OPERATION OF ASWAN HIGH DAM RESERVOIR UNDER IMPACT OF POTENTIAL CLIMATE CHANGES SCENARIOS

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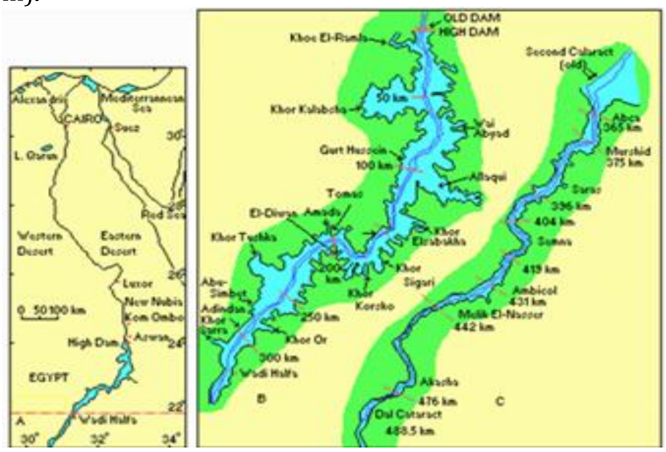
Abstract - Just north of the border between Egypt and Sudan lies the Aswan High Dam, a huge rock fill dam which captures the world's longest river, the Nile River, in the world's third largest reservoirs, Lake Nasser. The dam, known as Saad el Aali in Arabic, was completed in 1970 after ten years of work. Egypt has always depended on the water of the Nile River. The two main tributaries of the Nile River are the White Nile and the Blue Nile. The source of the White Nile are the Sobat River Bahr al-Jabal (The "Mountain Nile") and the Blue Nile begins in the Ethiopian Highlands. The two tributaries converge in Khartoum, the capital of Sudan where they form the Nile River. The Nile River has a total length of 4,160 miles (6,695 kilometers) from source to sea. The Aswan Dam benefits Egypt by controlling the annual floods on the Nile River and prevents the damage which used to occur along the floodplain. The Aswan High Dam provides about a half of Egypt's power supply and has improved navigation along the river by keeping the water flow consistent. There are several problems associated with the dam as well. Seepage and evaporation accounts for a loss of about 12-14% of the annual input into the reservoir. The sediments of the Nile River, as with all river and dam systems, has been filling the reservoir and thus decreasing its storage capacity. This has also resulted in problems downstream. The operation of the reservoir might face challenge in the 21st century due to global warming and related climate changes. The climate change scenarios are rainfall, evaporation and the inflow into AHDR. These scenarios are stochastic and vary year by year, as a result of climate change it is expected that the average Nile flow will change accordingly with significant yearly fluctuation. The main issue of this research is to investigate the potential impacts of changing climatic conditions on the operational performance of AHDR. BlueM, a model developed by the Institute for Hydraulics and Water Resources Engineering, Section for Hydrology and Water Management of the Darmstadt University of Technology, Germany, will be used to discuss and assess the potential modification of operation rules for the reservoir. BlueM is a deterministic integrated open modeling framework with special reference to reservoir systems. The modeling framework allows for the evaluation of different climate change scenarios generated by global climate models, which will be used as input to the model for simulating future inflows to the reservoir*An abstract summarizes, in one paragraph (usually), the major aspects of the entire paper in the following prescribed sequence. The abstract of your paper must 250 words or less. This electronic document is a "live" template. The various components of your paper [title, text, heads, etc.] are already defined on the style sheet, as illustrated by the portions given in this document. Do not use special characters, symbols, or math in your title or abstract. The authors must follow the instructions given in the document for the papers to be published. This template, modified in MS Word 2007 and saved as a "Word 97-2003 Document (Size 10 & Italic , cambria font)*

Key Words*: Nile basin, Aswan High Dam, Climate change scenarios, operation rules,* Egypt demand

