Effect of lag time on the water balance Of Aswan High Dam Reservoir

By

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Abstract

In the agreement between Sudan and Egypt in 1959, the total annual water losses from Aswan High Dam Reservoir (AHDR) were estimated primarily as $10*10^9$ m^3 for the full utilization of the Nile water. These losses consist of $9*10^9$ m^3 as annual evaporation losses from water surface and $1*10^9$ m^3 as seepage and absorption losses. The hydrological data (water level and discharge) at Dongola station as inlet (750 km upstream AHD), just upstream AHD, and at Aswan station as outlet (6.5 km downstream AHD) were collected and analyzed. The length of back water curve in AHDR is 500 km upstream AHD and Dongola station is 250 km upstream that curve. Then Dongola station represents the natural flow conditions of the river while Aswan station is under full control. Taking into consideration the lag time between Dongola and AHD, it was found that there is a considerable variation in the annual losses values for different years. It ranges between $4*10^9$ m^3 to $18*10^9$ m^3. This difference depends on the case of flood (high, moderate, or low), water level at AHD, and water level at Dongola station. The estimation of actual water losses is the aim of this research. The estimation and prediction of water losses will help in the regulation of AHDR especially in the high flood years such as the year 1978, 1989 and 1998.

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Problem identification

Before the construction of AHD and for design purpose, the expected losses were estimated according to the observation of evaporation at Wadi-Halfa and Aswan by using half of pitch evaporimeter observation values. After the construction of AHD, in order to measure the actual items of evaporation losses, a network has been established by installing a manually operated floating station at Aswan (3 km upstream AHD) and another shore station, to collect the meteorological data required for evaporation studies. The losses have been calculated as an average annually. In these studies, no weight has been given to the effect of lag time between the inlet and the outlet of AHD reservoir. In the water balance equation, there are two items represent the discharge at the inlet and at the outlet. In the application of this equation at such a huge reservoir (500 km length, 12 km width in average, and 6500 km^2 surface area at water level 182 m above Sea level), the time consumed by water to travel from the inlet to the outlet should be given an important consideration. In this research, the lag time has been included in the water balance equation and its effect in the total losses has been considered.

Research objectives

The estimation and prediction of water losses will help in the regulation of AHD reservoir especially in the high flood years such as year 1978, 1989, and 1998. Therefore the objectives for this research are to:-

1- Estimate the actual water losses in AHD reservoir since 1964.

2- Develop an equation which correlates between water level at Dongola station and water level just upstream AHD, and the lag time.

3- Estimate the actual values for the lag time during the period (1965-1993) based on ten days mean.

Estimation of lag time

The difference between the annual summation of the inlet water to the reservoir and the annual summation of the outlet water from the reservoir represents the change in the annual storage and the annual total loss in any reservoir. The annual summation combined the rising and falling stages. In the Nile River there are two stages namely:

1- The rising stage phenomena: it is distinguished by the remarkable increase in the discharge values, and the increase in the river levels stages. For Nile River this generally, starts by the end of July and arrives its peak around the middle of September.

2- The falling stage phenomena: all remaining observations (October to June) are classed as falling stage values.

The lag time of water (i.e. traveling time) between two stations in the river calculated by following the movement of waves between these two stations. Therefore:-

The water flow velocity, C, from Dongola station to AHD station is given by the following

$$C = \frac{1}{b} . \frac{dQ_w}{dh} \tag{1}$$

equation (H.C. Frijlink 1964)

Where C: is celerity of water flow

Q_w: is the discharge at Dongola station

h: is the corresponding water depth at Dongola station

b: is the average width between the two stations.

$$T = \frac{L}{C} \tag{2}$$

The time is calculated according to the equation:

Where L: is the distance between the two stations

T: is time

C: is celerity

An example of calculation the lag time between Dongola (750 km upstream AHD) and Dal Cataract (500 km upstream AHD) in case of discharge 60 million m^3 /day at Dongola is as follows:

