Hydrological Model for the High Aswan Dam Reservoir Management

M. M. Soliman[1], M. A. Gad[2], Ashraf M. El-Moustafa[3]

Abstract

The management of the High Aswan Dam Reservoir (HADR) is one of the most important issues related to water resources studies in Egypt. The ministry of water resources and irrigation puts an operation rule to start the water year by the first of August with a water level upstream High Aswan Dam (HAD) not more than (175.00)m.

The present paper discusses the effect of various parameters on the management of High Aswan Dam Reservoir during high flood years and drought years. Those parameters may be summarized as the release scenario of the High Aswan Dam, the Tushka spillway geometric parameters and the starting water level upstream the dam in the beginning of August.

The paper presents the development of a hydrological model for the HADR which aims to help in the management policy of the reservoir. The developed hydrological model will enable maximum beneficial use of water. The model is an aggregated multi-criteria decision making problem where flood control, hydroelectric power, and water demand have to be satisfied at HAD. Simultaneously, the energy production from HAD and overflow from Tushka spillway were considered and the mismatch of water demand and supply being possibly minimized.

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

Introduction

Hydrologic routing employs the use of the continuity equation and either an analytical or an empirical relation ship between storage within the reach and discharge at the outlet. In its simplest form, the continuity equation can be written as inflow minus outflow equals the rate of change of storage within the reach:

Additional terms can be added to this formula according to its importance and the available data for calculation. One of those important terms in the study of great reservoirs with large surface area is the evaporation factor which acts as an outflow from the reservoirs but in an upward direction, also precipitation can be considered as the evaporation with a negative sign. Bank storage and groundwater-lake interaction are also two important factors that may be considered specially for reservoirs and big rivers.

1. Professor of Engineering Hydrology - Faculty of Engineering - Ain Shams University.
2. Teacher - Irrigation and Hydraulics Department - Faculty of Engineering – Ain Shams University.
3. Teacher - Irrigation and Hydraulics Department - Faculty of Engineering – Ain Shams University, elmoustafa010@yahoo.co.uk

Bernard L. Golding (1981) developed a Basic language program for routing floods through storage reservoirs or detention basins by the storage-indication working curve method (Modified Plus Method). A sample program was included and explained step-by-step. Standard flood routing equations were included. Many municipalities require that post-development runoff cannot exceed pre-development runoff in their subdivision regulations. Building a retention basin that acts as a small flood control reservoir normally did this. **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. **Abbas Seifi and Keith W. Hipel (2001)** proposed a new method for long-term reservoir operation planning with stochastic inflows. In particular, the problem was formulated as a two-stage stochastic linear program with simple recourse. Multiple inflow scenarios, leading to a very large deterministic model that is hard to solve using conventional optimization methods, approximated the stochastic inflows. An efficient interior-point optimization algorithm was presented for solving the resulting deterministic problem.

The Problem Definition

The question of operation of the HAD was neglected for a long time after the dam has been constructed as it seemed simple as the inflows were large enough so the water could always be released to meet downstream requirements and any water remaining was simply used to fill the reservoir behind the dam.

The ministry of irrigation currently decides the daily release from the HAD, and the ministry of electricity determines the distribution of discharges over the 24 hour period in order to effectively integrate the hydroelectric generation into the daily requirements of the national grid.

The development of river basin policy and management plans involves a spectrum of concerned parties and organizations, only a small fraction of which are presented by technical professionals. Easily-used and highly-interactive computer simulations provide one means by which these individuals can develop a conceptual and intuitive understanding for the complex physical behavior of river systems.

This paper introduces the development of a hydrological reservoir model that can be used for dam operation as the hydrodynamic models for such huge reservoir found to be time consuming if it to be used for dam operation.

Methodology

The following sections describe the development of a hydrological model (HADR Simulator) for dam operation along with its results. The model was based on the mass balance equation of the reservoir, which can be described as the summation of the inflow equal the summation of the out flow and can be represented in the following form:

The change in storage =

(Inflow – Releases – Tushka spillway overflow – Evaporation losses) Δt

As the water level in the reservoir is almost constant from the HAD upstream to Tushka spill way the release over the weir can be directly calculated from the water level using the weir equation presented by equation 1.

