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Estimation of Seepage Loss from Nasser Lake to the Adjacent Nubian Sandstone Aquifer, Southern Egypt

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Abstract: ***There is considerable amount of Nasser Lake seeps to adjacent Nubian aquifer, therefore water loss from this huge fresh water reservoir became a critical national problem considering the current water shortage throughout the area. During the present study, total values of seepage from the lake to adjacent Nubian Sandstone aquifer, fossil groundwater reservoir, was calculated from 1965 up till 2014 (50 years). This work reveals that average value of water seeps to Nubian sandstone aquifer is 47.46×10^6 m^3/year. Maximum value of loss was estimated in 1976 as 68.48×10^6 m^3, when the lake storage was 108.4×10^9 m^3 and the flow to the lake from the Nile was 81.5×10^9 m^3. Minimum loss from the lake estimated as 26.44×10^6 m^3 in 1987, when the storage in the lake was 47.26×10^9 m^3 and the income water was 48.8×10^9 m^3. The results reveal that seepage loss from Nasser Lake is strongly affected by temporal changes in lake recharge, by the geology of the area and on extent to which the lake stages are above or below the level of the adjoining land. It was observed from the fluctuation of groundwater levels to the rise and drop of the lake levels that the degree to which the lake contributes water to the Nubian sandstone aquifer varies greatly from place to place along its eastern and western shorelines. The general trend in water seepage from Nasser Lake, over a 50-year period, shows continuous decrease relative to the first 10 years of the lake filling.***

Keywords: Seepage loss, hydrogeology, Nubian Sandstone aquifer,High Dam, Nasser Lake

1. Introduction

Nasser Lake was created after the construction of the High Dam (1965-1971). It considered as one of the largest manmade lakes in the world (Fig. 1).Nasser Lake extends to about 500 km in length, of which 150 km belongs to Sudan, and over a width ranging from 10 to 30 km (average width, 12 km). The average flow of the Nile is 84 billion cubic meters per year, 55.5 billion cubic meters are allocated to Egypt and 18.5 billion cubic meters are allocated to Sudan. Nasser Lake contains approximately 155 milliard cubic meters of fresh water over a surface area of about 6000 km2(Aly et al., 1993; High Dam Authority 1988).

The exchange processes between surface water and groundwater vary both in time and space (Brunke and Gonser, 1997; Woessner, 2000).Quantification of groundwater and surface water interaction is an important hydrological investigation for its central role in conjunctive management of groundwater resources (Barlow et al. 2003). Water loss is a big problem throughout the world. In the arid and semi-arid regions, attention is being focused on the search for new methods to conserve existing water supplies.

There is a considerable amount of Nasser Lake fresh water seepage in the adjacent Nubian aquifers (Evans et al. 1991). The water loss from this huge fresh water reservoir became a critical national problem considering the current water shortage throughout the area. The estimation and quantitatively examine of the seepage loss has been used in different locations along the world (Kinzli et al., 2010; Oblinger et al., 2010; Mupenzi et al., 2012; Akbar et al., 2013; Karmaker and Dutta 2013;Ghobadian and Fathi-Moghadam 2013; Shanafield et al., 2014; Noorduijn et al., 2014).

The main significant of the present study is to calculate the total value of seepage loss fromthe surface water ofNasser Lake, west and east banks,to the adjacent Nubian Sandstone aquifer for the period from 1965 up till 2014 (50 years).To elucidate the factors that affects the seepage loss from the lake. Also, to determine the inter-relationship between the water levels of Nasser Lake and the groundwater levelsof the Nubian aquifer from the storage beginning in the lake up till2014.

