# Managing Water and Salt Balance of Wadi El-Rayan Lakes, El-Fayoum, Egypt

# دراسة الإتزان المائى والملحى لبحيرات وادى الريان بالفيوم

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**خلاصة:**

تهدف الدراسة الحالية إلى دراسة الإتزان المائى والملحى للنظام المائى المتكون من تحويلة الوادى والقناة المكشوفة ونفق وادى الريان وبحيرات وادى الريان عن طريق بناء نموذج رياضى أحادى وثنائى الأبعاد (SOBEK-1D2D). ولقد تم إختبار عدد من السيناريوهات. أظهرت النتائج أن أفضل سيناريو للوضع الحالى هو سيناريو رقم (٤) وأفضل سيناريو للإدارة في المرحله المستقبلية بعد إضافة مساحات جديدة من الأراضى الزراعية والمزارع السمكية هو سيناريو رقم (٥). وتوصى الدراسه بخطة لإدارة المياه ونوعيتها مكونة من عدة خطوات لمساعدة متخذي القرار فى إدارة أفضل لبحيرات وادى الريان بمحافظة الفيوم.

## ABSTRACT:

The present paper aims to manage water and salt balance of Wadi El-Rayan Depression, El-Fayoum, Egypt. Data measurements from the study area were collected and analyzed. SOBEK-1D2D was employed and different scenarios were tested. The results of the study indicated that scenario 4 is the best for the current condition to manage Wadi El-Rayan Lakes in a better way. Also scenario 5 is the most suitable for the future condition. In conclusion, the management problem of water and salt balance is solved. A number of management steps are recommended to help the decision makers to set a management plan for Wadi El-Rayan Lakes.

***Keywords:*** Water and salt balance; Water management; Wadi El-Rayan Depression and SOBEK.

## 1. INTRODUCTION

El-Fayoum depression is a closed basin, about 85 Km south-west of Cairo. It is located in the limestone plateau of the western Egyptian desert with an altitude ranging from (25) meters above mean sea level at Lahoun intake to (42) meters below sea level at Qaroun Lake, Figure (1). Its area is 425000 feddan. Qaroun Lake is located in the north with surface area of approximately 336.8 $km^2$. Irrigation water is delivered from the Nile through Bahr Youssef and Bahr Hassan Wassef canal. The natural drainage system discharges its water into Qaroun Lake. The main drains of El-Fayoum are: Batts Drain in the eastern part and El-Wadi Drain in the western part of El-Fayoum. Together with several minor drains discharge into Qaroun Lake. Since 1973, a part of the water in El-Wadi Drain is diverted to Wadi El-Rayan Depression through Tahwelat Al-Wadi, Al-

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Makshofa drains and Wadi El-Rayan Tunnel in the limestone ridge between these two depressions. This water represents about 30% of the total drainage water of El-Fayoum, in order to control the water levels of Qaroun Lake, to comply with the horizontal expansion plan and to increase the agricultural area, *Veer M., et. al (1993).*

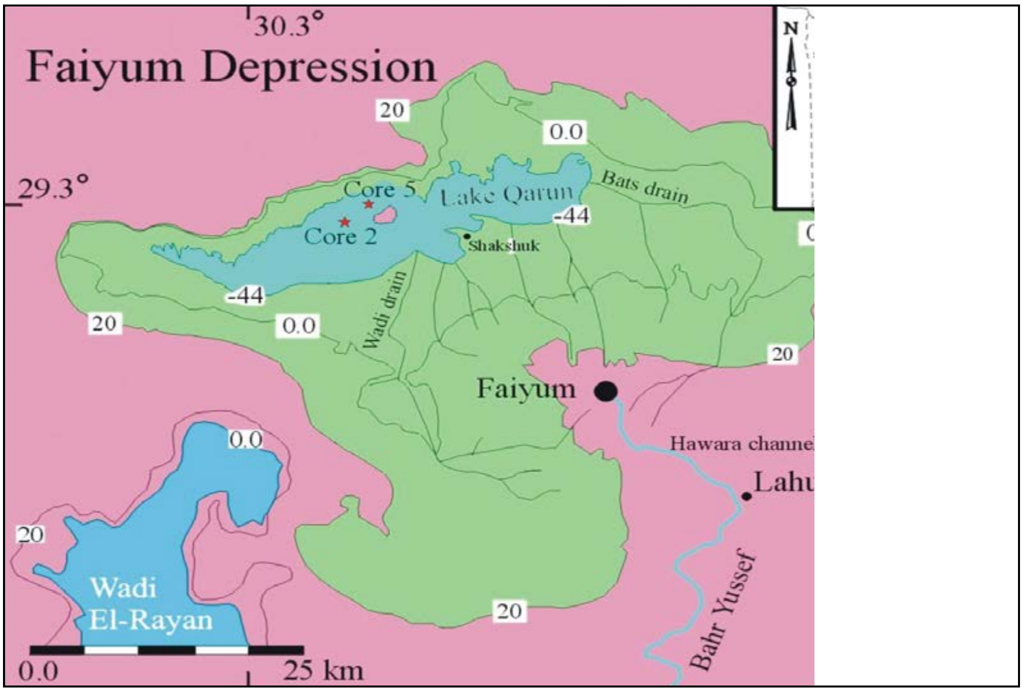


**Fig. 1**: Location of the study area in Egypt

Tahwelat Al-Wadi and Al-Makshofa drains were designed to have a trapezoidal cross section with a maximum discharge of 12 $m^3/s$. Tahwelat Al-Wadi has a length of 7.84 km. It starts from Al-Makshofa Drain (km 0.0) and ends at El-Wadi drain (km 7.84). The bed width ranges between 8 and 6 m at the end with side slopes of 2:1. The water surface slope is 10 cm/km. Al-Makshofa Drain has a length of 9.24 km. It starts from Tahwelat Al-Wadi (km 0.0) and ends at Wadi El-Rayan Tunnel (km 9.24). The bed width ranges between 5 and 8 m at the end with side slopes of 2:1. The water surface slope is 15 cm/km, *Amer. M.H., (1992).*

There are three mixing pumping plants on Al-Makshofa Drain: El-Nezla, El-Banat and El-Gas stations consist of 3, 3 and 2 units. Each pump station has a mixed discharge of 1, 1 and 0.5 $m^3/s$, respectively. Tagen Mixing Plant that was constructed on El-Wadi Drain was used to divert water to Tahwelat Al-Wadi. This station consists of eight units with only six units in work and it has a discharge of 4.6$m^3/s$.

The design discharge of Wadi El-Rayan Tunnel is 12 $m^3/s$. The drainage water from Wadi El-Rayan Tunnel to Wadi El-Rayan Depression led to the formation of two lakes in Wadi El-Rayan Depression that adds an environmental dimension and touristic value to El-Fayoum Province, where Wadi El-Rayan Depression is considered as a natural reservation in Egypt.

