

## A Decision Support System for Total Phosphorus Management in Lake Manzala

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**Abstract:** Eutrophication of lakes can have significant negative ecological, health social and economic impacts on human use of a primary and finite resource. Lake Manzala has suffered from a high level of eutrophication, due to the heavy load of nutrients especially phosphorus. Reduction of Total Phosphorous System (RTPS) has been conducted to solve the high level of eutrophication and pollution problems of Lake Manzala, which are unstructured and complex problem. It is a propose system use Decision Support System (DSS) which contain model. The main component of RTPS is the inclusion of RTP model that was implemented in this study to understand the geo-chemical behavior of total phosphorous (TP) across water and sediments boundary and to calculate its concentration in the whole lake water volume ( $P_1$ ) and sediment volume ( $P_2$ ) as a result of discharging loads. The resulting seasonal budgets showed that the TP input values to Lake Manzala (from drains and re-suspension process) were more than the output values (out flowing and settling) during the four seasons of the year. These reflected the imbalance (an accumulation) of TP inside the lake and indicated that this lake is in a highly eutrophic status. This model is considered as a useful water quality management tool in designing TP reducing scenarios. The first scenario is the reduction of TP concentration in water drains, while the second one is the reduction of TP concentration in water drains and Lake Sediment. Furthermore, in each scenario there are multiple alternatives through ratios of reduced TP. It was found that 30% reduction of TP from each drain could act as an important solution for quick recovery of the lake condition to reach  $560.56 \text{ mg}\cdot\text{m}^{-3}$  of TP's initial concentration ( $1590 \text{ mg}\cdot\text{m}^{-3}$  in spring season) after 10 days and a maximum  $433.37 \text{ mg}\cdot\text{m}^{-3}$  after 100 days.

[Mona M. Mustafa, Nadia B.E. Badr, Maged M.A. Hussein, Abir Abdel Hamid Mahmoud Amer and Alaa El Din Mohamed El-Ghazali. **A Decision Support System for Total Phosphorus Management in Lake Manzala.** *Life Sci J* 2015;12(11):99-110]. (ISSN:1097-8135). <http://www.lifesciencesite.com>. 11. doi: [10.7537/marslsj121115.11](https://doi.org/10.7537/marslsj121115.11).

**Keyword:** DSS, Model, Total Phosphorus, Eutrophication, Lake Manzala

### 1. Introduction

Lake Manzala is a natural resource and considered highly important in terms of its socio-economic aspects. It is the largest of the northern Nile Delta coastal lakes<sup>[1,2]</sup>. It is considered as a vital and valuable natural resource area for fish catch, wildlife, hydrologic and biologic regime and table salt production. It produces about 50 percent of the fish catch of the northern lakes and fresh water fisheries<sup>[3]</sup>. Moreover, its geographical, social and economic aspects are very important as it lies within the borders of five Egyptian governorates (Dakahlia, Damietta, Port Said, Ismailia and Sharkiya)<sup>[4]</sup>. Its annual fish production represents about half of the total fish yield of the northern Delta lakes, and about one fifth the (non-marine) fish yield of Egypt.

However, Lake Manzala suffered from a high level of eutrophication, one of the most serious problems facing the ecology of freshwaters<sup>[1]</sup>, due to the heavy load of nutrients, especially phosphorus

and nitrogen compounds from agricultural run off, sewage and drains discharges. Increase of nutrients load in the southern sector of the lake could exceed the environmental assimilation capacity and tolerance limits of major commercial fish species. The northern sector and parts of the western sector, which are relatively unaffected by wastes and nutrient loading, provide a reservoir for "natural" fish and other aquatic species. Preservation of these areas for that purpose would allow for greater flexibility in fisheries and lake management. Thus, the fish which is dwelling the lake have become nearly polluted now; this may lead to many side effects to the consumers and population<sup>[3]</sup>.

Phosphorus is one of the major nutrients that lead to eutrophication phenomenon. Therefore, understanding its sources and transfers in Catchments, as well as knowledge about its fate in aquatic system is needed in identifying and reducing this risk<sup>[5]</sup>.

Decision Supports Systems (DSS) are computer-based information systems designed in such a way that help decision maker to select one of the many alternative solutions to a problem. It helps organization to increase production, reduce costs, increase profitability and enhance quality. It is an interactive system with an organized collection of models, people, procedures, software, databases, telecommunication, and devices, which helps decision makers to solve unstructured or semi-structured problems<sup>[6]</sup>.

The general types of quantitative models used in DSS include algebraic and differential equation, various decision analysis tools including analytical hierarchy process; decision matrix and decision tree; multi-attribute and multi-criteria models; forecasting models; network and optimization models and discrete event simulation models; and quantitative behavioral models for multi-agent simulations. Any given one of those should provide a simplified representation of a situation that is understandable to a decision maker<sup>[7]</sup>.

This research aimed to solve eutrophication problem of Lake Manzala by using Reduction Total Phosphorous System (RTPS). It is a propose system use Decision Support System (DSS) which contain RTP model that aims to build simulation based model to optimize the ecosystem of Lake Manzala.

## 2. Materials and Methods

This research will scan the environment to identify problem situation and its conditions through study area and proposed system to determine the ecosystem problem of Lake Manzala.

### 2.1 Study Area

Lake Manzalah is the largest natural Lake and economically the most important Nile Delta Lake in Egypt. It is situated at the eastern margin of the Nile Delta between 31°00' - 31°30' N latitude and 31°45' - 32°22' E longitude with an area of 120 km<sup>2</sup><sup>[8]</sup>. The morphometrical and physical parameters of Lake Manzala are shown in Table 1.

