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# Water Quality Modelling of Northern Lakes Case Study (Egyptian Northern Lakes)

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## Abstract

Since the shallow coastal lakes are not only one of the most valuable ecosystems in the world but also some of the most threatened as they receive the wastewater discharged from the watershed, it was important to develop a more detailed modelling component for the lake system. Nowadays, relative to the present advances in computational sciences, hardware and software, improvement in rivers, catchments and lakes modelling has been only modest since the past few decades. The main objective of the study is to examine and evaluate the impact of alternative water quality management practices in the selected drainage catchment, and their effect on the environmental condition of the lake as an important component of the watershed. A hydrodynamic and water quality model was used to study the current status of coastal lakes subject to the discharges and pollution loadings coming from the agricultural drains and the point sources discharge directly to the lake, through simulating the flow circulation inside the main basin of the lake, the transport and advection of the pollutants due to the effluent discharges from drains and other sources of pollutants, and identify and develop the most critical surface drainage water quality indicators to simulate and predict the temporal and spatial variation of pollution.

**Keywords:** water quality, modelling, coastal lakes, pollution, Mariout Lake

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## 1. Introduction

The aim of modelling of surface water quality is to construct a mathematical model of the water body in order to simulate variation in water quality with the variation in initial and boundary conditions. The modelling is applied to solve problems related to water quality by analysing

the occurring phenomena and finding dependencies between them as well as to attempt to predict and quantify effects of the changes in the aquatic environment [1]. Over the past 75 years, engineers have developed water quality models to simulate a wide variety of pollutants in a broad range of receiving waters. In recent years, these receiving water models are being coupled with models of watersheds, groundwater, bottom sediments to provide comprehensive frameworks predicting the impact of human activities on water quality [2].

Mathematical modelling of lakes water quality started to receive high attention in the 1960s. According to [3], mathematical models of lakes have evolved along two different lines. First, there was the extension of the zero-dimensional model to one-, two- and three-dimensional models. Then, there were the modelling activities that focused primarily on a better and more detailed description of the chemical-biological processes [4]. From the survey of the literature, many lake models have been applied in various regions, and as a result of several applications, models have become more and more complex.

Modelling of water quality in lakes involves the representations of effluent quality, mixing pattern, physical and chemical processes and biological growths and their role in the removal and release of substances. Such models can be classified into physical, chemical or biological models that simulate lakes eutrophication. Another classification may be as long-term planning models or short-term operational models. Several water quality studies have been performed on lakes in general and on shallow lakes in particular, for example, [5–9].

The objective of this chapter is to illustrate the technique of building a hydrodynamic and water quality model as application on one of the Egyptian coastal lakes (Mariout Lake).

## 2. Lake Mariout, one of Egyptian Northern Delta lakes

The northern delta lakes provide many economic, environmental and social benefits to the people of Egypt and the Mediterranean. Some of these benefits are easy to quantify. For example, the 1998 catch from the four lakes — Burullus, Idku, Manzala and Mariout — amounted to LE 1.05 billion, or roughly 35 percent of the country's total fish income. The lakes currently provide passive primary and secondary treatment of wastewater that would be equivalent to hundreds of millions of dollars worth of new treatment plants. Other important and valuable benefits are much harder to quantify. It is unknown how much property damage and economic dislocation Lake Mariout prevented in 1992 when Alexandria experienced severe flooding, or how much the lake contributes to agricultural production by buffering against seawater intrusion of groundwater supplies. Beyond Egypt, it is difficult to value the benefit that those wetlands provide to sustain migratory birds of the entire Eastern Mediterranean/Black Sea region. In the future, with predicted sea level rise and the frequency of coastal storms on the increase, the lakes may be even more important to prevent natural disasters [10].