For Q_w = 50 million m3 /day h = 9.13 m

For Q_w = 70 million m3 /day h = 9.38 m

$$\frac{dQ_w}{dh} = \frac{(70 - 50) * 10^6 \, m^3 /day}{(9.38 - 9.13)m} = 80 * 10^6 \, m^2 /day \tag{3}$$

Average width of the river between Dongola and Dal Cataract = 636 m

$$C = \frac{1}{b} \cdot \frac{dQ_w}{dh} = \frac{(80 * 10^6)m^2/day}{636m} = 12.576 * 10^4\, m/day \tag{4}$$

$$T = \frac{L}{C} = \frac{(750 - 500) * 10^3\, m}{12.576 * 10^4\, m/day} = 1.99 days \tag{5}$$

In the estimation of lag time between Dongola and AHD, there are two different reaches. The first between Dongola and Dal Cataract which represents the end of back water curve, and the second is between Dal Cataract and AHD.

By applying this procedure, based on ten days mean, on the distance from Dongola to AHD We deduced a general equation in the form:-

$$T = \frac{A}{W^B} \tag{6}$$

Where *T*: is the lag time between Dongola and AHD in days

$$A = A_1(W.L. - H) + A_2 \tag{7}$$

$$B = B_1(W.L. - H) + B_2 \tag{8}$$

W: is the water level at Dongola gauge in m

Where *W.L.*: is water level just upstream AHD and *H*: is a specific value for water level upstream AHD and it takes the values (170.5, 160.5, 150.5, 140.5, 130.5, 120.5 m)

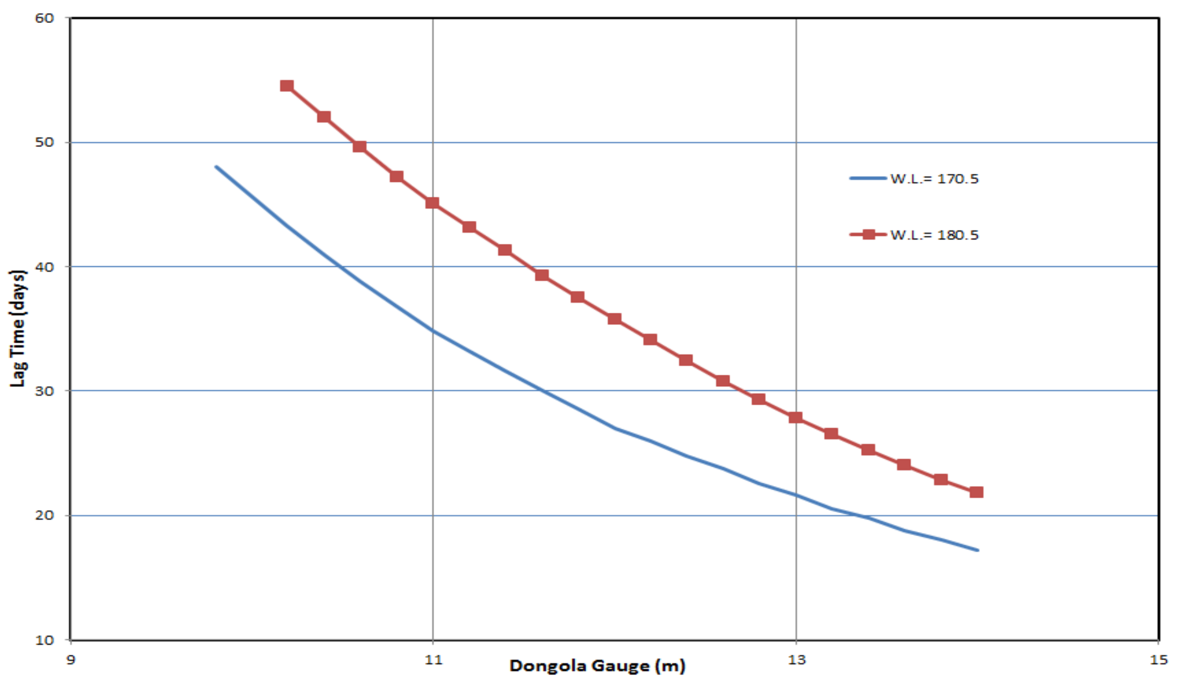
A_1, A_2, B_1, B_2: are constants depend on *H* values.