**Table 1:** Morphometrical and Physical Parameters of Lake Manzala

Maximum depth (m)	2.20 m	Source: Present study
Mean depth (m)	1.50 m	Source: Present study
Area (m <sup>2</sup> )*	120×10 <sup>6</sup>	Source: [8]
Water volume (m <sup>3</sup> )	180×10 <sup>6</sup>	Source: Present study
Sediment volume (m <sup>3</sup> )	120×10 <sup>3</sup>	Source: Present study
Porosity of upper 10 cm sediment layer	0.66	Source: [9]
Density of solid phase in sediments (kg.m <sup>-3</sup> )	2650	Source: [10]

Lake Manzala is a highly dynamic aquatic system that has undergone considerable physical, chemical and biological changes during the past century. This was as a result of different aspects of human impacts of which closing and/or opening of straits, establishment of Aswan High Dam, silting of the lake, continuous drying processes for cultivation purpose and human settlement as well as pollution

with different kinds of water discharge into the lake. Six main agricultural drains (Hadous Drain (D1), Bahr El Bakar Drain (D2), El-Serw Drain (D3), Ramsis Drain (D4), Faraskur Drain (D5) and Matariya Drain (D6)) use to flow into Lake Manzala and affect its water quality (Fig 1 and Table 2). Drainage water contributes about 98% of the total annual inflow to Lake Manzala.

**Table 2:** The main six drains with their relative contribution of the total flow in water

Drain	The total flow in water	Serving
Bahr el-bakar (D1)	49%	790000 feddans
Ramsis (D2)	25%	536000 feddans
Hadous (D3)	13%	68700 feddans
Mataria (D4)	4%	about 24 km long
El-Serow (D5)	4%	20000 feddans
Faraskour (D6)	2%	50000 feddans

The drains convey large amount of nutrients, especially from Bahr-El-Bakar, Ramsis and Hadous drains that are heavily contaminated by sewage and industrial wastes. The northern part of the lake is affected by marine water invasion through Boughaz El Gamil. Sea water may be introduced into the lake during windy days; invading the area at the lake-sea

connection by marine water and expelled from the lake by the normal flow of the drain water. Through these outlets, the exchange of water and biota between the lake and the adjoining Mediterranean Sea is possible.

## 2.2 Sampling

Water sampling was conducted seasonally in September, January, April and July (2010-2011), representing autumn, winter, spring and summer, respectively. One day in the middle of each season was select to represent the whole season. Eight stations were selected to represent the different ecological areas of Lake Manzala, (El-Genka (S1), Mataria (S2), El-Serow (S3), Faraskour and Inaniya (S4), El Zarka (S5), Lagan (Middle of Lake) (S6), El-

Bashteir (S7), and Boughaz El-Gamil (S8)) (Fig 1).

Surface water samples were collected in plastic bottles of one-liter capacity each at 10 cm below the surface water using a silicon/Teflon water pump (Fig.1). The sediment samples from the lake were also collected at the same stations. The 250 ml water samples were immediately frozen without filtration for determination of TP. Also the sediment samples were kept frozen in plastic containers until analysis.

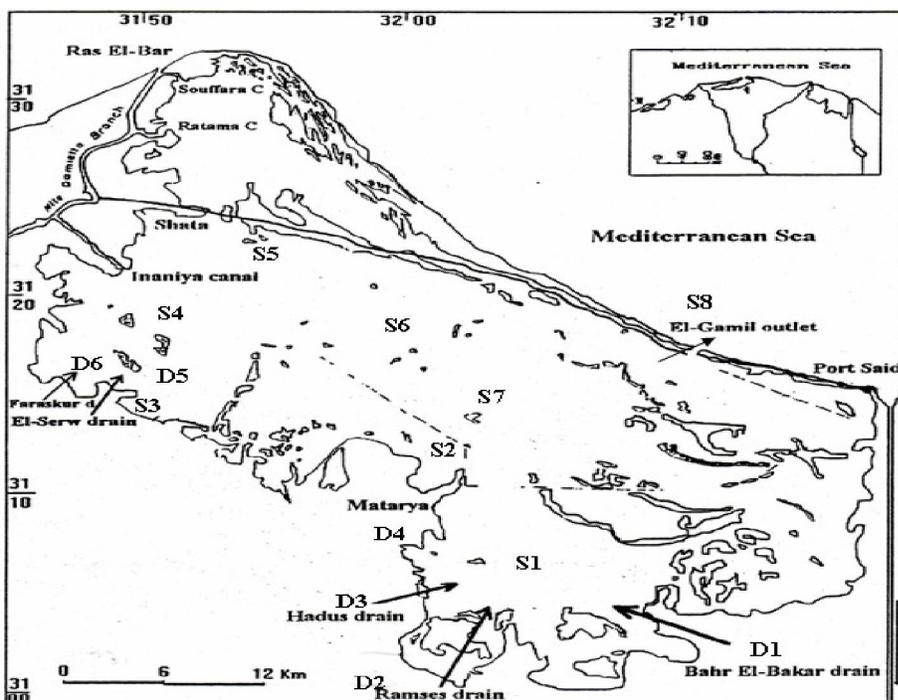


Fig. 1: Location of Lake Manzala with Selected Drains and Stations.

## 2.3. Methods

The frozen water samples were thawed prior to the determination of TP using the molybdenum blue spectrophotometric method<sup>[11]</sup>. The TP in the thawed sediments was determined using the method modified by Golachowska<sup>[12]</sup>. Satisfactory reproducibility for TP in the sediments was obtained in replicate samples (the relative standard deviation for 5 samples was less than 8%).