The upper lake of Wadi El-Rayan; Lake 1 is linked to the lower lake; Lake 2 through a number of waterfalls and a channel of 4 m width. The water level of the upper lake fluctuates with about 40 cm annually due to evaporation losses, inflow and outflow through the year, while the water level of the lower lake decreases by about 50 to 70 cm per year due to over pumping. The waterfalls were semi-dried in October 2002. The low water level of lakes affected the environment of lakes and decreased the fishing activity.

The currently agriculture lands around the lakes are 4000 feddans in Sedi Al-Khedr Village in addition to an area of 900 feddans of fish farms. Moreover, the target is to reclaim new lands of 4000 feddans and add an area of 1400 feddans fish farms, depended on the water of the Wadi El-Rayan Lakes.

Currently, operating El-Nezla and El-Banat pumping stations simultaneously to satisfy the peak demands during the summer resulted in a drainage flow of around 57 MCM/year to the upper Lake of Wadi El-Rayan. Due to the mean evaporation of the upper lake, its water level is decreased. Therefore, there will be insufficient flow to meet the pumping station requirements for the new expansion area between the two lakes of Wadi El-Rayan Depression.

As a result, the lower lake waterfalls were almost completely dry. The quality of both upper and lower lakes is deteriorating. This endangers the sustainability of the reclamation area in the Wadi El-Rayan Depression and fish farms. Therefore, it was due to study the reasons affecting the water levels of the lakes and how to better manage the system.

The present research was thus initiated with the objective of examining the water and salt balance of the water system formed by diverting the water through Tahwelat Al-Wadi, Al-Makshofa drains and Wadi El-Rayan Tunnel to the Wadi El-Rayan Depression using the hydrodynamic numerical model "SOBEK-1D2D". SOBEK Rural-1D module combined with SOBEK-2D module were used for simulating the drains as 1D and the lakes as 2D.

The investigation phases executed during the course of the present research are presented in this paper under the following headlines:

- Executing site visits
- Undertaking and analyzing the field measurements

- Modeling the problem in hand
- Analyzing and presenting the model results

## 2. EXECUTING SITE VISITS

Several site visits were carried out in order to perceive a complete data picture about the study area. During these visits, observations were documented, measurements were undertaken and photos were captured.

## 3. UNDERTAKING AND ANALYZING THE FIELD MEASUREMENTS

Field investigations were executed and data was assembled. Bathymetric survey (i.e. using high technology instruments, such as DGPS, Total Station, Echo Sounder, and Range Finder) were performed.

*A bathymetric and hydrometric survey* was performed in order to provide the data for the setup and calibration of the numerical model used in the study.

*A transportable automated meteorological station*, model 9600 was installed for continuous recording of temperature, wind speed and wind direction measurements.

*A bathymetric survey* was executed to cover Tahwelat Al-Wadi, Al-Makshofa Drain, Wadi El-Rayan Tunnel and Wadi El-Rayan Lakes. The bathymetric survey for Tahwelat Al-Wadi and Al-Makshofa drains covered cross-sectional details each 100 m and measurement of water surface slope each 1 km. Also, status of the hydraulic structures such as mixing plants, bridges, trash rack, etc. along the study area was investigated.

On the other hand, *flow velocities were measured* at five different locations. The field measurements of Wadi El-Rayan Tunnel covered the exploring of the tunnel through its manholes. The bathymetric survey of Wadi El-Rayan Lakes covered cross-sectional details ranged from 0.5 to 0.9 km that depends on the nature of the lakes and measurement of water levels.

*A Van Veen grab sampler was used to collect 15 bed material samples* from the same locations of the velocity measurements cross section (3 samples for each cross section) for Tahwelat Al-Wadi, Al-Makshofa drains and 6 bed material samples even distributed to cover Wadi El-Rayan Lakes.

*The bed samples were analyzed* to provide the bed properties such as grain size distribution, density and specific gravity.

Also, six water samples distributed over the surface of the lakes were collected. *Water samples were also assembled* to provide the salt concentration loads and the water salinity, *Harbeck, and Meyers, (1970).*

*Moreover, evaporation was measured* at Wadi El-Rayan Lakes by the WMRI.

*All the executed measurements were analyzed* from which the following was deduced:

- The bathymetric survey and hydraulic measurements revealed that the observed longitudinal profile of Tahwelat Al-Wadi has a bed level that is higher than of the designed profile with an amount of 50 to 190 cm, while the observed longitudinal profile of Al-Makshofa Drain has a bed level of 50 to 100 cm higher than that of the designed profile.
- The measured cross sections of the two drains revealed the presence of silting in the middle of the cross sections. The observed width of Al-Makshofa Drain is hugely reduced and it is about 5 m before Wadi El-Rayan Tunnel. The observed trash rack of 2 m width in front of Wadi El-Rayan Tunnel is clogged by weeds and plankton.
- Field measurements revealed also that current water levels of Tahwelat Al-Wadi at the discharge of 5 $m^3/s$ are higher than the design water levels at discharge of 12 $m^3/s$ by a value of 20 to 58 cm. Whereas, the present water levels of Al-Makshofa Drain at the discharge of 5 $m^3/s$ are higher than that of the design water level at discharge of 12 $m^3/s$ by a value of 56 to 146 cm. The discharge diverted to Wadi El-Rayan Depressions was measured by the CAMWRI of El-Fayoum.
- The bathymetric survey and hydraulic measurements of Wadi El-Rayan Lakes revealed that the measured width of the upper Lake of Wadi El-Rayan ranges from 3.60 to 7.70 km, and the bed levels range from (-34.40) to (-10.00) m+MSL, while the measured width of the lower Lake ranges from 2.20 to 7.0 km, and its bed levels range from (-50.00) to (-32.00) m+MSL.
- Evaporation and salinity were measured at Wadi El-Rayan Lakes by the WMRI. Figure (2) shows the average daily lake evaporation and drain inflow to Wadi El-Rayan Lakes.

# 4. MODELING THE PROBLEM IN HAND

Use of hydrodynamic simulation models seems to be one of the most important tools for understanding the hydraulic behavior of canals and shallow lakes. Over years, several mathematical models have been developed to study the flow dynamics of the canal system. Finite-difference methods were developed in the 1970s and applied to branching and looped networks. The unsteady-flow simulation models subsequently developed are either upstream-control or downstream-control oriented and employ either local or central criteria to handle scheduled, arranged, or on-demand methods of water delivery, *Clemmens, et al., (2005).*

Some of the available hydraulic models are *CANALMAN, DUFLOW, CARIMA, MODIS, USM, and Branch Canal Network Model*. The problem in hand was modeled using SOBEK. The description of the model together with its calibration process so as the modeled scenarios and the modeling itself are presented here, as follows:

