ASSESSING THE VARIABILITY OF INFLOWS AT ASWAN HIGH DAM DUE TO OUTFLOW CHANGES FROM VICTORIA LAKE RESULTING FROM CLIMATE CHANGE

Mohamed Nour El Dien, Aly El. Bahrawy, Ayman Nasar, Sherien Zahran

ABSTRACT

In this research the Nile Decision Support System (NILE-DST) was tooled to assess the variability of the inflows at Aswan High Dam (AHD) due to the outflow changes from Victoria Lake resulting from climate changes and the increase in water demands. Different scenarios were established where the outflow from Victoria Lake was decreased by 3,10,18,25,37,55,75 and 100%. The scenarios considered a *time span* of 63 years (1913-1976) in which a natural flow period (1913-1976), a dry period (1920-1960) and a wet period (1961-1976) were distinguished. The model was run and results of inflows at the different river nodes (i.e. Victoria Lake, Packwash, Mogalla, Sudd Exit, Malakal, Gabl El-Aulia, Dongola and AHD) and the properties of the reservoirs (i.e. storage capacity, water level and evaporation)] were obtained. These results were analyzed and plotted. From these plots the impact of the variability in the outflow from Victoria on the AHD was assessed. On the other hand, an adaptive solution (constructing a diversion canal "Jonglie Canal" to by-pass the swamps in order to decrease the evaporation losses) was proposed in order to compensate for the inflow reduction at AHD. As a *conclusion* from this research, it was found that the AHD will be considerably affected by the variability of the outflows from Victoria Lake. It was also found that Jonglie Canal would serve as a compensator.

فى هذاالبحث تم إستخدام نموذج (Nile-DST) Nile Decision Support System وذلك لتقييم لإختلاف التـصرف الداخل إلى السد العالي و ذلك نتيجه للتغيرات التى تحدث للتصرفات الخارجه من بحيرة فيكتوريا نتيجة للتغيرات المناخية و إستخدامات المياه. فقد تم تخطيط عدة سيناريوهات لتعبر عن تغير تصرفات بحيرة فكتوريا و قـد تـم الأخذ فى الإعتبار بتخفيض التصرف بنسبة ٣، ١٠، ١٨، ٢٥، ٣٧، ٥٥، ٧٥، ١٠٠.% و قـد إختـصت هـذه السيناريوهات بحقبة زمنية مقدارها ٦٣ عام (١٩١٣-١٩٧٦) حيث تم إكتشاف فتـرة جافـة (١٩٢٠-١٩٦٠) و فتره رطبة (١٩٦١-١٩٧٦). و تم تشغيل النموذج و بواسطته تم حساب التصرفات عند أماكن مختلفة و تم تحديد صفات الخزانات المختلفة و منسوب المياه. و تم تحليل هذه النتائج و توضيحها بيانيا و منها تم تقدير تأثير تغيـر التصرفات فى بحيرة فيكتوريا على السد العالى. و بناء عليه تم إقتراح حل يوائم هذا التغير و هـو إنـشاء قنـاة جونجلى لتذلل كل العقبات و تقلل البخر. كما تم تمثيل هذا الحل و من نتائجه إتضح أن التصرفات القادمـة إلـى السد العالى سوف تتحسن و بالتالى فقد أوصى البحث بتنفيذها حتى تعدل التصرفات القادمة إلى السد العالى.

Keywords: Nile Decision Support System, Aswan High Dam, Victoria Lake, Jonglie Canal.

1. INTRODUCTION

The Nile River Basin is a major basin in the world where its inhabitants are especially sensitive to climate change. Along its 3,000 km course, the Nile losses a huge amount of water by evaporation. This makes water supply extremely sensitive to temperature and precipitation variations. Climate change is thus likely to impose additional pressures on water availability, water accessibility and water demand in Africa. The population at risk, due to water stress, in Africa is expected to be between 75-250 million and 350-600 million by years 2020 and 2050, respectively, **IPCC (2007).**

This study was thus initiated with the objective of assessing the variability of the inflows at Aswan High Dam (AHD) due to the outflow changes from Victoria Lake resulting from climate changes and the

increase in water demands. In this paper, the following are displayed:

- an overview to the Nile River Basin together with Victoria Lake
- the tooled NILE-DST "Nile Decision Support System" so as its theory and structure
- the established scenarios to Victoria Lake outflows and their assumptions
- the analysis, results and the adaptive solution (Jonglie Canal)
- conclusions and recommendations

2. NILE RIVER BASIN AND VICTORIA LAKE

Regarding the Nile River Basin, Figure (1), its annual runoff potential is estimated to be approximately 85 billion cubic meters (BCM). The Nile River Basin has low specific discharge (total

runoff per drainage area) as compared to other major river basins and exhibits great difference in water availability among the sub-basins. The per capita availability of water in the Nile Basin countries will decrease due to population growth. Thus, the per capita availability of water for lower riparian countries is highly dependent upon mutual cooperation with upstream countries. Moreover, the trans-boundary nature of the river further aggravates the problem. *As for the Nile River*, it is a home and source of livelihood to approximately 160 million people. It is the longest river in the world with a total length of 6700 km. It traverses an extremely wide band of latitudes, from 4° south to 32° north. The total area draining into the Nile River system is about 3 million km² and extends over 10 African countries. *Regarding Victoria Lake*, Figure (2), it is located in the middle of the three Eastern African countries. Most of its northern half is in Uganda, southern half in Tanzania and a relatively small northeastern portion gulfing into Kenya. The lake shores are shared by three countries (i.e. Tanzania, Uganda and Kenya). The lake is located within 0.2°N-3.0°S and 31.5°E-34.5°E. It is 400 km long and 280 km wide. Its extensive water surface is situated at an altitude of 1134 m AMSL. The lake's drainage basin covers an area of about 195,000 km² that extends to parts of Rwanda and Burundi to the west of the lake. Compared to other lakes, Victoria Lake is quite shallow; with mean (maximum) depth of 40m (84m) and a coastline of about 3440 km. Victoria Lake Basin climate is characterized by periodic episodes of wet/dry conditions. Some recent events include the 1961/62, 1997/98 and 1997/98 floods that left behind a huge trail of damage to property and infrastructure. On the other hand, the lake water temperatures usually follow the magnitude of solar radiation input but with some lag. Over the lake surface, the mean monthly solar radiation is estimated to be 240-270 W/m² and the surface water temperatures ranges between 24°C and 28° C. The temperature so as human activities and amount of precipitation affect the lake level.