## 3. Results and Discussion

Table 3 shows the average TP concentration in surface water (mg/l) of selected stations recorded in Lake Manzala during the four seasons and Table 4 shows TP Concentrations (mg/L) in drains water during the four seasons and TP concentrations (mg/g) in the surface sediments of Lake Manzala during the spring seasons.

## 3.1. Total Phosphorus Model of Lake Manzala

### 3.1.1. Water Balance

The water balance of a lake is usually evaluated by the basic hydrological equation in which the change in storage of the water volume in the given area per time is equal to the rate of water inflow from all sources minus the rate of water outflow<sup>[13]</sup>, seasonally water balance elements of Lake Manzala is shows in Table 5 and Fig.2. The water balance for Lake Manzala can be written according to the equation developed by Chapra<sup>[14]</sup>:

$$S = \frac{dV}{dt} = Q_{in} - Q_{out} + G + PA_s - EA_s \quad \dots\dots(1)$$

Where:

- S = storage ( $m^3 \cdot d^{-1}$ )
- V = volume ( $m^3$ )
- T = time in days (d)
- $Q_{in}$  = total water inflow ( $m^3 \cdot d^{-1}$ )
- $Q_{out}$  = total water outflow ( $m^3 \cdot d^{-1}$ )
- G = ground water flow ( $m^3 \cdot d^{-1}$ )
- P = precipitation ( $m^3 \cdot d^{-1}$ )
- E = evaporation ( $m^3 \cdot d^{-1}$ )
- $A_s$  = lake surface area ( $m^2$ )

**Table 3:** Local and seasonal variations of TP in surface water (mg/l) of selected stations of Lake Manzala

Stations	Autumn	Winter	Spring	Summer
El-Genka (S1)	1.65	2.57	2.41	0.89
Mataria (S2)	1.74	1.64	1.98	1.78
El-Serow (S3)	0.82	0.43	0.52	0.72
Inaniya (S4)	0.68	0.44	1.38	1.74
El Zarka (S5)	0.65	0.67	2.04	0.34
Lagan (Middle of Lake) (S6)	1.34	0.63	1.39	0.43
El-Bashteir (S7)	1.98	1.17	2.08	0.76
Boughaz El-Gamil (S8)	1.77	1.14	0.91	1.11
Average	1.33	1.09	1.59	0.97
STDVE	0.540	0.733	0.650	0.543

**Table 4:** TP Concentrations (mg/L) in drains water during the four seasons and TP concentrations (mg·g<sup>-1</sup>) in the surface sediments of Lake Manzala during the spring seasons.

Drains	TP Concentrations (mg/l) in the Surface Water				TP Concentrations (mg·g <sup>-1</sup> ) in the Surface Sediments
	Autumn 2010	Winter 2011	Spring 2011	Summer 2011	Spring 2011
D1	1.97	2.98	3.77	2.86	18.2
D2	1.76	2.21	1.82	1.28	8.69
D3	1.88	2.91	1.73	1.35	9.17
D4	1.79	1.96	1.98	1.98	4.032
D5	0.95	0.69	0.64	0.79	25.05
D6	0.766	0.73	1.68	1.79	14.68
Average	1.302	1.64	1.66	1.436	13.03

**Table 5:** Seasonally Water Balance Elements of El-Manzala Lake (x10<sup>6</sup> m<sup>3</sup>)

Seasons	Drainage Inflow	Rainfall	Evaporation	Out Flow
Autumn	1257.25	11.47	318.98	949.71
Winter	735.36	34.74	275.21	494.89
Spring	905.36	12.34	348.68	569.02
Summer	1232.53	0.34	334.71	898.16

There are six water sources to Lake Manzala, land runoff ( $Q_{in}$ ) including Bahr El-Bagar, Ramsis, Hadous, Mataria, El-Serow and Faraskour Drains in addition to precipitation (P). These are opposed by water sinks; evaporation (E) and outflow water from the lake through Boughaz El-Gamil ( $Q_{out}$ ). Precipitation directly on the surface area of Lake Manzala is restricted mainly to winter season with an average daily amount of  $0.386 \times 10^6 \text{ m}^3$ . The average amount of the evaporated water from the lake (restricted to the summer season) was estimated to be  $3.719 \times 10^6 \text{ m}^3 \cdot \text{d}^{-1}$ . The ground water loads require an estimation of the average phosphorus concentration in the seepage area. As we did not include its effect in the model, this term was neglected. The seasonal amount of the water outflow from Lake Manzala ( $\text{m}^3 \cdot \text{d}^{-1}$ ) was obtained from the direct measurements using a water current meter at Boughaz El-Gamil.

The water balance of Lake Manzala integrates in

each season shows in Fig. 2. It shows that the amounts of the outflow water to the sea ranged from  $5.49 \times 10^6 \text{ m}^3 \cdot \text{d}^{-1}$  in winter to  $10.55 \times 10^6 \text{ m}^3 \cdot \text{d}^{-1}$  in autumn where the water input was primarily from the overland sources. Therefore, this lake can be classified as a "drainage lake" [9]. The calculations for water balance of Lake Manzala in the four seasons indicate that the total input values were equal to the total output values; which mean that there were no drastic changes in the lake volume throughout the year. The residence time ( $\tau$ ) of the lake water in each season, calculated from division of the lake volume by the lake outflow rate that changes from one season to another (are 10.5523, 5.4988, 6.3224 and  $9.9796 \times 10^6 \text{ m}^3 \cdot \text{d}^{-1}$ ) for autumn, winter, spring and summer, respectively, with the annual average value of  $8.0883 \times 10^6 \text{ m}^3 \cdot \text{d}^{-1}$ . There for the water exchange time ( $\tau$ ); 32.7344 days in winter and 18.0368 days in summer [13].