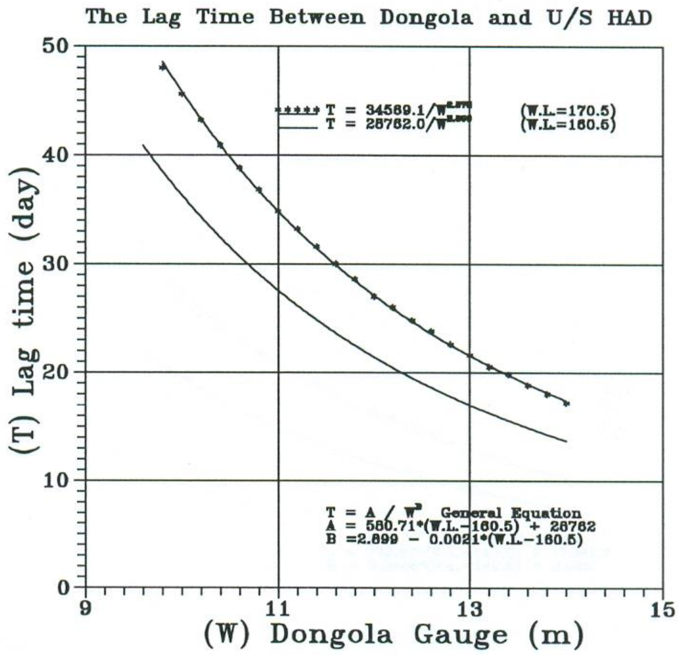
These constants have been estimated for different water levels at AHDR and the different forms of this equation are indicated in figures 1 to 7. These equations have been applied for the period from 1965 to 1993 using the ten days mean of water level at Dongola station and upstream AHD to estimate the lag time values. These values were used to get the average annual values of lag time, where they found to range between 10 days to 49 days. The results obtained from these curves are indicated in table 1.