1.INTRODUCTION

The Aswan High Dam Reservoir plays a key role in water resources of Egypt. It is extends for 500 km along the Nile and covers an area of about 6,000 km2, of which northern two-thirds (Lake Nasser) is in Egypt and one-third (Lake Nubia) in Sudan. The reservoir has a large annual carry-over capacity of 168.90 x 109 m3 [Ministry of water resources and irrigation, 2005]

Construction of AHD on the River Nile in southern Egypt began in 1960 and was completed on 1972 to develop industries using generated electric power and to stabilize water supply for irrigation. The dam created AHDR, one of the world's largest artificial lakes (fig. 1), south of Aswan. AHDR covers the area between Lat. 21o30' N and 24o00' N, Long. 31o20' E and 33o30' E [Selim et. al., 2002], and extends to about 500 long (more than 350 km in Egypt and the rest in Sudan) with a maximum width of 35 km and covers an area of 6500 km2 at its highest water level (182 m).



. *Fig 1**: location and extent of Aswan High Dam Reservoir*

The reservoir has a large annual carry-over capacity of 168.90 x 109 m3 [Ministry of water resources and irrigation, 2005]. Releases from AHD account for over 95% of the water resources of Egypt, making the Nile River the effective single source of freshwater for Egyptian agriculture, population, navigation and industry. Studies of climate change impacts on the Nile River show that the basin is extremely sensitive to temperature and precipitation changes [Strzepek and Yates, 2000]. An increase of 10% of average annual precipitation would lead to an average increase in annual flow of 40%. Similarly, a decrease in 10% in precipitation would lead to a reduction of the annual flow with more than 50% [Ministry of water resources and irrigation, 2005]. This paper focuses on the sensitivity of reservoir operation as a result of different climatic scenarios. The intent in this paper is to use reservoir performance measures to evaluate the potential implications of climatic change for reservoir operations

2 .The Current Reservoir Operation Policy

AHDR operation polices were determined by the Ministry of Water Resources and irrigation according to different restrictions such as 1) maximum allowed water outflow should not exceed 250-300 x 106 m3/day to avoid excessive erosion and bank overtopping. 2) The water levels upstream Aswan High Dam should be kept at 175.00 m at the beginning of water year (Au-gust 1st) to fulfill high and low flow requirements. 3) The minimum allowed water discharges should be released to fulfill irrigation, navigation, drinking and other requirements and Sudan abstractions [Sadek and Aziz, 2005].

3. Inflow at AHDR

Annual inflow records at Dongola in Sudan (representing the inflow to AHDR [Yao and Georgakakos, 2003] have been collected and published by Ghaas, 1998 and Sutcliffe & Parks, 1999, in order to get an idea about the high and low flows for 83 years during the period from 1912 to 1994 (fig. 2). The mean flow varied significantly depending upon the period considered, the mean annual flow from 1912-1964 (before operation of AHD) was 2754 m3/s (86.86 x 109 m3) with a standard deviation of 398 m3/s (12.56 x 109 m3). The mean annual flow from 1965-1994 (after operation of AHD), on the other hand, was 2214 m3/s (69.81 x 109 m3) with a standard deviation of 443 m3/s (13.98 x 109 m3).