3. NILE–DST MODEL (THEORY AND STRUCTURE)

The Nile Decision Support Tool was developed as part of the Nile Basin Water Resources Project under the sponsorship of the Food and Agriculture Organization of the United Nations (FAO). The Nile-DST was developed in Georgia Institute of Technology. It includes six main components namely database, river simulation and management, agricultural planning, hydrologic modeling, remote sensing and water quality. *Regarding the theory of the model*, it is based on a set of equations which describe the response of the various system elements (reservoir and routing model reaches) to various

inflow and release scenarios. The dynamics of the reservoirs are modeled by water balance equations, while that of the routing reaches by the routing equation, Yao and Georgakakos, (2003). *As for the Nile RSM*, its function is to process the data and quantify the response of the basins to water use, and development/management scenarios. The Nile RSM includes models that fall under the categories of river-reservoir simulation, system optimization and scenario assessment. *Regarding the structure of the NileDST-RBM*, it includes 14 existing and planned reservoirs (Victoria, Kyoga, Albert, Gebel Ailia, Tana, Karadobi, Mabil, Mendaia, Border, Roserires, Sennar, Girba, Merwe, AHD), 20 existing and planned hydro power plants (Owen Falls, Bujagali, Kalagala, Karuma, Ayogo North, Ayago South, Murchison, Tana, Tana-Beles, Karadobi, Mabil, Mendaia, Border, Roseires, Sennar, Girba, Merowe, AHD, OAD, and Toshka), 13 inflow nodes, 16 river nodes (Victoria Lake, Packwash, Mongalla, Sudd Exit, Malakal, Gabal El-Aulia, Dongola and AHD), and 15 demand nodes, Figure (3).

4. PROPOSED SCENARIOS AND ASSUMPTIONS

The average annual outflow from Victoria Lake during the period 1913-1976 was 27 BCM. Eight (8) scenarios were proposed to represent the outflow from Victoria Lake. The proposed scenarios were to decrease the outflow from Victoria Lake by 3,10,18,25,37,55,74,100% (i.e. 1,3,5,7,10,15,20,27 BCM which represent 26,24,22,20,17,12,7,0 BCM, respectively). It is to be noted that increasing the outflow was considered but is not displayed in this paper. The proposed scenarios were based upon an *assumption*. This assumption is "water outflow from Victoria Lake might decrease due to":

- producing food by irrigation water not by rain which might cause the consumptive potentially to increase by 5-10 BCM per year over the next 40 to 50 years
- climate change and withdrawal increase to meet the human activities

On the other hand, *a reference scenario* was established for comparison purposes. The rules used for this scenario were as follows:

- Victoria, Kyoga, and Albert Lakes follow the natural outflow policy.
- Roseries, Sennar, and Girba follow the customized operating rules used in practice.
- The AHD releases according to the downstream demand target levels
- The Gebel El Aulia reservoir operates according to its target elevation rule.

The above scenarios were simulated under three cases. These are:

- Natural flow during the period (1913-1976)

•• Wet period (1920-1960)

• Dry period (1961-1976)

5. ANALYSIS, RESULTS AND ADAPTIVE SOLUTION

From the simulated scenarios results (i.e. water levels, storage, net evaporation of the reservoirs so as the inflows to the nodes) were obtained, analyzed and presented. It is to be noted that only a sample of the results at AHD is given here. Figure (4), (5) and (6) show the average annual inflows for all the modeled scenarios at AHD, during the natural flow period *(with a maximum of 100 BCM)*, dry and wet periods, respectively. On the other hand, Figures (7a,b,c) show the quantity, change and % change in the inflow at AHD as a result of decreasing the outflow from Victoria Lake during the natural flow period, respectively. As for Figures (8a,b,c) and (9a,b,c) they show the same but for the dry and the wet periods, respectively. The obtained quantity, change and percentage change of inflow at AHD were subjected to a regression analysis from which the equations representing the impact trends were obtained and are given on these figures and Table (1). On all the above figures, the reference scenario results are given for comparison purposes.

Based on the above figures, clear was that the AHD would be affected by 0.25-4.5, 0.25-4 and 0.3- 5.5% due to the outflow decrease from Victoria Lake (by 3-100%) during the natural flow period, dry and wet periods, respectively . *Therefore, an adaptive solution was proposed.* This solution was to implement a diversion canal that could avoid any obstruction (i.e. swamps) in order to decrease the evaporation losses. This diversion is Jonglie Canal (360km long). It originates from Bahr El-Gabal and flows till it meets the White Nile at the upstream junction to Sobat. The canal will be implemented in 2 phases (phase 1: carrying 20 Mm³/d and phase 2: carrying 40 Mm³/d). This canal was simulated by the model under the different scenarios. The results were obtained, analyzed and presented on Figures (10), (11), (12) and (13). They show the: .