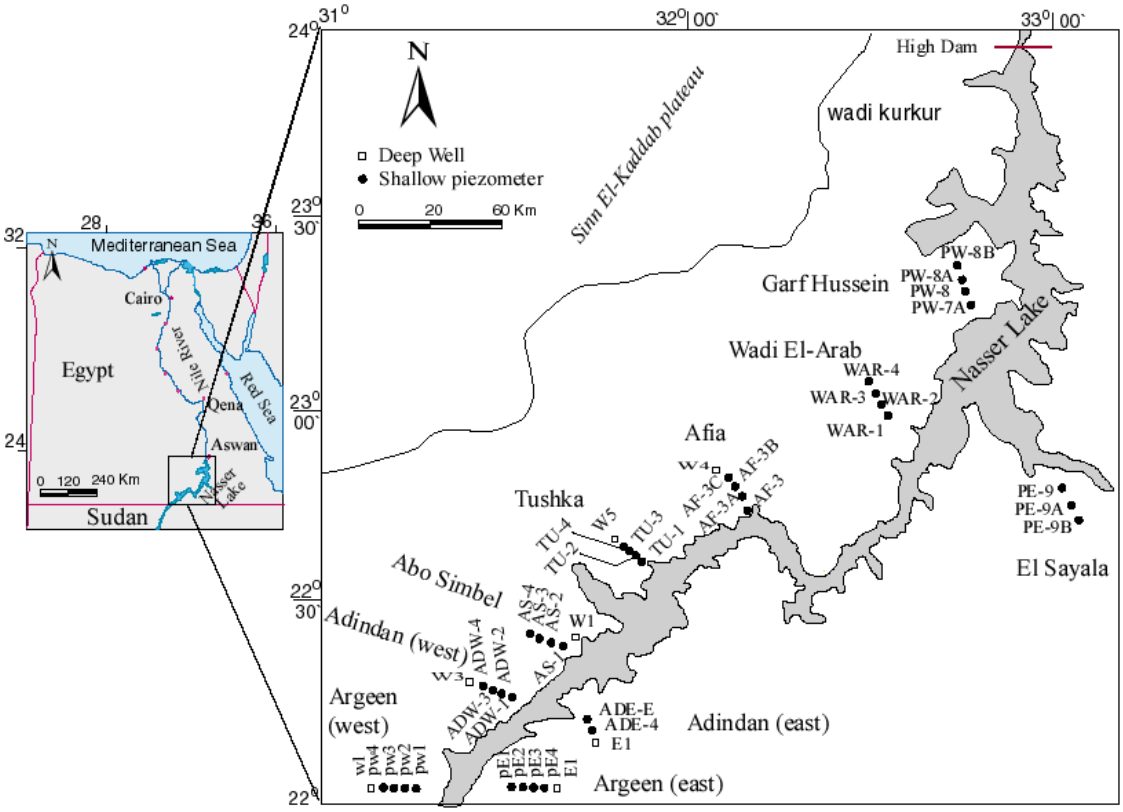


Figure 1: Location and well distribution map of the Lake Nasser area

2. Study Area

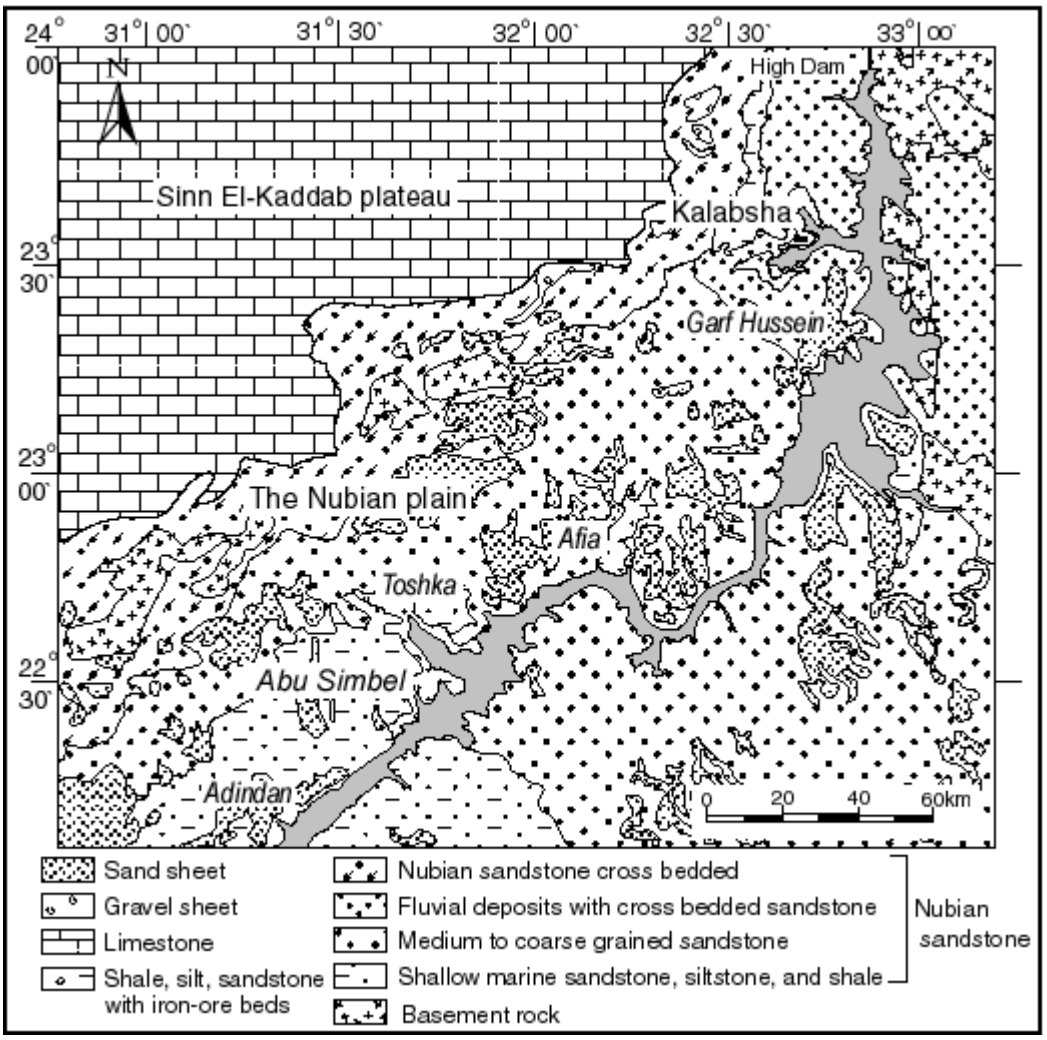
In Nasser Lake area, the Nubian Sandstone represents small portion of the very well known Nubian Sandstone Aquifer System in the Eastern Sahara, which covers the entire area of southwest Egypt, southeast Libya, northeast Chad, and northern Sudan, so it constitutes the main source of groundwater in this area.The aquifer is composed mainly of sandstone with shale and clay intercalations with a total thickness ranging between 390 and 592 meters(El Ramly 1973).

The hydrogeology of the study area was studied by several authors asSelim 1986; Tamer et al., 1987; Sherief and Ahmed 1990; Mousa 1991; Kim J. and Sultan 2002; Yan et al., 2003; Elewa 2006; Shedid 2006; and Ghoubachi 2012. Hydrogeologically, El-Shazly et al. (1977)supposed that the sediments make up the Nubian aquifer system may be subdivided regionally into two or three water-bearing layers with intervening shale or sandy shale confining units, some of them are hydraulically connected with the interfingering and local facies change. The shallow or upper water-bearing horizons exist under the free water table, whereas the lower or deeper water-bearing horizons exist under confined conditions. In the lake region, El Ramly (1973)noticed a clear hydraulic connection between the upper and lower layers of the Nubian sandstone aquifer.

3. Materials and Methods

The levels of the surface water of Nasser Lake within a time interval between 1965 and 2014 are measured daily by AHDA (Table 1). The present authors used them to delineate the illustrations, to calculate the seepage loss from the lake and to determine seepage loss/surface water inter-relationships for 50 year period.

The water levels of the groundwater in 44 observation wells (piezometers) were monitored monthly by the authors and the AHDA from 1965 up to 2014. These piezometers are located at 10 sectors along both sides of Nasser Lake (Figs. 3 & 4 and Table 4). The lithological and hydrogeological data of the drilled wells in each sector around the lake were used to calculate the hydraulic conductivityof the Nubian aquifer, the thickness of the seepage face and the hydraulic gradient at each sector along the study area (Table 1). The values of seepage loss from Nasser Lake banks to the Nubian sandstone aquifer were calculate for the 50 year period using the hydrogeological data and applying Darcy's law.



Figur 2: Geological map of the Nasser Lake area (modified after Conoco (1987)

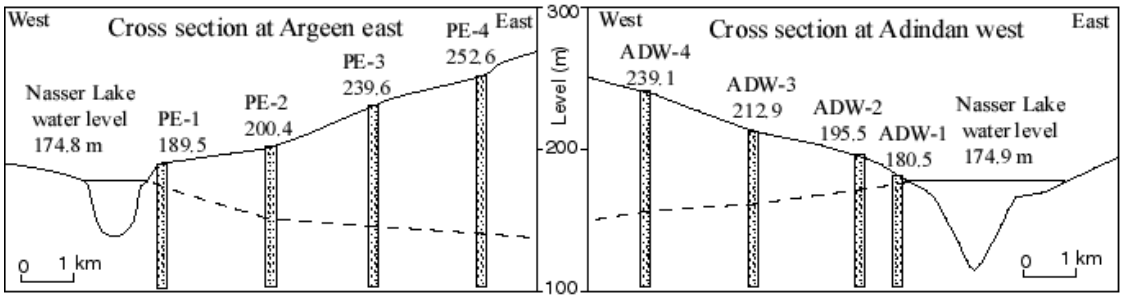


Figure 3: An example of Cross-section at Argeen (east side of Nasser Lake) and at Adindan (west side of Nasser Lake).