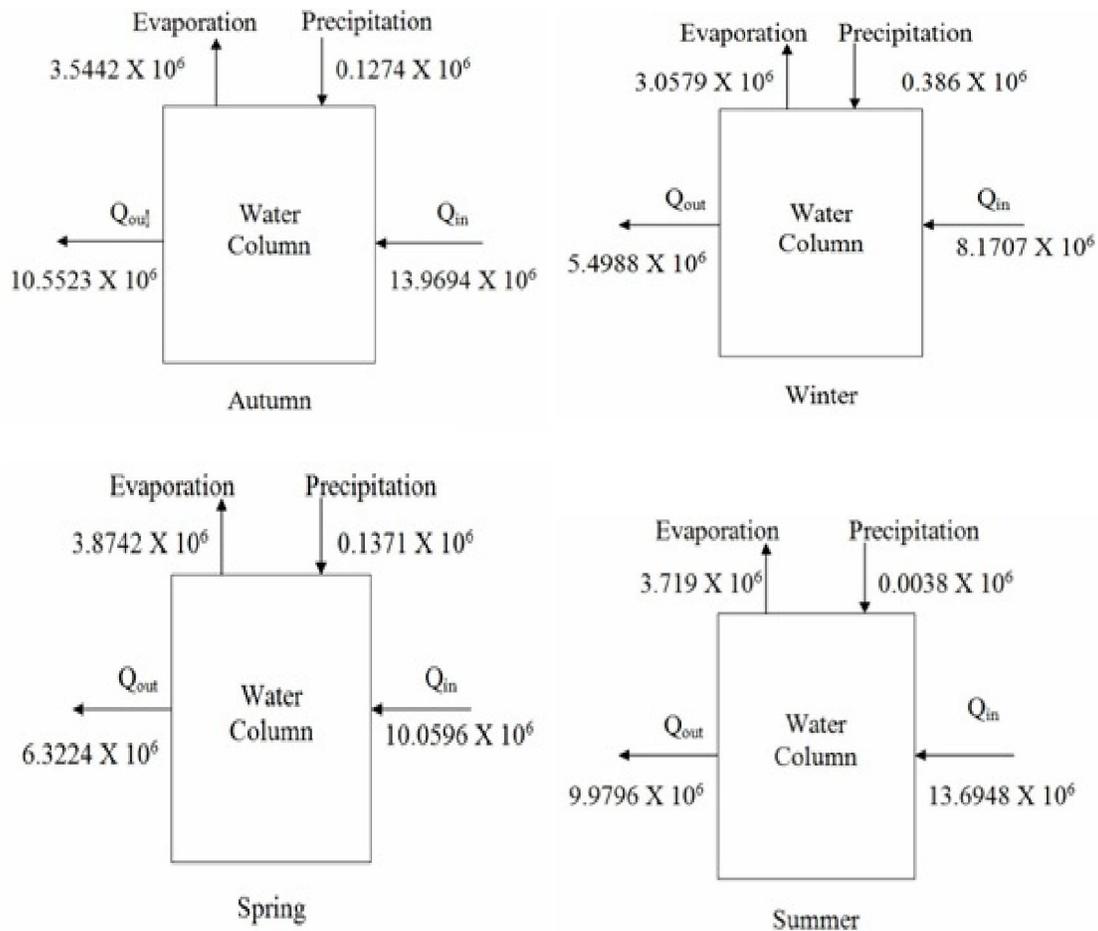


Fig. 2: Water balance in Lake Manzala ( $\text{m}^3 \cdot \text{d}^{-1}$ ).

### 3.2. Proposed System

This case will propose RTPS for reducing the source of TP in Lake Manzala. RTPS is an effectiveness DSS intended to support decision makers to solve high level of eutrophication problem of Lake Manzala. It consists of three interacting components: Environmental Database, RTP model and easy-to use interface.

#### 3.2.1. Components of RTPS

RTPS components are the following and as shown in Fig. 3.

##### 3.2.1.1. Environmental Database:

Relevant environmental information of Lake Manzala was amalgamated and entered into a data base that is managed by a Database Management System (DBMS) to aid decision maker. Collected data are as follows:

- Morphometrical parameters of Lake Manzala (Table 1).
- Initial concentration of TP for Lake Manzala (Average of each season) (Table 3).

- Input loads of TP for Lake Manzala (Table 6).
- TP Concentrations ( $\text{mg/L}$ ) in drains water during the four seasons and TP concentrations ( $\text{mg} \cdot \text{g}^{-1}$ ) in the surface sediments of Lake Manzala during the spring seasons (Tables 4).
- Total suspended matter ( $\text{mg} \cdot \text{m}^{-3}$ ) for spring season [15].

##### 3.2.1.2. RTP Model:

The objective of the model was to simulate the mass balance of TP in water and sediments of Lake Manzala. It utilizes algebraic and differential equation to optimize the ecosystem of Lake Manzala; hence, it is a quantitative model. Also, it depends on time; hence, it is a dynamic model. RTP gives decision makers a variety of choices, which assists their decision making process.

##### 3.2.1.3. User interface:

It is used to communicate with and command the RTP. A user interacts with the RTP model to obtain output data.