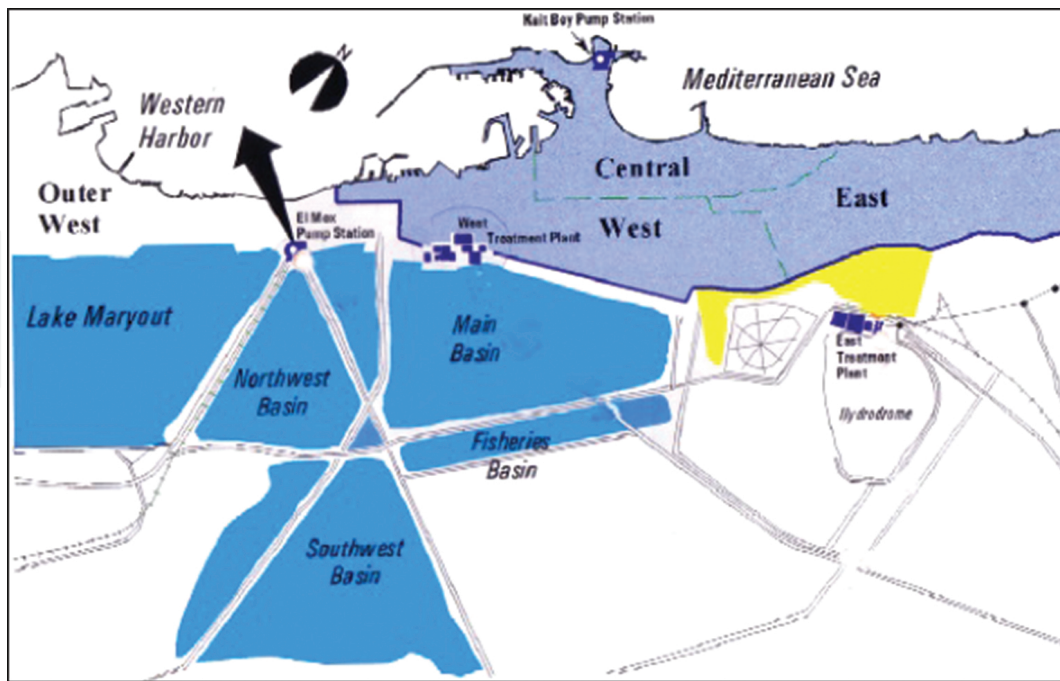


Figure 1. Lake Mariout location.



Figure 2. Lake Mariout satellite image and sample location.

Lake Mariout is the smallest of the northern lakes and perhaps the most threatened. Lake Mariout lies between Latitude  $31^{\circ} 07' \text{ N}$  and Longitude  $29^{\circ} 57' \text{ E}$  along the Mediterranean coast of Egypt. The lake environment was continuously subjected to quality degradation due to human pressure as well as land reclamation reducing the area of the lake.

Currently, the lake is divided artificially into four main basins as shown in **Figures 1 and 2**, namely, 6000 feddans basin (Main Basin), 5000 feddans basin (South Basin), 3000 feddans basin (West Basin) and 1000 feddans basin (Aquaculture Basin). These ponds are dissected by roads and embankments as follows [11]:

- The Main Basin is about  $14.77 \text{ km}^2$  with an average depth of 0.8 m. This basin receives water from the El-Nubariya canal and Omoum drain, the heavily polluted water by industrial wastes; and untreated sewage from municipal and industrial outfalls of El-Qalaa drain had been diverted through the new Richa drain. West Wastewater Treatment Plant effluent had been discharged along the north of the basin. One minor inflow is a discharge of waste from a textile plant into a ditch which crossed Qabarry. The Main Basin is bisected by the Nubariya canal, and the triangular area between this canal and the Omoum drain is also considered as part of the Main Basin.
  - The Western Basin is about  $11.59 \text{ km}^2$  with average water depths of 0.7 m. Adjacent to this basin, salt marshes are located and are producing 1,000,000 kg of unrefined salt per year. They are surrounded by many industrial and petrochemical companies.
  - The Southern Basin covers  $33.77 \text{ km}^2$ , and is partially divided by El-Nubariya canal, although breaks in the canal embankments allow water to pass from one sub-basin to the other. This basin is very shallow and average water depths are 0.68 m. The main source of water is El-Omoum drain and El-Nubariya canal. Along the length of the El-Omoum, a series of breaches allow flow to leave the drain and enter the basin. Along the western boundary, a series of breaches allow exchange of water between the basin and the El-Nubariya canal. This basin consists of heavily vegetated areas and fish farms. Also, considerable wetland loss in this portion of the basin was recorded. Many petrochemical and petroleum companies, such as Amria and Misr Petroleum companies, discharge their wastes into the north part of this basin.
  - The (Fisheries) Aquaculture Basin covers  $9.44 \text{ km}^2$  (849 feddans), and it consists of a series of small basins separated by earthen berms. This facility is a research centre for fish farming and is operated by the Alexandria Governorate. There are two sources of water for this facility. One is small pump stations which pump  $400,000 \text{ m}^3/\text{day}$  from Abis drain and which run parallel to the basin. The other is small openings from El-Omoum drain.

Comparison of the chemical composition of Lake Mariout water with that of proper sea water and drainage water shows that the lake water presents an intermediate composition between both sea and drainage water. This phenomenon can be explained by seepage from the sea. Such explanation is supported by the low level of water and by the water balance which is supported by older data of the salt content of wells in Mariout region. There are three main canals (El-Qalaa, El-Omoum and El-Nubariya) that are considered the main inflows to the lake. El-Qalaa drain is located at north-east while El-Omoum and



El-Nubariya canals are at the east and south of the lake, respectively. Other inflows are the water treatment plant (WTP) and the discharges from the petrochemical area nearby the north western basin. El-Omoum and El-Nubariya canals are less polluted drains, considering their nutrients (N, P) and DO concentrations. El-Omoum receives mainly agricultural drainage water; moreover, the drain receives both raw and treated wastewater from several defined and undefined sources. Therefore, these drains also contribute to the nutrient loadings in the lake, but to a lesser extent. Additionally, non-point sources such as agricultural run-off containing pesticides and fertilizers are also contributing to the deterioration of the environmental quality of the lake [12].

As a result of the high nutrient loading, the lake has become anthropogenic-polluted and eutrophic. Eutrophication of lakes is a natural process that can be accelerated by man's activities that introduce an excess of nutrients together with other pollutants. Main sources of nutrients and pollutants can include: human sewage, industrial waste, farm and urban run-off. Currently, the lake is 60% covered by aquatic vegetation (*Phragmites australis* and *Eichornia crassipes*). High nutrients and low DO concentrations have been observed specially at the Main Basin, which in turn affects the ecological processes occurring in the lake and therefore its whole environmental condition [13].

