

Water Budget Estimate for Environmental Management At Al-Burullus Lake, Egypt

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ABSTRACT

Al-Burullus Lake is located along the Mediterranean coast between the two branches of the Nile River. It receives most of drainage waters of the Nile Delta region through the drainage system. Recently, the marine ecosystem in the lake has been deteriorated. To re-establish the pre-deterioration environmental case, water balance of the lake has been investigated. Studies revealed that rainfall, agricultural drainage discharges, groundwater contribution, human activities, evaporation, and water interaction between the lake and the Mediterranean sea represent water cycle elements of the lake.

Rainfall records of about 80 year has been collected and checked. Statistical analysis revealed that the area is subjected to mean annual rainfall of about 187 mm. The lake receives mean annual inflows from agricultural drainage waters of about 3.9 billion cubic meters. Groundwater studies reveal that the main aquifer system of the delta contributes to the lake about 90 thousand cubic meters per day. The tidal effect investigations concluded that the tide effect is negligible. Social studies revealed that there are about 185 thousand people interact directly with the lake. This number of people discharges a daily volume of about 28 thousand cubic meters. Daily evaporation losses from the lake vary from 3.57 to 4.9 mm with daily average value of about 4.2 mm.

Hydrologic routing has been implemented and values of outflow discharges and the change in water stored in the lake have been estimated. Analysis of results indicated that inflows to the lake are greater than outflows. The change in the lake level is positive all over the year. Results demonstrate that water level fluctuates between zero and 61 cm above mean sea level. That means water in the lake is in continuous movement toward the sea. When winter closure was considered, water level of the lake moved down to 26 cm below mean sea water level. Accordingly, an environmental management policy to re-establish the pre-deterioration case and to manage excess drainage water has been proposed.

INTRODUCTION

Al Burullus Lake is situated along the Mediterranean coast and occupies a more or less, a central position between the two branches of the Nile. Recently, the marine ecosystem in the lake has been deteriorated due to the continuous water discharges into the lake from the drainage system. To re-establish the pre-deterioration environmental case, water balance of the lake has been investigated. Many studies have been carried out. Rainfall records of about 80 years have been analyzed. Agricultural drainage discharges for the study period (1997-

2000) have been checked and investigated. Evaporation records have been investigated and the mean daily and mean monthly values were estimated. The interaction between groundwater aquifer system in the Nile delta has been studied. The tidal effect also has been taken into consideration. The impact of human activities has been estimated. Quantitative estimates for the above-mentioned elements have been defined. To define the water cycle of the lake, reservoir hydrological flood routing has been implemented. Accordingly, interaction between the lake and the Mediterranean Sea has been defined. Discharges of water movement as well as water volumes have been calculated. In addition, the case of winter closure has been considered in flood routing process.

PHYSICAL CHARACTERISTICS

Al-Burullus lake extends between $31^{\circ} 22' - 31^{\circ} 26'$ N and $30^{\circ} 33' - 31^{\circ} 07'$ E. It's a shallow brackish lake connected with the sea by a small outlet (Boughaz), about 44 m width near El Burg village. The length of the lake is about 65 km., and its width varies between 6 and 16 km, with an average of about 11km. The depth of the lake ranges between 0.42 and 2.07 m. The eastern sector of the lake is the shallowest, showing an average depth of 0.8m. The present area of the lake is about 410 km² (100,000 feddan), of which 370 km² is open water. The capacity of the lake is about 330 million cubic meter. The southern part of the lake receives agricultural drainage water through 8 drains and one brackish water canal, while saline water enters the lake from the sea through El-Boughaz.

Before the construction of the Aswan High Dam, the lake used to receive the Nile floods in late summer and autumn. Many factors have contributed to the hydrological evolution of the lake. The more important of which is the development of the perennial irrigation and drainage system. Accordingly, the lake has become the discharging sink of several drains, Figure (1). Such drains discharge agricultural drainage waters that contain less salinity loads than seawater and massive quantities of fertilizers into the lake. As a result, water in the lake is characterized by decreasing salinity and high nutrient loads. Also, reeds spread widely at the southern border of the lake.