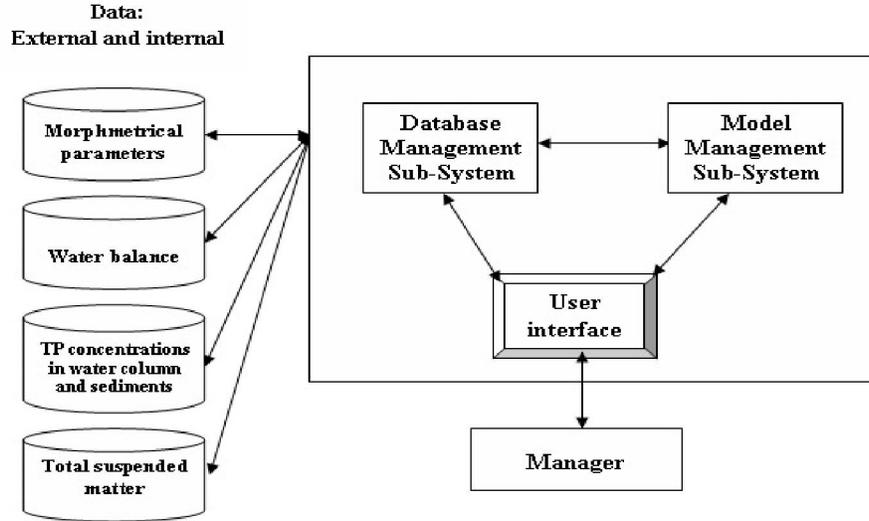


Fig. 3: Components of RTPS for Lake Manzala.

**3.2.2. RTP Model**

Due to the growing complexity and uncertainty in many decision situations, managers seek models to plan for their research topics and decision-making such as the quantitative models. Quantitative models are the dominant components that provide the primary function of a decision support system. It is designed so a user can manipulate parameters of the model with ease so as one could analyze data to have a positive outputs. RTP Model is quantitative model.

In this model will address the Assumptions of RTP Model, the Mass Balance Equations for TP in water Column and sediments, Parameterize of RTP and analytical solution for Model.

**3.2.2.1. Assumptions of RTP Model**

The major assumptions used in the RTP model include the following:

- The atmospheric input is considered as a minor source of phosphorus (P) to coastal waters, because Phosphorous is particularly not volatile<sup>[16]</sup>. Consequently, the model did not consider TP loads from rainfall and dry precipitation.
- In this case, ground water and shoreline erosion in the Lake Manzala were not considered owing to the lack of reliable data and the belief that these are small with respect to the other loads. According to [17], Groundwater flows can be particularly important in areas of porous limestone that is relevant to some tropical limestone islands.
- The lake is considered as a well-mixed basin (as a continuous stirred tank reactor) with a continuous interaction between water and sediments (assumed to be with an equal areas). The volume of sediments was calculated by multiplication of their surface area by thickness of 10 cm.

**3.2.2.2. Mass Balance Equations for Total Phosphorus in Water Column and Sediments**

As is common in shallow lakes, the movement of boats and moderate wave height in Lake Manzala are enough to induce re-suspension of the bottom sediments and can result in a large contribution to the total nutrient load in the lake water. Studies in a shallow, wind-exposed lake in Denmark [18] showed that the phosphorous loads induced by re-suspension could be 20-30 times greater than that released from undisturbed bed sediments. As such, sediments feedback could have a potential source of phosphorus to the overlying lake waters, which in turn have a significant impact on the recovery of such system especially in shallow lakes [14, 19].

The following are the time dependent mass balance equations that govern the total phosphorus concentration in the water column and sediments layer [14]:

$$V_1 \frac{dp_1}{dt} = W_{in} - W_{out} - v_s A_s P_1 + v_r A_s P_2 \dots (2)$$

$$V_2 \frac{dp_2}{dt} = v_s A_s P_1 - v_r A_s P_2 - v_b A_s P_2 \dots (3)$$

- Where:
- $V_1$  &  $V_2$  = volumes of lake water and sediments, respectively ( $m^3$ )
  - $P_1$  &  $P_2$  = TP concentrations in water column and sediments, respectively ( $mg.m^{-3}$ )
  - $W_{in}$  = TP loads to the lake system
  - $W_{out}$  = TP loads out of the lake system
  - $v_s$  = settling velocity from water column to sediments ( $m.d^{-1}$ )
  - $v_r$  = re-suspension velocity from sediments to water column ( $m.d^{-1}$ )
  - $v_b$  = burial velocity from the enriched surface layer to the deep sediments ( $m.d^{-1}$ )

The first term in the water column mass balance equation describes the external loads, while the second

one describes the outflow sink. The third and fourth terms give a net deposition of TP, including settling and re-suspension processes, respectively. For the sediments equation, the burial term is present in addition to other processes; settling and re-suspension.

**3.2.2.3. Parameterize of RTP Model**

RTP model parameters include: in/out Loads to the Lake System, settling, re-suspension and burial Process.

**3.2.2.3.1. Loads to the Lake System**

The total input load term ( $W_{in}$ ) in the mass balance equation is listed in Table 6. It is the sum of the TP loadings ( $mg.d^{-1}$ ) from Bahr El-Bakar Drain ( $W_1$ ), Ramsis Drain ( $W_2$ ), Hadous ( $W_3$ ), Mataria ( $W_4$ ), El-Serow ( $W_5$ ) and Faraskour ( $W_6$ ) (equation 4) [14].