Applying a hydrodynamic and water quality numerical modelling study at Lake Mariout will help to give some answers to both planning and technical questions of water quality managers, decision makers and those of technical engineers working on the sampling, monitoring and analysis of water quality parameters. Specifically, the main objectives of the hydrodynamic and water quality numerical model study can be summarised as follows:

- Studying the current status of the Lake Mariout and using the available data to simulate the Main Basin of Lake Mariout subject to the discharges and pollution loadings coming from the agricultural drains and the point sources discharge directly to the lake.
- Investigate the flow circulation inside the Main Basin of Lake Mariout and its effect in minimizing the negative impacts on the water quality of the lake.
- Investigate the transport and advection of the pollutants due to the effluent discharges from drains and other sources of pollutants.
- Identify and develop the most critical surface drainage water quality indicators to simulate and predict the temporal and spatial variation of pollution.
- Examine and evaluate different modelling scenarios to study the impact of alternative water quality management practices in the selected drainage catchment, and their effects on the environmental condition of the lake as an important component of the watershed.
- Perform sensitivity analysis for modelling parameters and variables, showing the response of the model to influential parameters and coefficients used in the modelling process, especially those with high degree of uncertainties on their values.
- To achieve the study objectives, the following scope of work can be summarised as follows:

- Data collection including both hydrographic and bathymetric survey for the Main Basin of Lake Mariout, which is necessary to fulfil the hydrodynamic and water quality simulations of the numerical model of the main basin of Lake Mariout.
- Develop a two-dimensional hydrodynamic and water quality numerical flow model to simulate the flow pattern in the lake vicinity of the study area, and the discharges and pollution loadings coming from the agricultural drains and the point sources discharge directly to the lake.
- After the model development, calibration is conducted in order that the model will be ready for different potential model scenarios. This will help to investigate the impact of alternative water quality management processes and their effects on the environmental condition of the lake. The analysis of the model scenarios forms the basis to assess and select the optimum solution for minimizing the pollution coming from the agriculture drains and other point source of pollution to the lake.

### 3. Data collection and field measurements

The setup, testing and application of a lake model of hydrodynamics and water quality require a variety of different data sets to specify boundary or input conditions and for model calibration and verification.

In case of Mariout Lake, data collection includes historical data on the wind conditions, water temperature, evaporation rate and the precipitation rate in the project site. Wind data were extracted from the work of [14], the data show that the predominant wind direction is 22.5° NW with a wind speed of approximately 3.75 m/s. The average monthly temperature in Lake Mariout ranged from 13 to 29°C in a study carried by [15]. The annual average evapotranspiration used in the model was calculated with the Penman-Monteith method [16], where the crop coefficient  $K_c$  (reed) used in the calculation was extracted from a study based on field experiment and measurements carried out in three locations in the UK [17]. The precipitation value used in the model corresponds to the average precipitation of year 2007, (0.66 mm/day) as presented in the Lake Mariout data acquisition report (NIOF, 2007[sn1]). The topography and bathymetry data used in the model were provided by NIOF in a DEM format with resolution of 45 m reference is made to [18].

Field measurements were carried out in coordination with the National Institute of Oceanography and Fisheries (NIOF) for 2 weeks. The samples were taken from nine sites representing the Main Basin and discharge points of Qalaa drain, Omoum drain, Nubariya canal and El-Max pumping station as shown in **Figure 2**; the measurements comprised the following:

- Water flows ( $\text{m}^3/\text{h}$ ) which determines the inflow, outflow in the Main Basin.
- Water levels within the basin to a fixed point.
- Basic physical parameters: temperature, salinity and total suspended matter.

- Organic matter of the lake.
- Nutrient variables: ammonia, nitrates and phosphorus compounds.
- Biological data including: chlorophyll-a, phytoplankton, zooplankton.
- Microbiological data: faecal coliform and total coliform.

Results of field measurements of hydraulic parameters are shown in **Table 1** and results of field measurements of water quality parameters are shown in **Table 2**.

Site no.	Site name	Cross section (m <sup>2</sup> )	Average weekly water velocities (m/s)	Average weekly water discharges (m <sup>3</sup> /hour)
2	Nubariya canal (desert road)	122.00	0.44	192480
3	Omoum Drain (desert road)	097.00	0.42	146658
5	Fisheries Hole in dam	001.60	0.30	001699
6	End Omoum diversion before Nubaria	136.00	0.11	053000
7	El-Max Pumping Station	243.00	0.30	263193
8	Western Water Treatment Plant	003.40	1.22	015105
9	Qalaa Drain outlet in Main Basin	008.90	0.86	027602