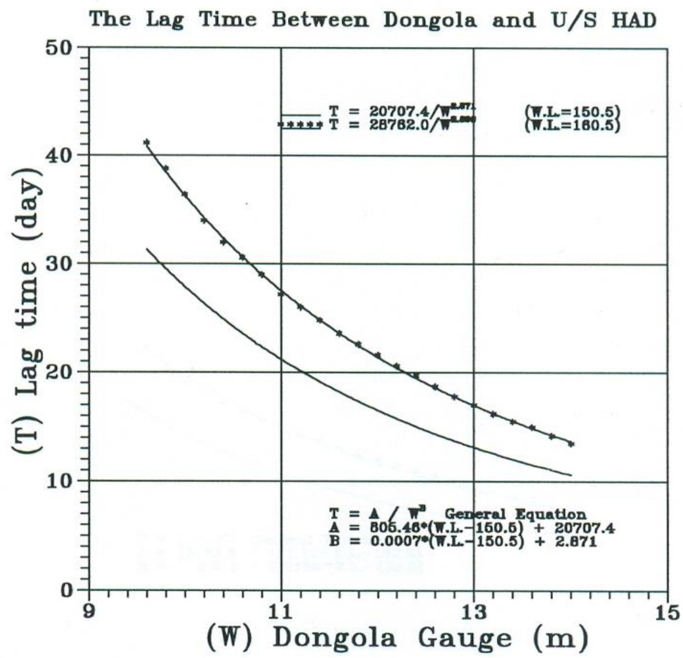
Table 1: Lag time from Dongola to AHD

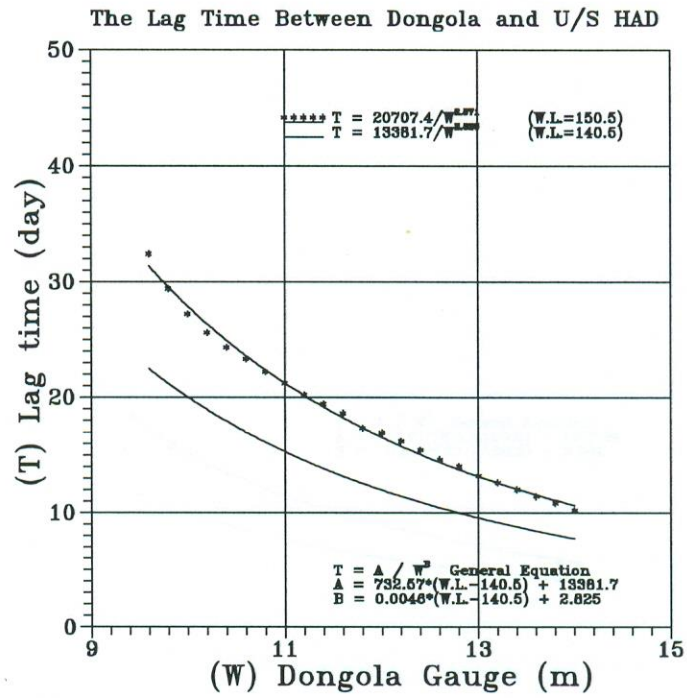
Year	Lag time (days)	Year	Lag time (days)
1965	10	1980	49
1966	14	1981	49
1967	18	1982	49
1968	25	1983	46
1969	31	1984	45
1970	34	1985	38
1971	37	1986	38
1972	40	1987	33
1973	38	1988	39
1974	37	1989	39
1975	39	1990	40
1976	46	1991	42
1977	47	1992	40
1978	47	1993	40
1979	48		

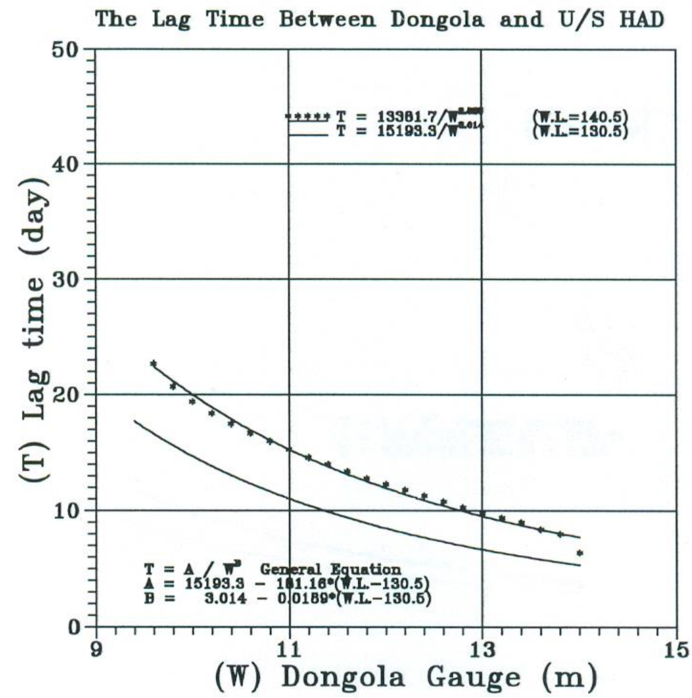
Figure 1: Lag Time Between Dongola and u/s AHD