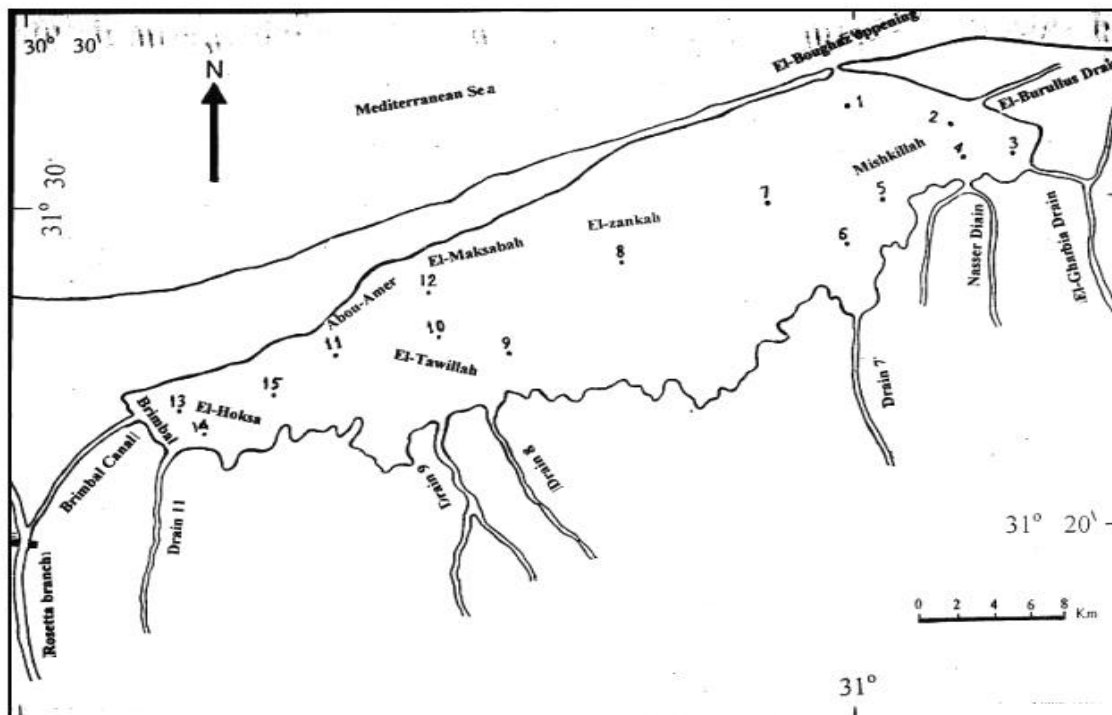


Figure (1) Location map for the study area

HYDROLOGIC ANALYSIS

WATER RESOURCES

Rainfall

Rainfall data recorded at Al-Burullus lighthouse (31° 26' N, 31° 05' E) for a period of 80 year (1912-1992) has been collected and examined. According to the World Meteorological Organisation (WMO) recommendations, data collected from the station has been considered as a representative for the whole lake as the area of Al-Burullus is less than 600 Km². Monthly records of rainfall data have been treated and statistically analysed. Mean monthly values and standard deviations have been estimated and presented in Table (1) while figure (2) shows the statistical distribution for mean monthly rainfall (Normal Distribution).

Table (1) Statistical Analysis of Monthly Rainfall at Al-Burullus Lake.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mean	48.06	32.70	16.72	4.58	1.45	0.00	0.00	0.00	0.61	7.80	27.95	48.78	187.37
SD	32.89	32.52	25.39	7.00	2.88	0.00	0.00	0.00	0.00	15.78	26.53	41.79	82.59