**Table 1.** Water flow measurements.

Code	Temp °C	Trans cm	EC mS/cm	TDS g/l	TSS g/l	Sal ‰	pH	DO mg/l	BOD mg/l	COD mg/l	NH3 µg/l	NO2 µg/l	NO3 µg/l	TN µg/l	PO4 µg/l	Tp µg/l
West Nubaria PS	25.7	35	7.68	4.82	0.040	4.81	7.18	7.38	4.90	22.09	971	89.6	332.6	1981.2	54.2	115.36
Nubaria Canal Desert Road	22.1	60	5.26	3.49	0.034	3.48	7.68	5.60	4.12	21.64	723	106.4	529.4	1844.7	66.7	161.04
Ommoun Desert road	22.3	60	3.45	2.34	0.034	2.33	7.52	5.82	4.66	20.22	2164	150.5	470.1	3492.6	194.7	566.64
End of Qalaa Diversion Canal before Nubaria Canal	22.8	15	2.39	1.21	0.111	1.21	7.33	0.00	111.56	88.96	19956	0.00	0	22856.1	915.2	1203.84
Western WTP	24.6	10	1.99	1.14	0.125	1.14	7.12	0.00	140.12	92.92	20996	0.00	0	24869.3	1019.7	1335.84
Main Basin	21.1	40	3.65	2.40	0.034	2.39	8.68	9.12	5.06	32.32	2640	102	150.8	3886.6	165.8	436.92
Noha El Max station	21.3	35	5.9	3.59	0.043	3.58	7.32	5.42	4.92	40.84	4610	92.6	212.5	6365.7	190.3	528.24
Fisheries hole in dam	22.1	15	2.41	1.28	0.115	1.28	7.67	0.00	120.04	90.69	19670	0.00	0	22886.4	928.4	1244.76
End of Qalaa drain	23.8	20	2.34	1.26	0.109	1.26	7.22	0.00	123.12	89.50	20030	0.00	0	23386.1	905.3	1236.84

**Table 2.** Measured water quality parameters in Mariout Lake.



The following section represents the hydrodynamic and water quality modelling studies that were carried out to investigate the efficiency of the water circulation system and water quality parameters inside the Main Basin of Mariout Lake. The model setup, calibration and the analyses of the results of model scenarios are included. Depending on the model results and analysis, the conclusions and recommendations are presented.

## 4. Water quality model development

Delft3D Software Package of Delft Hydraulics, the Netherlands, was used to develop the hydrodynamic numerical flow and water quality model which simulates the flow pattern and the water quality inside the lake. Delft3D is an integrated, powerful and flexible software, which was developed by Deltares, the Netherlands. The hydrodynamic and water quality modules were used in this study. Consequently, a brief explanation of these modules is in the following section.

The FLOW module of Delft3D is basically a multi-dimensional (2D and 3D) hydrodynamic (and transport) simulation which calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing on a curvilinear, boundary-fitted grid [19]. The WAQ module of Delft3D for water quality modelling the spatial resolution generally consists of the resolution of the underlying flow field as generated by the hydrodynamic model itself or of flows on integer multiples of those hydrodynamic grid cells. For water quality modelling, there also is external forcing in the form of waste loads, meteorology, open boundary concentrations, etc. [20].

### 4.1. Setup of the hydrodynamic model

The hydrodynamic model simulates the flow pattern in the Main Basin vicinity. All parameters and variables in the model have units according to the SI conventions. The coordinate system used for the model is in WGS-84 Geographic UTM system Zone 35. All metric coordinates in this report will be given in this coordinate system. The depths and water level information in the flow model are defined relative to a levelling datum, which is equal to mean sea level (MSL). The following sections present the steps of development of Mariout hydrodynamic model.

#### 4.1.1. Grid generation

The first step in the schematization process is the design and generation of the computational grid. The computational grid is a curvilinear grid to avoid the stair case problem which affects the numerical accuracy. In the design of a curvilinear grid, it is important to follow the land boundaries as good as possible. For the generation of a computational grid, the following items are important:

- the areas which require the highest resolution;
- the orthogonality of individual cells;

- the spatial variation of the dimensions of the cells;
- the total number of computational points.

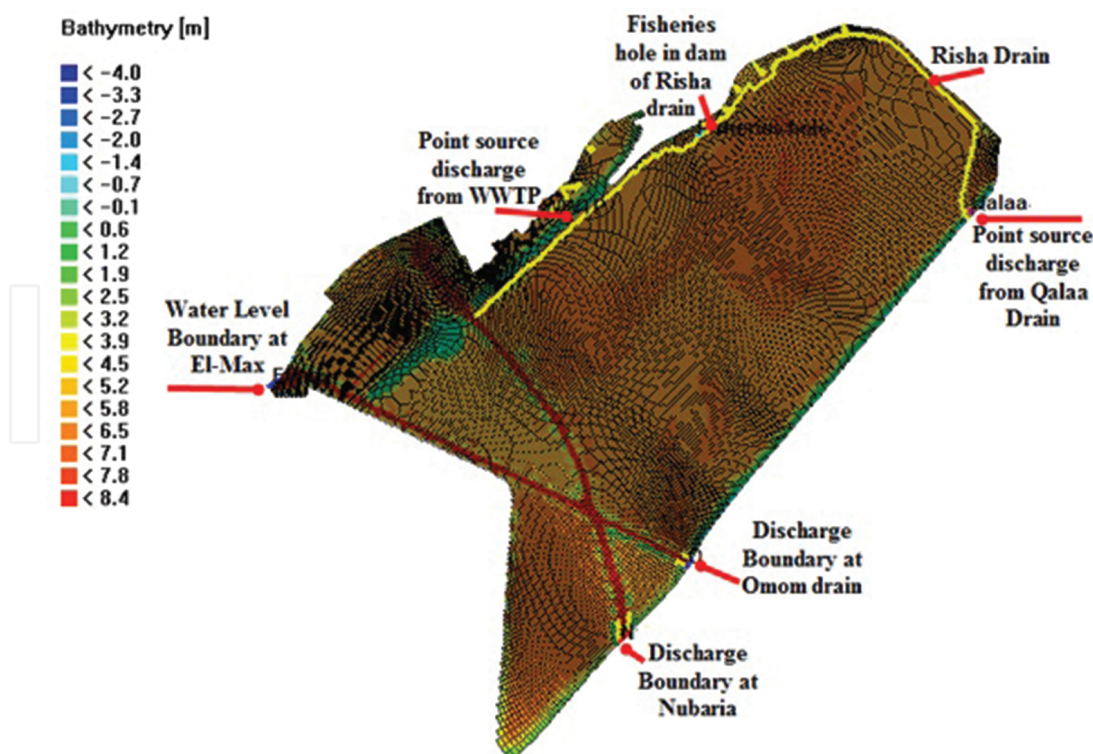
The resulting computational grid is a compromise between the above items, the selected dimensions of the model and the location of the boundaries. The general layout of the computational grid of the Mariout model is given in **Figure 2**.