➤ inflow at the AHD after operating Jonglie Canal phase 1 and 2 *(the inflow increased from a maximum of 100BCM, Figure (4), to be > 100BCM after the operation of Jonglie Canal)*

➤ water level at AHD that will range between 180 and 170 m, after operating Jonglie Canal Phase 1 and 2

➤ AHD storage that will range between 142 and 70 BCM, after operating Jonglie Canal Phase 1 and 2

➤ net evaporation at AHD that will range between 16 and 9 BCM , after operating Jonglie Canal Phase 1 and 2

6. CONCLUSIONS AND RECOMMENDATIONS
From the above figures, it was concluded that:

• The inflow at AHD would be reduced by 0.25-4.5, 0.25-4 and 0.3- 5.5% due to the outflow decrease from Victoria Lake (by 3-100%) during the natural flow period, dry and wet periods, respectively. This means it will be mainly affected during the wet period, relatively less affected during the natural flow period and the least effect occurs during the dry period.

• The established graphs [figures (7, 8 and 9)] could foresee the quantity, change and % change in the inflow at AHD due to the decrease in the outflow from Victoria Lake.

•• The derived equations [Table (1)] could predict the quantity, change and % change in the inflow at AHD due to the decrease in the outflow from Victoria Lake.

•• The derived equations would support decision makers to predict and manage the water inflows at the AHD during wet (floods) and dry seasons (droughts).Using such equations might reduce the hazards during floods as precautions will be previously undertaken.

• Jonglie canal proved to be a reasonable adaptive solution that might compensate the reduction of the inflow at AHD.

•• After operating Jonglie Canal Phase 1 and 2, the following will occur:
  ▪ The inflow at AHD will increase from a maximum of 100BCM (before operating the canal) to be > 100BCM.
  ▪ The water level at AHD will be between 180 and 170 m.
  ▪ AHD storage will be between 142 and 70 BCM.
  ▪ The net evaporation at AHD will be between 16 and 9 BCM.

It is thus further recommended to:

• execute more researches to predict climate variability at local and regional scale

• undertake more research in the field of decision support system modeling for the entire watershed areas in Nile basin

• develop an integrated plan for adaptation and mitigation of the impact of climate changes

• develop a socio-economic and an environmental modules linked with the DST-NILE basin to study the assessment of the impacts on sustainable development

7. REFERENCES

[1] *Georgakakos, A.P., and H. Yao, (2003).* The Nile Decision Support Tool (Nile DST): River and Reservoir Simulation and Management, prepared

for the Food and Agriculture Organization of the United Nations, *Technical Report*, Georgia Water Resources Institute and Georgia Tech.

[2] *IPCC, 2007.* Working Group II Fourth Assessment Report: *Impacts, Adaptation and Vulnerability.* Available online at www.ipcc-wg2.org

[3] *Johns, T. and Co-authors, 2005.* HadGEM1 – Model description and analysis of preliminary experiments for the IPCC Fourth Assessment Report. Hadley Centre Technical Note 55, Met Office, UK, 74 pp.

[4] *Mohamed, Y.A., van den Hurk, J.J.M., Savenije, H.H.G. and Bastiaanssen, W.G.M., 2005.* Hydroclimatology of the Nile: results from a regional climate model. *Hydrol. Earth Syst. Sci. Discuss.*, 2, 319-364.

[5] *New, M., Hulme, M. and Jones, P., 2000.* Representing twentieth-century space-time climate variability. Part II: Development of 1901-96 monthly grids of terrestrial surface climate. *J.Climate*, 13(13), 2217-2238.