SD = Standard Deviation

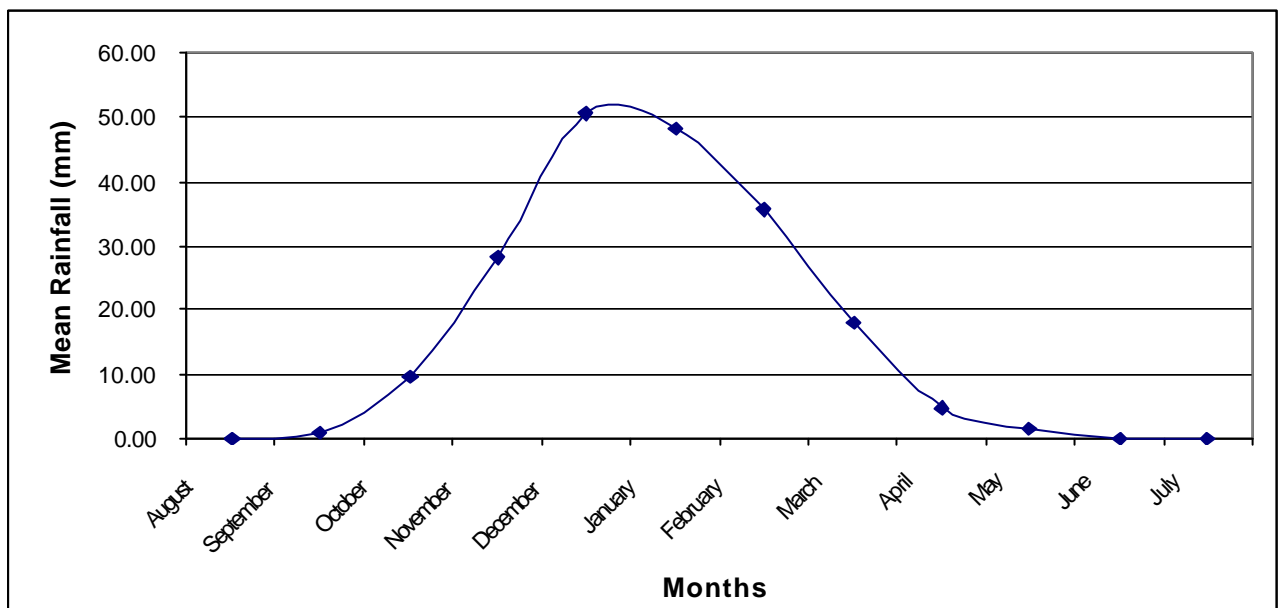


Figure (2) Statistical Distribution for Mean Monthly Rainfall (Normal Distribution).

Drainage Discharges

The lake receives an annual water volume of about 3.9 billion cubic meters through a system of 8 drains and a brackish water canal called Prempal. The mean monthly and the mean annual volumes of water that were discharged into the lake through each drain are presented in Table (2). The amounts presented in the table represent the mean values for four years (1997-2000). The drainage system collects agricultural drainage water from about 950 thousand feddan in the catchment area. Drainage water is discharged into the lake through a group of pumping stations at the end tail of the drains except Al-Gharbia drain that discharges its water freely without pumping.

Tidal Effect

According to Fanos (1992), the tide at Al-Burullus headland is estimated as the difference between the mean high water level (33-cm) and the mean low water level (18-cm). Fanos (1992) considered the difference (15-cm) is small and concluded that the tidal effect is small. Accordingly, the tidal effect has been neglected.

Human Activity

The human activities are represented by outflow/inflow of water from or to the lake by local communities in the surrounding areas. Social studies revealed that there are about 185 thousand people interact on daily basis with the lake. These numbers of people discharge their domestic effluents directly to the lake. Water consumption for such number of people (based on average rate of 150 l/day/capita) would be as much as 27,750 m³/d. This rate of water has been considered in evaluating the water budget of the lake.

Table (2) Monthly Average Drainage Water Inflows to the Lake (million m³).