Q_{Tushka} = K B (WL – Crest Level)$^{1.569}$ (1)

Where:

B is the spillway crest width in meters.

WL is the water level in the reservoir.

The evaporation losses and storage can be calculated as a function in water level as presented by Figure 1, Figure 2, equation 2 and equation3.

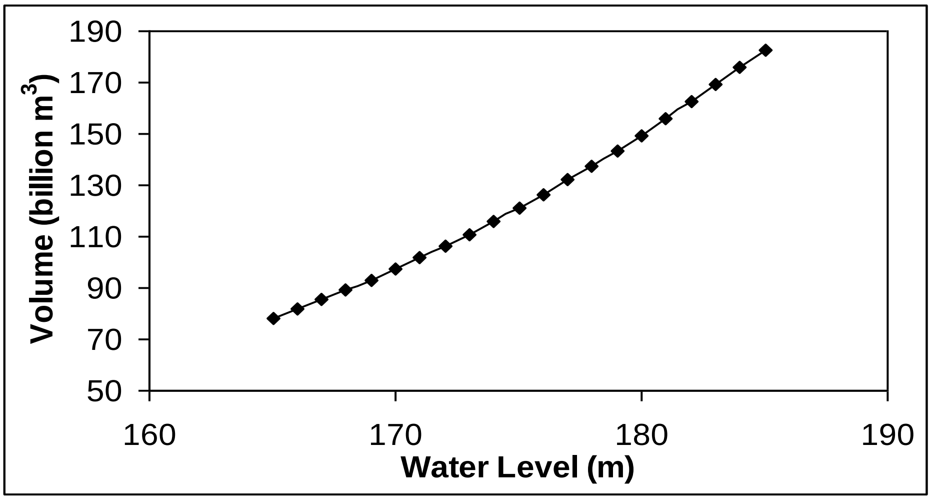

Figure 1: Storage Vs Water Level in the Reservoir

$S = 2 \times 10^{-15} \times (WL)^{7.4647}$ (2)

Where:

S is the stored water volume in billion cubic meters.

WL is the water level in the reservoir.

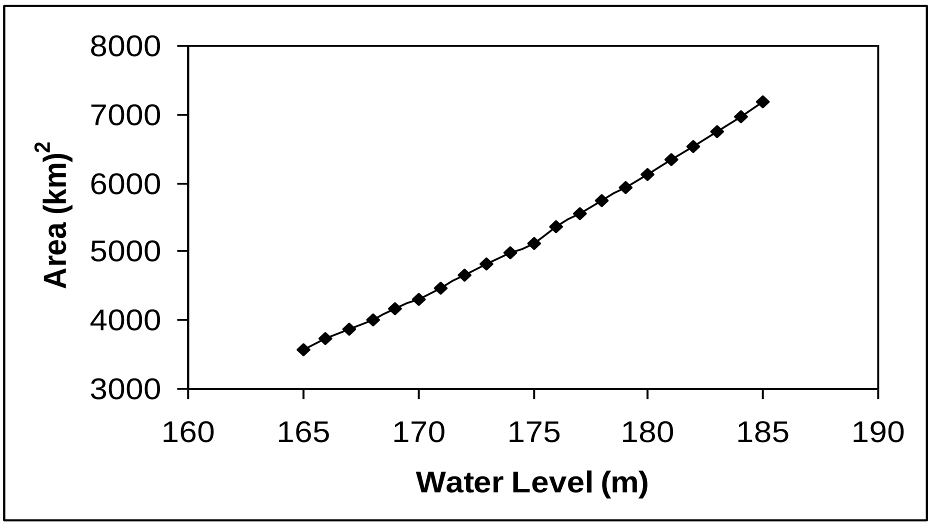

Figure 2: Surface area Vs Water Level in the Reservoir

$$A = 1 \times 10^{-10} \times (WL)^{6.0889} \qquad (3)$$

Where:

A is surface area in square kilometers.