Figure (2) Victoria Lake Basin
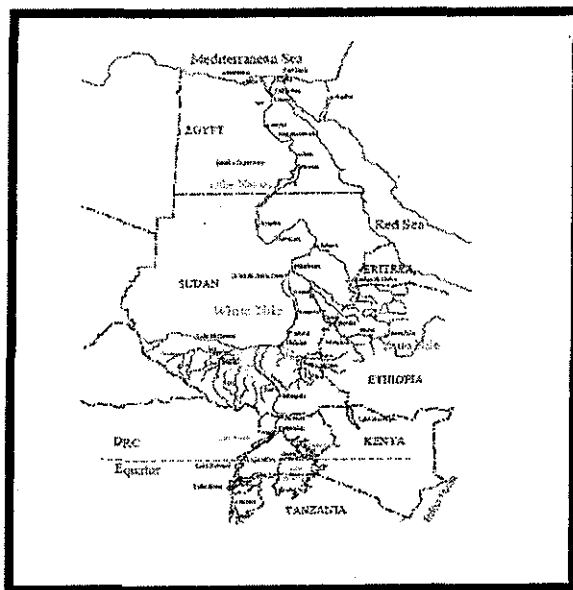
Figure (1): A map of the Nile Basin
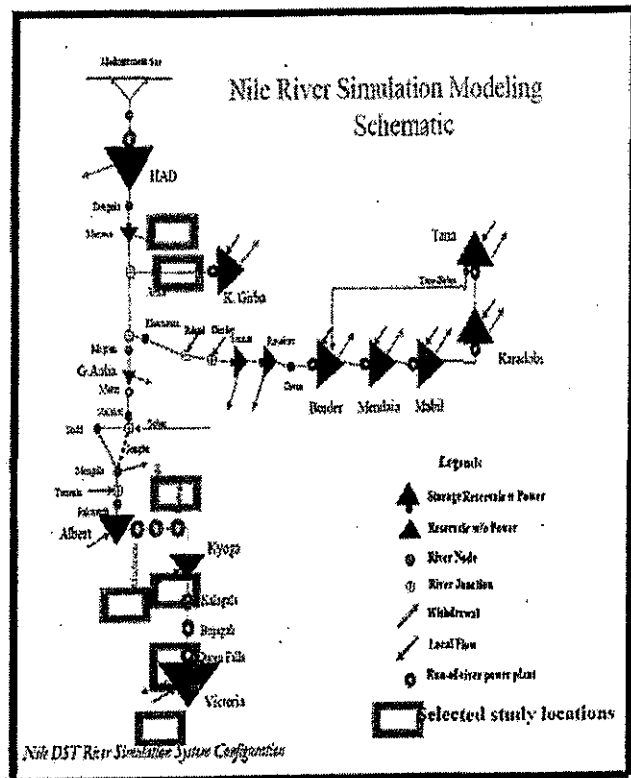
Figure (3) Scheme of Nile-DST
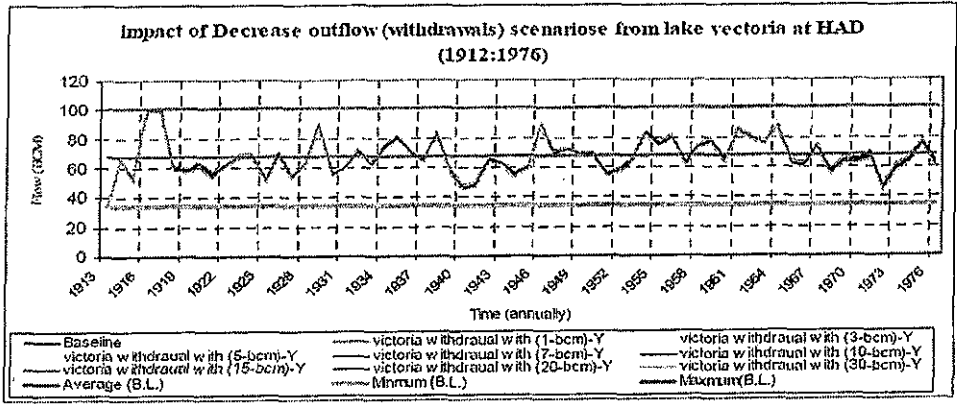
Figure (4) Average annual hydrograph for the different scenarios
at *HAD* during the period of *natural flow 1913-1976*
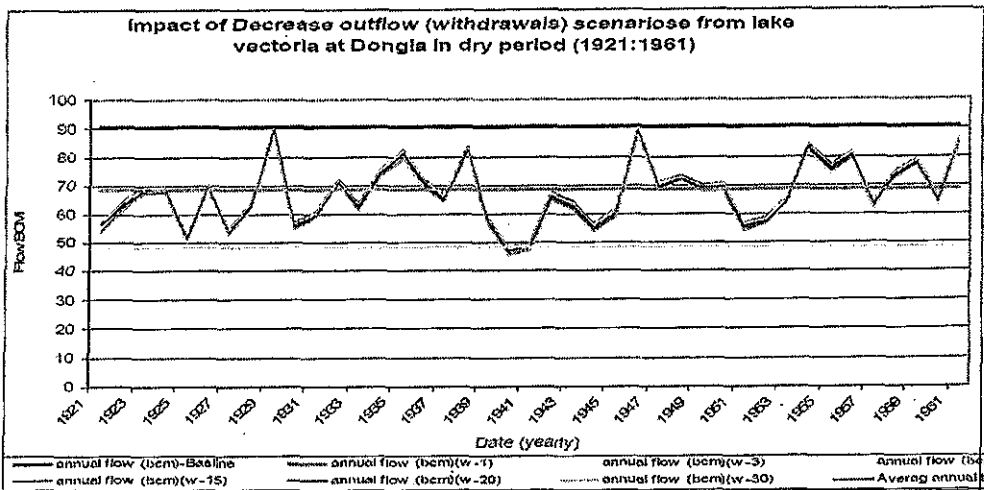
Figure (5) *Average annual hydrograph for the different scenarios*