#### 4.1.2. Depth schematization

The schematization of the land boundaries and the water depths have been derived from the hydrographic survey data. The bathymetric data have been mapped through an interpolation procedure on the computational grid of Mariout model. In this way, each coordinate of the computational grid of the model is given a depth value. The transition between the regions covered by different bathymetric data sources have been checked and smoothed where necessary.

#### 4.1.3. Boundary conditions

In the flow simulations of a specific area with two open boundaries, it is preferable to set up one boundary as a discharge boundary and the other one as a water level boundary. In Lake Mariout model, the open boundary for Nubariya Canal and Omoum Drain were selected as a discharge boundary. The boundary at El-Max Pumping station was selected as water level boundary, while other sources like Qalaa drain and the West Water Treatment Plant were



**Figure 3.** Model schematization with all boundaries and sources of discharge.

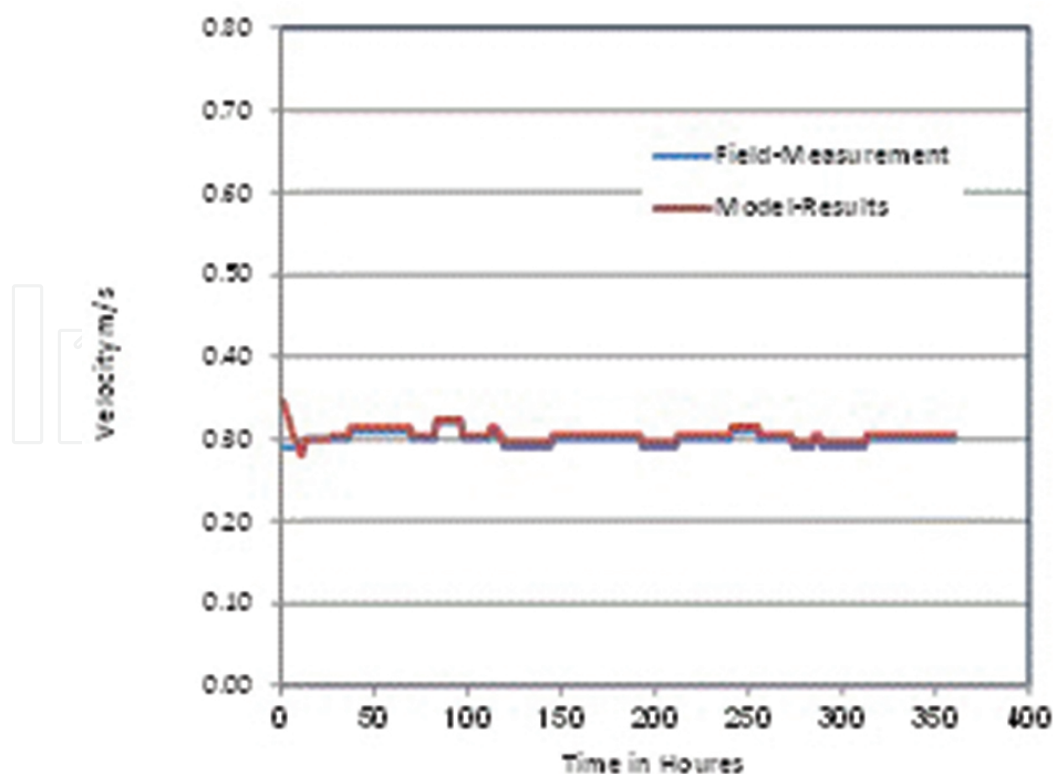
simulated as source point discharge. During the calibration phase, the discharges and water level measurements at the location of the open boundaries and at the other sources of water were used in the model. In the model scenarios (production simulations), the discharge data imposed in the discharge boundary is based on the dominant flow condition. The water levels associated with these discharges were used for each scenario as a water level boundary. The relevant water levels associated to these discharges were obtained from the historical data available about the Lake Mariout. **Figure 3** shows the model schematization with all boundaries and the source points of discharges.

#### 4.1.4. Parameter settings

A uniform water density of  $1025 \text{ kg/m}^3$  was used, representing the salt water density. The acceleration of gravity was set to  $9.81 \text{ m/s}^2$ . The value for the horizontal eddy viscosity is set to  $1.0 \text{ m}^2/\text{s}$ . The time step was selected for the model simulations based on the grid size and the Courant Number. Time step of 0.5 min (30 s) was used in the simulations. This time step fulfils the numerical criteria and the Courant Number requirements.