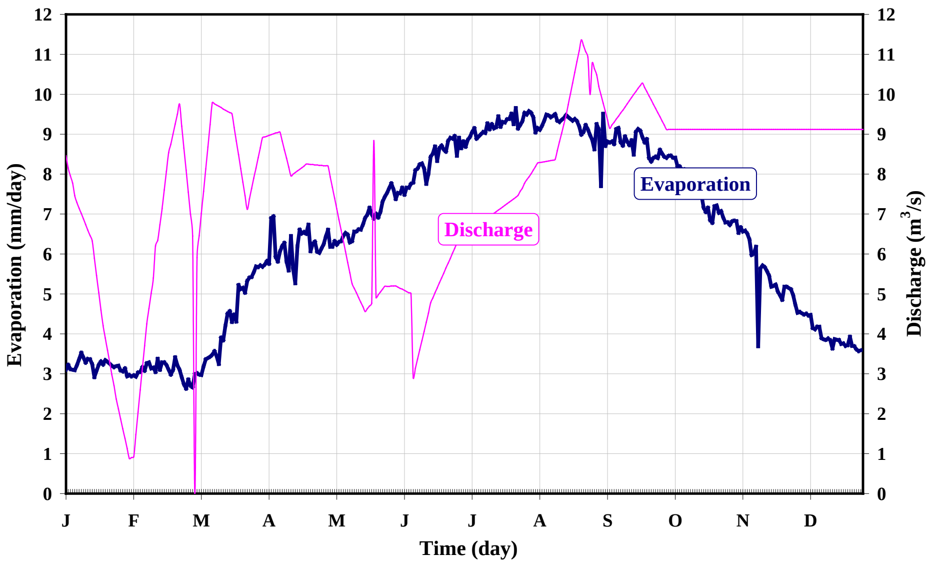


**Fig. 2**: Average daily lake evaporation and discharges of Wadi El-Rayan Lakes

## 4.a. Model Description

SOBEK is a powerful 1D and 2D model developed by WL| Delft Hydraulics, the Netherlands for flood forecasting, drainage systems, irrigation systems, sewer overflow, ground-water level control, river morphology, salt intrusion and water quality.

SOBEK is equipped with a very robust numerical scheme that handles drying and flooding and sub- and super critical flows efficiently. Its map-based user interfaces for the product lines: River, Lowland and Urban, are accompanied by a powerful process database and editor to enable the formulation of water quality processes by the user. There is a flexible link to various Geographical Information System (GIS) systems.

SOBEK also allows for the integration of user-defined modules through the use of specific data exchange formats. Its unique integrated format means that the effectiveness of measures taken can be checked to keep your system running at high efficiency. The manual or automatic operation of pumps, sluice gates, weirs, storage tanks and other structures can all be incorporated into the model, giving a realistic picture of how a system behaves in extreme scenarios. Its results are displayed as maps, graphs, tables and animations helping researchers to analyze and communicate their ideas. SOBEK is based on high-performance computer technology. That means it can handle water networks of any size (big or small) and complexity. It automatically configures itself to the type of water system you're modeling. All numerical computations have self-selecting time steps and are extremely robust, *Delft Hydraulics, (2005).* The program calculates water depths and velocities in the study area, which is represented by a two-dimensional grid. The flow module is capable of simulating a fully unsteady flow in the drains. Moreover, SOBEK can simulate the evaporation form a saline shallow lake. These modules can be operated separately or in-combination. The data transfer between the modules is fully automatic and modules can be run in sequence or simultaneously to facilitate the physical interaction. The combined 1D2D model was built in order to:

- determine the capacity of the Tahwelat Al-Wadi, Al-Makshofa Drain and Wadi El-Rayan Tunnel and to determine the factors that affect their efficiency;
- study the possibility of increasing the discharge to the Wadi El-Rayan Lakes;
- determine the water level of the Wadi El-Rayan Lakes under different conditions of the policy of reuse of wastewater and mixing plants in addition to the withdrawal of water for the irrigation;
- determine the volume of the lakes at different elevations;
- design different scenarios to ensure the sufficient water levels of lakes that meet the needs of the target farm lands and fish farms;
- determine the salinity of Wadi El-Rayan Lakes.

## 4.b. Model Setup

The setup of the hydraulic model involves specifications of drain cross sections, layout of the drain network and upstream and downstream initial and boundary conditions. Both the upstream and downstream ends of the three prementioned drains are identified. The maximum selected distance between two neighboring points is also required for the network definition. The topographical identification is extracted from the index map of the Nile River System that is stored in SOBEK model. In SOBEK, the cross section database can be regarded as a library storing data for a large number of cross sections, organized in such a way that every cross section is identified by drain name and topographical identification, *Contractor, and Schuurmans, (1993).* The cross sections data are available at discrete points along the system. In this study, a space interval of 100 m is selected; thus, cross sections are defined in the model setup at every 100 m.

The Geographical Information System (GIS) software was used extensively during the development of maps and the DEM was used in the present study. As for, the production of Wadi El-Rayan Lakes grid, the Wadi El-Rayan Lakes were simulated through a grid with vertical and horizontal gridlines 100 m apart. The simulated area was divided into a mesh of 130 x 80 cells. Also, floating and mixing pump station were simulated including the water inlet to fish farms. Figure (3), shows the model schematization.

The initial conditions can be specified as global values of water levels and discharges for the entire drain network or as local values at different distances of a particular canal. These initial conditions are specified in the supplementary data file. The boundary conditions may be internal or external. The internal boundary conditions includes the specifications of nodal points and structures, whereas the external boundary conditions includes the specification of constant values for h or Q or time varying values for Q or h at the starting point and endpoint.

The daily discharges at the system source, during the survey and the water level at the downstream end, are specified in the time series database file to serve as boundary conditions.

Before running the model, control parameters such as simulation period, simulation time step, data to be stored and storage time have to be specified. The simulation period is specified by start and end dates defined by year, month, day, hour and minute.

SOBEK checks the actual time and reads all data given as a time series during the simulation. The courant number was used for selecting the time step which is calculated to control the simulation process.

## 4.c. Model Calibration

In the present study, the hydraulic resistance number (Chezy roughness coefficient) is considered as the model calibration parameter. After setting up the model, an initial run is made with the measured value of Tahwelat Al-Wadi and Al-Makshofa drains for hydraulic resistance number was 37 using the measured discharges and water levels. A comparison is made between the observed and simulated water levels along the length of the canal. Some adjustments are done with the hydraulic resistance number until the measured and simulated values are in close agreement.

Figures (4) and (5), show that the simulated water levels are in close agreement to the observed water levels.

Wadi El-Rayan Lakes also were calibrated for hydraulic resistance number of 35 using the averaged measured discharge, evaporation and water levels of year 2010.

For the simulation period of one year, a simulation time step of one day is selected. The observed and simulated values are in close agreement, Figure (6). Confident with the calibration results, the model could be further implemented to simulate the problem in hand.