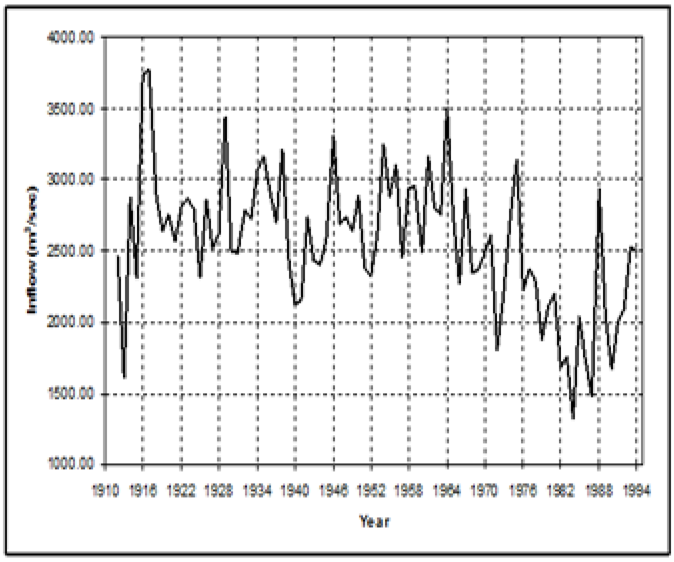


Fig 2: The Average Anuual inflow of the Historical Data at dongla from (1912-1994) (source: Sutcliffe &Parks, 1999)

4. Climate Change Scenarios

Strzepek and McCluskey (2007) employed a version of a conceptual rainfall-runoff model called WatBal (Water Balance) to ascertain the possible impacts of climate change on surface water availability for Egypt. A subset of the 20 scenarios produced by the Climate Research Unit (CRU), University of East Anglia, Norwich, UK. These data, provided on a 0.50 grid, represent the World Meteorological Organization's (WMO) standard reference 'baseline' for climate change impact studies. The available data was employed to represent a range of equally plausible future climates (expressed as anomalies of the baseline 1961–1990 climate) with differences at-tributable to the different climate models used and to different emission scenarios that the world may follow. This study derived 20 scenarios using five different models (CSIRO2, HadCM3, CGCM2, ECHAM and PCM) based on two different emission scenarios (A2 & B2), where:

CSIRO2: CSIRO Atmospheric Research, Australia.
HadCM3: Hadley Center for Climate and Prediction and Research, UK.
CGCM2: Meteorological Research Institute, Japan.
ECHAM: Max Planck Institute for Meteorology, Germany.
PCM : National Center for Atmospheric Research, USA.
A2 : describes a very heterogeneous world with high population growth, slow eco-nomic development and slow technological change.
B2 : describes a world with intermediate population and economic growth, empha-sizing local solutions to economic, social, and environmental sustainability

The results for decadal average changes for 2050 and 2100 in annual values for stream flow are presented in Table 1.To estimate the effect of low water levels on operation of Aswan high dam reservoir

Table 1: Estimated % change in stream flow for Egypt (Strzepek & McCluskey, 2007)

	A2- Scenarios									
	CGCM2-A2		CSIRO2-A2		ECHAM-A2		HadCM3-A2		PCM-A2	
Baseline	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
100%	75%	50%	92%	87%	107%	124%	97%	99%	100%	114%
	B2- Scenarios									
	CGCM2-B2		CSIRO2-B2		ECHAM-B2		HadCM3-B2		PCM-B2	
Baseline	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
100%	81%	70%	88%	82%	111%	124%	96%	96%	114%	193%

Nine scenarios were selected from the climate change scenarios generated by Strzepek and McCluskey and presented in Table 2. The selected climate change scenarios will be used as a multiplier to the historical natural series (1968-2000) to the model for simulation future inflows to the lake.

Table 2: *Selected scenarios for % change in stream flow at the entrance of Nasser Lake used in the simulation that generated from Blue M model*

Scenarios	% change in stream flow
S1	100 % "Baseline"
S2	92 % (decreased by 8 %) in comparing by scenario 1
S3	81 % (decreased by 19 %) in comparing by scenario 1
S4	70 % (decreased by 30 %) in comparing by scenario 1
S5	50 % (decreased by50%) in comparing by scenario 1
S6	107 % (increased by7%) in comparing by scenario 1
S7	114 % (decreased by14%) in comparing by scenario 1
S8	124 % (decreased by24%) in comparing by scenario 1
S9	193 % (decreased by93%) in comparing by scenario 1

