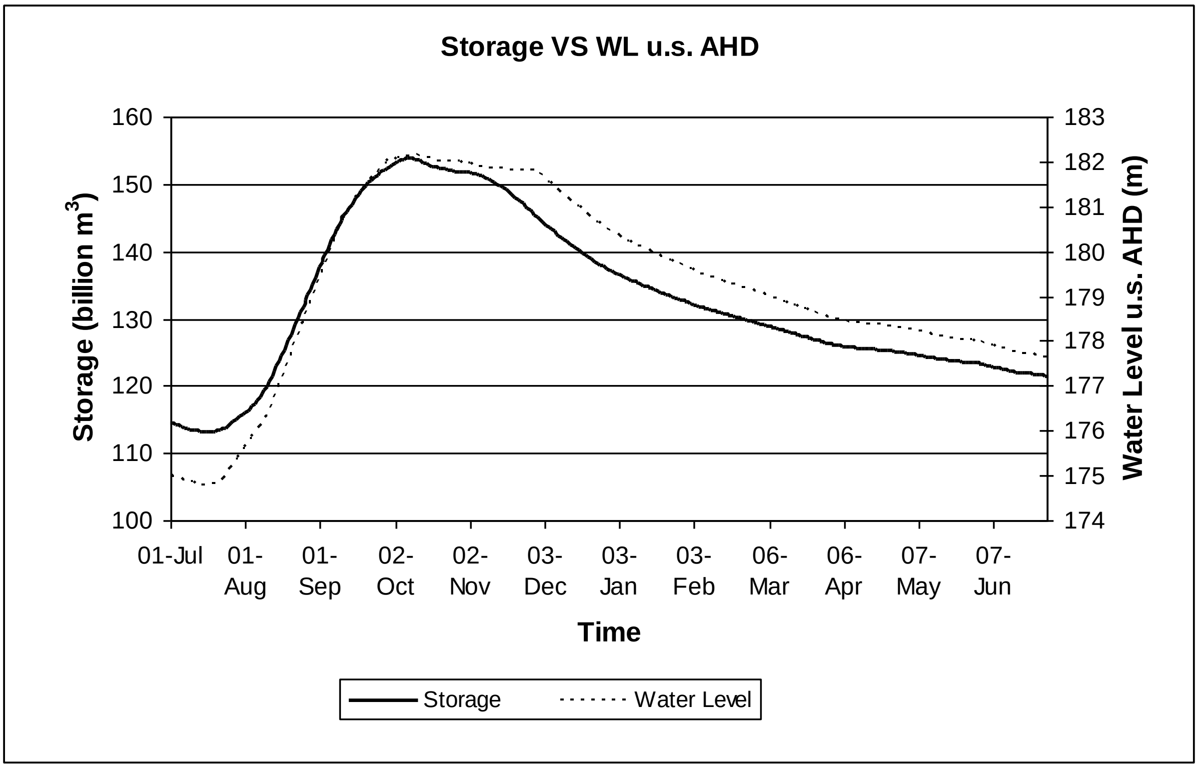

Figure 14: Storage and Water level u.s. AHD Vs. Time

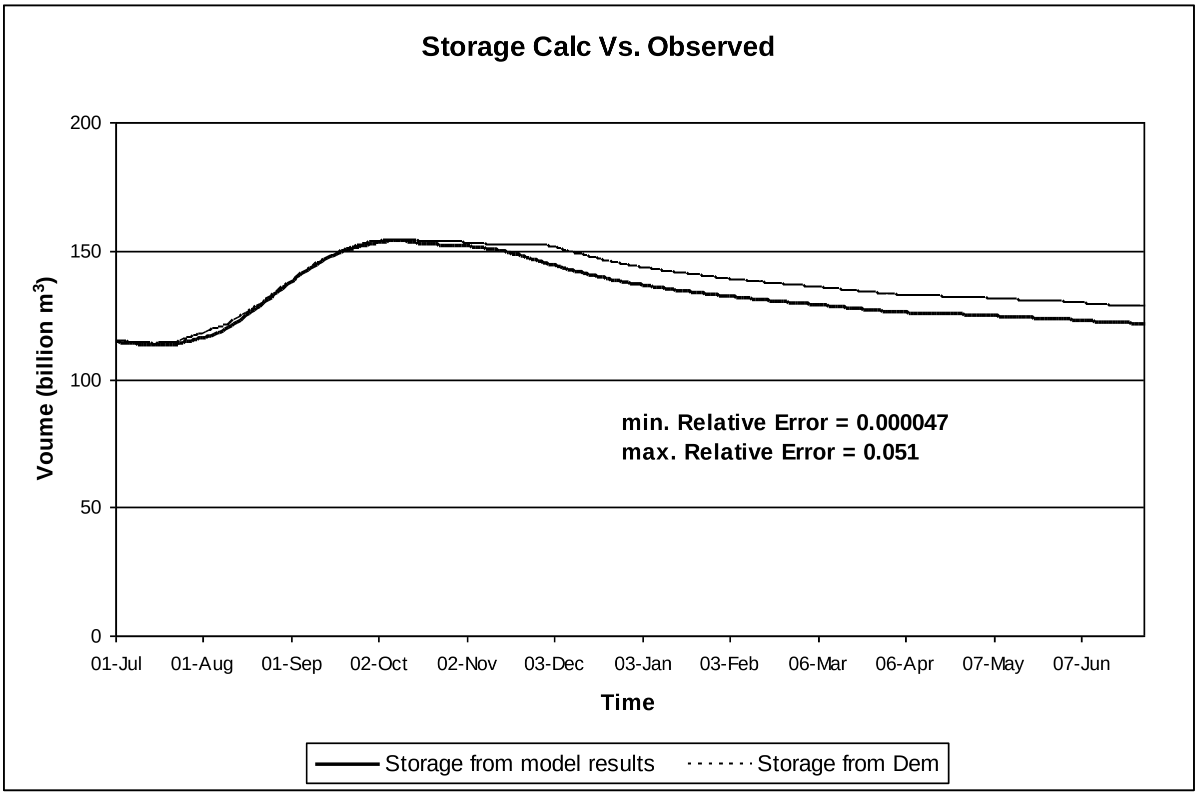

Figure 15: Model Verification

Conclusions and recommendations

It was found that if we started by the first of July with a water level in the reservoir of (175.00)m the maximum water level that will be reached is (182.15)m by the mid of October, which is more than the maximum designed level (182.00) m. And, this will cause water to overflow the Western spillway of the AHD.

The decision makers put a scenario to insure that the water level by the first of August is not more than (175.00)m. By applying this scenario the maximum water level that was reached was (181.55)m by the mid of October which is less than the maximum designed level

From these results it is proposed to start by the first of July with a water level in the reservoir of (174.85)m and the water level will just reach the (182.00) m level by the mid of October, and this will increase the storage in the reservoir by 2.898 billion m^3 than the proposed scenario by the decision makers.

Summary

1 - The GIS is a powerful to in data preprocessing specially for numerical models.
2- Further study on surveying the AHD reservoir bed should be made to obtain better bathymetry.
3- Hydraulic routing gives more accurate results than hydrologic routing. Yet, it needs more time and effort.

4- The resulted model will help in the operating of AHD for better management of the reservoir. This study will be carried out in the Ph.D. thesis of Eng. Ashraf M. El Moustafa.
5- Continues simulation of successive flood wave is a must for the management of the Dam.

References

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