RESERVOIR HYDROLOGIC ROUTING FOR WATER BALANCE OF AL-BURULLUS WETLAND, EGYPT

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ABSTRACT

Al-Burullus wetland receives most of agricultural drainage water of the middle delta region in Egypt. Recently, the marine ecosystem in the wetland has been deteriorated due to unbalanced water resources. Accordingly, water balance of the lake has been investigated.

Water resources studies revealed that inflow waters to the wetland include rainfall, agricultural drainage discharges, groundwater contribution, and effluents resulted from human activities, while evaporation and discharges to the sea through Boughaz Al-Borg represent the total outflow term in the flood routing equation.

To define the interaction between the wetland and the Mediterranean Sea water, reservoir hydrologic routing has been implemented. Furthermore, a diagram that represents the relation between the change in storage within the lake and outflow to the sea has been developed. The values of outflow discharges and the change in water stored in the lake have been estimated. Furthermore, typical inflow-outflow hydrographs have been initiated for the wetland.

Results of flood routing indicate that inflow waters represented mainly by agricultural drainage waters dominate the fluctuation of water level in the lake. Analyses also demonstrate that water level fluctuates between 28 and 61 cm above mean sea level. That means water in the lake is in continuous movement toward the sea.

Results of water balance indicate that rainfall represents about 2%, groundwater contributes about 0.8% to the system, human activities represents about 0.2% while agricultural drainage waters represent 97%. On the other hand, evaporation losses consume 16% of the total annual water volume in the wetland. Outflow to the sea represents 80% while the change in storage represents 4% of the annual water balance in the wetland.

1 INTRODUCTION

Al Burullus wetland represented by 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. It extends between 31° 22´ – 31° 26´ N and 30° 33´ – 31° 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 0.8 m. The present area of the lake is about 410 km^2 (100,000 feddan), of which 370 km^2 is open water.

Before the construction of the Aswan High Dam, the lake used to receive the Nile floods in late summer and in 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. The southern border of the lake receives most of the agricultural drainage water of 74.3% of the Nile Delta region. The average volume of water in the lake (at zero mean sea levels) is estimated at 328 million cubic meters. Annual volume of about 3.9 billion cubic meters is discharged into the lake through the agricultural drainage system. On the other hand, saline water enters the lake from the sea through El-Boughaz at the time of least irrigation requirements in the winter season, Figure (1).

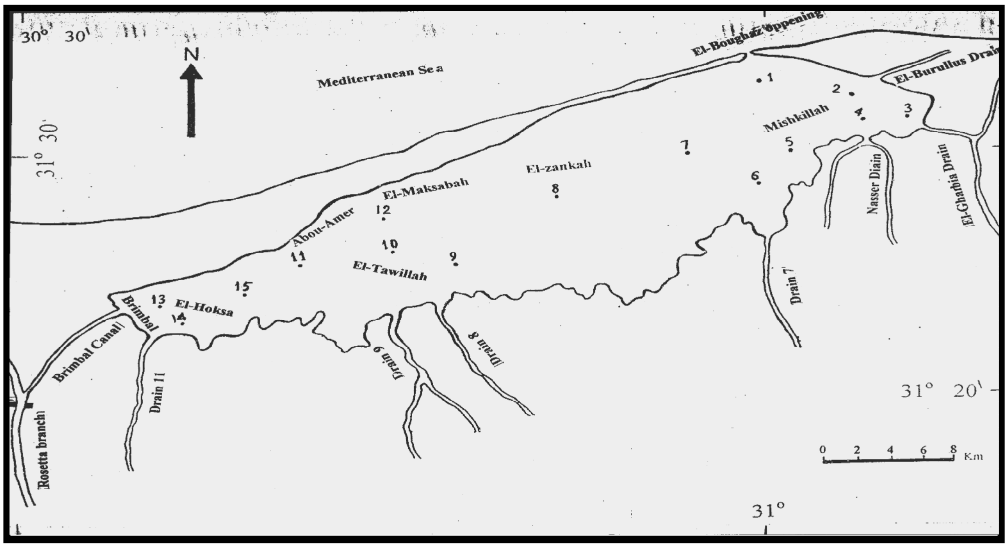

Figure (1) Layout of Al-Burullus wetland

Recently, the marine ecosystem in the lake has been deteriorated due to the continuous water discharges into the lake from the drains for the years 1997 - 2000. To re-establish the pre-deterioration environmental case, water balance of the lake has been investigated. To define the water balance, hydrological flood routing has been implemented. Accordingly, interaction between the lake and the Mediterranean Sea has been defined and the change in the storage has been defined.