5.The Modeling Approach

The AHDR is modeled and its operation is simulated using the software BlueM [Lohr, 2001]. BlueM, developed by the Institute for Hydraulics and Water Resources Engineering, Sec-tion for Engineering Hydrology and Water Management (ihwb) of Darmstadt University of Technology - Germany, is a software package for rive basin management. It allows for the integrated simulation, analysis and optimization of discharge and pollution loads in rural and urban catchments, including processes in the water body, using physically-based hydrologic approaches. Figure 3 shows the communication between BlueM components and their external usage. The model core BlueM.Sim has two interfaces: an interface which complies with the Open MI standard and a .NET interface that provides direct access to the model. Additionally, simulation results are also saved in an ASCII file. BlueM. Analyzer is a pure Open MI-component (implementing the I Listener-Interface of Open MI). BlueM. Wave imports result data from ASCII files. BlueM. Opt can access model engines via a generic interface (implemented as a strategy pattern) or via text files.

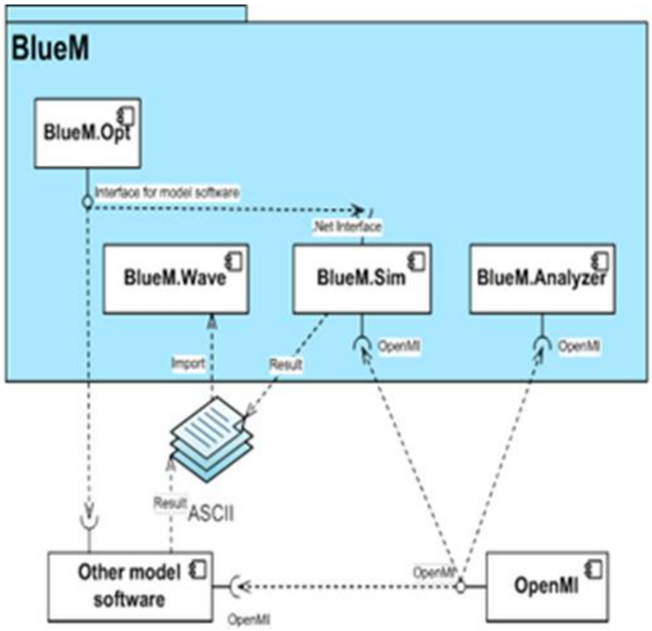


Fig 3: Interfaces of the Blue M components outer word interfaces

The operation of a reservoir is described by the water balance equation under various con-straints concerning storage volume, outflow from the reservoir and water losses (see fig. 4). The water balance equation applied on a monthly basis has the following form:

$$\frac{dV(t)}{dt} = \sum_{i=1}^{n_{in}} Q_{in,i} + \sum_{j=1}^{n_{out}} Q_{out,j} \qquad (1)$$

$$\frac{dV(t)}{dt} = I_t - Q_t - M_t - D_t - T_t - S_t - E_t \qquad (2)$$

Where:
It : Mean inflow to the storage in month t (m3).
Qt : Amount of water discharged from the storage in month t downstream the dam (m3).
Mt : Amount of water released from the emergency spillway in the dam in month t (m3).
Dt : The water demand for Toshka project (South Valley) in month t (m3).
Tt : Amount of water released from Toshka spillway in month t (m3).
St : Seepage losses from the storage reservoir in month t (m3).
Et : Mean evaporation from the storage reservoir in month t (m3).
Et = ((At + At+1) / 2) * Ct*1000

At : Reservoir area at beginning of month t (km2).
At+1 : Reservoir area as at the end of month t (km2).
Ct : Evaporation coefficient pertaining to month t (mm).