4. Results and Discussion

As detected from the lithological loges of different wells drilled in study area, the Nubian Sandstone aquifer is built up of water bearing sands and sandstone, separated by semi-confining clay and sandy-clay intercalations (Figs. 2 and 4).It directly overlays the basement complex as shown from deep wells lithology of W1, W2, and E2, in Abo Simble west, Argeen west, and Argeen East sectors respectively.

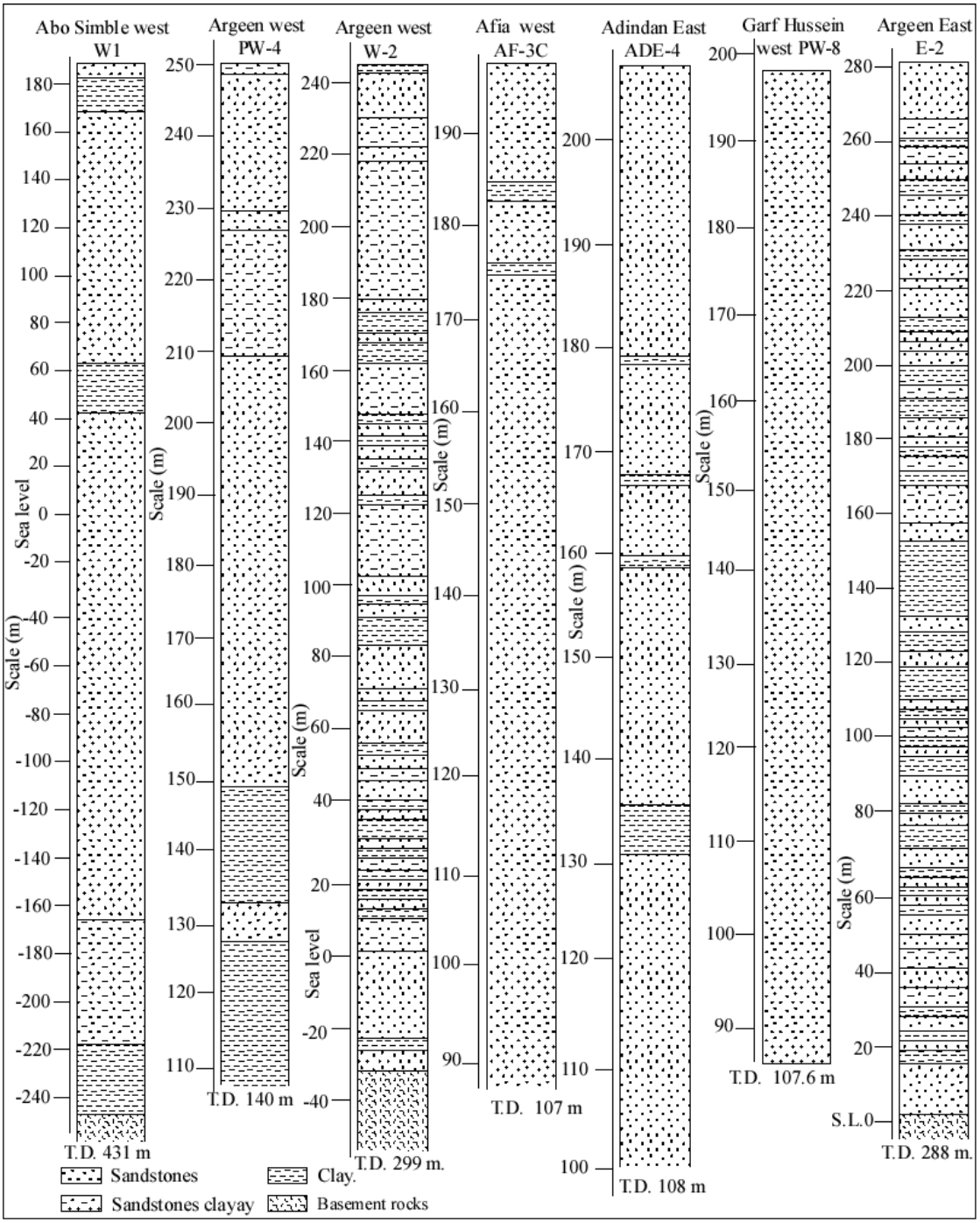


Figure 4: Some examples of lithological logs at Wells W1, PW-4 & W2, AF-3C, ADE-4, PW-8, and E2, in Abo Simble west, Argeen west, Afia west, Adindan east, Garf Hussein west and Argeen east sectors respectively in the study area.

4.1- Seepage loss from Nasser Lake to the adjacent Nubian aquifer

It is common and natural phenomena, that there should be seepage flow from and to lakes. This phenomenon occurs as a consequence of the difference in levels of the adjoining groundwater table, and the free surface of the lake. The fluctuation of piezometric levels relative to the rise and drop of the lake levels shows that the degree to which the lake contributes water to the Nubian sandstone aquifer varies greatly from place to place along eastern and western shorelines (Fig. 5).Estimating of the water seepage from Nasser Lake into the adjacent Nubian sandstone aquifer is one of the main factors influencing the water balance of the lake. Up till now, little has been done to determine the amount of seepage from Nasser Lake to the adjacent rock formations, particularly in the eastern part of the lake.

The previous work undertaken in Nasser Lake region was concentrated on selected areas and did not cover the whole region on both sides of the lake, which referred to the lack of data. Moreover, the methods which were used for accurate determination of water losses that occur by seepage from Nasser Lake are not satisfactory as their calculations depend upon theoretical, geophysical and graphical methods. Abu El Wafa and Labib, 1971calculated theoretically the total losses from high dam at level 156.5 m to be 1000 mm^3/year by calculated the inflow and outflow in the reservoir area. Yan et al., 2003calculated the recharge from only southwestern side of Lake Nasser andTushka lakes to the Nubian aquifer.

Metwaly et al., 2006estimated the water seepage from northwestern side of Lake Nasser along a horizontal distance of 47.5 km from the western shoreline. They gave a value of seepage was (2.6×10^6 m^3/year). Selim et al., 2008 and Hamdan et al., 2013calculated the recharge from 4 sections only at the western shoreline of Lake Nasser to the adjacent Nubian aquifer from 2000 to 2006. The maximum value of seepage detected at Garf Hussein (27.71×10^6 m^3/year), while the minimum value recorded in Adindan section ($0.61\times10^6 m^3$/year). Abed El Moneim et al., 2014estimated the seepage from the western shore line of the lake through 6 sections only using the available data of 2009, the calculated seepage values was 238.13 x10^6 m^3/year.