WL is the water level in the reservoir.

HADR Simulator

The HADR Simulator interface was designed using the Visual Basic programming language. It was designed to be used interactively through out message boxes that pop out according to the user clicks. It is easy to use as the input and output files are written and read in text format, which can be exported to any data processing program that can display them in charts. Figure 3 shows the HADR Simulator starting window as you initiate the program and the flowchart, Figure 4 , describes the model parts.

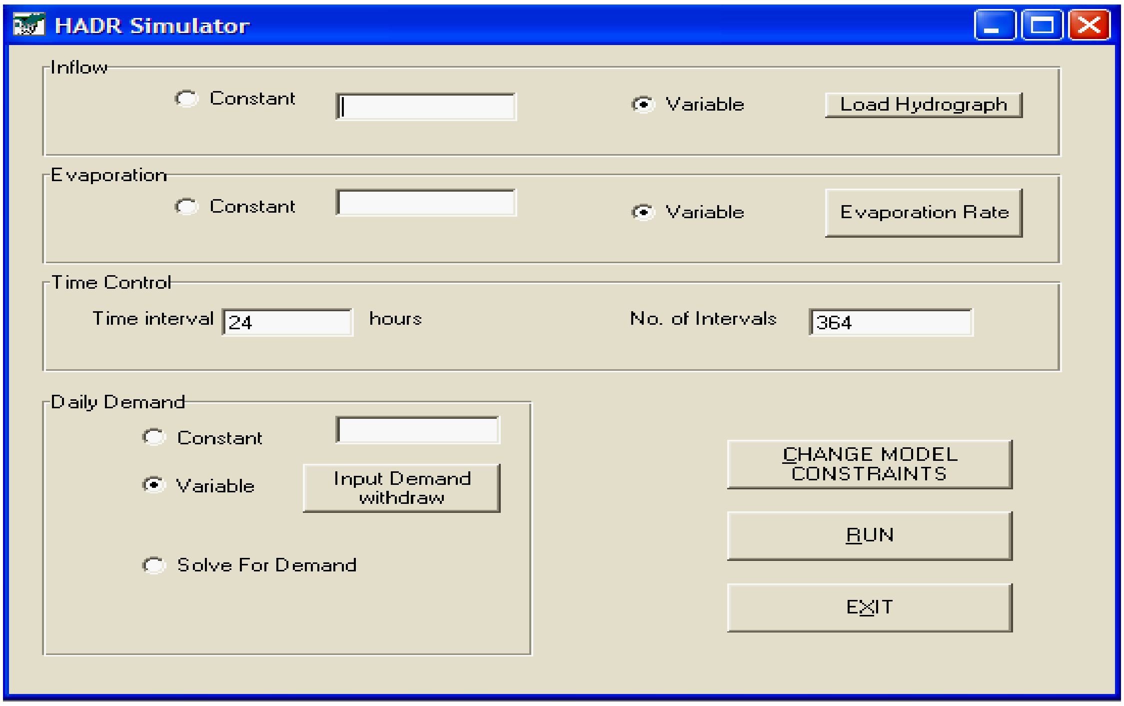

Figure 3: HADR Simulator main window

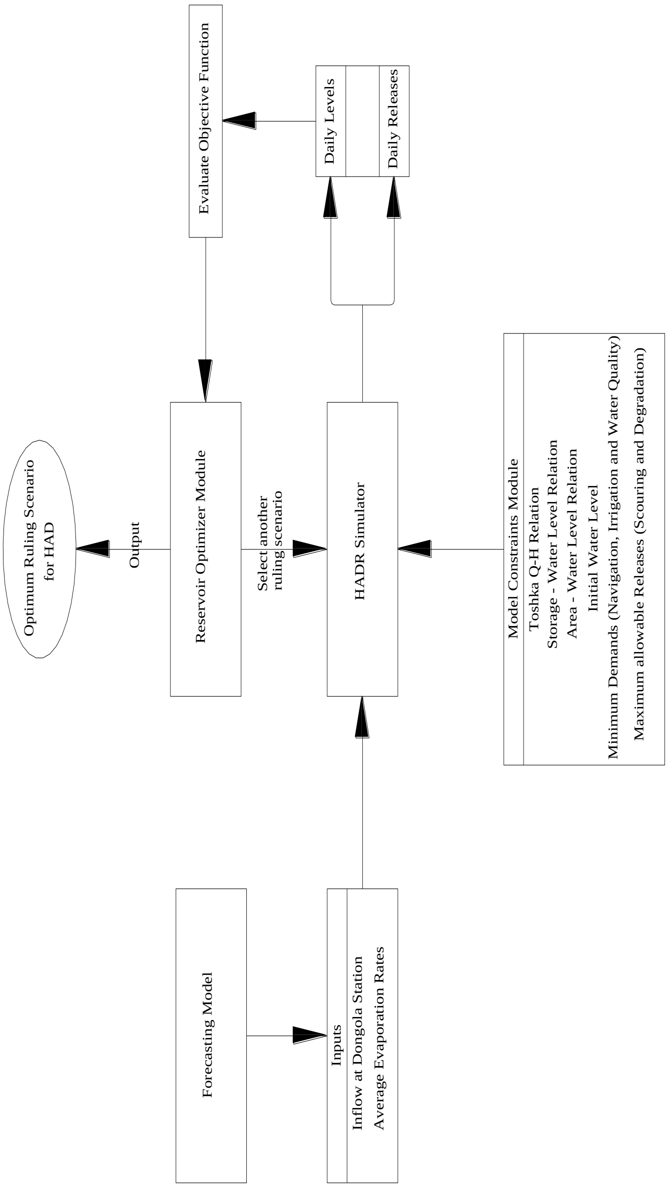

Figure 4: Flow chart of HADR Simulator Model

Model Constraints

The model constraints can be summarized in the following points;

- Maximum releases from HAD was assumed to be 280 million m^3/day as the maximum capacity of the river cross sections downstream to prevent scouring of the bed downstream the Nile Barrages.

- Minimum releases from HAD was assumed to be 60 million m^3/day for navigation, hydropower and water quality reasons.

- The released volume should not exceed Egypt share of Nile water, which is 55.5 billion m^3/year, according to the Nile Basin Countries Agreement.

- The starting water level upstream HAD before the beginning of the year, and the target ending water level obtained from a long term forecasting model.

- Water level – Area and Water level – Storage relations.

- Tushka spillway boundary conditions, as Water level – Q relation.

Figure 5 shows the window used to change the model constraints interactively during the model run, the present values are those driven from equations presented in the previous chapter.