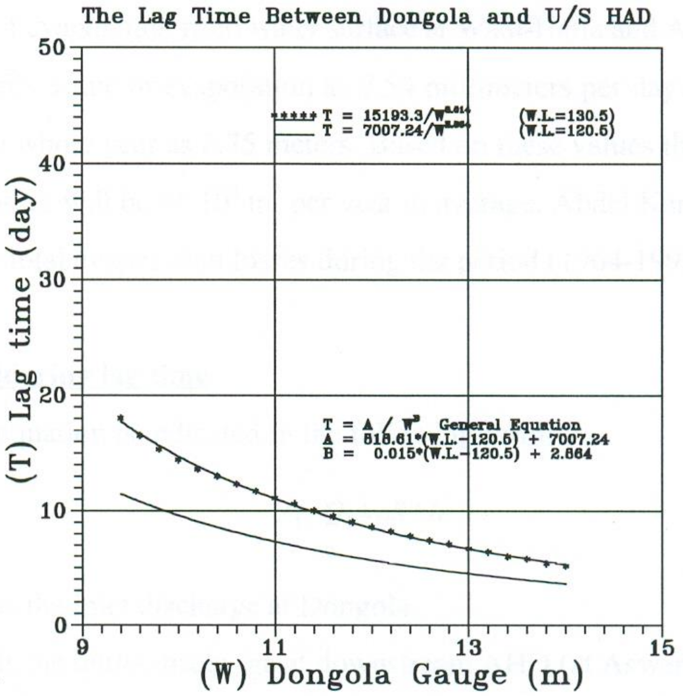


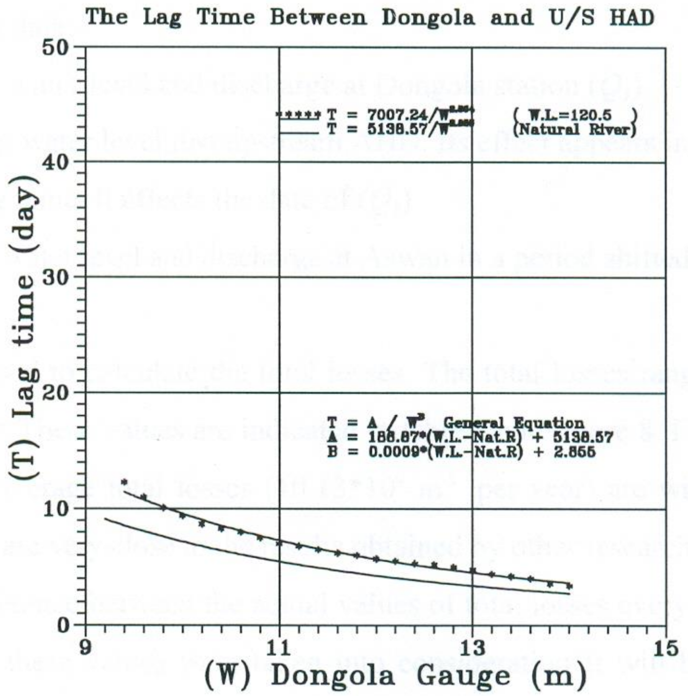

The Lag Time Between Dongola and U/S HAD
T = 34569.1/W
T = 28762.0/W
(W.L.=170.5)
(W.L.=160.5)
T = A / W^B General Equation
A = 580.71*(W.L.-160.5) + 28762
B =2.899 - 0.0021*(W.L.-160.5)
50
40
30
20
10
0
9
11
13
15
(T) Lag time (day)
(W) Dongola Gauge (m)


The Lag Time Between Dongola and U/S HAD
T = 20707.4/W
T = 28762.0/W
(W.L.=150.5)
(W.L.=160.5)
T = A / W^B General Equation
A = 805.46*(W.L.-150.5) + 20707.4
B = 0.0007*(W.L.-150.5) + 2.871
50
40
30
20
10
0
9
11
13
15
(T) Lag time (day)
(W) Dongola Gauge (m)


The Lag Time Between Dongola and U/S HAD
$T = 20707.4/W$ (W.L.=150.5)
$T = 13381.7/W$ (W.L.=140.5)
$T = A / W^B$ General Equation
$A = 732.57*(W.L.-140.5) + 13381.7$
$B = 0.0046*(W.L.-140.5) + 2.825$
(T) Lag time (day)
(W) Dongola Gauge (m)
0
10
20
30
40
50
9
11
13
15