#### 4.1.5. Model calibration

During the model calibration, the measured depth averaged flow velocities and water levels which were carried out by the National Institute of Oceanography and Fisheries (NIOF) were compared with the model results. Tuning of the roughness parameter in the model was carried



**Figure 4.** Flow velocity comparison at point fisheries hole in dam.

out to obtain the best match between the model and the field measurements. Manning roughness coefficient was varied between 0.02 at non-vegetated area and 0.06 at the heavy vegetated area along the model area to give the best match between the measurements and the model computations. **Figure 4** shows the comparison between the measured and computed flow velocity values. The results for water level and currents were in good agreement with the measurements, which confirms that the model simulates the flow pattern in the main basin of Lake Mariout in the right way.

## 4.2. Water quality model setup

To apply the Delft3D-WAQ module, the following steps must be followed:

- Get the result from the hydrodynamic simulation and make it suitable for application in the water quality simulation (coupling process).
- Selection of the substances and water quality processes to be included in the model.
- Preparation of initial conditions, boundary conditions, waste loads, simulation time, output variables and identification of monitoring points.
- Run the simulation and check the output.
- Calibrate and verify the model.

### 4.2.1. Selection of the processes involved in the water quality model

In Delft3D-WAQ module, the constituents of a water system are divided into functional groups. A functional group includes one or more substances that display similar physical and/or (bio)chemical behaviour in a water system. Functional groups can interact with each other directly or indirectly. PLCT (Processes Library Configuration Tool) is used to choose the substances and water quality processes to be modelled. The selected substances groups and parameters are described in **Table 3**.

Substance group	Selected model parameters	Associated processes
General	Continuity, water temperature, salinity	Temperature and heat exchange
Oxygen-BOD	BOD-COD-DO	Mineralization BOD and COD, sedimentation COD, re-aeration of oxygen
Suspended matter	Inorganic matter (TSM)	Sedimentation, resuspension
Eutrophication	Ammonium (NH <sub>4</sub> ), nitrate (NH <sub>3</sub> ), ortho-phosphate (PO <sub>4</sub> )	Nitrification of ammonium Denitrification of nitrates

**Table 3.** Model parameters and associated processes.

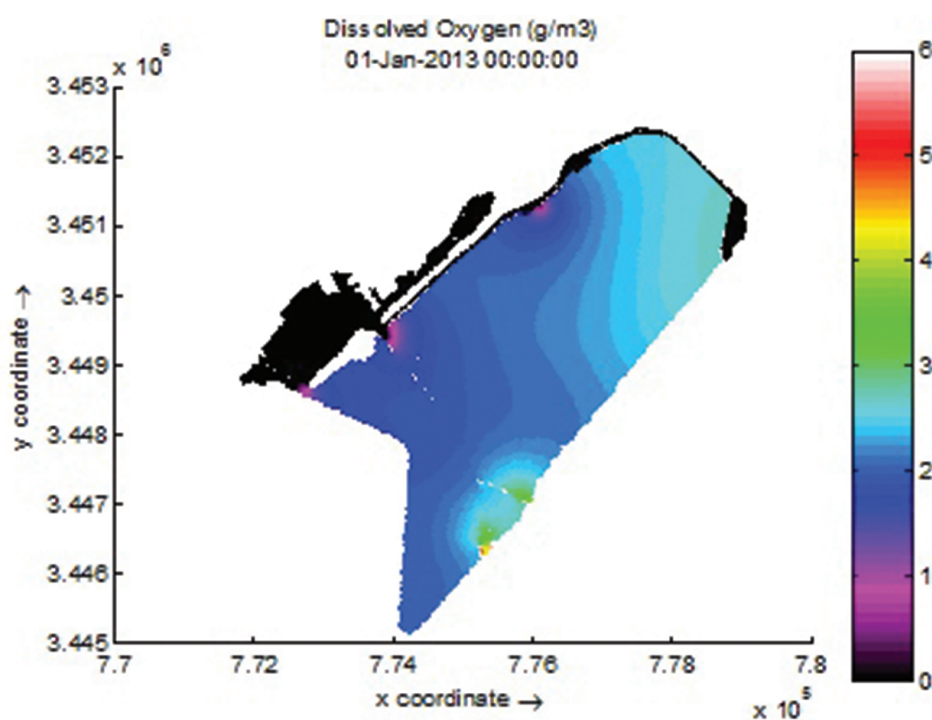
#### 4.2.2. Model boundary conditions and observation locations

Average historical monthly values have been selected for initial conditions of water quality parameters inside the lake. The continuity parameter which checks the mass balance of the model was set to  $1 \text{ g/m}^3$ . The model simulation period was selected as the same period for the hydrodynamic modelling, namely, for 1 month. Water quality model time step was set to 1 min. The default values were taken as input for some selected modelled substances, that they are by default constant in time and space. However, process parameters are changed in the process parameters data group because they can vary in time and/or space. Initially, process parameters will have the default value that is taken from the PLCT.

The water quality model boundary sections are selected to be the same boundary sections for the hydrodynamic model at the locations of the main input sources to the lake, where all discharges enter the lake shown in **Figure 3**. At the two sections for the Omoum drain outlet and Nubariya canal outlet, concentrations for different modelled parameters are defined as time-varying boundary conditions. The concentrations used at the boundaries are time series average monthly concentrations for the modelling period.