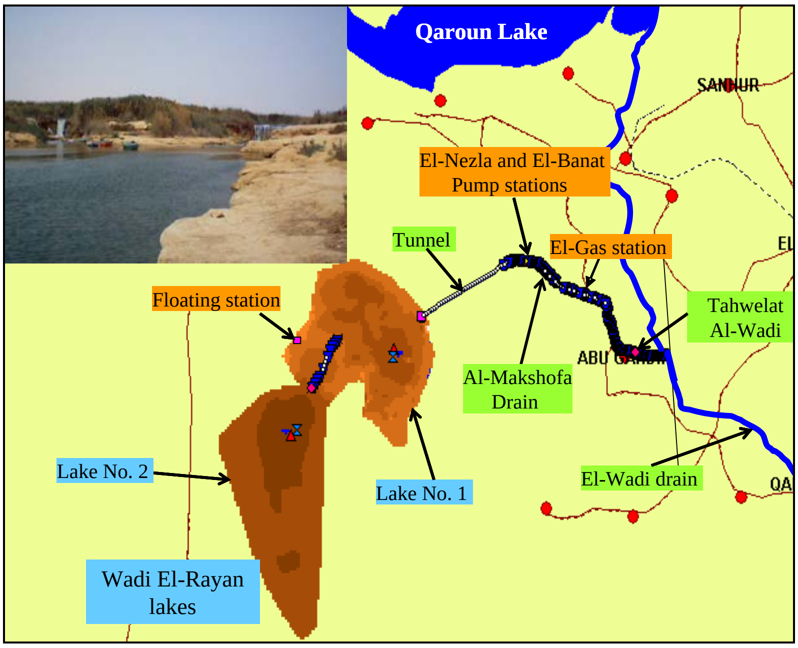


**Fig. 3**: Model schematization

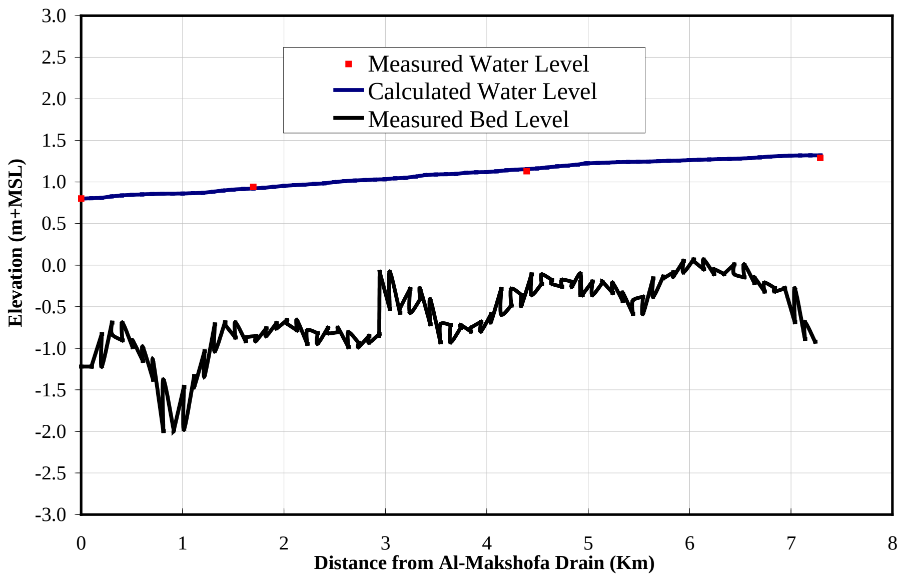


**Fig. 4**: Model calibration

(Comparison between observed and simulated water levels along Tahwelat Al-Wadi)

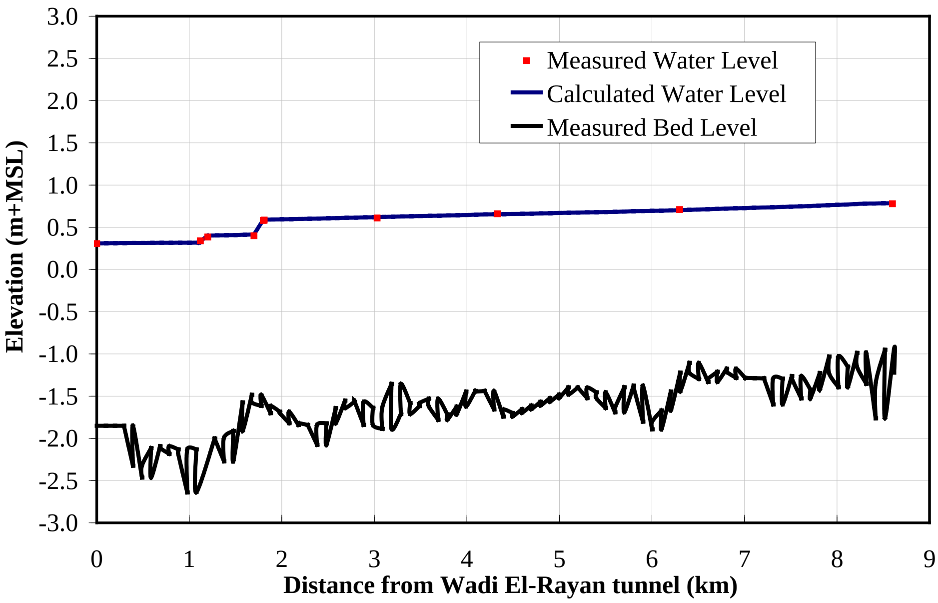


**Fig. 5**: Model calibration
(Comparison between observed and simulated water levels along Al-Makshofa Drain)

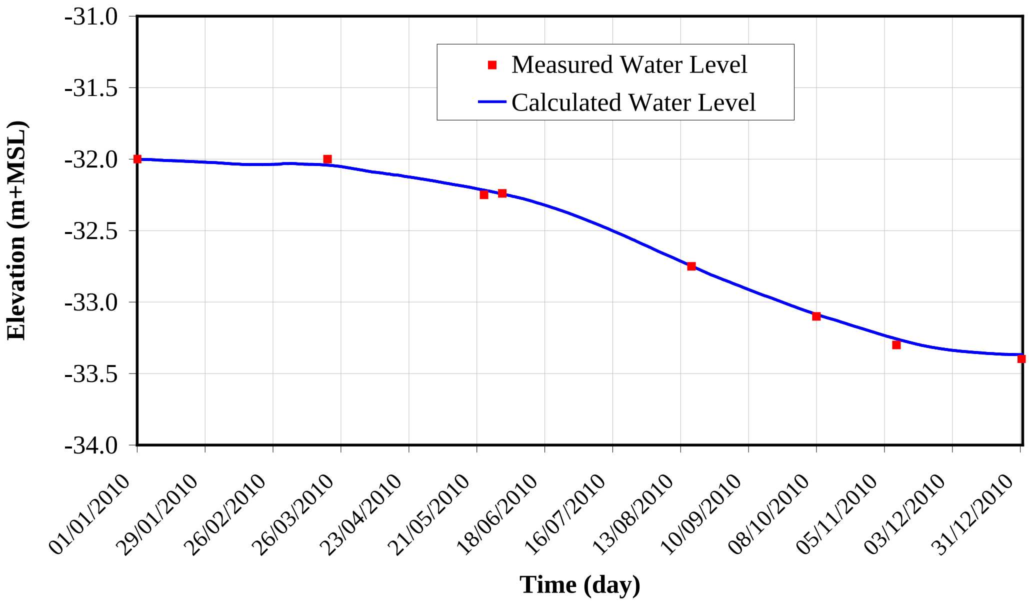


**Fig. 6**: Model calibration
(Comparison between observed and simulated water levels along lower Lake of Wadi El-Rayan)

## 4.d. Model Simulation

The water management alternatives were tested by SOBEK. These alternatives satisfied the following conditions:

- Adequate water supply in order to meet the water requirement.
- A high degree of overall system performance.
- A minimum drainage outflow to Wadi El-Rayan Lakes must be secured in order to maintain a permanent, safe, environmentally acceptable and to

meet the leaching requirement for salinity control.