The present study aims to estimate the total values of water seepage into the adjacent Nubian sandstone aquifer from both east and west sides of Nasser Lake from 1965 (construction of the High Dam) up till 2014 (50 years). Moreover, the relationship between the amounts of seepage from Nasser Lake relative to the amounts of the lake water storage will be discussed.During the present study, Darcy's law was applied to calculate the seepage values of surface water from Nasser Lake shorelines to the adjacent Nubian Sandstone aquiferusing the following equation:

$$Q = K\ I\ A \quad \ldots\ldots(1)$$

Where Q is the *water seepage from the lake to the adjacent aquifer* (m^3/day), K is the *hydraulicconductivity* (m/day), I is the *hydraulicgradient* (unitless), and A is the area of flow or the cross-sectional area (m^2).

The *hydraulicgradient* estimated from the following equation:

$$I=\Delta h/l \quad \ldots\ldots(2)$$

Where Δh is the difference between the water levels in the observation wells and l is the distance between the lake shoreline and the successive piezometers. The area of flow (discharge) calculated using the following equation:

$$A=TL \quad \ldots\ldots(3)$$

Where T is the thickness of the seepage face (m), and L is the length of the seepage face (m).

According to the present study, the thicknesses of the water-bearing layer (seepage face) vary from 25 to180 m with average 64 m, and the calculated hydraulic gradient shows a value ranges from 0.003 to 0.007 (Table 1). The *hydraulicconductivity* values vary from 0.0864 to 0.709 m/day with an average of 0.315 m/day.

Table 1: The estimated the hydraulic conductivity, the thickness of the seepage face, and the hydraulic gradient of different sectors along Lake Nasser area.

Section	hydraulic conductivity (m/day)	Thickness of the seepage face (m)	Average of hydraulic gradient
Garf Hussein (West)	0.709	80	0.007
Garf Hussein (East)	0.355	100	0.005
Wadi El-Arab (West)	0.709	40	0.004
Afia (West)	0.166	80	0.005
Toshka (West)	0.1536	30	0.004
Abo Simble (West)	0.0864	50	0.005
Adindan (West)	0.0864	30	0.003
Adindan (East)	0.173	180	0.003
Argeen (West)	0.356	25	0.004
Argeen (East)	0.356	25	0.004

Table 2: Elevation and total depth of the piezometers around Nasser Lake

Sectors	Observation wells	Elevation (m)	Total depth (m)	Sectors	Observation wells	Elevation (m)	Total depth (m)
Garf Hussein west	PW-7	193.8	102	Wadi El-Arab west	WAR-1	195.1	110
	PW-8	196.1	107.6		WAR-2	195.9	110
	PW-8A	197.3	101		WAR-3	198.7	108
	PW-8B	190.4	100		WAR-4	206.7	110
Garf Hussein East	PE-9	183.8	97.4	Adindan East	ADE-3	186.5	88.0
	PE-9A	184.8	105		ADE-4	206.07	107.9
	PE-9B	185.8	105		E1 (deep)	214.52	273.3
Afia west	AF-3	196.6	103.3	Tushka west	TU-1	187.09	100
	AF-3A	189.5	95		TU-2	197.66	98.0
	AF-3B	194.1	104		TU-3	199.9	111
	AF-3C	197.9	107		TU-4	210.81	125
	W4 (deep)	253.0	211		W5 (deep)	225.09	386
Abo Simble west	AS-1	188.3	98.4	Adindan west	ADW-1	180.46	82.0
	AS-2	185.6	95		ADW-2	195.49	97.0
	AS-3	193.2	101		ADW-3	212.93	114.6
	AS-4	198.3	108		ADW-4	239.07	140.1
	W1 (deep)	188.6	431		W3 (deep)	245.49	390.3
Argeen west	PW-1	187.7	100	Argeen East	PE-1	189.46	66.1
	PW-2	204.9	105		PE-2	200.39	105
	PW-3	219.3	120		PE-3	231.51	145
	PW-4	237.5	140		PE-4	251.95	165
	W2 (deep)	244.5	299		E2 (deep)	278.35	288

The values of water seepage from Nasser Lake to the adjacent Nubian Sandstone aquifer at the previously mentioned 10 sectors, for the period 1965 to 2014, will be discussed in the following (Tables 2 &3):

1- Garf Hussein west

The distance between this sector and the High Dam is 100.6 km. It contains four observation wells PW-7, PW-8, PW-8A, and PW-8B and their depths are 102, 107.6, 101, and 100 m

respectively. The calculated values of seepage loss in this sector vary from 13.04 × 10^6 (calculated in 1988) to 29.56× 10^6 m³ (calculated in 2002) with an average of 20.43 × 10^6 m³/year**.** The present study, indicates that the value of surface water seeps to this sector is the highest relative to the other sectors, which can be related to the high value of hydraulic conductivity of the Nubian aquifer in this area, and to the large area of discharge (Table 3 & Fig. 5)

2- Garf Hussein east (El-Sayala)

This sector locate at the eastern bank of Nasser Lake and comprises three wells PE-9 (97.4 m depth), PE-9A (105m depth), and PE-9B (105m depth).The seepage loss reached its maximum value in 2011 (8.7 × 10^6 m³), while its minimum value was 1.2 × 10^6 m³ in the period from 2002 to 2005 (continuous decrease in the lake level recorded in the same period). The average value of the surface water seeps to this sector calculated as 5.61 × 10^6 m³ (Table 3).

3- Wadi El-Arab west

Four observation wells, drilled in 2007, were used to calculate seepage loss values at this section (WAR-1, WAR-2, WAR-3, and WAR-4) and their depths vary from 108 to 110 m. These piezometers initiated in 2007 and the groundwater level was measured from this year up till now. The obtained seepage values range between 2.19 million m³ in the year 2012 to 6.07 million m³ in 2009 (average seepage is 3.85 million m³/year).

4- Afia west sector

Afia sector locates at west side of Nasser Lake and contains a deep well (W4) of 211 m depth in addition of four other wells AF-3, AF-3A, AF-3B, and AF-3C and their depths are 103.3, 95, 104, and 107 m respectively. The seepage loss values which calculated using the five piezometers range from 0.33 × 10^6 m³ (in 1992) to 8.5 × 10^6 m³ (in 1976). Average of seepage loss values at this sector is 3.09 × 10^6 m³/year (Table 3).