#### 4.2.3. The water quality model calibration

**Figure 5** shows the simulation of dissolved oxygen in Mariout Lake as an example of output from the model. In this study, the water quality model calibration is done on the conventional water quality parameters or oxygen group, nutrients group and coliform group (faecal and total) and process parameters are adjusted for of calibration. The model calibration was carried



**Figure 5.** Simulation of dissolved oxygen in Lake Mariout.



out by visual comparison of simulations and measurements in graphs, together with the calculation of the statistical error values such as mean relative error (MRE), the root mean square error (RMSE) to examine the performance of the model.

The simulated water quality parameters were plotted in graphs to make comparisons with respect to the observations in Lake Mariout during field survey, which were used to check how the simulations fit the observations. Besides, MRE was used to quantify the agreement of the model, by dividing the residuals by the observed values. In this study, the calculation of RE and MRE was based on the following equations:

$$RE = (C_{sim} - C_{obs}) \times 100 \div C_{obs}$$

$$Sum RE \div n$$

where  $C_{sim}$  and  $C_{obs}$  are the simulated and observed values, respectively, and  $n$  is the number of cases. The MRE denotes the mean relative difference between simulations and observations.

**Table 4** shows the different values of RE and MRE for the modelled parameters at this level. **Figure 6** shows the calibration results of dissolved oxygen that shows good agreement with field measurements. It is noted that at the entrance of the Qalaa drain to the lake, the DO has the lowest values; in general, the DO measurements are close to the simulated results with an RME value of 5.11%. **Figure 6** shows the calibration results of dissolved oxygen that shows good agreement with field measurements.

Location/parameter	DetN (RE%)	NH4 (RE%)	NO3 (RE%)	CBOD5 (RE%)	COD (RE%)	DO (RE%)	FCOLI (RE%)	TCOLI (RE%)
Omoum Drain	5.13	5.87	1.70	3.41	1.84	0.40	27.78	0.64
WWTP	10.98	8.96	14.63	13.23	10.35	9	19.31	0.07
Fisheries Hole	3.36	1.36	6.54	1.69	4.00	9	10.14	1.11
Elmax	1.88	9.03	3.36	2.97	7.30	7.7	0.03	9.77
Main Basin Middle	0.09	8.46	6.87	6.93	11.51	0	2.39	3.22
Nobariya Canal	0.75	2.69	0.52	2.69	0.04	0.70	6.09	1.18
Qalaa Drain	10.89	4.57	6.87	4.08	4.19	9	0.41	13.31
MRE	4.72	5.01	5.79	5	5.6	5.11	9.45	4.19

**Table 4.** Relative error for the calibrated model parameters.

The simulated BOD and COD results are very close to the measured values at most locations within the lake, and the MRE value is around 5% for BOD5 and 5.6% for COD. For eutrophication parameters group, the values show agreement between measured and modelled parameters with mean relative error 4.7% for DetN, 5% for NH4 values and 5.7% for PO4 values that are considered acceptable for this kind of water quality modelling. For bacterial parameters, the faecal coliform values show a difference between simulated and observed values at

locations in the Omoum drain outlet station, with a relative error of 27%. This could be due to the low-velocity distributions at these locations around the lake edges; but the overall MRE for all measurement locations is within an acceptable range of 9% for faecal coliform and 4.2% for total coliform.

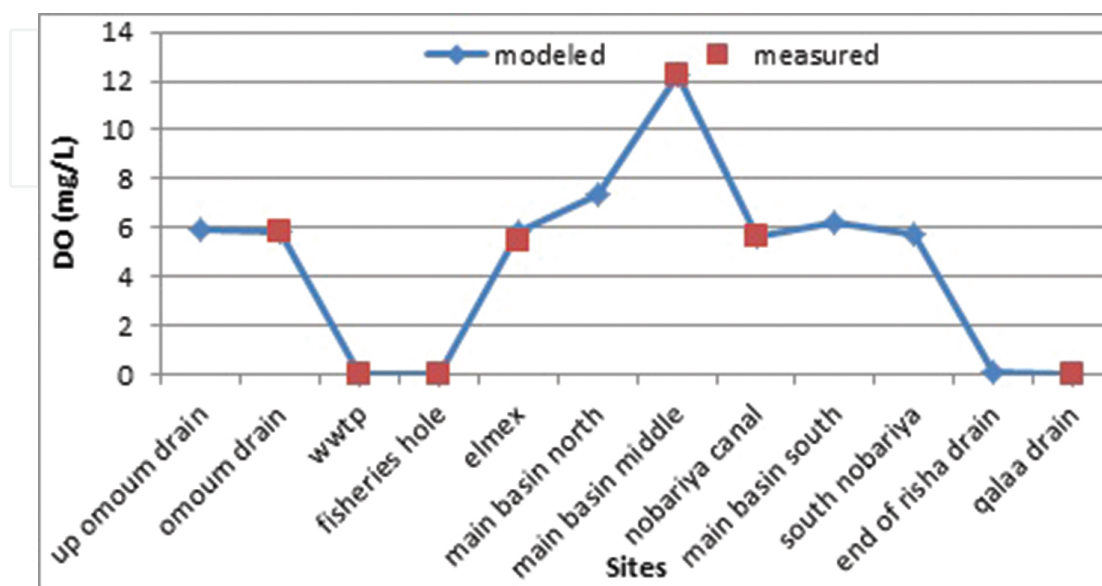


Figure 6. Comparison between measured and modelled DO.