**Table 6:** Input loads of TP ( $\times 10^9 mg.m^{-3}.d^{-1}$ ) for Lake Manzala in the four seasons.

Season	Bahr El-Bakar	Ramsis	Hadous	Mataria	El-Serow	Faraskour	Input Phosphorous loads ( $10^9 mg d^{-1}$ )
	$W_1$	$W_2$	$W_3$	$W_4$	$W_5$	$W_6$	
Autumn	7.22	1.04	13.19	0.53	1.72	0.45	24.153
Winter	8.64	0.98	8.65	0.46	0.81	0.32	19.863
Spring	11.31	0.87	8.13	0.48	0.74	0.81	22.337
Summer	10.85	0.78	8.66	0.61	1.56	1.09	23.528

**3.2.2.3.2. Loads out of the lake system**

The TP load carried out from the lake to Boughaz El-Gamil by the outflow stream can be represented by the following equation [14]:

$$W_{out} = Q_{out}P_1 \dots\dots\dots (5)$$

**3.2.2.3.3. Settling Process**

Settling represents uniform loss, which can be formulated as a flux of mass from the surface area of the lake to the sediments. Thus, a term for settling in the mass balance can be developed as [14]:

$$v_s A_s P_1 \dots\dots\dots (6)$$

The settling velocity is called “apparent” because it represents the net effect of the various processes that act to deliver element to the lake’s sediments. According to [20], the settling velocity can be calculated by the following equation [14]:

$$v_s = \frac{H}{\sqrt{\tau_w}} \dots\dots\dots (7)$$

Where:

H = average depth of the lake (m)

$\tau_w$  = water residence time (day)

**3.2.2.3.4. Re-suspension Process**

To quantify the re-suspended sediments and the resulting contribution to TP load in the lake water, the re-suspension process can be estimated by the following equation [14]:

$$v_r A_s P_2 \dots\dots\dots (8)$$

The load from each drain was calculated by multiplication of the inflow concentration of TP by the volumetric flow rate of the water discharged. These loads included the leaching and drainage of fertilizers and other soil nutrients.

$$W_{in} = W_1 + W_2 + W_3 + W_4 + W_5 + W_6 \dots\dots\dots (4)$$

Where:

$W_1$  = TP load from Bahr El-Bakar Drain ( $mg. d^{-1}$ )

$W_2$  = TP load from Ramsis Drain ( $mg. d^{-1}$ )

$W_3$  = TP load from Hadous Drain ( $mg. d^{-1}$ )

$W_4$  = TP load from Mataria Drain ( $mg. d^{-1}$ )

$W_5$  = TP load from El-Serow Drain ( $mg. d^{-1}$ )

$W_6$  = TP load from Faraskour Drain ( $mg. d^{-1}$ )

The  $P_2$  value was modified from  $mg/kg$  to  $kg/m^3$  by multiplying  $P_2$  concentration by the density of solid phase in the sediments Table 1. The resuspension velocity can be calculated from the following formula [14]:

$$v_r = v_s \frac{m_i}{(1 - \phi)\rho} - v_b \dots\dots\dots (9)$$

Where:

$m_i$  = average concentration of total suspended solids in each season ( $mg.m^{-3}$ )

$\phi$  = porosity of sediments layer (Table 1).

$\rho$  = density of solid phase in sediments ( $kg.m^{-3}$ ).

**3.2.2.3.5. Burial Process**

A burial mass transfer from the enriched surface sediment layer to the deep layer can be estimated by the following equation [14]:

$$v_b A_s P_2 \dots\dots\dots (10)$$

and the burial velocity can be calculated from the following formula [14]:

$$v_b = \frac{w_{in} - w_{out}}{A(1 - \phi)\rho} \dots\dots\dots (11)$$

**3.2.2.4. Analytical Solution for RTP Model**

In this study, RTP model is based on the analytical solution of a system of two linear non-homogenous differential equations (1 and 2), one for the water column and the other for the sediments. The following particular form of solution for the two differential equations will describe how the lake’s TP

concentrations ( $P_1$  and  $P_2$ ) change as a function of time following the change of TP loading [5]:

$$P_1 = L_1 C_1 e^{\alpha t} + L_2 C_2 e^{\beta t} + L_3 \dots (12)$$

$$P_2 = C_1 e^{\alpha t} + C_2 e^{\beta t} + L_4 \dots (13)$$

Where:

$$L_1 = \frac{\alpha V_2 + S_4}{S_3} \dots (14)$$

$$L_2 = \frac{\beta V_2 + S_4}{S_3} \dots (15)$$

$$L_3 = \frac{S_4 W}{S_1 S_4 - S_2 S_3} \dots (16)$$

$$L_4 = \frac{S_3 W}{S_1 S_4 - S_2 S_3} \dots (17)$$

$$S_1 = Q + v_s A_s \dots (18)$$

$$S_2 = v_r A_s \dots (19)$$

$$S_3 = v_s A_s \dots (20)$$

$$S_4 = v_r A_s + v_b A_s \dots (21)$$

$\alpha$  and  $\beta$  = roots of the equations

To obtain the constant values ( $C_1$  and  $C_2$ ), the initial conditions for TP in the water column ( $P_s$ ) and sediments ( $P_b$ ) at  $t=0$  were taken from the actual measured data (average concentration of six drains Tables 4 and 5):

$$P_s = L_1 C_1 + L_2 C_2 + L_3 \dots (22)$$

$$P_b = C_1 + C_2 + L_4 \dots (23)$$

From equations 22 and 23,  $C_1$  and  $C_2$  can be obtained

$$C_1 = \frac{P_s - L_1 (P_s - L_4) - L_3}{(L_2 - L_1)} \dots (24)$$

$$C_2 = P_b - \left[ \frac{P_s - L_1 (P_s - L_4) - L_3}{(L_2 - L_1)} \right] - L_4 \dots (25)$$

By using equations 24 and 25 and substitute into equations 12 and 13, we can get the final solution of  $P_1$  and  $P_2$ .