5- Tushka west sector

The distance between this sector and High Dam is 237 km. This sector consists of five observation wells, drilled in 2004. Four wells are shallow: TU-1, TU-2, TU-3, and TU-4 and their depths are 100, 98, 111, and 125 m respectively, one deep well (W5) with a depth of 386 m. The calculated seepage loss value in this sector vary from 1.37 × 10^6 to 2.06 × 10^6 m³/year (Fig. 5) with an average value of 1.83 × 10^6 m³/year (Table 3).

6- Abo Simble west

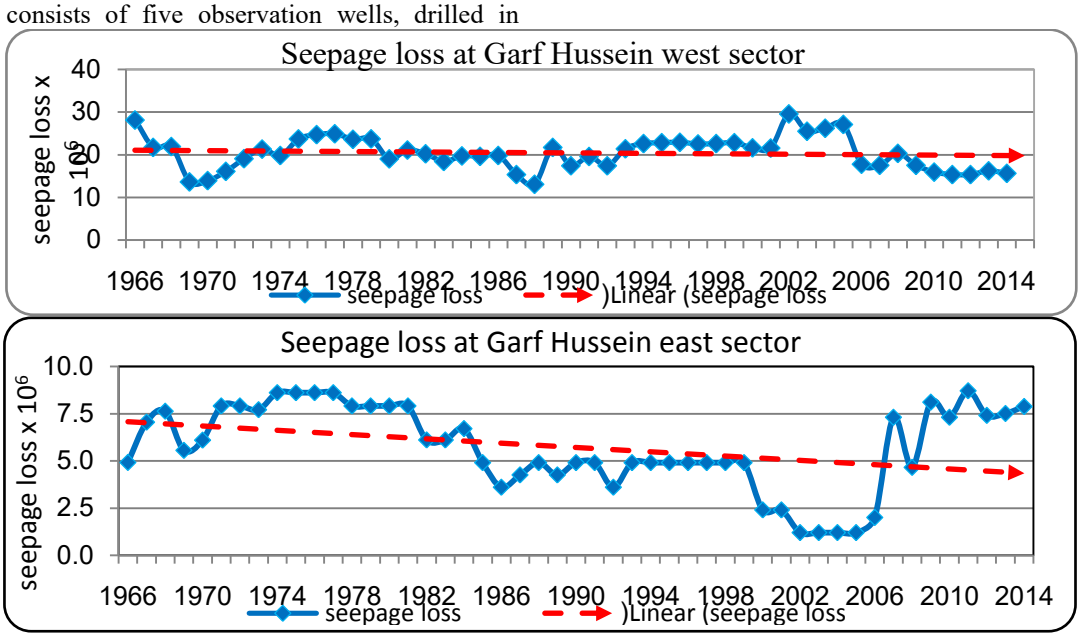
This sector consists of five piezometers drilled in 2002: AS-1, AS-2, AS-3, AS-4, and W1 and their depths are 98.4, 95, 101, 108, and 431 m respectively. The ground level at these wells range between 188 and 198.3 m. The minimum, maximum, and average seepage loss values to this sector are 1.29 × 10^6 m³ (in 2003), 1.96 × 10^6 (in 2007), and 1.63 × 10^6 m³/year respectively. The lake water seeps to this sector shows the least value, which may be due to the low hydraulic conductivity of the aquifer in this area.

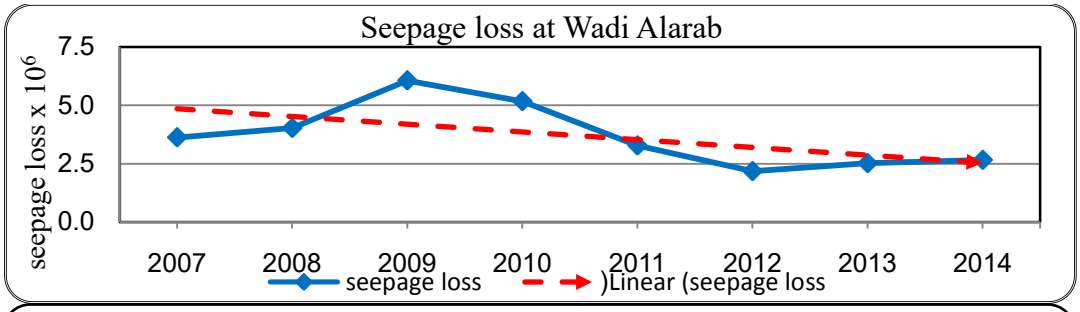
7- Adindan west sector

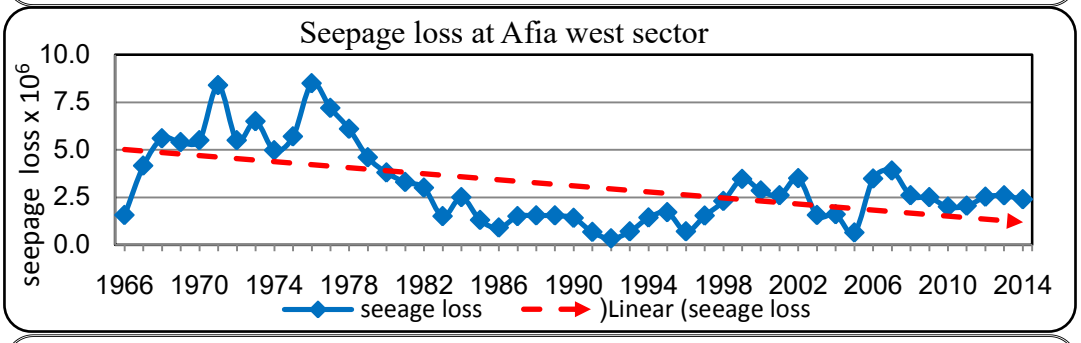
The estimated seepage loss at Adindan sector (west side of Nasser Lake) carried out using the collected data from five observation wells, ADW-1, ADW-2, ADW-3, ADW-4, and W3, where their depths are 82, 97, 114.6, 140.1, and 390.3 respectively. The ground elevation of these wells range between 180.4 and 245.5 m above sea level. The surface water seepage to this sector vary from 0.4 × 10^6 (in 2005) to 5.3 × 10^6 m³ (in 1999), and the average value is 2.49 × 10^6 m³/year.