2 WATER BALANCE FOR AL-BURULLUS WETLAND

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 wetland system. A water balance is often used to estimate the magnitudes of unknown hydrologic components such as outflow and the change in storage within the wetland. In order to estimate the magnitude of all water balance components, water resources have been investigated. The unknown outflow discharges and change in storage of the wetland had to be estimated. In this respect, water resources that represent the inflow term in the water balance process have been studied. Outflow discharges and the interaction between the Mediterranean Sea waters and wetland's water have been defined through the reservoir flood routing procedure.

2.1 Water Resources of the Wetland

2.1.1 Rainfall

Rainfall data recorded at Al-Burullus lighthouse (31º 36´ N, 31º 05´ E) for a period of 81 years (1912-1992) has been collected and examined. Monthly records of rainfall data have been treated and statistically analyzed. Mean monthly values have been estimated and illustrated in Figure (2) and tabulated in Table (1). The mean annual depth of rainfall is 187.37 mm. This depth of water provides the wetland with a mean annual volume of about 77.35 million cubic meters.

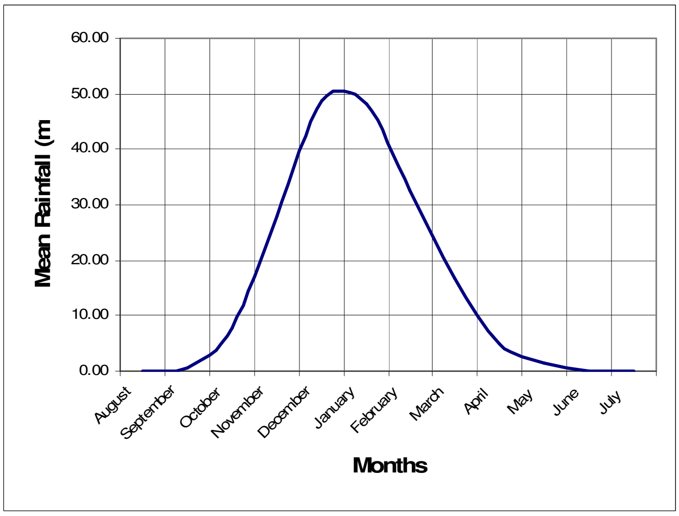

Figure (2) Mean Monthly Rainfall over the Wetland

Table (1) Mean Monthly and Annual Rainfall over Al-Burullus Wetland (mm)

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Rainfall	48.06	32.7	16.72	4.45	1.45	0.00	0.00	0.00	0.61	7.80	27.95	48.78	187.37

2.1.2 Drainage Discharges

The drainage system drains an annual volume of about four billion cubic meter into the wetland. The maximum rate of water that discharges into the lake takes place in July during rice cultivation season while the minimum rate takes place in February. Table (2) shows the monthly inflows of the drainage system to the wetland.

Table (2) Mean Monthly Drainage Inflows to the Wetland (million m^3), (1997-2000).

Month	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Inflow	259	241	293	287	321	370	424	411	395	320	300	284

2.1.3 Tidal Effect

According to Fanos (1992), the tide at El-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.

2.1.4 Human Activity

The human activities are represented by outflow/inflow of water from or to the wetland by local communities in the surrounding areas. Social studies revealed that there are about 185 thousands people live and interact on daily basis with the wetland. This number of people discharges domestic effluents directly to the lake. Water consumption for such number of people (based on average rate of 150 l/day/capita) was estimated as 27,750 m^3/d. This discharge of water has been considered in evaluating the water balance of the wetland.