Month	Therah	Burullus	Drain#7	Drain#11	Drain#8	Bur/West	Drain#9	Gharbia	Preupal	Total	%
JAN	32.93	4.89	27.77	45.08	29.75	7.44	65.00	32.22	13.70	258.78	6.63
FEB	36.83	4.56	31.75	39.91	28.58	7.37	65.00	21.37	5.70	241.07	6.17
MAR	40.11	5.74	32.23	56.71	29.64	10.45	65.00	36.41	16.75	293.04	7.50
APR	41.83	4.86	39.07	51.20	28.55	9.01	65.00	33.13	14.42	287.07	7.35
MAY	55.64	5.03	36.64	65.52	32.68	12.66	65.00	31.50	16.35	321.02	8.22
JUNE	60.64	4.40	44.53	78.16	37.29	16.62	65.00	48.53	15.46	370.63	9.49
JULY	72.59	5.87	51.32	85.00	48.46	18.19	65.00	60.21	16.99	423.63	10.85
AUG	72.34	6.30	52.00	77.62	49.55	17.35	65.00	52.37	18.02	410.55	10.51
SEP	64.14	6.79	48.18	71.87	41.90	14.14	65.00	60.01	23.32	395.35	10.13
OCT	46.65	5.80	39.48	56.67	33.12	9.83	65.00	44.02	19.12	319.69	8.19
NOV	42.89	5.55	36.60	53.75	33.18	9.86	65.00	32.36	20.30	299.49	7.67
DEC	43.08	5.96	36.53	41.49	32.97	6.83	65.00	33.63	18.80	284.29	7.28
Total	609.67	65.75	476.10	722.98	425.67	139.75	780.00	485.76	198.93	3904.6	100.0
%	15.61	1.68	12.19	18.52	10.90	3.58	19.98	12.44	5.09	100.00	

Groundwater Inflow/Outflow

To evaluate the groundwater inflow/outflow from Al-Burullus lake, a groundwater flow package has been used. The used package (TRIWACO) is a three-dimensional flow model based on the finite element method with triangular element and linear shape function using Galerkin method. The model is capable of simulating the interaction between surface water bodies and groundwater aquifer systems.

In the current study, the model was used to estimate the exchange between the lake and the groundwater aquifer system. The numerical simulation results indicate that the groundwater inflow to Al-Burullus area is about 88902 m³/day (2667060 m³/month), Table (3).

Table (3) Groundwater Balance of Al-Burullus Lake.

Interface	Groudwater flow to the lake(m3/d)
Bottom	63141
Boundaris	25761
Total	88902

WATER LOSSES AND OUTFLOW

Evaporation Losses

Evaporation measurements at adjacent stations in Port Said and Alexandria areas have been collected. An average value for daily evaporation at the study area in each month was estimated as presented in Table (4). The monthly values of evaporation have been transformed to volumes of water losses from the lake by considering the surface area of the lake. To involve evaporation losses in the water balance equation, time interval was introduced and considered.

Table (4) Average Daily and Monthly Evaporation at Al-Burullus Lake (mm).

Mean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily	3.57	3.89	4.23	4.62	4.9	4.77	4.75	4.66	4.66	4.33	3.95	3.7
Monthly	110.7	108.9	131.1	138.6	151.9	143.1	147.3	144.4 6	139.8	134.2 3	118.5	114.7
Monthly Volume (10⁶ m³)	45.39	44.65	53.45	54.37	62.28	58.67	60.39	59.23	57.32	55.03	48.59	47.03

Outflow to the Sea

To define the interaction between the lake and the sea, the resrvior hydrologic flood routing method was implemented. The flood routing was implemented in two different cases. The first was made by considering the continuous inflows from agriculture drainage for the study period (1997-2000). The second case was done by considering the winter closure policy during the month of January. Results of the flood routing for both cases are presented in tables (5-a) and (5-b).

Table (5-a) Results of the Flood Routing for Case One (continuous inflow).