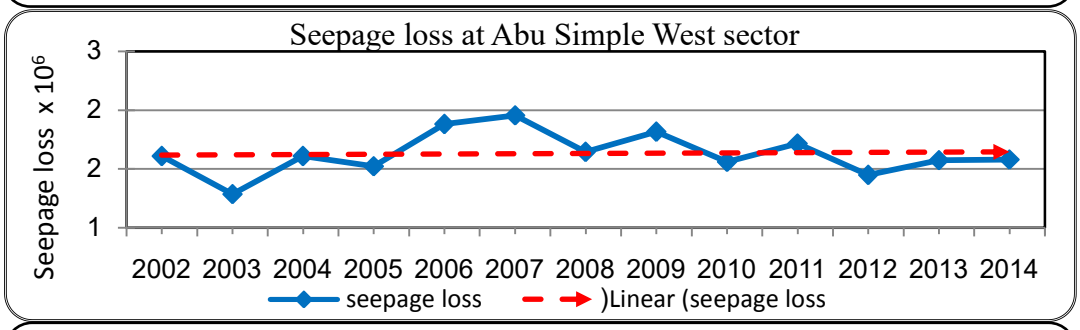
8- Adindan East sector

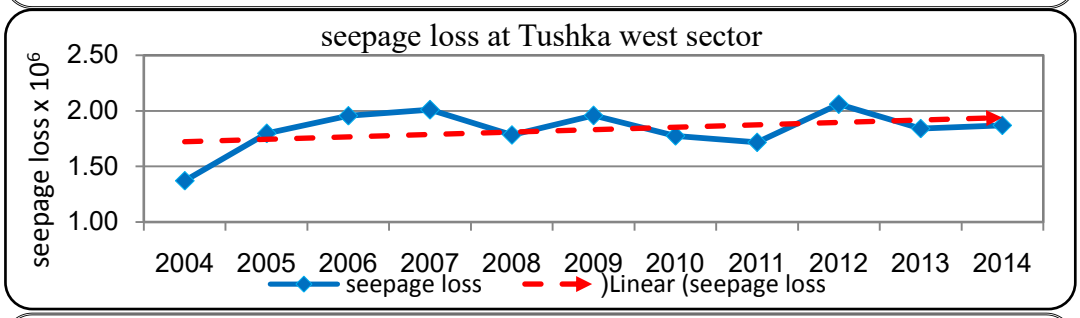
This sector locates at the eastern side of Nasser Lake at 316 km far from the High Dam. It contains three observation wells ADE-3 (88 m depth), ADE-4 (107.9 m depth), and E1 (273.3 m depth). The seepage loss values at this sector are relatively high, where Q-values range between 2.3 million m³ (recorded in 1985) and 23.5 million m³ (calculated in 1971) with an average of 12.9 million m³/year. The high Q-values in this sector related to the great thickness of water-bearing layer (seepage face), where it reach 180 m. It considered the greatest thickness of seepage face from all other sectors.

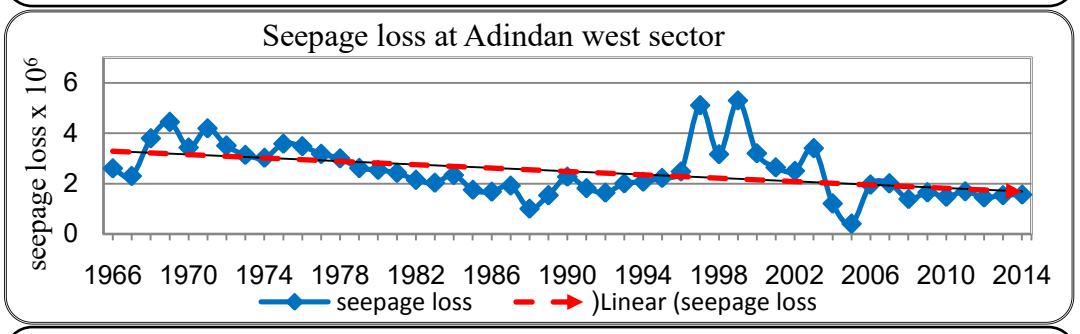


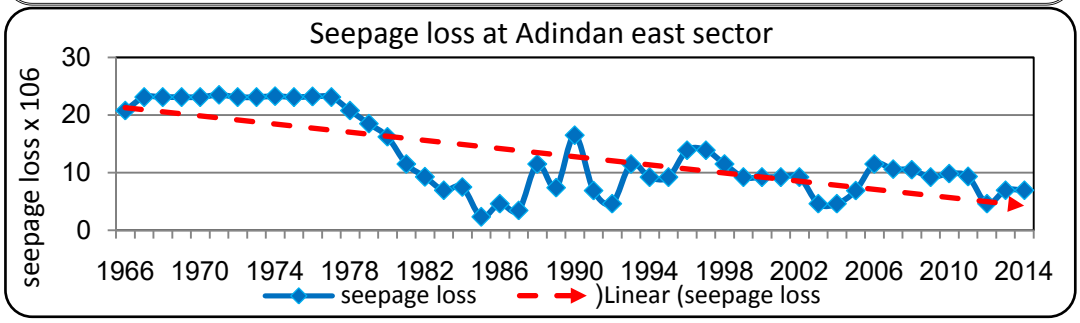












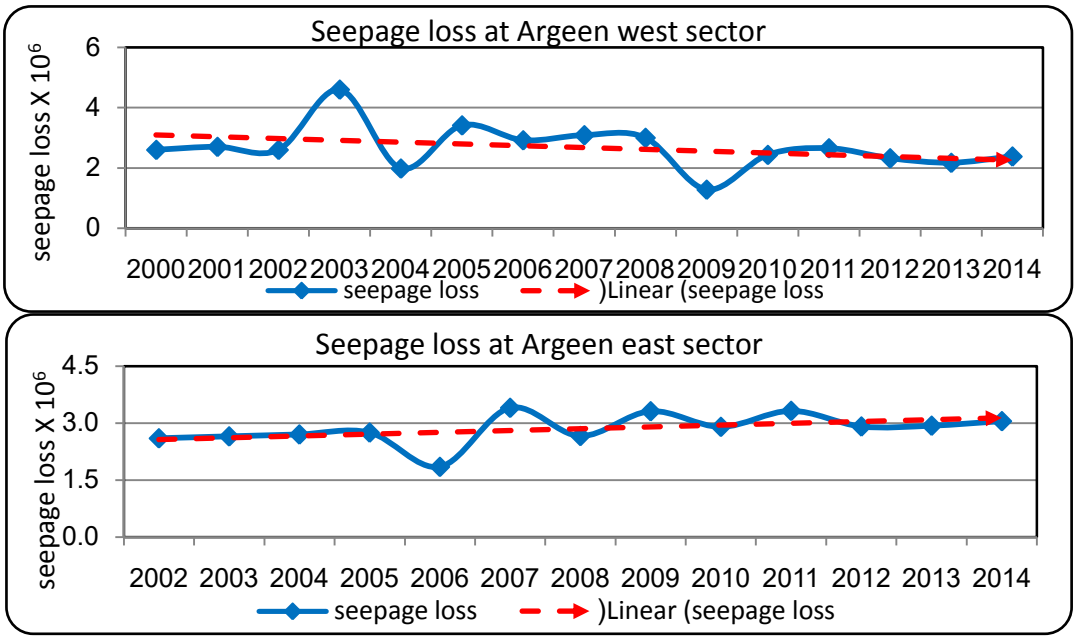


Figure 5: Water seepage from Nasser Lake sectors and general trend of water seepage.