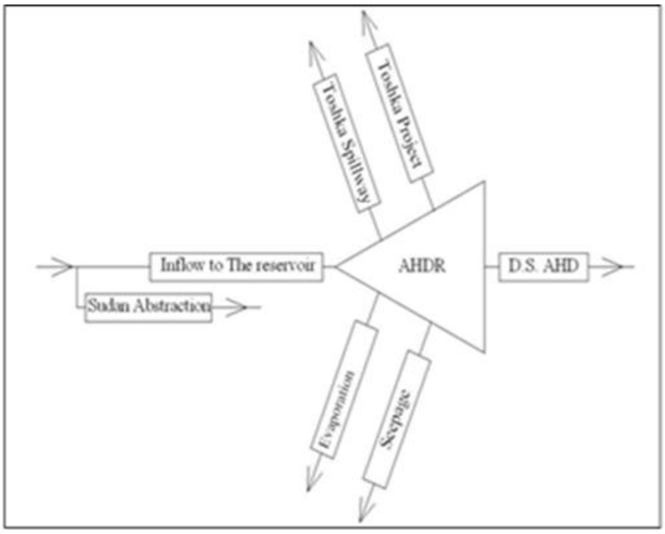


Fig 4 :management of Aswan High Dam Reservoir

The model also includes an equation which computes the potential monthly hydropower pro-duction as a function of three factors, (1) the volume of water discharged, (2) the gross head of this water, and (3) the efficiency of the couple turbine generator, which varies the amount of power produced. The following functional form represents this relationship:

$$Pt = 9.81 * Ht * Qt * Ce \qquad (3)$$

$$Et = Pt * Kt \qquad (4)$$

Where:

Pt : Power generated in month t (kW).
Et : Energy generated in month t (kWh).
Qt : Amount of water turbaned for energy generation in month t (m3)
Ht : Average height of water above turbines in month t (m) (reservoir monthly mean water level - 110)
110 meters assumed to be the constant level downstream of AHD (The water level down-stream AHD ranges between 107.5 and 113 m above sea levels [Georgakakos et al., 1997]).
Ce : Efficiency coefficient of turbines and generators (0.85).
Kt : Number of hours in t month (24* number of hours in month t) (hours**).**

6. Scenario Assessments

The future hydrologic scenarios developed have been used to assess the expected impacts to potential climate change. In the following discussion, the assessment results are summarized relative to the following criteria: water supply releases, reservoir level variations, Toshka spillway discharges, evaporation losses and Hydropower production

6.1. Sensitivity of water supply releases to climate change

In general mean annual withdrawal from the AHDR resulting from 9 climate scenarios selection of climate change scenarios that have been generated by Strzepek and McCluskey based on two different emission scenarios (A2 & B2) the results for decadal average changes for 2050 and 2100 in annual values for stream flow are presented in Table 3

Table 3 Annual withdrawal from the AHDR

scenarios	S1	S2	S3	S4	S5	S6	S7	S8	S9
maximum Annual withdrawal	73.54	63.08	55.5	55.5	55.50	79.21	85.7	96.08	165.87
average Annual withdrawal	56.7	53.8	51.5	48.9	40.6	59.1	61.9	66.6	104.3
minimum Annual withdrawal	47.2	47.2	47.2	41.3	25.3	47.2	52.7	55.5	55.5

Under baseline climate scenario S1, Egypt falls short of its target demand in approximately 27.6 % of years. This percentage decreases to (13.8,6.9,0and0) % of years for the increasing scenarios(S6,S7,S8and S9,respectively) and increases to (44.8,65.5,89.65,and 93) % of years for decreasing scenarios(S2,S3,S4and S5, ,respectively). Fig 5 shows that