The procedure for simulation and evaluation of management options are as follows:

- determine the maximum capacity of Tahwelat Al-Wadi and Al-Makshofa drains;
- define the relationship between the water levels and volume of Wadi El-Rayan Lakes to determine the desired average water level and its upper and lower limits;
- calculate the corresponding inflow into Wadi El-Rayan Lakes necessary to maintain these levels;
- simulate drainage flows from El-Wadi Drain for corresponding irrigation intake, and assumed reuse of drainage water at a varying number of mixing locations; as the physical characteristics and hydrology of the lake were studied.

# 5. ANALYZING AND PRESENTING THE MODEL RESULTS

The results of the simulations to the different alternatives were obtained, analyzed and presented, as follows:

## 5.a. Maximum Capacity of Drains

After model calibration, testing the capacity of Tahwelat Al-Wadi and Al-Makshofa drains at maximum discharge of 12 $m^3/s$ was conducted for the following cases:

- Current conditions.
- Cleaning the trash rack.
- Dredging the channels to reach the design cross-sections.

Passing the maximum discharge of 12 $m^3/s$ with the current conditions of Tahwelat Al-Wadi Drain, the model results revealed that, the computed water levels exceed bank levels, where, the water level is (+4.77) and (+4.79) m+MSL at the beginning and the end of the drain, respectively, which is more than the design water level by an average of 4.5 m and 3.69 m.

Likewise, when cleaning the trash rack in front of the tunnel, the model showed that, the computed water level decreased by 3.0 m. Moreover, after dredging of the drain to the design cross-sections, the results showed that computed water level is more than the design water level with an average of 0.13 m at the beginning of the drain and it is lower than the design water level with an average of 0.10 m at the end of the drain, Figure (7).

Passing the maximum discharge of 12 $m^3/s$ with the current conditions of Al-Makshofa Drain, the model results revealed that, the water levels are exceeding bank levels by an average of 2.1 m, where, the computed water level is (+3.87) and (+3.14) m+MSL at the beginning and the end of the drain, respectively, which is more than the design water level by an average of 4.28 m and 3.61 m, respectively. Correspondingly, when cleaning the trash rack in front of the tunnel, the simulation results demonstrated that, the computed water level is lower than the design one by an average of 0.26 m at the beginning and it is higher than the design water level by an average of 0.56 m at the end of the drain. The output of dredging process to reach the design bed levels showed that, the calculated water level is (+0.34) and (-2.48) m+MSL at the beginning and the end of the drain, respectively, where, the water level is lower than the design water level by an average of 1.33 m at the beginning of the drain and lower than the design water level by an average of 0.080 m at the end of the drain, Figure (8).

### 5.b. Relationship between Water Levels and Volume of Lakes

In order to mange the water balance, the relationship between the volumes of Wadi El-Rayan lakes was determined. The model was used to define this relationship. The model results revealed that, the water volume of upper lake is 671.01 MCM at corresponding water level of (-8.00) m+MSL and the water volume of lower lake is 881.61 MCM at corresponding water Level of (-26.00) m+MSL, Figure (9).