Months	I	(I ₁ +I ₂)/2	O1	Im-O	G2	dH	Cum. dH	Total dS
January	91.28		m3/s					m3*10 ⁶
February	82.30	86.79	43	43.79	58.00	0.28	0.28	113.50368
March	96.31	89.305	84	5.305	101.79	0.03	0.31	127.25424
April	91.85	94.08	90	4.08	107.10	0.03	0.34	137.8296
May	101.40	96.625	93	3.625	111.18	0.02	0.36	147.2256
June	121.70	111.55	97	14.55	114.80	0.09	0.45	184.9392
July	141.49	131.595	115	16.595	129.35	0.10	0.56	227.95344
August	136.89	139.19	130	9.19	145.95	0.06	0.61	251.77392
September	131.86	134.375	143	-8.625	155.14	-0.05	0.56	229.41792
October	104.69	118.275	131	-12.725	146.51	-0.08	0.48	196.43472

November	102.57	103.63	112	-8.37	133.79	-0.05	0.43	174.73968
December	100.6	101.585	109	-7.415	125.42	-0.05	0.38	155.52
January	91.28	95.94	108	-12.06	118.00	-0.08	0.30	124.26048

In both tables, I is the inflow during a certain month (time interval), O represents the outflow from the lake within the same interval, subscripts 1,2 represent month 1 and month 2, Im is the mean inflow of two sequences intervals, $G = (O/2 + dS/dt)$, dS is the change in lake storage, dH is the change in water level in the lake in the same interval, Cum. dH is the cumulative dH, and Total dS is the total storage increment at the lake

Table (5-b) Results of Flood Routing for Case Two (winter closure).

Months	I	$(I_1+I_2)/2$	O1	I_m-O	G2	dH	Cum. dH	Total dS
January	91.28		m3/s					m3*10 ⁶
February	82.30	86.79	43	43.79	58.00	0.28	0.28	113.50368
March	96.31	89.305	84	5.305	101.79	0.03	0.31	127.25424
April	91.85	94.08	90	4.08	107.10	0.03	0.34	137.8296
May	101.40	96.625	93	3.625	111.18	0.02	0.36	147.2256
June	121.70	111.55	97	14.55	114.80	0.09	0.45	184.9392
July	141.49	131.595	115	16.595	129.35	0.10	0.56	227.95344
August	136.89	139.19	130	9.19	145.95	0.06	0.61	251.77392
September	131.86	134.375	143	-8.625	155.14	-0.05	0.56	229.41792
October	104.69	118.275	131	-12.725	146.51	-0.08	0.48	196.43472
November	102.57	103.63	112	-8.37	133.79	-0.05	0.43	174.73968
December	100.6	101.585	109	-7.415	125.42	-0.05	0.38	155.52
January	0	50.3	108	-57.7	118.00	-0.36	0.02	5.9616
February	0	0	45	-45	60.30	-0.28	-0.26	-110.6784

WATER BALANCE OF AL-BURULLUS LAKE

The water balance is a systematic method for quantifying the hydrologic components that are important within a specified drainage system. It includes all of the major sources and sinks of water with the hydrologic boundaries of the system. The water balance is often used to estimate the magnitude of unknown hydrologic components such as outflow and the change in storage within any hydrologic system. In the current study, water balance was estimated for the continuous inflow case. To estimate the change in the storage for Al-Burullus lake, the water budget was estimated through the continuity equation in the following form:

$$I - O = (S/dT)$$

Results of the water balance are presented in table (6).

Table (6) Results of the Water Balance.

Month	Drainage	Human	Rainfall	GW	Evaporation	Ouflow	dS
January	258.78	0.83	19.71	2.67	45.39	111.46	116.29
February	241.07	0.83	13.41	2.67	44.65	217.73	21.58
March	293.04	0.83	6.85	2.67	53.75	233.28	13.38
April	287.07	0.83	1.88	2.67	54.37	241.06	14.00

May	321.02	0.83	0.59	2.67	62.28	251.42	36.22
June	370.63	0.83	0.00	2.67	58.67	298.08	43.88
July	423.63	0.83	0.00	2.67	60.39	336.96	23.24
August	410.55	0.83	0.00	2.67	59.23	370.66	-23.44
September	395.35	0.83	0.25	2.67	57.32	339.55	-35.60
October	319.69	0.83	3.20	2.67	55.03	290.30	-29.05
November	299.49	0.83	11.46	2.67	48.59	282.53	-24.26
December	284.29	0.83	20.00	2.67	47.03	248.83	-0.83
Total	3904.61	9.99	77.35	32.00	646.69	3221.86	155.41
%	97.03	0.25	1.92	0.80	16.07	80.07	3.86