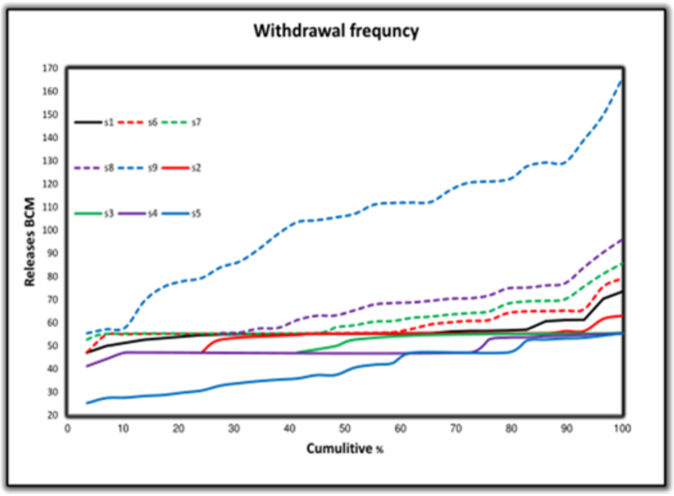


Fig 5 :frequency curve of annual withdrawal from AHDR BCM

6.2. Sensitivity of reservoir level variations to climate change

Figure 6 present the water level variation projected in the AHDR for baseline and eight scenarios based on two global emission scenarios A2 (B1)). From these figures, it can be concluded that the water levels upstream the dam are affected by the changes in the inflows. The maximum water levels upstream the AHD of all climate scenarios within the water year did not exceed 182 m, and the minimum water levels are under the minimum allowable limits (147 m). Table 4 is a summary characterization of variation in the reservoir level, this analysis represents in the water levels limits and corresponding percentage of occurrence for all climate scenarios

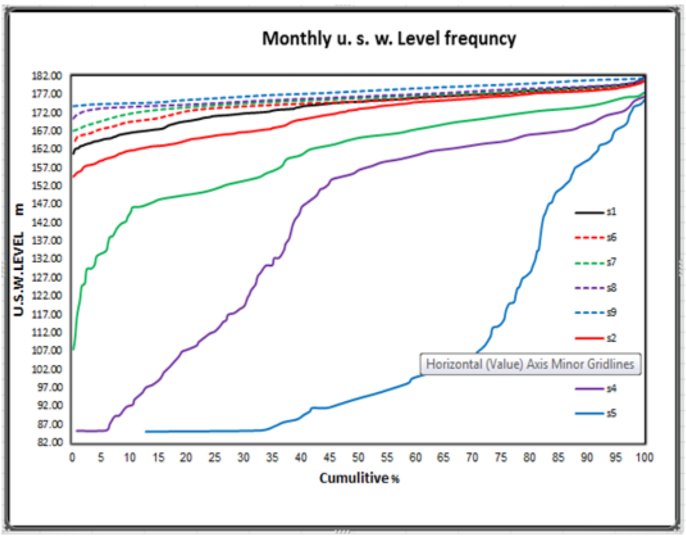


Fig 6 :frequency curve of u.s.w.level from AHDR

Table 4. Level variations characteristics in the AHDR

scenarios / Level (m)	S1	S2	S3	S4	S5	S6	S7	S8	S9
> 181	0.58	0.00	0.00	0.00	0.00	0.57	0.86	1.15	21.83
> 178	21.55	11.2	0.00	0.00	0.00	22.7	28.16	35.34	50.29
> 175	52.6	40.23	7.75	2.01	0.57	61.78	69.82	78.16	81.32
> 160	100	93.1	62.35	42.52	9.48	100	100	100	100
>147	100	100	87.93	59.77	16.66	100	100	100	100
≤ 147	0.00	0.00	12.06	40.23	83.34	0.00	0.00	0.00	0.00

6.3.Sensitivity of hydropower production to climate change

Figure 7 shows a wide spread in the average annual hydropower production at the AHD for the A2 and B1 global emission scenarios.