### 3.3. RTP Model Application

This model is important because of its simplicity and modest requirements. Parameter estimation methods, using theoretical equations and the required input data are reduced to morphometric data for the lake, as well as loads and a set of transport processes, as settling, re-suspension, and burial of the TP which are modeled as first-order processes. Ideally with this simulation of RTP model, the ecologists can assess system processes and responses and make quick decisions. The required input data of the total suspended matter and the calculated velocities for each season are summarized in Table 7.

**Table 7:** Seasonal average values of total suspended matter, settling, burial and re-suspension velocities for Lake Manzala.

Seasons	Total suspended matter (mg.m <sup>-3</sup> ) [15]	Settling velocity (m.d <sup>-1</sup> )	Burial velocity (m.d <sup>-1</sup> )	Re-suspension velocity (m.d <sup>-1</sup> )
Autumn	910	0.3632	$2.62 \times 10^{-4}$	0.089
Winter	550	0.2622	$6.49 \times 10^{-4}$	0.082
Spring	940	0.2811	$7.89 \times 10^{-4}$	0.150
Summer	360	0.3532	$5.91 \times 10^{-4}$	0.072

The estimated TP in the whole lake water volume ( $P_1$ ) and sediment volume ( $P_2$ ), resulted from the model are represented in Table 8. These are used in the calculation of TP seasonal budget. Fig. 4 illustrates the total sources/sinks processes of TP in whole lake. It was noticed that, the dynamics of TP concentrations is a result of interplay between external load changes and major internal fluxes defined by sedimentation and re-suspension processes. There were considerably more inputs to the water column (from drains and re-suspension process) than the

output processes (flushing and settling) in the four seasons, which reflect the imbalance (an accumulation) of TP in the geo-chemical cycle inside the lake. This change in phosphorous storage indicates that there is an overall gain and accumulation in water column and sediments in the lake from season to another. These surplus values were distributed among phytoplankton, hydrophytes and other indigenous plant organisms, which need further quantitative confirmation. The same conclusion was found by El-Shebly<sup>[21]</sup>.

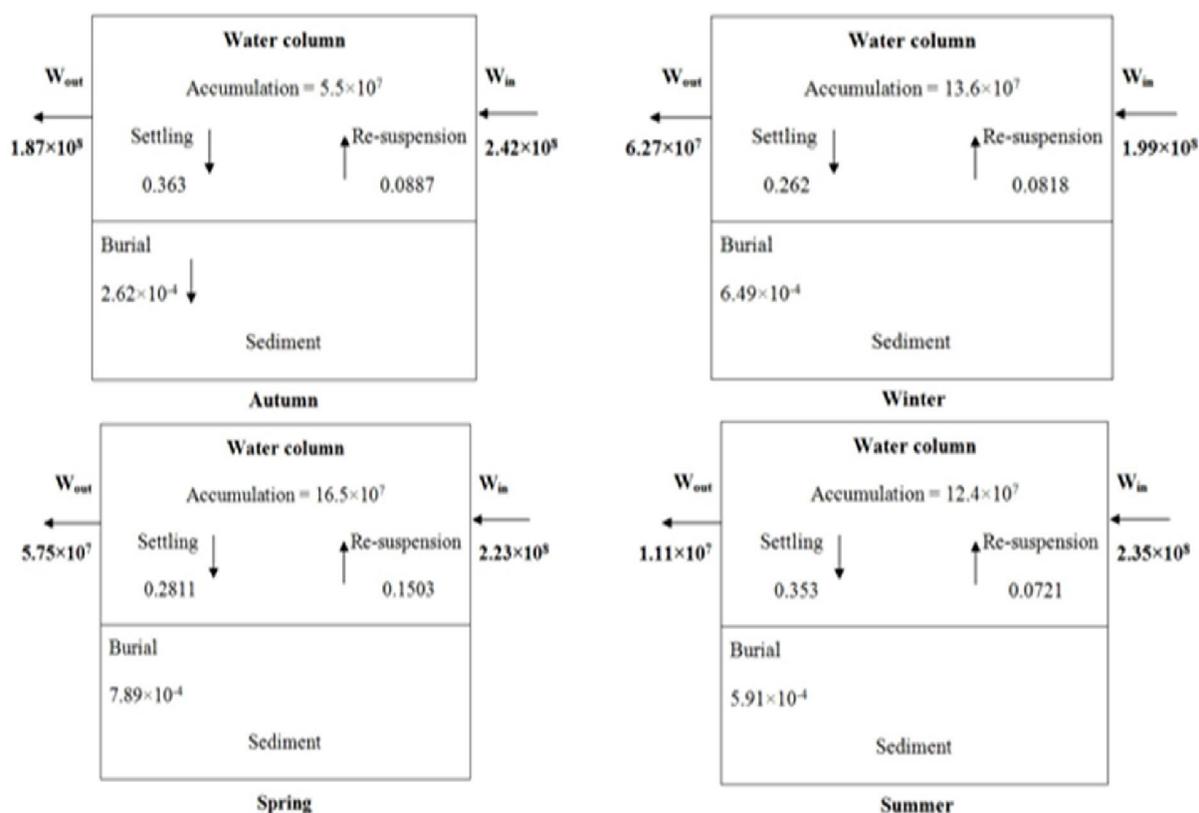
**Table 8:** TP Concentrations in the whole Lake Manzala water volume ( $P_1$ ) and sediment volume ( $P_2$ ).