The Lag Time Between Dongola and U/S HAD
$T = 13381.7/W$ (W.L.=140.5)
$T = 15193.3/W^{3.014}$ (W.L.=130.5)
$T = A / W^B$ General Equation
$A = 15193.3 - 181.16*(W.L.-130.5)$
$B = 3.014 - 0.0189*(W.L.-130.5)$
(T) Lag time (day)
(W) Dongola Gauge (m)
0
10
20
30
40
50
9
11
13
15


The Lag Time Between Dongola and U/S HAD
***** T = 15193.3/W^2.814 (W.L.=130.5)
T = 7007.24/W^2.664 (W.L.=120.5)
T = A / W^B General Equation
A = 818.61*(W.L.-120.5) + 7007.24
B = 0.015*(W.L.-120.5) + 2.664
(T) Lag time (day)
(W) Dongola Gauge (m)
0
10
20
30
40
50
9
11
13
15


The Lag Time Between Dongola and U/S HAD
***** T = 7007.24/W^2.664 (W.L.=120.5)
T = 5138.57/W^2.555 (Natural River)
T = A / W^B General Equation
A = 186.87*(W.L.-Nat.R) + 5138.57
B = 0.0009*(W.L.-Nat.R) + 2.555
(T) Lag time (day)
(W) Dongola Gauge (m)
0
10
20
30
40
50
9
11
13
15

Previous values of water losses

Aswan High Dam reservoir lies in a hot and extremely arid climate; therefore evaporation losses represent the major item of the total losses. Hurst and Black (1955) estimated water losses based on the observation of evaporation from water surface at Wadi-Halfa and Aswan. They estimated the mean annual daily value of evaporation as 7.54 millimeters per day and the total depth of water losses for the whole year as 2.75 meters. Based on these values they concluded that the total evaporation losses will be $9 * 10^9$ m^3 per year in average. Abdel Karim A, and Hassan O. (1993) deduced the total evaporation losses during the period (1964-1990) as $9.62 * 10^9$ m^3.

Water losses considering lag time

The water balance equation is indicated in the following form:

$$Q_1 = Q_2 \pm \_S + L \tag{9}$$

Where Q_1: is the inlet discharge at Dongola

Q_2: is the outlet discharge at downstream AHD (at Aswan)

$\_ S$: is the change in the storage; and

L: is the total loss

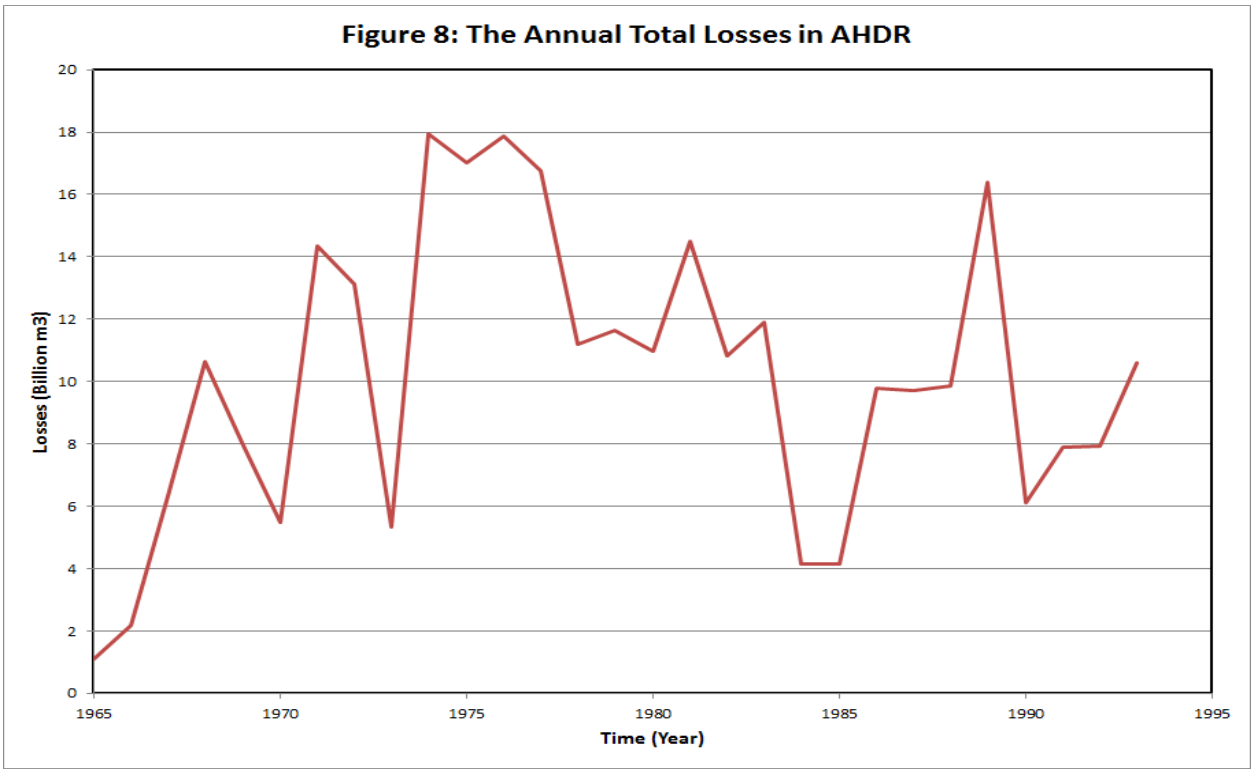
The water balance equation has been applied on AHD reservoir during the period (1965-1993) using the following data:-