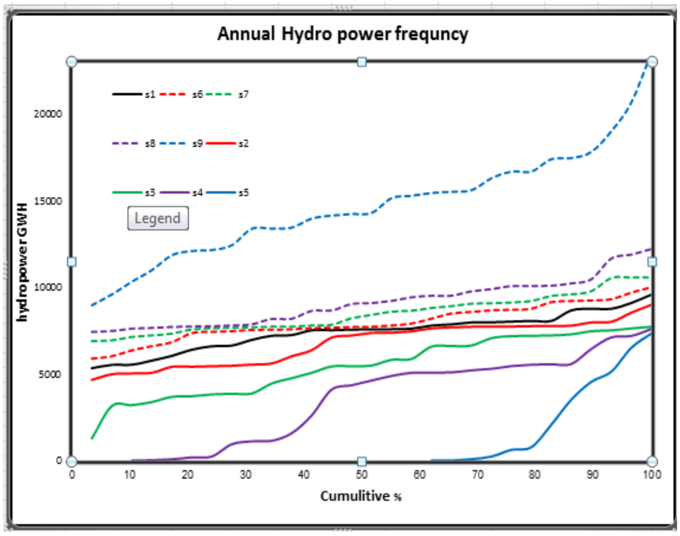


Fig 7 frequency curve of annual hydropower GWh from AHDR

Under the baseline climate scenario, annual hydropower production at the AHD varies between 5333 - 9577 GWh, with a mean of about 7422 GWh. The annual average power production at the AHD generally follows changes in stream flow, as shown in the table 5

Table 5: Annual hydropower production from the AHDR GWh

scenarios	S1	S2	S3	S4	S5	S6	S7	S8	S9
maximum Annual hydropower production	9577	8993	7725	7594	7339	10005	10575	12211	23525
average Annual hydropower production	7422	6789	5463	3521	1064	7969	8476	9133	14748
minimum Annual hydropower production	5333	4656	1285	0	0	5883	6896	7433	8962

There are a few aspects of the frequency distributions that are also notable, maximum annual hydropower production occurs scenario S9, and exceed 10000 GWh in approximately 90 % of years. For scenarios S4 and-S5, the hydropower production stops for 10% ,62% years, respectively due to the reservoir levels falling below the minimum level for the hydro -power generation, and the annual hydropower production is less than 8000 GWh in almost all years

6.4.Sensitivity of evaporation losses to climate change

According to climate change scenarios, the annual evaporation losses vary between 7.95- 13.48 BCM, with a mean of about 11.5 BCM for the baseline climate scenario S1. when the stream flow increasing in scenarios S6 , S7 , S8and S9, the annual average evaporation losses increases, but then decreases in scenarios S2,S3,S4and S5. Table 6 illustrates the change in evaporation resulting from a change in flows. Figure 8 illustrates the frequency distribution of the annual evaporation losses, from this figure it can be noticed that 100, 80,64and 48 percent of years at increase scenarios (S9, S8, S7 and S6,, respectively) had evaporation losses greater than 12.5 BCB, compared to the baseline percent of 38 %, while in almost all years at decrease scenarios (-50%,-30%,-19% and-8%) had evaporation losses less than 12.5

Table 6; Change in evaporation resulting from a change in flows

scenarios	S1	S2	S3	S4	S5	S6	S7	S8	S9
maximum Annual Evaporation	13.48	13.1	12.5	12.1	11.3	13.5	13.5	13.5	13.62
average Annual Evaporation	11.5	10.5	7.98	5.42	1.89	12.1	12.6	12.93	13.37
minimum Annual Evaporation	7.95	6.1	2.58	0.22	0.05	9.1	9.87	11.5	12.52