2.1.5 Groundwater Inflow/Outflow

To evaluate the groundwater inflow/outflow from Al-Burullus wetland, a three-dimensional 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 case, the model was used to estimate the exchange between the wetland and the groundwater aquifer system. The numerical simulation results indicate that the groundwater inflow to Al-Burullus area is about 88902 m^3/day (2667060 m3/month), Table (3).

Table (3) Groundwater Discharge to Al-Burullus Wetland

Interface	Groundwater flow to the Lake
Bottom	63141
Boundaries	25761
Total	**88902**

2.2 Outflows and Water Losses

2.2.1 Evaporation

Evaporation measurements at adjacent stations in Port Said and Alexandria localities have been collected and analyzed. An average value for daily and monthly evaporation at the study area in each month was estimated as presented in Table (4).

Table (4) Average Monthly Evaporation Volumes at Al-Burullus Wetland (10^6 m^3)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Volume	454	44.7	53.5	54.4	62.3	58.7	60.4	59.2	57.3	55.	48.6	47

2.2.2 Outflow to the Sea

To estimate the outflow from the lake to the sea, two steps were taken. The first step is to define the relationship between water level and discharge through Al-Boughaz. In this respect, few measurements were taken by Fanos (1992). These measurements were used in defining the first outflow volume as a pre-request for flood routing process. The second step is the application of the reservoir flood routing method.

2.2.3 Reservoir Flood Routing Procedure

The passage of an inflow hydrograph through a reservoir is an unsteady-flow phenomenon. The equation of continuity used in all hydrologic routing as the primary equation states that the difference between the inflow and outflow rate is equal to the rate of change in storage as follows:

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

This continuity equation could be rewritten as follows:

$$\frac{(I_1 + I_2)\Delta T}{2} - \frac{(O_1 + O_2)\Delta T}{2} = S_2 - S_1 \qquad (1)$$

In which I and O are the corresponding rates of inflow and outflow while S refers to the storage. ΔT is a suitable time interval for the routing period. The subscripts 1 and 2 refer to the start and end of any time step ΔT.

This continuity equation forms the basis of all the storage routing methods. The routing problem consists of finding outflow "O" as a function of time, given I as a function of time, and having information or making assumptions about S.

Any procedure for routing an inflow hydrograph generally has to adopt a finite difference technique and choosing a suitable time interval for the routing period ΔT.

At the beginning of a time step, all values in equation (1) are known except O2 and S2. Thus with two unknowns, a second equation is needed to be solved for O2 at the end of a time step. A second equation is obtained by relating S to O alone. The two equations are then used recursively to find sequential values of O through the necessary number of ΔT intervals until the outflow hydrograph can be fully defined.

For a reservoir connected to the sea (as the study case), the temporary storage, S, is directly and uniquely related to water level H, of water over sea level. The discharge from the "reservoir" is also directly and uniquely related to H. Hence S is indirectly a function of O, it is convenient to rearrange equation (1) to get the unknowns S2 and O2 on one side of the equation and to adjust the O1 term to produce:

$$\left(\frac{S_s}{\Delta T}+\frac{O_2}{2}\right)=\left(\frac{S_1}{\Delta T}+\frac{O_1}{2}\right)+\frac{I_1+I_2}{2}-O_1 \qquad (2)$$

Since S is a function of O, {(S/ΔT) + (O/2)} is also a specific function of O (for a given ΔT), replacing {(S/ ΔT) + (O/2)} by G, for simplification, equation 2 can be written as:

$$G_2 = G_1 + I_m - O_1 \qquad (3)$$

Where Im = (I1+I2)/2. The derivation for O and G are tabulated in Table (5). O is plotted against G and a curve has been developed for the study area to define the relationship between O and G as shown in Figure (3).