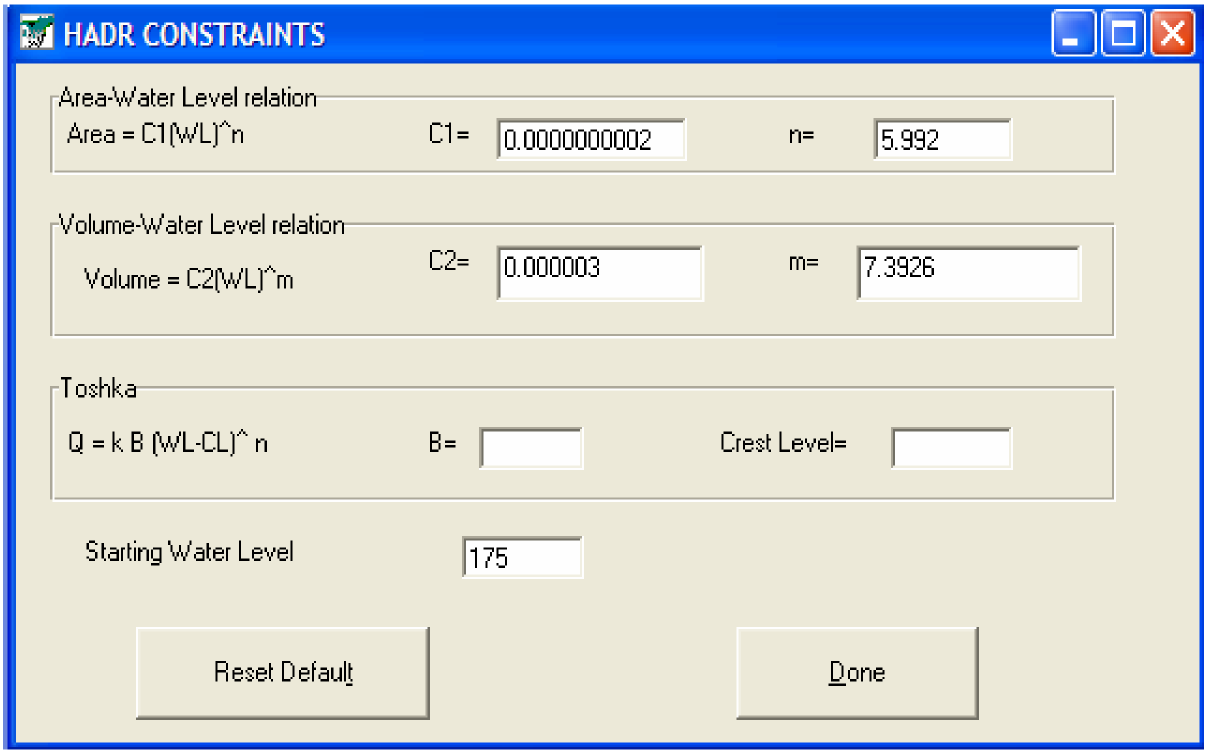

Figure 5: HADR Simulator, constraints window

Model Results

Hydrodynamic models Versus HADR Simulator

After the model was developed, a comparison between its results and those of the hydrodynamic model had to be made. The following figure shows that both results almost match. The HADR Simulator proved to be an easy and fast tool to be used in the reservoir management.

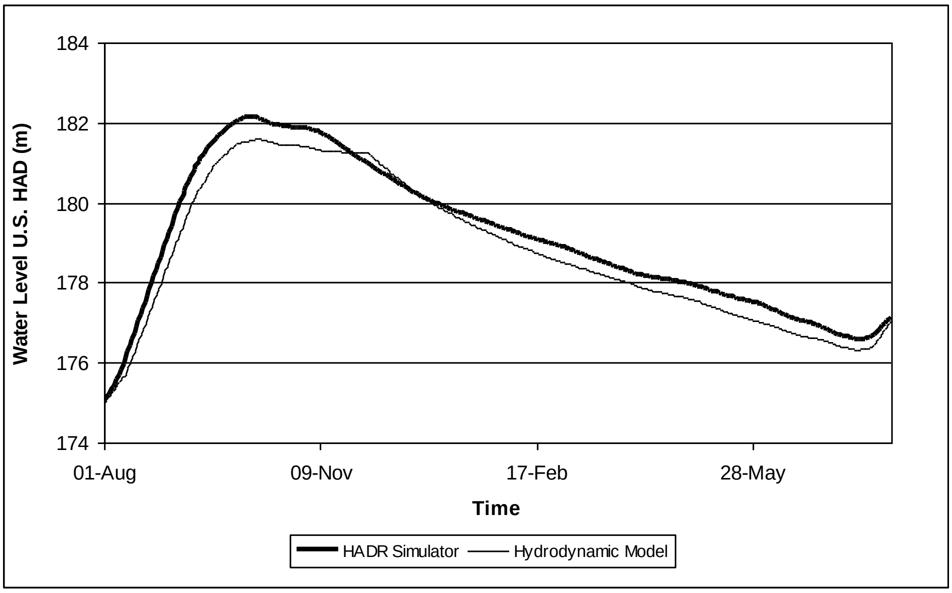

Figure 6: HADR Simulator results Vs Hydrodynamic model results

Effect of Varying the HAD Releases

The management of the reservoir flood concerns the control of the HAD releases in such a way that maximize the objective function of the model such as the water level and, or the hydropower. To test this effect, the developed model was used to calculate the water level with a two release scenarios, maximum and minimum, previously proposed by the High Aswan Dam Authority (HADA) and assuming the maximum recorded hydrograph at Donqola gagging station as the inflow at the upstream.