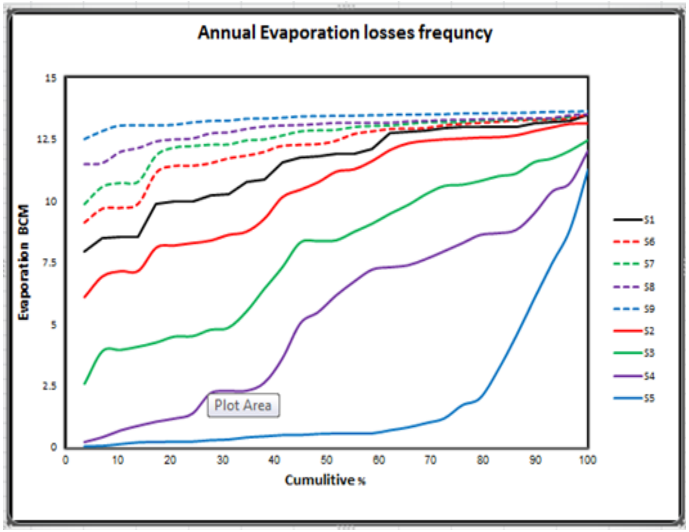


Fig 8 : frequency curve of annual Evaporation from AHDR BCM

6.5.Sensitivity of Toshka spillway discharges to climate change

Annual discharges to Toshka spillway vary between 1.032, 13.39 BCB with a mean of about 1.81 BCM and occur in approximately 42 % of years for the baseline climate scenario (figure 9. The outflows discharged to Toshka Spillway are influenced by change in the annual inflow and level upstream the AHD. For example, discharges to Toshka spillway are negligible in decrease scenario due to reduction of the reservoir water levels in this case. Table 7 is a summary characterization of variation in the annual discharges to Toshka spillway

Table 7: Annual discharges to Toshka spillway variations characteristics in the AHD

scenarios	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*
maximum Annual discharge to T .S.W	13.4	7.32	0.00	0.00	0.00	14.7	15.4	15.3	17.20
average A Annual discharge to T .S.W	1.81	0.68	0.00	0.00	0.00	2.78	4.00	5.85	11.58
minimum Annual discharge to T .S.W	1.03	0.01	0.00	0.00	0.00	0.15	0.17	0.02	0.74

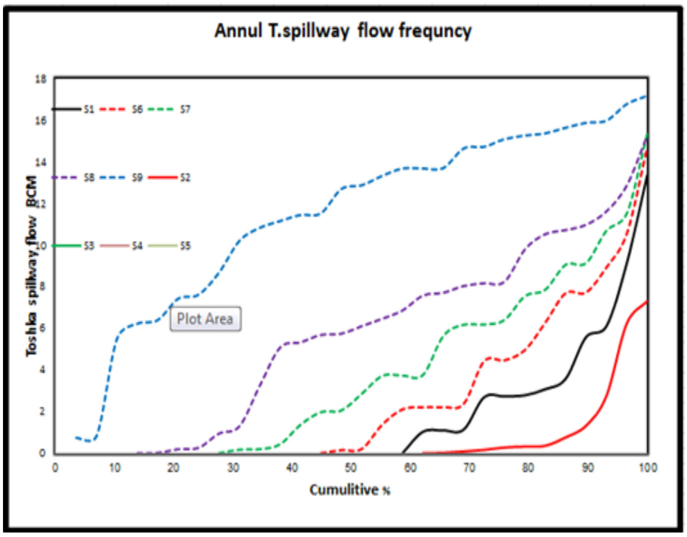


Fig 8 : frequency curve of annual discharge to Toshka spillway BCM

7.Conclusions and Recommendations

1- The study showed how climate changes affected the reservoir operation in case of flood or drought scenarios.

2- For an extreme reduce scenarios, irrespective of the level of inflow reduction, Egypt might have to face a severe drought

3- 2- For an extreme increase scenarios, Egypt has been facing a severe flood might affect the Hydraulic Structures located along the stream

4- Hydropower production at AHD is projected to increase in the increase scenarios to (107-198) percent of historical average production, But hydroelectric power generated by the dam decreases sharply at dryer scenarios.

5- The water level drops sharply in extreme dryer scenarios which lead to hydropower generators stopped

6- Climate impact assessments on the AHDR operation have produced meaningful results that can now be incorporated in water management and policy-making considerations;

7- Current operating rules for the dam's reservoir may need to be developed to suit the potential changes, whether to increase or to decrease

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