RESULTS

Results of the flood routing and water balance indicate the following:

- ? The agricultural drainage water dominate water resources in the system. It presents about 97% of inflow water to the lake, while rainfall, human activities, and groundwater contribute 3% only.
- ? In case (1), the drainage system discharges about 3.20 billion m³ annually to the sea through the lake. This amount, in addition to the change of storage in the reservoir, represents about 80% of the total water resources in the system.
- ? This volume of excess water resources within the system makes water level in the lake during the whole year above the mean sea level.
- ? Volumes of outflow in addition to (dS) in table (5.a) represent monthly excess water to be used in developing plans.
- ? The negative sign in the (dS) column does not represent low levels below the mean sea level, but it means the outflow is greater than the net inflow in a specific time interval.
- ? Results indicate that at the time of winter closure (January) water level in the lake was below the sea level with about 26 cm as presented in table (5.b).
- ? This case allowed sea water to move into the lake with a volume of about 110 million cubic meters. Water levels in the normal case and in the case of winter closure are illustrated in figures (3) and (4).

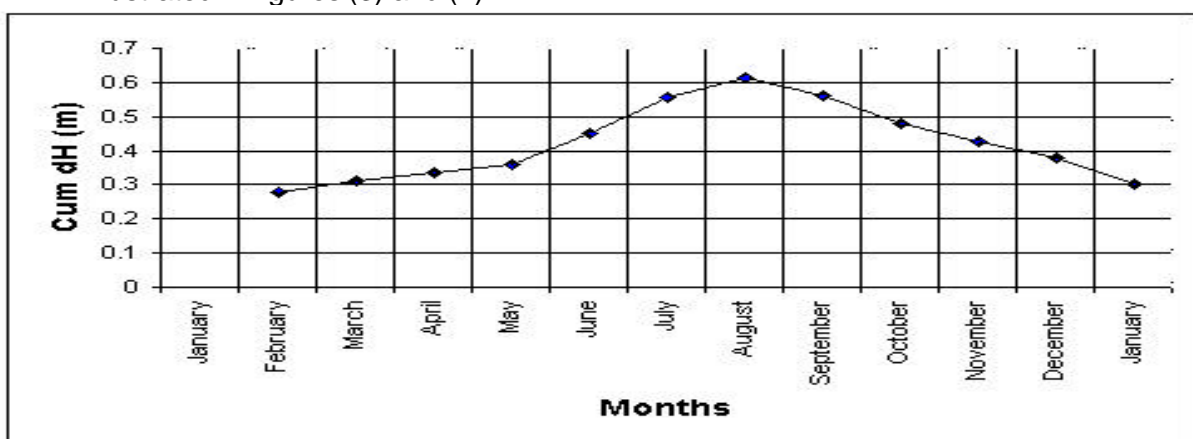


Figure (3) Water level in Case 1



Figure (4) Water level in Case 2

ENVIRONMENTAL MANAGEMENT POLICY

Results of water balance indicate that 80% of water resources (expressed as outflow) is an excess water. This percent presents an annual water volume of 3.2 billion cubic meter. Monthly volumes are illustrated in figure (5), while figure (6) represents the excess cumulative water volumes over the study period in case (1).