9- Argeen west sector

Argeen sector locates in the southern border of Egypt (near Sudan) and its distance from the High Dam is 313.5 km. It is the far zest sector from High Dam area and has high ground elevation (vary from 187 to 144.5 m above sea level). Five piezometers, drilled in 2001, were monthly measured to calculate the seepage loss to them. Four of them are shallow PW-1, PW-2, PW-3, and PW-4 where their depths are 100, 105, 120, and 140 respectively. The deep well (W2) has depth of 299m. The seepage loss values which calculated, using the five piezometers, range between 1.28 × 10^6 m³ (in 2009) to 4.6 × 10^6 m³ (in 2003). The average seepage loss values at this sector is 2.7 × 10^6 m³/year

10- Argeen East sector

This sector locates at the eastern side of Nasser Lake at the opposite side of the previous sector. The seepage loss values were calculated using the records of five piezometers (drilled in 2001). Four of them are shallow and numbered: PE-1 (66.1 m), PE-2 (105 m), PE-3 (145 m), and PE-4 (165 m), while the fifth is a deep well (E2) and has 288 m depth. The ground elevations of this sector vary from 189.4 m to 278.3 m above sea level (Table 4). The seepage loss values at this sector range between 1.85 million m³ (recorded in 2006) and 3.4 million m³ (calculated in 2007) with average of 2.83 million m³/year.

Table 3: The water seepage loss calculation (Seepage × 10^6 m³/year) and average water level at Nasser Lake from 1964 to 2014

year	Garf Hussein west	Garf Hussein East	Afia west	Adindan west	Adindan East	Total seepage × 10^6 m³/year	lake level (average in m.)
1965	22.83	3.36	2.19	2.05	13.9	44.33	126.28
1966	28.13	4.91	1.56	2.6	20.8	58.0	131.92
1967	21.7	7.04	4.16	2.3	23.1	58.3	142.9
1968	21.9	7.62	5.6	3.8	23.1	62.02	151.1
1969	13.6	5.55	5.4	4.44	23.1	52.09	156.18
1970	13.9	6.09	5.5	3.43	23.1	52.02	159.83
1971	16.08	7.9	8.4	4.19	23.5	60.07	163.63
1972	19.05	7.9	5.5	3.5	23.1	59.05	165.17
1973	21.3	7.7	6.5	3.14	23.1	61.74	162.85
1974	19.8	8.6	4.97	3.02	23.3	62.39	165.75
1975	23.69	8.6	5.7	3.58	23.1	64.67	170.09
1976	24.7	8.6	8.5	3.48	23.2	68.48	174.83
1977	24.9	8.6	7.2	3.17	23.1	66.97	174.86
1978	23.6	7.9	6.1	3.0	20.8	61.4	175.35
1979	23.7	7.9	4.6	2.61	18.5	57.31	175.26
1980	19.01	7.9	3.8	2.54	16.22	49.47	174.22
1981	21.08	7.9	3.3	2.42	11.5	46.2	174.13
1982	20.2	6.1	3.0	2.14	9.26	40.7	172.66
1983	18.4	6.1	1.5	2.03	6.95	34.98	169.01
1984	19.7	6.7	2.5	2.34	7.5	38.74	169.34
1985	19.6	4.9	1.3	1.75	2.3	29.85	160.9
1986	19.8	3.6	0.9	1.68	4.6	30.58	161.08
1987	15.32	4.22	1.5	1.92	3.45	26.44	161.66

year	Garf Hussein west	Garf Hussein East	Afia west	Adindan west	Adindan East	Total seepage × 10^6 m³/year	lake level (average in m.)
1988	13.04	4.9	1.54	1.0	11.5	31.98	168.82
1989	21.7	4.25	1.54	1.53	7.4	36.42	169.79
1990	17.39	4.9	1.41	2.27	16.5	42.47	167.3
1991	19.56	4.9	0.67	1.82	6.9	33.85	166.46
1992	17.39	3.6	0.33	1.64	4.6	27.56	167.72
1993	21.37	4.9	0.7	2.01	11.5	40.48	170.53
1994	22.6	4.9	1.43	2.07	9.2	40.2	173.63
1995	22.8	4.9	1.71	2.22	9.2	40.83	175.21
1996	22.9	4.9	0.7	2.48	13.9	44.88	175.45
1997	22.5	4.9	1.53	5.1	13.9	47.93	177.37
1998	22.6	4.9	2.3	3.16	11.5	44.46	178.13
1999	22.8	4.9	3.46	5.3	9.2	45.66	178.91
2000	21.6	2.4	2.85	5.8	9.2	41.85	178.88
2001	21.55	2.4	2.6	2.64	9.2	41.09	178.76
2002	29.56	1.2	3.5	2.5	9.2	52.77	177.66
2003	25.5	1.2	1.56	3.4	4.6	44.8	175.62
2004	26.2	1.2	1.6	1.2	4.6	42.46	174.86
2005	27.09	1.2	0.64	0.4	6.9	45.71	172.79
2006	17.76	2.0	3.48	1.95	11.5	45.29	173.1
2007	17.5	7.3	3.9	2.0	10.6	55.39	176.2
2008	20.3	4.65	2.6	1.38	10.5	52.55	175.62
2009	17.5	8.1	2.5	1.64	9.2	53.38	177.66
2010	15.9	7.3	2.0	1.47	9.85	50.37	173.59
2011	15.32	8.7	2.05	1.69	9.3	49.75	169.93
2012	15.32	7.4	2.52	1.45	4.6	42.22	174.14
2013	16.2	7.5	2.59	1.54	6.95	45.82	173.23
2014	15.61	7.87	2.39	1.56	6.95	45.93	172.43
Minimum	13.04	1.2	0.33	0.4	2.3	26.44	126.28
Maximum	29.56	8.7	8.5	5.3	23.5	68.48	178.61
Average	20.43	5.61	3.09	2.49	12.9	47.46	168.58

Table 3: Continued.