Table (5) Derivation of O and G for the auxiliary curve of O versus G

dH	O	S/ΔT	G
0.10	11.565	15.8179	21.60
0.20	32.711	31.6358	47.99
0.30	60.094	47.4537	77.50
0.40	92.521	63.2716	109.53
0.50	129.3	79.0895	143.74
0.60	169.97	94.9074	179.89
0.70	214.19	110.725	217.82
0.80	261.69	126.543	257.39
0.90	312.26	142.361	298.49
1.00	365.72	158.179	341.04
1.10	421.93	173.997	384.96
1.20	480.75	189.815	430.19
1.30	542.08	205.633	476.67

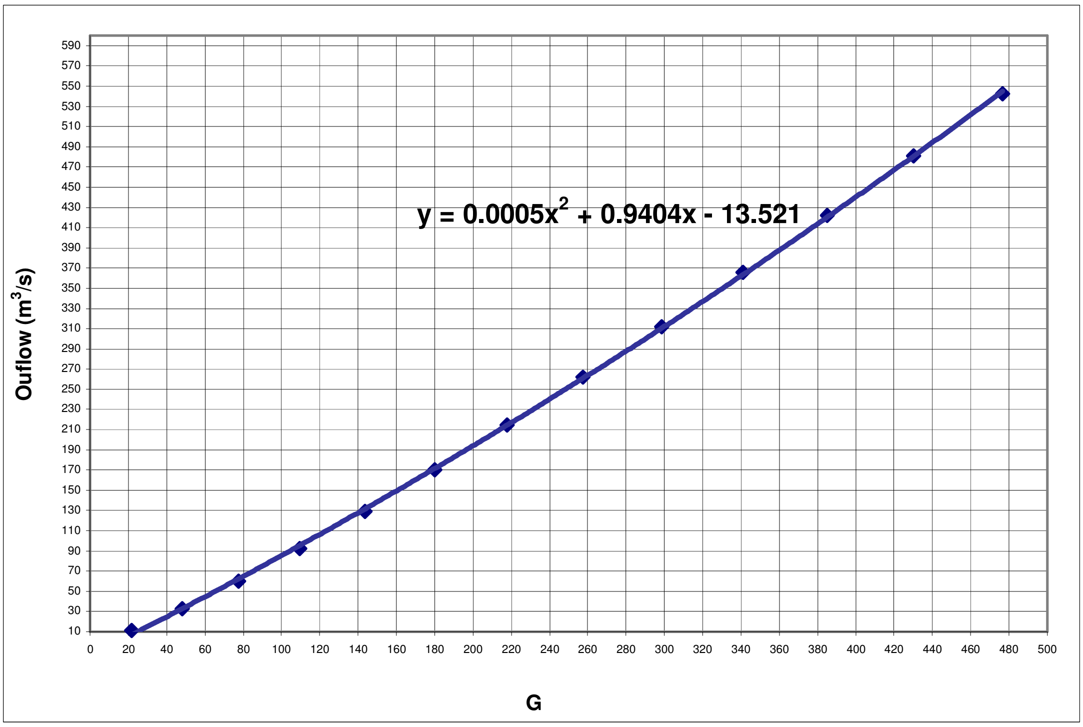

Figure (3) Developed auxiliary curve of O versus G

Equation 3 and the auxiliary curve of Figure 3 provide an elegant and rapid step-by-step solution. At the beginning of a step, G1 and O1 are known from the previous step.

2.3 Results of Reservoir Hydrologic Flood Routing

For the study period, 1997-2000, flood routing results are presented in Table (6). In the study case, agricultural drainage water was discharged continuously for the study period as there was no winter closure. Results presented in the table include inflow and outflow in cubic meters per second. G2 values also are defined in the table. The corresponding change in the water level dH as well as cumulative dH values related to the storage in the lake are presented also.

Additionally, the outflow hydrograph is illustrated in Figure (4). The figure shows a typical inflow/outflow hydrographs resulted from reservoir flood routing procedure.