at HAD during the dry period 1920-1960
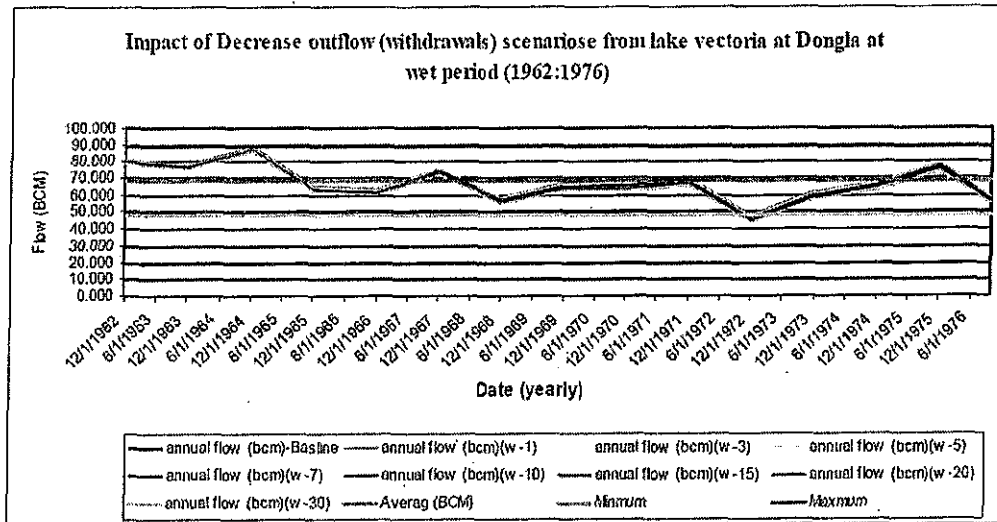
Figure (6) Average annual hydrograph for the different scenarios
at *HAD* during the *wet period 1961-1976*
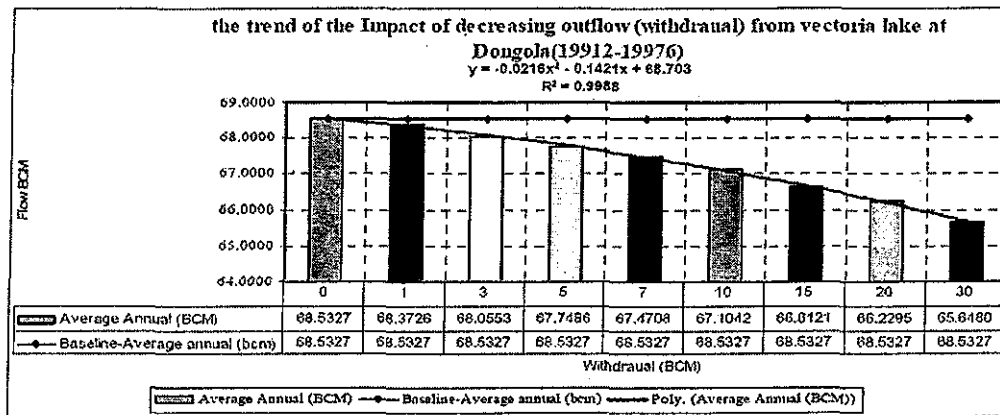
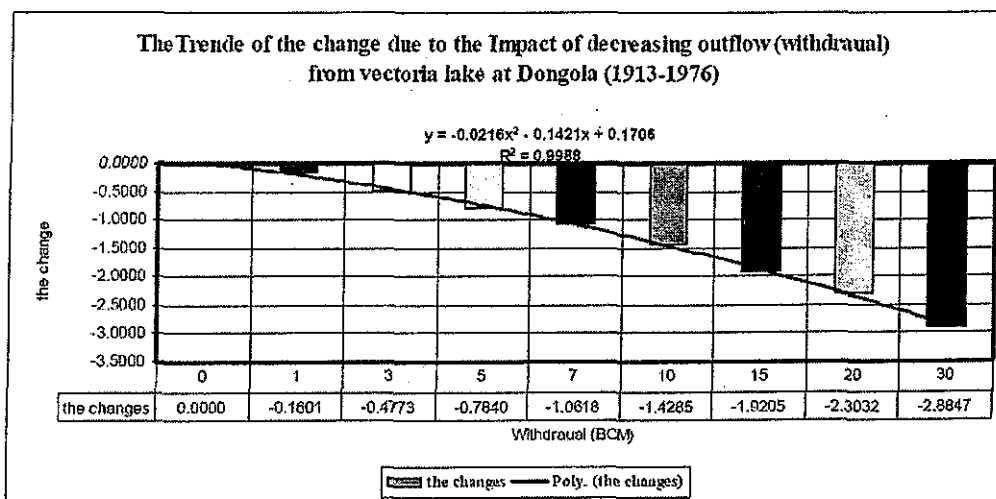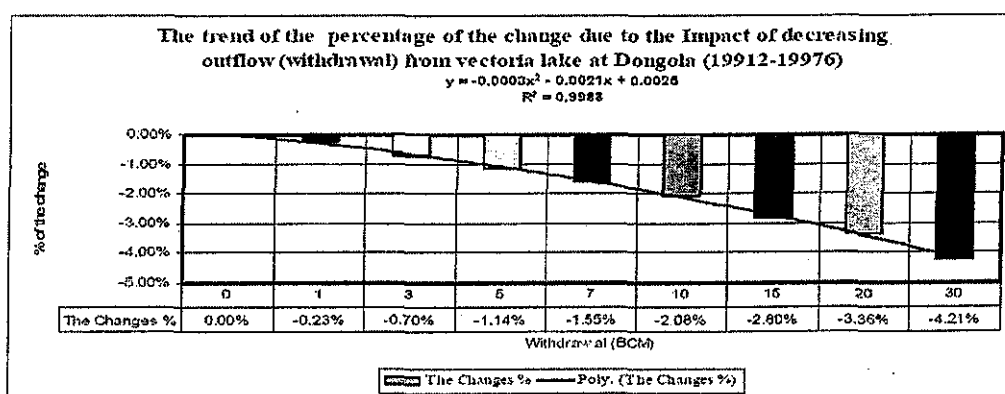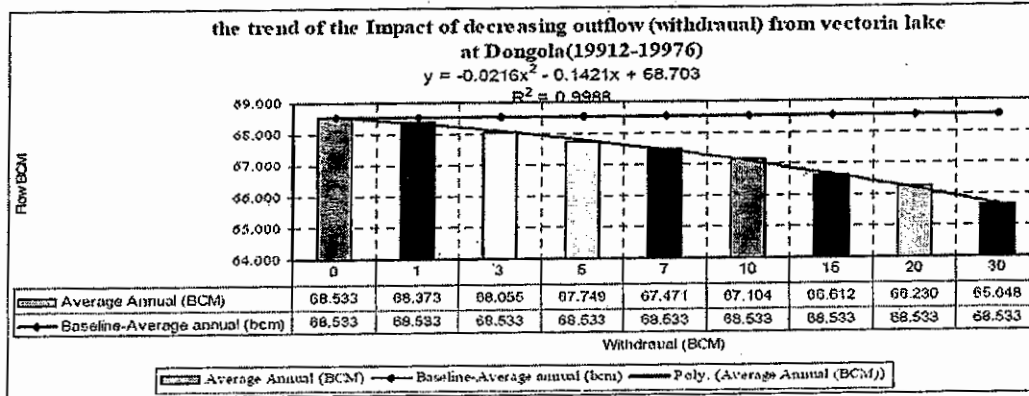**Figure (7a)** The trend of the inflow at AHD for the different scenarios during the period of natural flow 1913-1976