Figure 7 shows the results of those two scenarios from which it could be noticed that the proposed release scenario affect the water level during the period from the beginning of November to the end of April. During this period the incoming flood is in its peak while the demand is in its lowest values, as shown in Figure 8.

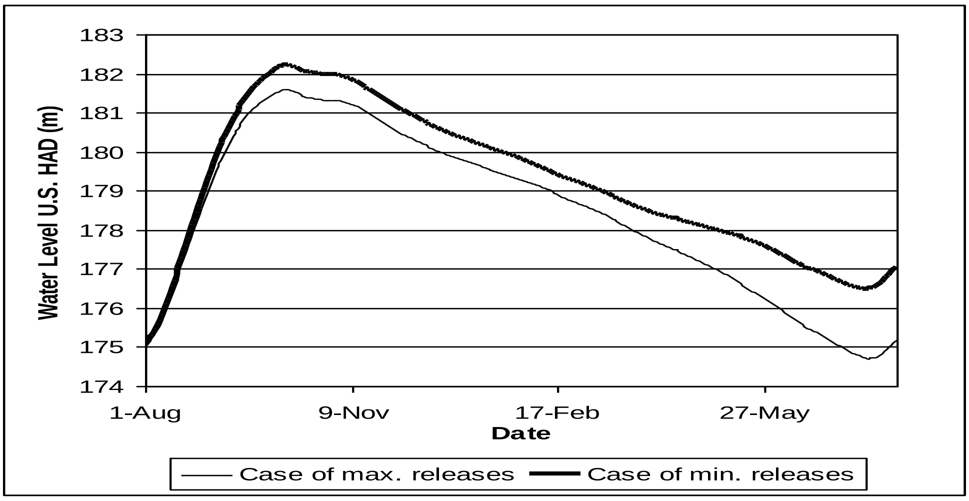

Figure 7: Water levels resulted during maximum and minimum proposed release scenarios

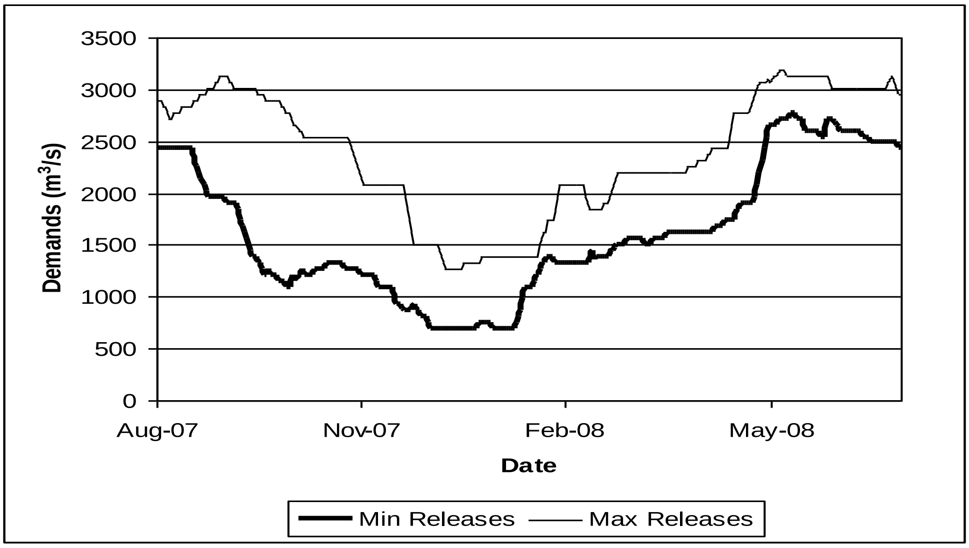

Figure 8: Maximum and minimum demands scenarios, previously proposed by the HADA (1990-2003).