- Ten days mean of water level and discharge at Dongola station (Q_1).
- The corresponding water level just upstream AHD. Its effect appears in ($\_ S$).
- The calculated lag tame. It affects the date of (Q_1).
- Ten days mean of water level and discharge at Aswan in a period shifted by the calculated lag time (Q_2).

These data were used to calculate the total losses. The total losses ranged between $4*10^9$ to $18*10^9$ m^3 per year. These values are indicated in table 2 and figure 8. From These results we conclude that the average total losses ($10.13*10^9$ m^3 per year) are within the range of the designed value and are very close to the results obtained by other researchers. However there is a considerable difference between the actual values of total losses every year and the average designed value. If these values were taken into consideration it will help in more realistic regulation of water in AHD reservoir.

Table 2: The estimated total losses from 1965 to 1993

Year	Losses ($*10^9$ m3)	Year	Losses ($*10^9$ m3)
1965	1.09	1980	10.96
1966	2.20	1981	14.50
1967	6.35	1982	10.81
1968	10.65	1983	11.89
1969	8.05	1984	4.15
1970	5.48	1985	4.15
1971	14.35	1986	9.79
1972	13.13	1987	9.71
1973	5.35	1988	9.84
1974	17.96	1989	16.37
1975	17.00	1990	6.12
1976	17.88	1991	7.91
1977	16.75	1992	7.92
1978	11.19	1993	10.60
1979	11.63		
Total losses			293.75
Average losses / year			10.13



Conclusion

The total annual water losses from the reservoir of $10*10^9$ m^3 was assumed before the construction of AHD, as mentioned in the 1959 agreement between Egypt and the Sudan. The estimation based on the observations of evaporation from water surface at Wadi- Halfa and Aswan. Former researchers estimated the actual annual water losses which include seepage, absorption and evaporation losses as $9*10^9$ m^3. Their calculations were based on the water balance equation for the period (1965 to 1990) but they did not consider the effect of lag time.

Taking into consideration the effect of lag time in the water balance equation, the total losses were estimated, in the period (1965 to 1993) in the range of $4*10^9$ m^3 to $18*10^9$ m^3. This means that there is a considerable difference between the designed and the estimated total water losses. The estimated values of the water losses should be verified either by actual measurements or by the computer models.

Recommendations

1- Since the evaporation losses represents the major item in comparison to the seepage losses, it is recommended to establish an automatic hydro meteorological network covering the reservoir. This will help in having more realistic assessment of evaporation from AHDR.

2- A two dimensional model for water routing is recommended. This will help in the predication of the total losses and a better regulation of water in AHD reservoir.

References

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