Results indicate that the elevation of water within the wetland varies from 28 to 61 cm above sea level. Also, the change in the storage maintains continuous outflow to the sea through El-Boughaz

2.4 Water Balance Components

To evaluate the change in the storage for Al-Burullus wetland and outflow discharges within the time interval, the water balance components were estimated. Results of the water balance are presented in Table (7). A schematic diagram for water balance is illustrated in Figure (5)

Table (6) Results of the Reservoir Hydrologic Flood Routing

Month	**I** (m3/s)	**(I1+I2)/2**	**O** (m3/s)	**Im-O**	**G2**	**dH**	**Cum. dH**	**T.Storage**
January	91.28							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	0.55	227.95344
August	136.89	139.19	130	9.19	145.95	0.06	0.61	251.77392
September	131.86	134.375	140	-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

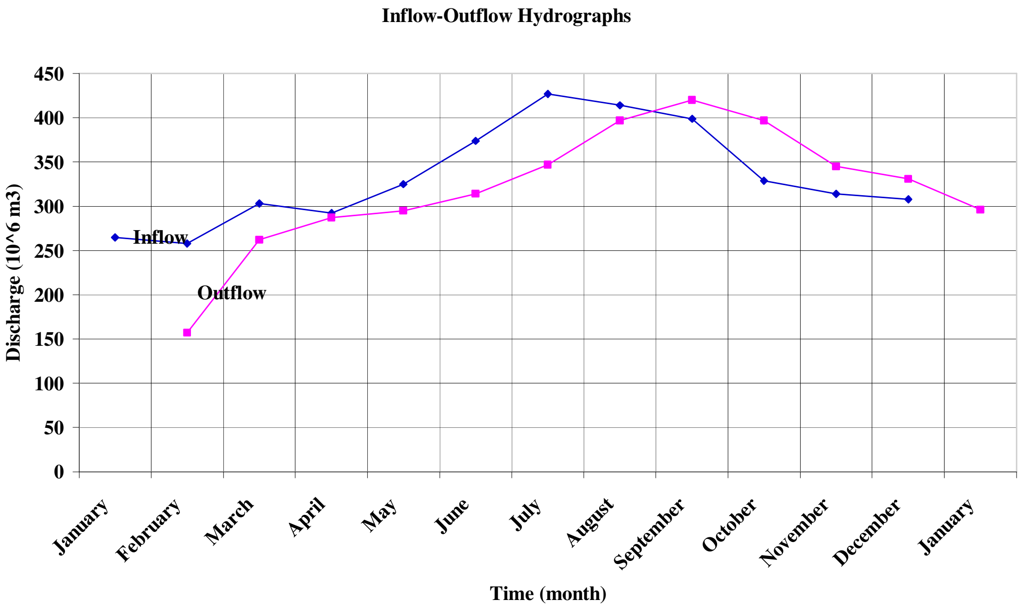

Figure (4) Typical inflow-outflow hydrographs for Al-Burullus wetland.

Table (7) Results of the Water Balance (10^6 m^3)

Month	Drainage	Human	Rainfall	GW	Evaportion	Ouflow	dS	Total H (cm)
January	258.78	0.83	19.71	2.67	45.39	111.46	116.29	0.28
February	241.07	0.83	13.41	2.67	44.65	217.73	21.58	0.31
March	293.04	0.83	6.85	2.67	53.75	233.28	13.38	0.34
April	287.07	0.83	1.88	2.67	54.37	241.06	14.00	0.36
May	321.02	0.83	0.59	2.67	62.28	251.42	36.22	0.45
June	370.63	0.83	0.00	2.67	58.67	298.08	43.88	0.55
July	423.63	0.83	0.00	2.67	60.39	336.96	23.24	0.61
August	410.55	0.83	0.00	2.67	59.23	370.66	-23.44	0.56
September	395.35	0.83	0.25	2.67	57.32	339.55	-35.60	0.48
October	319.69	0.83	3.20	2.67	55.03	290.30	-29.05	0.43
November	299.49	0.83	11.46	2.67	48.59	282.53	-24.26	0.38
December	284.29	0.83	20.00	2.67	47.03	248.83	-0.83	0.30
Total	3904.61	9.99	77.35	32.00	646.69	3221.86	155.41	
Water Balance Components (%)	**97.03**	**0.25**	**1.92**	**0.80**	**16.07**	**80.07**	**3.86**	