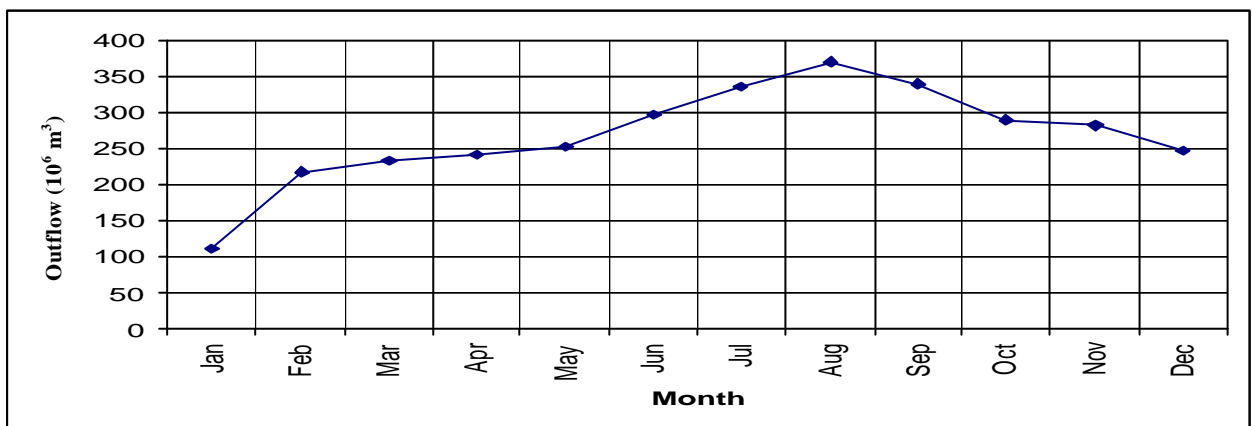


Figure (5) Monthly excess water volumes in case (1)

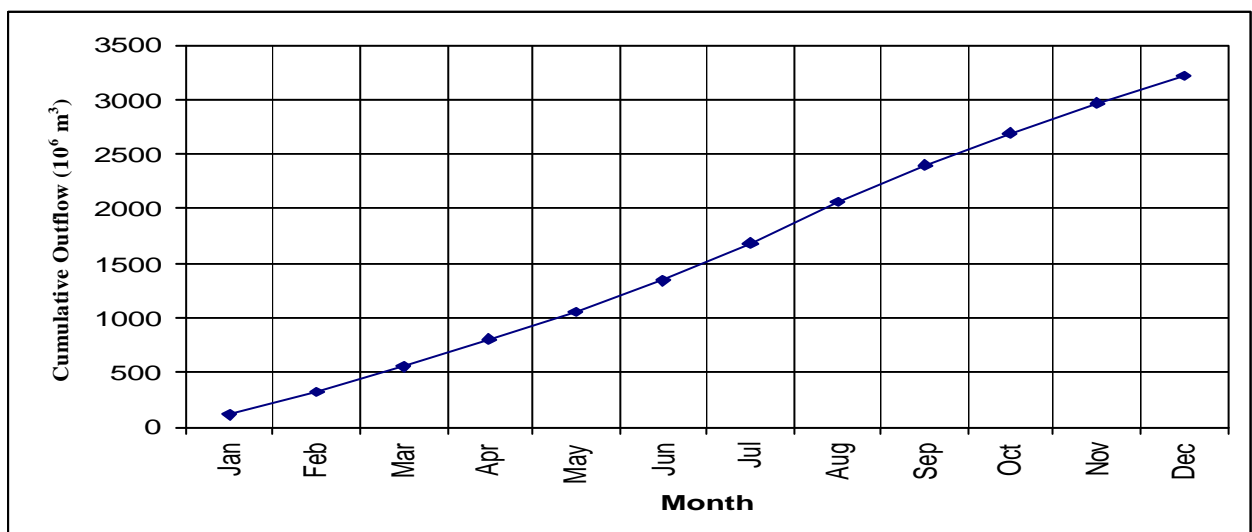


Figure (6) Cumulative annual outflow in case (1).

This volume of water could be discharged outside the lake for environmental management to achieve one of the following two policies.

- (1) Establishment of marine ecosystem.
- (2) Reuse of agricultural drainage waters.

In the establishment of marine ecosystem policy, the excess water could be discharged to the Mediterranean Sea through a proposed canal number (1) that connects Al-Moheet drain to Al-Gharbia main drain as shown in figure (7). In this respect, marine environment will replace brackish water environment and socio-economic status of fishermen will be improved as the sea fish is required inside the country as well as abroad. In addition, sea water is almost free of pollution. Also, reeds distribution at the southern part of the lake will be demolished and water will have the opportunity to move freely.