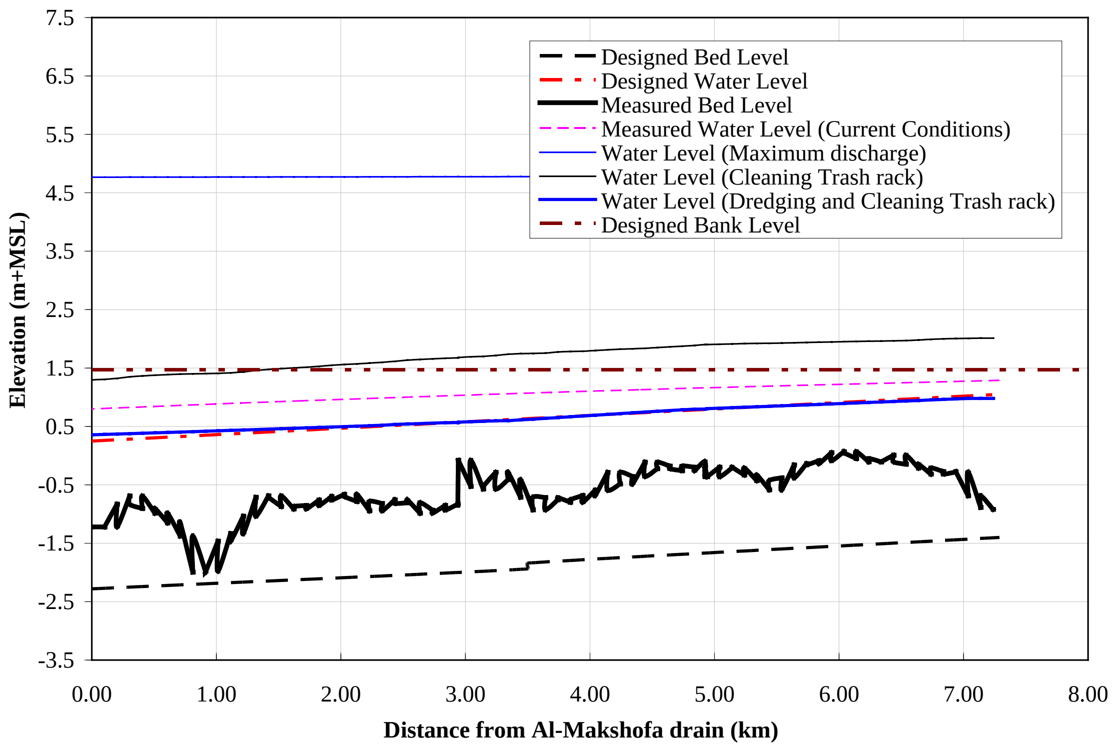


**Fig. 7**: Different longitudinal profiles of Tahwelat Al-Wadi Drain

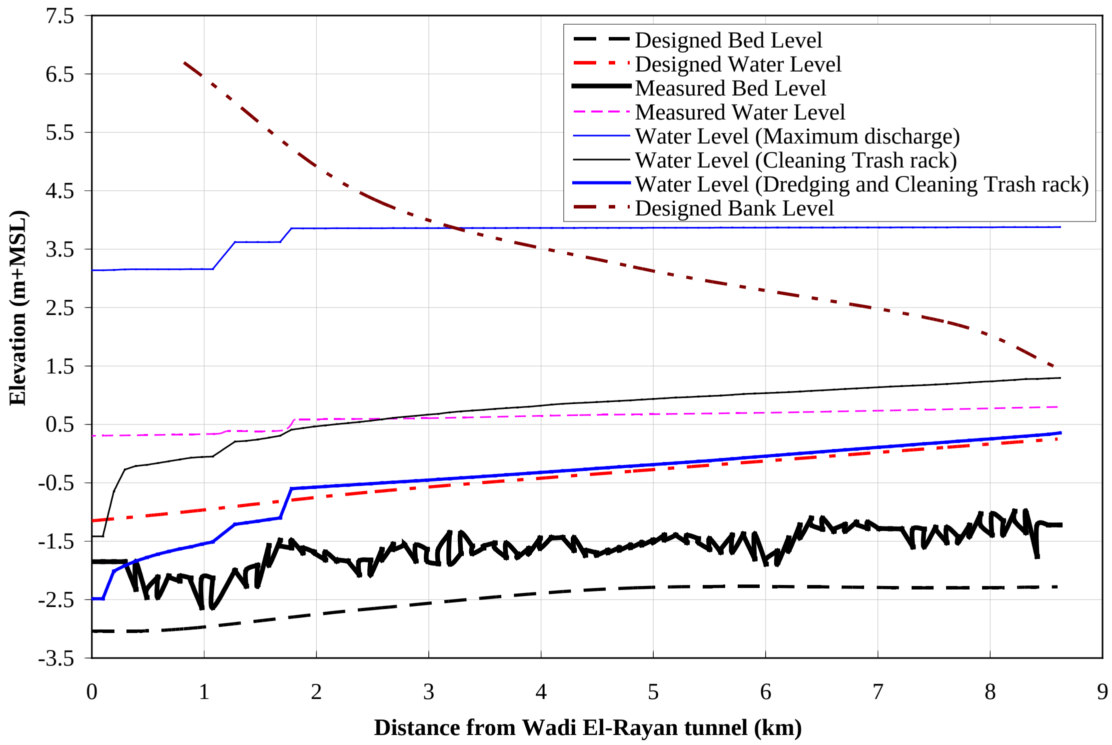


**Fig. 8**: Different longitudinal profiles of Al-Makshofa Drain

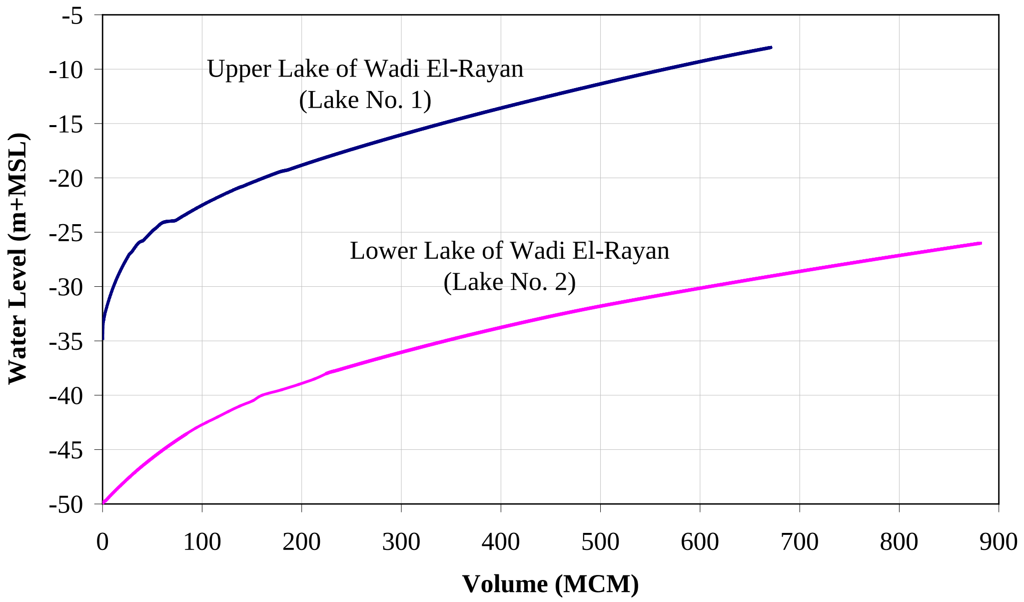


**Fig. 9**: Relationship between water Levels and volume of Wadi El-Rayan Lakes

## 5.c. Water Balance Scenarios

The collected data were incorporated in the design process of five scenarios. The simulated scenarios are stated in Table 1. These scenarios were simulated in the calibrated model.

***Scenario (1)***

Scenario 1, investigates the current status during a simulation period of one year, on the basis of considering discharges and evaporation losses of Wadi El-Rayan Lakes as the average of years 2009, 2010 and 2011. An area of 4000 feddans is cultivated land and 900 feddans are fish farms. The model results of this scenario showed that, the computed water level of the upper lake is decreased until (-10.360) m+MSL in August, and then rose again to (-10.047) m+MSL at the end of the year, this refers to the existence of the upper lake equilibrium, Figure (10)

Likewise, for the lower lake, the results showed that computed water level is decreased to reach (-32.546) m+MSL at the end of the year, Figure (11). The simulation results demonstrated that, the mean evaporation value of the upper and lower lakes are about 113.95 and 127.3 MCM, respectively.

Table 1: Tested scenarios in operation

| **Scenario** | **Model Inputs** | **Conditions** |
|---|---|---|
| 1 | • Current conditions,<br>• Average daily discharge of 2009, 2010 and 2011,<br>• Average daily evaporations of 2009, 2010 and 2011,<br>• Current water salinity | • Current conditions,<br>• 4000 feddans farm lands by floating units and,<br>• 900 feddans fish farms. |
| 2 | • Same as scenario No. 1 | • Same as scenario No. 1, in addition to<br>• Newly reclaimed Lands (4000 feddans) and,<br>• Fish farms (1400 feddans). |
| 3 | • Same as scenario No. 1, in addition to:<br>• Discharge of 0.5 $m^3$/s from Bahr El-Nezla to Al-Makshofa drain during (November, December, January) | • Same as scenario No. 2, in addition to<br>• Stop of mixing plants on Al-Makshofa Drain during (October, November, December) |
| 4 | • Same as scenario No.3, in addition to<br>• Feed the upper lake of Wadi El-Rayan by discharge of 0.66 $m^3$/s, this by shut down of one unit of Tagen mixing plant for 14 hours per day | • Same as scenario No. 1, in addition to<br>• Stop of mixing plants on Al-Makshofa drain during (October, November, December) |
| 5 | • Same as scenario No.1, in addition to<br>• Feed the upper lake of Wadi El-Rayan by an averages monthly discharge of 1.64 m3/s from Tagen mixing plant. | • Same as scenario No. 3, |

***Scenario (2)***

Determinants of this scenario are as scenario (1) but with operation of the new expansion area in Wadi El-Rayan, newly reclaimed lands of 4000 feddans and fish farms of 1400 feddans. The model results of an area of 8000 feddans cultivated lands and 2300 feddans fish farms revealed that, the computed water level of the upper lake is decreased until (-10.540) m+MSL in August and then is raised again to (-10.176) m+MSL at the end of the year, Figure (10). Likewise, for the lower lake, the results showed that computed water level is decreased to reach (-32.96) m+MSL at the end of the year, Figure (11). This indicates a significant fall of the water levels and quality of the lower lake and evidence of deterioration of the lake. This is due to the fact that the evaporation and the water supply to the newly expanded area consume all inflow. This endangers the sustainability of the reclamation area in Wadi El-Rayan depression.