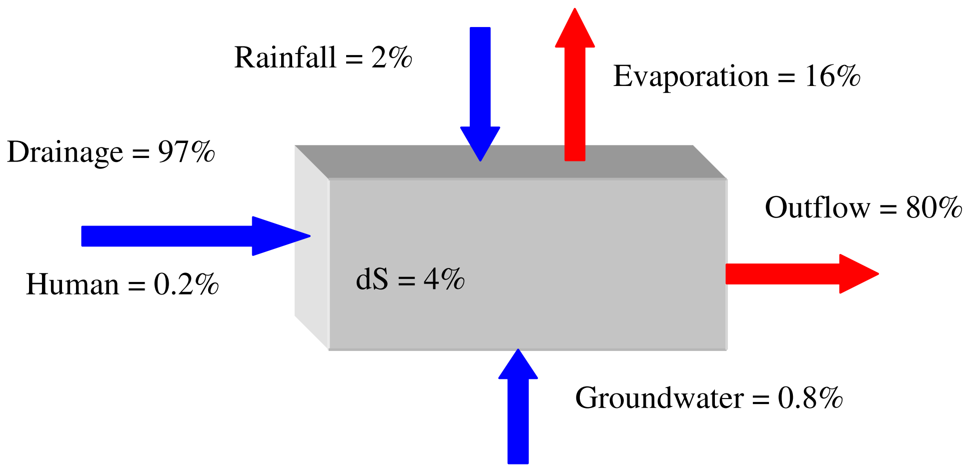

Figure (5) A Schematic Diagram for the Water Balance of Al Burullus wetland.

3 Analyses of Water Balance Results

According to the hydrologic flood routing process implemented, results of the water balance indicate the following:

Drainage water represents about 97% of the total water resources in the system.

Rainfall represents less than 2% of the total water resources in the system.

Groundwater contribution also represents less than 1% of the total water resources in the system.

Evaporation losses represent about 16% of the total water resources in the system.

The drainage system discharges annual volume of about 3.20 billion m^3 to the sea through the lake. This amount, in addition to the change of storage in the reservoir, represents about 84% of the total water resources in the system.

The negative sign in the (dS) column in the tables does not represent low levels below the mean sea levels, but it means the outflow is greater than the net inflow in a specific time interval.

In order to re-establish the pre-deterioration status of the lake, 84% of the water resources should be discharged outside the lake. This percent represents about 3.38 billion cubic meters annually.

This volume of excess water resources within the system makes water level in the lake during the whole year above the mean sea level. In order to make use of this huge amount of drainage water, it is recommended to convert this water to the development projects areas to the east of the wetland.

Volumes of outflow and (dS) represent monthly excess water that could be used in developing plans.

4 SUMMARY AND CONCLUSION

Al-Burullus wetland receives most of agricultural drainage water of the middle delta region in Egypt. Recently, the marine ecosystem in the lake has been deteriorated due to the continuous water discharges into the lake from the drains for the years 1997 - 2000. To re-establish the pre-deterioration environmental case, water balance of the wetland has been investigated. To define the water balance, hydrological flood routing has been implemented. Accordingly, interaction between the lake and the Mediterranean Sea has been defined and the change in the storage has been estimated. Moreover, a diagram that represents the relation between the change in storage within the lake and outflow to the sea has been developed. The values of outflow discharges and the change in water stored in the lake have been estimated. In addition, typical inflow-outflow hydrographs have been initiated for the wetland.

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Results of water balance indicate that rainfall represents about 2%; groundwater contributes about 0.8% to the system, human activities represents about 0.2% while agricultural drainage waters represent 97%. On the other hand, evaporation losses consume 16% of the total annual water volume in the wetland. Outflow to the sea represents 80% while the change in storage represents 4% of the annual water balance in the wetland.

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