Figure (7b) The trend of the change in the inflow at AHD for the different scenarios during the period of natural flow 1913-1976

Figure (7c) The trend of % change in the inflow at AHD for the different scenarios during the period of natural flow 1913-1976

Figure (8a) The trend of the inflow at AHD for the different scenarios
during the dry period 1920-1960
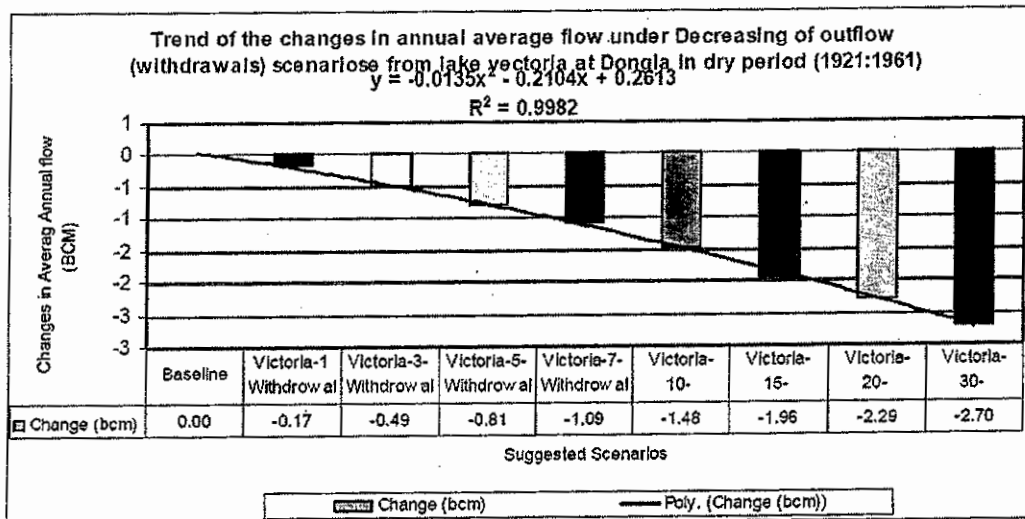
Figure (8b) The trend of the change in the inflow at AHD for the different scenarios
during the dry period 1920-1960
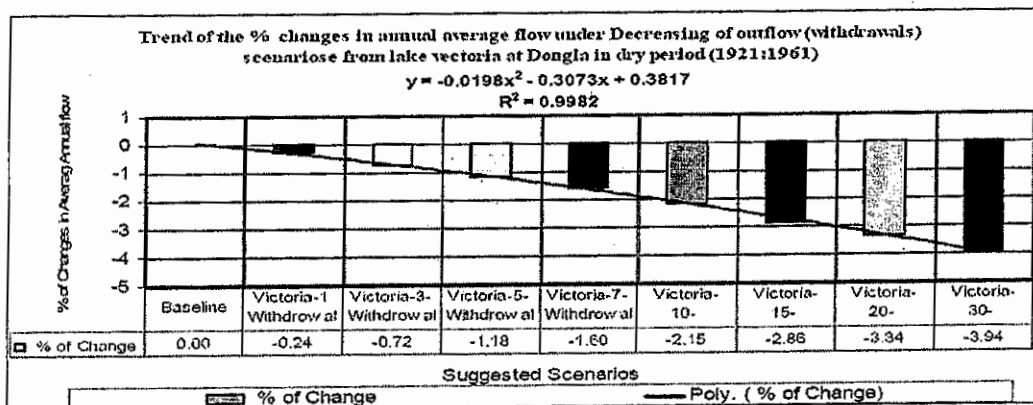
Figure (8c) The trend of % change in the inflow at AHD for the different scenarios
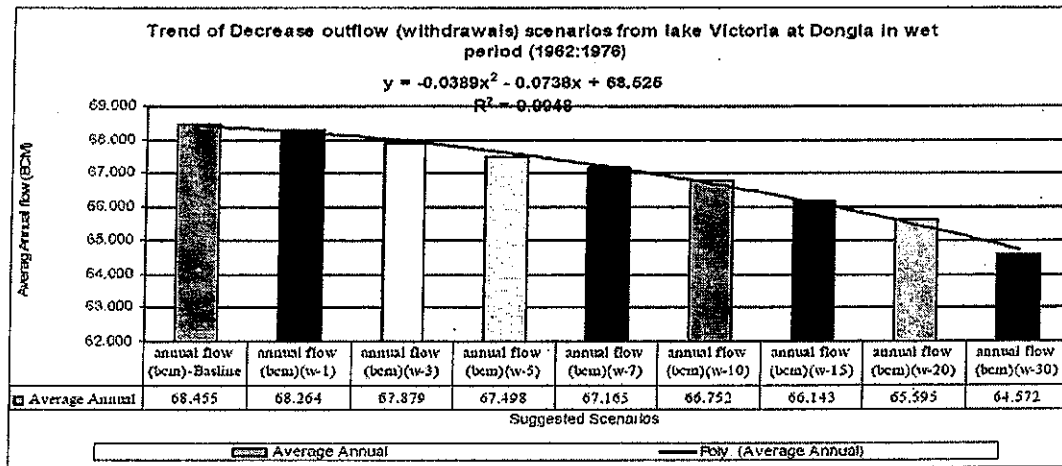during the dry period 1920-1960