***Scenario (3)***

This scenario is as scenario (2) with stop using of mixing plants, El-Nezla, El-Banat and El-Gas in the months of October, November and December and, increased discharge to Wadi El-Rayan Lakes by 0.5 $m^3/s$ from Bahr El-Nezla to Al-Makshofa Drain during November, December and January. The model results of this scenario revealed that, the computed water level of the upper lake is decreased until (-10.540) m+MSL in August, and then is increased again to (-9.91) m+MSL at the end of the year, this refers to the balance of the upper lake with small increase of water level, Figure (10). For the lower lake, the simulation results showed that, the computed water level is decreased to reach (-32.76) m+MSL at the end of the year, figure (11). This indicates that the water level of the lower lake has not been changed significantly despite the increase of water supply. The simulation results showed that, the mean evaporation value of the upper and lower lakes are bout 113.04 and 124.25 MCM, respectively.

***Scenario (4)***

Determinants of this scenario are as scenario (3) with an addition of a source of water supply of 0.66 $m^3/s$ this by shut down of one unit of Tagen mixing plant for 14 hours per day to the upper lake. This scenario investigates a current condition of an area of 4000 feddans of farming and 900 feddans of fish farms. The model results of this scenario revealed that, the computed water level of the upper lake is reached to (-9.72) m+MSL at the end of the year, this level is higher than the initial water level by an average of 28 cm, Figure (10). Likewise, for the lower lake, the results showed that calculated water level is decreased to reach (-32.06) m+MSL at the end of the year, which is lower than the initial water level by an average of 6 cm, Figure (11). The simulation results demonstrated that, the mean evaporation of the upper and lower lakes are bout 113.32 and 129.94 MCM, respectively.

***Scenario (5)***

In this scenario, the upper lake has been feed by water from Tajen mixing plant, as in Table 2, to achieve the water balance of both lakes when 8000 feddans and 2300 fish farms are farmed, The model results of this scenario revealed that, the computed water level of the upper lake is reached to (-9.94) m+MSL at the end of the year, this level is higher than the initial water level by an average of 0.06 m, Figure (10). Likewise, for the lower lake, the results showed that, the calculated water level is decreased to reach (-31.97) m+MSL at the end of the year, which is higher than the initial water level by an average of 0.03 m, Figure (11). The simulation results demonstrated that, the mean evaporation value of the upper and lower lakes are bout 113.32 and 129.94 MCM, respectively.

Table 2: Calculated monthly discharges that satisfy the water balance

| **Month** | **Discharge ($m^3/s$)** |
|---|---|
| January | 1.13 |
| February | 1.22 |
| March | 1.53 |
| April | 1.81 |
| May | 1.75 |
| June | 1.95 |
| July | 2.21 |
| August | 2.01 |
| September | 1.86 |
| October | 1.54 |
| November | 1.37 |
| December | 1.25 |
| Average | 1.64 |

## 5.d. Salt Loads of Different Scenarios

Salinity of Wadi El-Rayan lakes were checked by determining the salt loads and salinity for each water balance scenario, Table 3. The model results of revealed that, the lowest value for salinity is in scenario (4) and it is about 1.44 and 8.42 g/l for the upper and lower lakes, respectively. On the other hand, the highest value of the salinity is in scenario (5) that valued about 1.51 and 9.18 g/l for the upper and lower lakes, respectively. Generally, there is no significant difference in the value of salinity between the different scenarios, especially for the upper lake.

Table 3: Salinity and salt load of different scenarios

| No. | Lake No. 1 | | Lake No. 2 | |
|---|---|---|---|---|
| | Salt load (tons) | Salinity (g/l) | Salt load (tons) | Salinity (g/l) |
| 1 | 979012 | 1.48 | 4043568 | 8.81 |
| 2 | 950343 | 1.51 | 4009073 | 6.15 |
| 3 | 971804 | 1.49 | 4023858 | 8.98 |
| 4 | 1019613 | 1.44 | 4083204 | 8.42 |
| 5 | 950343 | 1.51 | 4020774 | 9.18 |