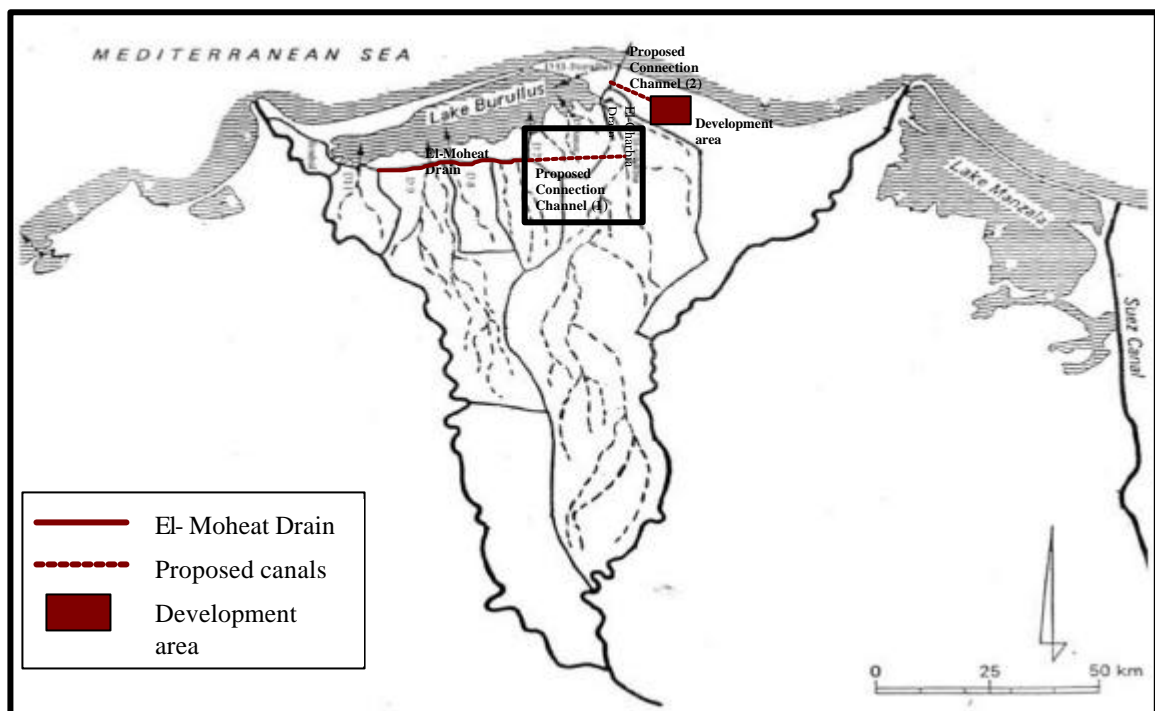


Figure (7) Proposed canals and development area for management policies

The second policy of reusing agricultural drainage water will save an annual amount of water as 3.2 billion cubic meters from outflow discharges beside quantities of storage changes and evaporation losses. This quantity of water could be discharged to development areas located to the east of the lake by digging two open canals as shown in figure (7). As the water is agricultural drainage water, type of cultivations in that area should be tree forests or roses type cultivation. The amount of water that could be saved would support the irrigation requirements for about 300,000 fed. The monthly inflows that could be saved are presented in table (7).

Table (7) Proposed Monthly Inflows (10⁶ m³) to Development Areas.

Month	Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Inflow	210	200	240	235	265	300	350	335	325	260	245	235

If the winter closure is considered, this volume of water would be about 2.99 billion m³ annually by neglecting January inflow.

RECOMMENDATIONS

- ? Water balance of the lake should be estimated on regular basis.
- ? Monitoring system should be installed for hydrological parameters and water quality measurements in the lake as well as in the catchment area. The system should contain stage borders, loggers, flow measurements, groundwater observation wells, and meteorological stations.
- ? A hydrologic model need to be developed for the lake.
- ? Sea water intrusion and its impact on the groundwater aquifer system in the Nile Delta should be studied if any of both management policies would be implemented.
- ? Two activities are running nowadays. These activities are the construction of a new boughaz and the construction of a new port. The impact of these activities should be assessed.

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