Effect of Varying the Initial Water Level

The water level in the reservoir by the 1st of August, which is defined in the model as the initial water level, is the level to start the simulation with.

Various simulations were carried out to test the affect of varying this level with maximum releases to the Nile River downstream HAD and during a flood year, maximum expected flood recorded at Donqula station. The resulted water levels upstream HAD during those simulations are presented in Figure 9.

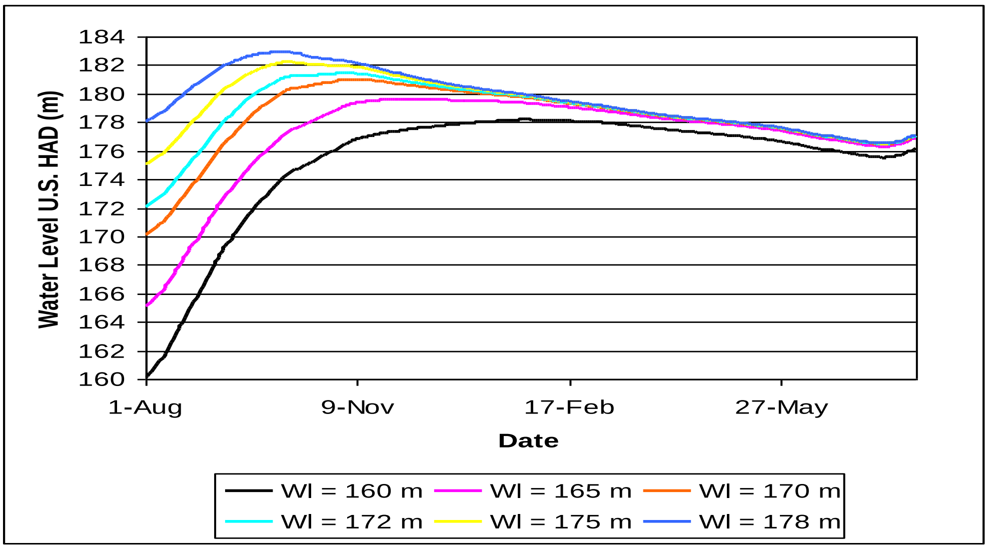

Figure 9: Water level U.S. HAD during a flood year and with minimum releases scenario

From this figure, it could be noticed that, in case of a flood year the initial starting water level will not affect the ending water level. As the lake keep filling and the change in water level due to change in storage will become slightly noticeable because the top width of the reservoir cross sections become very wide, any small change in water level will cause great variation in the total storage of the reservoir.

Almost all the proposed scenarios did not exceeded the maximum designed level of the HAD, which is 182 meter above mean sea level. Except, if we started with an initial water level of 178 m.

The ending water level, almost in all cases, will reach some where between level 176 and level 177 meter which will cause threats to the dam if two successive extreme floods is expected in two successive years.

Another set of simulations were carried out to test the affect of varying the initial water level in the reservoir with minimum releases to the Nile River downstream HAD and during a drought year. The resulted water levels upstream HAD during those simulations are presented in Figure 10.