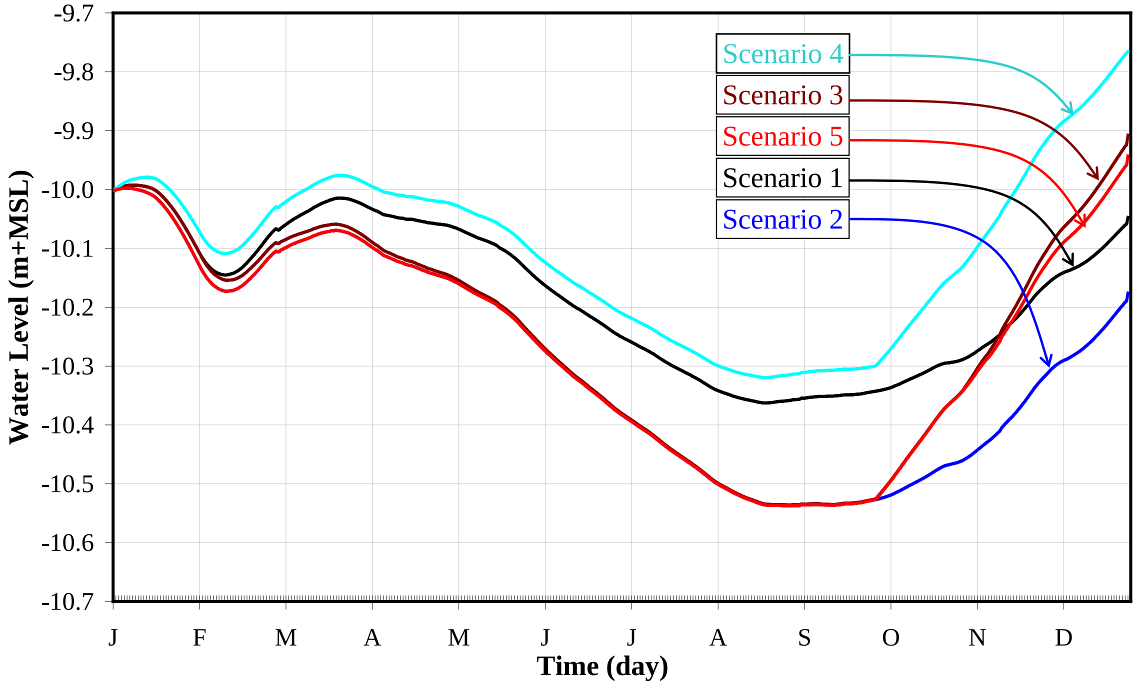


**Fig. 10**: Profiles of water levels of one year period for upper Lake (Lake No. 1) of Wadi El-Rayan lakes

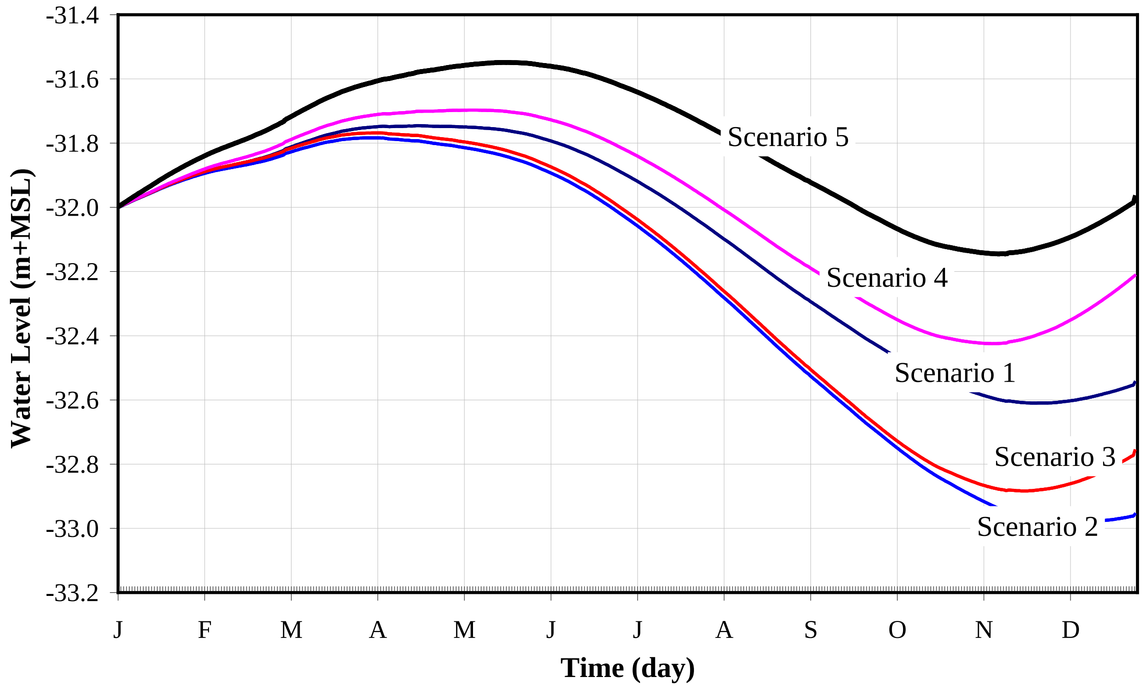


**Fig 11**: Profiles of water levels of one year period for Lower Lake (Lake No. 2) of Wadi El-Rayan lakes

# 6. CONCLUSIONS AND RECOMMENDATIONS

The SOBEK 1D2D model was applied to Wadi El-Rayan Depression using the measured data of the bathymetric and hydrographic survey, meteorological data and salinity. The main goal was to figure out the appropriate solution to solve the problems of delicate balance.

Based on the conducted work in this study, the following conclusions were drawn:

- In order to pass the design discharge of 12 $m^3/s$, the trash rack should be periodically cleaned, and Tahwelat Al-Wadi and Al-Makshofa drains should be dredged to reach the design cross-sections.
- The total dredging volumes of Tahwelat Al-Wadi and Al-Makshofa drains are 109.80 $m^3$ and 90.399 thousand cubic meters, receptively.
- A trash rack should be installed on Al-Makshofa drain to prevent weeds and debris and should be installed in front of the entrance of the tunnel by an average of 40 m to be at wide cross section with minimum velocity in order to be able to clean.
- The water volume of the upper lake of Wadi El-Rayan is 671.01 MCM at corresponding water level of (-8.00) m+MSL and the water volume of the lower lake is 881.61 MCM at corresponding water Level of (-26.00) m+MSL.
- The upper lake is water balanced in the current conditions where the water level is decreased by an average of 40 cm in August and then getting almost the same to reach the level of (-10.047) m+MSL at the end of the year, while the water level of the lower lake is decreased annually by an amount that averaged to 55 cm.
- The evaporation losses of the upper and lower lakes in the current conditions are 113.9 and 127.3 MCM, respectively.
- In order to reach the balance state of lakes in the current conditions, it is recommended to stop the reuse plants on Al-Makshofa Drain in the months of October, November and December. Also stop a unit of Tajen Station for 14 hours daily during the same period, (scenario 4).
- In order to reach the balance state of the lakes in case of cultivated area of 8000 feddans farm lands and 2300 fish farms, it is recommended to feed the upper lake by the source of water of 1.64 $m^3/s$ from Tajen Station throughout the year in addition to stop reuse plants on Al-Makshofa Drain during October, November and December (scenario 5).

- It is necessary to have a development plan in this region in stages. It is not recommended to start in the infrastructure of any reclamation project or fish farms before ensuring the availability of the water demands for this project.
- The cooperation with Wadi El-Rayan protected sector and other environmental authorities is highly recommended before beginning any development projects.

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## 8. REFERENCES

1. Amer. M.H. (1992). *Fayoum oasis of Egypt. Water Research Center*, El Kanater, Egypt
2. Clemmens A. J., Bautista E., Wahlin B. T., et al. (2005), *Simulation of Automatic Canal Control Systems, Journal of Irrigation and Drainage*, 131, pp.324-335.
3. Contractor, D. N., and Schuurmans, W. (1993). *Informed use and potential pitfalls of canal models*. J. Irrig. and Drain. Engrg., ASCE, 119(4), 663–672.
4. Harbeck, G.E. and J.S. Meyers. (1970). *Present-day evaporation measurement techniques*. J. Hydraulic. Div., Proc. ASCE96 (HW), 1381-1390.
5. Veer M., Wormgoor, J.A., Girgs R., and Wolters W. (1993), *Water Management in Tertiary Units in Fayoum*, Kluwer Academic Publishers, the Netherlands, Irrigation and Drainage Systems7, pp.69-82
6. WL| Delft Hydraulics (2005), SOBEK River/Estuary User Manual, SOBEK Help Desk.

## NOTATION:

| | |
|---|---|
| 1D | : one dimensional, |
| 2D | : two dimensional; |
| CAMWRI | : Central Administration of the Ministry of Water Resources and Irrigation; |
| cm | : centimeter; |
| DEM | : Digital Elevation Model; |
| DGPS | : Differential Global Positioning Systems |
| g/l | : gram/liter; |
| h | : stage above datum/water level (m+MSL); |
| km | : kilometers; |
| m | : meter; |
| MCM | : Million Cubic Meters; |
| MSL | : Mean Sea Level; |
| Q | : discharge ($m^3\ s^{-1}$); |
| WMRI | : Water Management Research Institute. |