year	Toshka west	Abo Simble west	Argeen west	Argeen East
2001	N.D.	N.D.	2.7	N.D.
2002	N.D.	1.61	2.6	2.6
2003	N.D.	1.29	4.6	2.65
2004	1.37	1.61	1.98	2.7
2005	1.8	1.52	3.41	2.75
2006	1.96	1.88	2.92	1.85
2007	2.01	1.96	3.09	3.4
2008	1.78	1.64	3.0	2.66
2009	1.96	1.82	1.28	3.31
2010	1.77	1.56	2.43	2.9
2011	1.72	1.72	2.65	3.32
2012	2.06	1.45	2.32	2.91
2013	1.84	1.57	2.17	2.93
2014	1.87	1.58	2.38	3.05
Minimum	1.37	1.29	1.28	1.85
Maximum	2.06	1.96	4.6	3.4
Average	1.83	1.63	2.7	2.83

N.D. wells not drilled yet

4.2 The total value of seepage from Nasser Lake to the Nubian aquifer

This work reveals that the average value of the water seeps from Nasser Lake to the Nubian sandstone aquifer is 47.46 × 10^6 m^3/year. The maximum value of loss was estimated in 1976 as 68.48 × 10^6 m^3, when the lake storage was 108.4 × 10^9 m^3 and the flow to the lake from the Nile was 81.5 × 10^9 m^3 (Table 3). The minimum loss from the lake estimated as 26.44 × 10^6 m^3 in 1987, when the storage in the lake was 47.26 × 10^9 m^3 and the income water was 48.8 × 10^9 m^3 (Table 3).

Garf Hussein west sector has higher seepage loss from the other sectors along the Nasser Lake shorelines. This is related to a high hydraulic conductivityvalue (0.709 m/day) with relatively high thickness of the seepage face (80 m), and might be due to the existence of faulting in this locality. The minimum value of seepage loss was detected at Afia west sector, where the estimated value was 0.33 × 10^6 m^3/year. This case might probably be attributed to poor permeability of the aquifer at this sector or to the lithology or the tectonics in this area.

4.3 The general trend in water seepage from Nasser Lake

The seepage losses to the different sectors around Nasser Lake are plotted in Fig. 5; to determine the general trend of seepage over 50-year period. The general trend in water seepage from Nasser Lake shows a continuous decrease relative to the first 10 years of the lake filling. It can be concluded that after the lake reached maximum storage capacity the annual recharge to the Nubian aquifer decreased from 68.48 × 10^6 m^3 in 1976 to 26.44 × 10^6 m^3 in 1987. The trend of decreasing recharge is consistent with the gradual reduction of hydraulic gradient between the lake stage and the groundwater level in the Nubian aquifer.

Since 1998, as the reservoir has approached maximum storage capacity, several new lake reservoirs (Tushka Lakes) have developed in the lowlands west of Nasser Lake.The recharge from these lakes to the Nubian aquifer has been

rising (10^5 m^3/yr in 1998 to 10^6 m^3/yr in 2002); and recharge from the Tushka Lakes approximates recharge from Nasser Lake (Yan et al. 2003). The increase of seepage loss of Argeenwest sector may be related to the high value of the hydraulic conductivity of the aquifer (0.356 m/day). Also, the seepage loss at Abu Simble is affected by the recharge from Tushkalake. Generally, seepage loss to the Nubian aquifer is significantly affected by recharge from Nasser Lake and the Tushka Lakes as well as by the hydraulic properties.

4.4 Relationship between Water level in Nasser Lake and Seepage loss

The water levels in Nasser Lake from 1965 up to 2014 were measured daily and the minimum, maximum, and average for each year were summarized in table (5). The water level reached its maximum value in November 1999 (181.6 m), while the lowest level was recorded in July 1965 (115.74 m).

The relationship between the surface water at Nasser Lake and the seepage loss (Fig. 6) show slightly direct relation. The present study reveals that the seepage loss from Nasser Lake is strongly affected by the temporal changes in lake recharge, by the geology of the area and on extent to which the lake stages are above or below the level of the adjoining land.

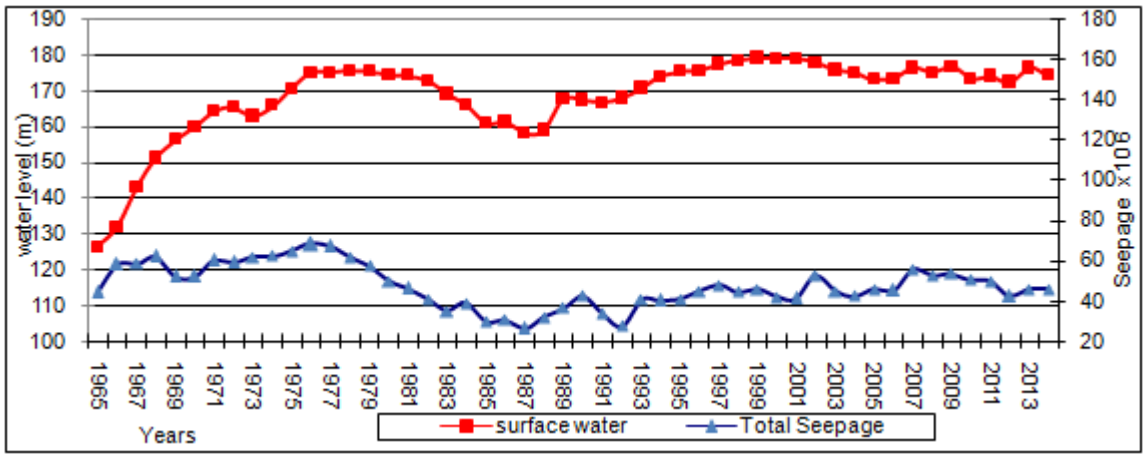


Figure 6: Relation between water level of Nasser Lake and the total seepage loss (m^3/year) from 1965 up to 2014 at Nasser Lake

5. Summary and Conclusions

Present study reveals that the average value of water seeps from Nasser Lake to Nubian sandstone aquifer is 47.46 × 10^6 m^3/year. Maximum value of loss was estimated in 1976 as 68.48 × 10^6 m^3, when the lake storage was 108.4 × 10^9 m^3 and the flow to the lake from the Nile was 81.5 × 10^9 m^3. Minimum loss estimated as 26.44 × 10^6 m^3 in 1987, when storage in lake was 47.26 × 10^9 m^3 and income water was 48.8 × 10^9 m^3.

The results reveal that the seepage loss from Nasser Lake is strongly affected by the temporal changes in lake recharge by the geology of the area and on extent to which the lake stages are above or below the level of the adjoining land. It was observed from the fluctuation of groundwater levels to the rise and drop of the lake levels that the degree to which the lake contributes water to the Nubian sandstone aquifer varies greatly from place to place along its eastern and western shorelines. The general trend in water seepage from Nasser Lake, over a 50-year period, shows a continuous decrease in its value relative to the first 10 years of the lake filling. Generally, seepage loss to Nubian aquifer is significantly affected by recharge from Nasser Lake and the Tushka Lakes.

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