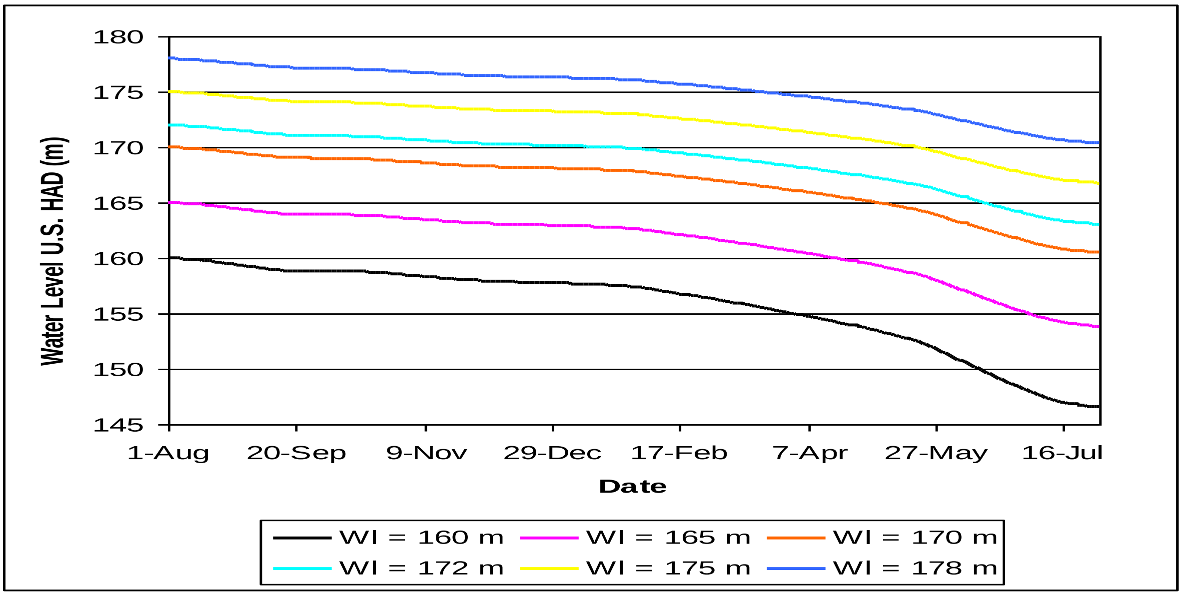

Figure 10: Water level U.S. HAD during a drought year and with minimum releases scenario

From this figure, it could be noticed that, in case of a drought year the initial starting water level will affect the ending water level noticeably. As the HAD Reservoir is releasing minimum demands to the downstream, the change in water level due to change in storage becomes noticeable, any small change in the storage will cause great variation in the water level upstream the dam.

If the proposed initial level in the reservoir is less than 170 meter this will cause great threat on the strategic storage of the water and may reduce the power generated from the turbines to a very law levels. If we started with an initial water level of 160 m or less this may cause to completely empty the live storage from the reservoirs and cause the turbines to shut down.

If two successive draught years followed each other this will threat the country economy as the water level in the reservoir will fall below the dead storage water level unless a release operation rule is suggested in such case to reduce the release flow to the downstream as much as possible.

Conclusion and recommendations

1. A hydrological model for dam operation, HADR Simulator, was developed for the purpose of dam operation.
2. The initial water level in the reservoir before the start of the flood is very important factor to be considered during the management process, Also is the target ending water level.
3. During flood years there is almost no danger on the HAD except if we started at the 1st of August by a level more than 176 m.
4. If two successive high floods is expected the release scenario is to be modified to insure that the water level upstream the HAD will not exceed 182m.

5. During drought years the release scenario is to be modified to insure that the water level upstream the HAD will not drop in a dramatic way that threat the strategic storage in the reservoir.
6. For the purpose of dam operation a hydrological model is sufficient with a reliable long term forecasting model of the Nile basin.

References

M. Soliman, A. Bahaa, M. Gad and Ashraf M. El-Moustafa (2007). “Flood Routing through Lake Nasser Using 2D Model”, PhD thesis.

Bernard L. Golding (1981), “Flood Routing Program”, Civil Engineering—ASCE, Vol. 51, No. 6, June 1981, pp. 74-75.

Abbas Seifi and Keith W. Hipel (2001), " Interior –Point Method for Reservoir Operation with Stochastic Inflows", Journal of Water Resources Planning and Management, Vol. 127, No. 1, January/ February, 2001. ASCE, ISSN 0733-9496/01/0001-0048–0057.

Stanley S. Butler (1982), “Point Slope Approach for Reservoir Flood Routing”, Journal of the Hydraulics Division, Vol. 108, No. 10, October 1982, pp. 1102-1113.