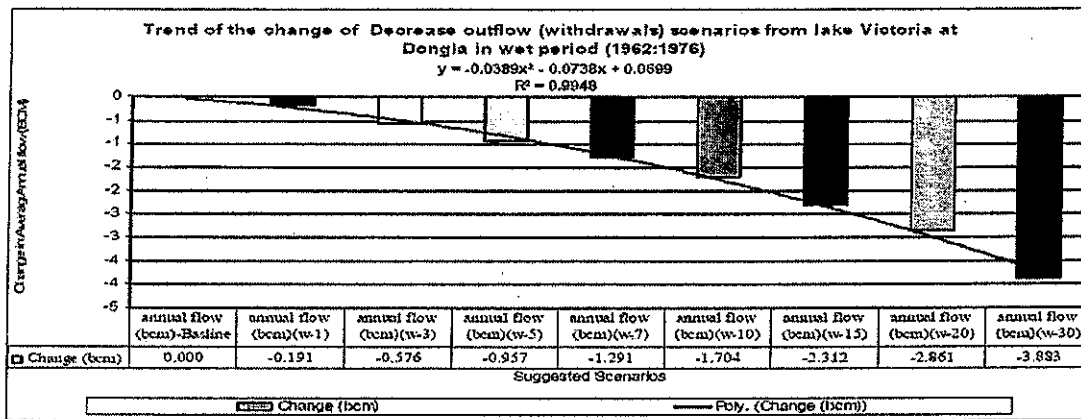**Figure (9a)** The trend of the inflow at AHD for the different scenarios during the wet period 1960-1976

Figure (9b) The trend of the change in the inflow at AHD for the different scenarios during the wet period 1960-1976
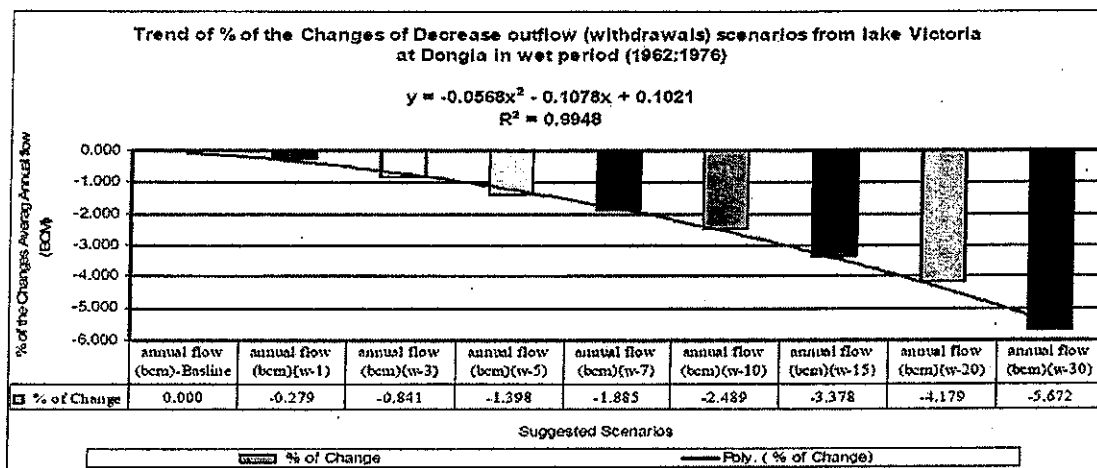

Figure (9c) The trend of % change in the inflow at AHD for the different scenarios during the wet period 1960-1976

Table(1) The equations defining the trends of the quantity, change and % change of the inflow at AHD due to the decrease in the outflow from Victoria Lake During the natural flow period, dry and wet periods.

Trend	Equation	R^2	Type
	Natural Case		
	Y1 = -0.0216x - 0.1421x + 68.703	R^2 = 0.9988	Quadratic
Flow (BCM)	Y1 = -0.0135x - 0.2104x + 68.717	R^2 = 0.9982	Quadratic
	Y1 = -0.0389x - 0.0738x + 68.525	R^2 = 0.9948	Quadratic
	Dry Period		
	Y2 = -0.0216x - 0.1421x + 0.1706	R^2 = 0.9988	Quadratic
Changes (BCM)	Y2 = -0.0135x - 0.2104x + 0.2613	R^2 = 0.9982	Quadratic
	Y2 = -0.0389x - 0.0738x + 68.525	R^2 = 0.9948	Quadratic
	Wet Period		
	Y3 = -0.0003x - 0.0021x + 0.0025	R^2 = 0.9988	Quadratic
% Of Change	Y3 = -0.0198x - 0.3073x + 0.3817	R^2 = 0.9982	Quadratic
	Y3 = -0.0568x - 0.1078x + 0.1021	R^2 = 0.9948	Quadratic

Where

Y1 : The inflow at AHD
Y2: the changes in the inflow at AHD
Y3: the percentage change in the inflow at AHD
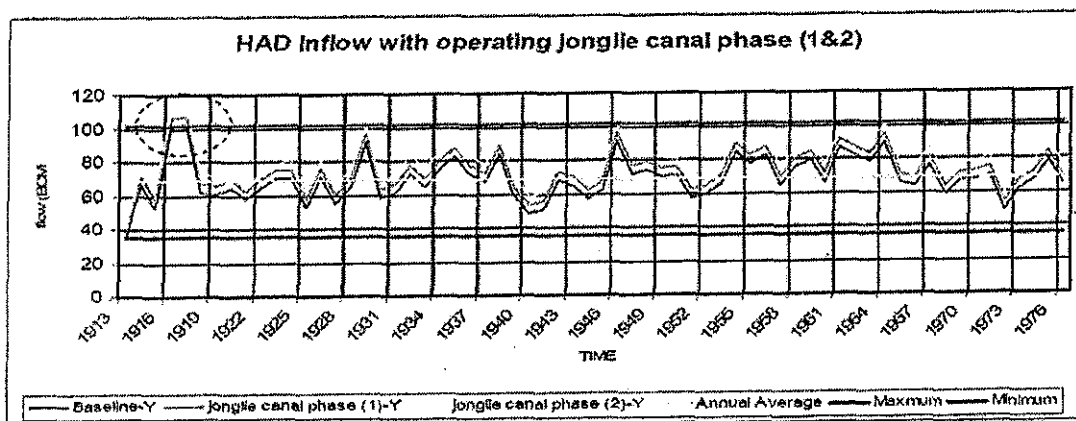X: the decrease in the outflow from Victoria Lake