## 5. Conclusions

Unfortunately, Lake Mariout, one of the Egyptian coastal lakes, suffers from almost all possible environmental problems. In order to evaluate the environmental condition of the Lake Mariout, a 3D hydrodynamic and water quality model that simulates the lake response to pollution loading from the watershed has been developed using the Delft3D hydrodynamic module coupled with the DWAQ module. The model refers to the lake's Main Basin model including watershed simulation scenarios.

First, the 2D hydrodynamic model was developed to simulate the hydrodynamic behaviour of the lake through simulating the water velocity, current and flow within the lake basin. The developed, well-structured hydrodynamic model was also capable of describing the physical and hydrodynamic processes of the water system. Second, a reliable water quality model lake system in this research work is coupled with the developed and calibrated hydrodynamic 2D model. The basic water quality modelling component simulates the main water quality parameters including the oxygen compounds (BOD, COD, DO), nutrients compounds (NH<sub>4</sub>, TN, TP) and finally the temperature, salinity and inorganic matter.

The calibration was conducted to compare the model results with the observed data at the different locations for both the hydrodynamic and the water quality models. The model results

and calculations are in reasonable agreement with the measured concentrations. This developed calibrated model is able to predict the basic water quality indicators of the lake system and ready to conduct any scenarios for watershed water quality management.

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## References

- [1] Chapra S., Surface Water Quality Modeling. 1997; MacGraw Hill, N.Y.
- [2] Chapra S. C., Engineering water quality models and TMDLs. Journal of Water Resources Planning and Management, 2003; Vol. 129(4): pp. 245–355.
- [3] Jorgensen S. E., Ecological modeling of lakes. In Orlob G.T., Mathematical Modelling of Water Quality: Streams, Lakes and Reservoirs. 1983; John Wiley & Sons, New York, ISBN 047-1100315.
- [4] Jorgensen S. E., Kamp-Nielsen L., Christensen T., Windolf-Nielsen J., Westergaard B. Validation of a prognosis based upon a eutrophication model. Ecological Model, 1986; Vol. 32: pp. 165–182.
- [5] Collins C. D., Evaluating Water Quality for Lake Management. Final Report. Technical Report, 1988; PB-89-148159/XAB. New York State Museum, Albany, NY, USA.
- [6] Stephan G. H., Fang X., Model simulations of dissolved oxygen characteristics of Minnesota lakes: past and future. Environmental Management, 1993; Vol. 18(1): pp. 73–92.

- [7] Sagehashi M., Sakoda A., Suzuki, M. A mathematical model of a shallow and eutrophic lake (the Keszthely Basin, Lake Balaton) and simulation of restorative manipulations. *Water Research*, 2001; Vol. 35(7): pp. 1675–1686.
- [8] Buttcher D., Approaches for Nutrient Management in the Lake Okeechobee Watershed, Symposium Handbook, Practical Management for Good Lake Water Quality. 2003; New Zealand.
- [9] Zacharias I., Gianni A., Hydrodynamic and dispersion modeling as a tool for restoration of coastal ecosystems. Application to a re-flooded. *Environmental Modelling and Software*, 2008; Vol. 23(6): pp. 751–767.
- [10] EEAA (The Egyptian Environmental Affairs Agency), Annual Report for the Environmental Monitoring Program for the Northern Lakes, 2012; Ministry of Environment, Egypt.
- [11] ALAMIM (Alexandria Lake Mariout Integrated Management), Integrated Action Plan, EC-SMAP III, March 2009; American Public Health.
- [12] Hossam M. N., Salem A. A. S., Evaluation of drainage water quality for reuse: a case study of the Omoum drain in Egypt. *Lowland Technology International*, 2003; Vol. 5(2): pp. 27–38.
- [13] Mateo M. Á., Lake Mariout: An Ecological Assessment, Laura Serrano and Oscar Serrano (CEAB-CSIC), WADI Project (Water Demand Integration; INCOCT- 2005-015226) and CEDARE (Centre for the Development of the Arabic Region), 2009.
- [14] SOGREAH, Alexandria Integrated Coastal Zone Management AICZM, Egyptian Pollution Abatement Project EPAP II,). Base line Conditions, 2008.
- [15] Mahlis A. M., El-Wakeel S. K., Morcos S. A., The major cations in Lake Mariout waters. *Hydrobiologica*, 1970; Vol. 36(2): pp. 253–274.
- [16] Allen R. G., Pereira L. S., Raes D., Smith M., Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. *FAO Irrigation and Drainage*, Paper 56. 1998; FAO, Rome.
- [17] Fermor P. M., Gilbert J. C., Gowing D. J. G., Reedbed evapotranspiration rates in England. *Hydrological Processes*, 2001; Vol. 15(4): pp. 621–631.
- [18] NIOF (National Institute of Oceanography and fisheries). Lake Mariout Data Acquisition. 2008.
- [19] Delft3D-FLOW, Simulation of Multi-Dimensional Hydrodynamic and Transport Phenomena, Including Sediments. 2015; Delaters, The Netherlands.
- [20] D-Water Quality, Water Quality and Aquatic Ecology Modelling Suite. 2015; Delaters, The Netherlands.