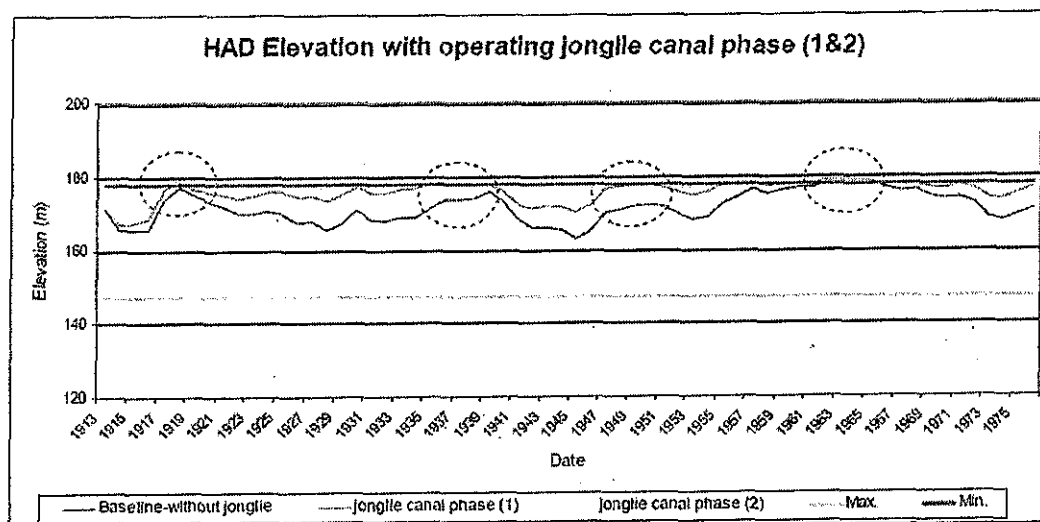**Figure (10)** inflow at AHD after operating Jonglie Canal phase 1 and 2

Figure (11) the water level at AHD after operating Jonglie Canal Phase 1 and 2
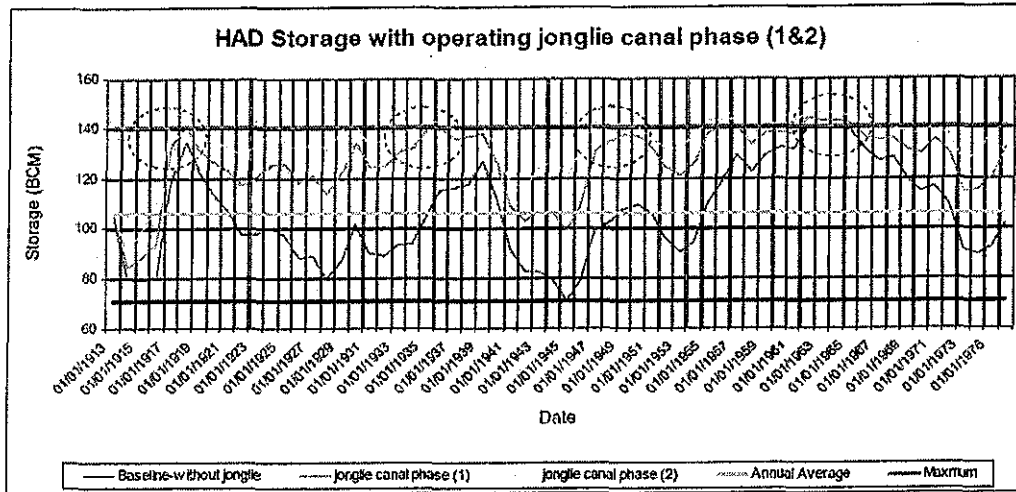
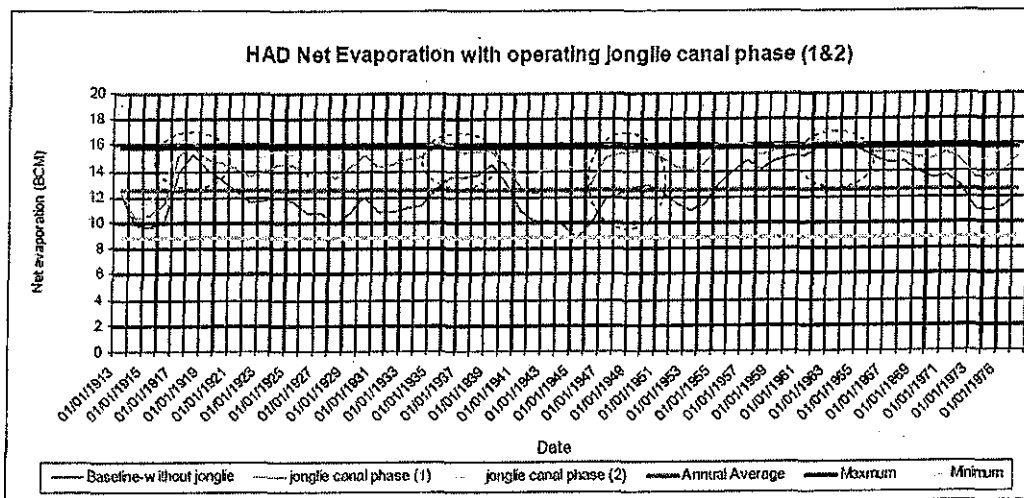**Figure (12)** AHD storage after operating Jonglie Canal Phase 1 and 2

Figure (13) net evaporation at AHD after operating **Jonglie Canal Phase 1 and 2**