Seasons	Total phosphorous concentrations	
	$P_1$ (mg)	$P_2$ (mg)
Autumn	$1.995 \times 10^{11}$	$5.314 \times 10^{14}$
Winter	$1.779 \times 10^{11}$	$5.314 \times 10^{14}$
Spring	$2.498 \times 10^{11}$	$5.314 \times 10^{14}$
Summer	$1.511 \times 10^{11}$	$5.314 \times 10^{14}$

Excluding winter season, the input loads from agricultural drainage were considered the major source of TP to the water column of Lake Manzala. Inside the water, the settling process (sedimentation) is considered as a significant component of TP sink processes compared to the outflow process Fig. 4. For the sediments system, a high burial process was recorded in the four seasons, where the maximum value of  $7.89 \times 10^{-4}$  mg.d<sup>-1</sup> was found in spring. The temporal (seasonal) variations of TP accumulation values in the water column indicate that the higher value ( $16.5 \times 10^7$ ) was recorded in spring due to the higher re-suspension load value compared to the other seasons (Fig. 4).

Chlorophyll a is a universal indicator of Phytoplankton and showed wide variations on the sampling date throughout the eight sampling sites with a mean concentration about  $62.65 \text{ mg.m}^{-3}$ [22]. Lower

Chlorophyll a levels were measured in the northern strip of the lake. This low level of Chlorophyll a concentrations at these sites is attributed to the regular tidal flushing of the Mediterranean seawater via Boghaz El-Gamil inlet; however, higher levels were recorded in other locations along the lake. The maximum concentrations of recorded Chlorophyll were  $101.1 \text{ mg.m}^{-3}$  and  $125 \text{ mg.m}^{-3}$ , at sites via El-Serw Drain and (Hadous and Bahr El-Bakar) Drains. Both sites receive significant amount of wastes. El-Serw Drain, in the western corner, receives high amount of agricultural and sanitary wastes. Hadous and Bahr El-Bakar, in the south-eastern corner receives mixed amount of sanitary, agricultural and industrial wastes[22]. This result agreement with [23, 24] indicated that the phosphate concentrations in spring and summer were suitable for micro and macro algal blooms to occur.



**Fig. 4:** Total Phosphorous Budgets in Lake Manzala Water Column and Sediments during Autumn, Winter, Spring And Summer Seasons (mg.d<sup>-1</sup>).

Chapra and Tarapchak<sup>[14]</sup> chased the acceptable meansummer chlorophyll-levels to be in the range from  $2.7 \text{ mg.m}^{-3}$  to an excessive level of  $9.0 \text{ mg.m}^{-3}$ . These values are equivalent to the TP levels ranging from  $13.4 \text{ mg.m}^{-3}$  (acceptable) to  $30.7 \text{ mg.m}^{-3}$  (excessive). However, based on the results of model, the TP concentrations in Lake Manzala water (P<sub>1</sub>) were 1059.14, 978.84, 1463.53 and 825.21 mg.m<sup>-3</sup> for autumn, winter, spring and summer seasons,

respectively. Based on acceptable TP values obtained by Chapra<sup>[25]</sup>, it was clear that the trophic status of Lake Manzala is in a risk condition. Comparison between accumulated values of TP in the water column of Lake Manzala recorded in the present study with values calculated from the previous work done by El-Shebly [21], Table 9, indicates that the seasonal amount of TP storage has increased between 3-8 fold as a direct results from the increasing loads.

**Table 9:** Total loads and accumulated values of TP ( $\times 10^9$  mg.d<sup>-1</sup>) for present and previous studies of Lake Manzala in four Seasons.

Seasons	TP loads $\times 10^9$ mg.d <sup>-1</sup>		TP accumulated values
	1994	2010-2011	2010-2011
Autumn	1.95	9.12	$5.5 \times 10^7$
Winter	0.98	11.48	$13.6 \times 10^7$
Spring	3.00	11.62	$16.5 \times 10^7$
Summer	3.65	10.05	$12.4 \times 10^7$

### 3.4. Temporal aspects of phosphorous reduction

For the need of better environmental protection in Egypt, its water resources and the health of Egyptian citizens are of high priority of the government. Egypt has stipulated the necessity for land and water management strategies. Regulation of fertilizers and pesticides and development of agricultural legislation in harmony with an effective environmental policy, especially for Nile Delta Lakes must be enforced. The present study indicates that Lake Manzala is considered as a highly eutrophic lake, due to the excessive phosphorus loading from agriculture drains, especially in spring season. Accordingly, a phosphorous reduction trial in the drains of the lake was implemented at the beginning of spring with the assumption of constant discharging rates. In order to identify the temporal response of the lake water to reduced TP loads, the model can be applied using two control options with the following scenarios:

#### 3.4.1. Control of TP concentration in external inputs

In this case, there are also multiple alternatives through ratios of reduced in the water, whether this ratios constant or variable in each drains. In this study, TP concentration in spring season for each drain was reduced by 10%, 20% and 30% of its initial value ( $1590 \text{ mg.m}^{-3}$ ). The behavior of  $P_1$  is summarized in Table 10 and exemplified in Fig. 5. It was noticed that, by elimination of TP by 30% in the six water drains, the response time of TP concentration in the Lake was lowered to  $560.56 \text{ mg.m}^{-3}$  of its initial value after 10 days in spring season. This meaning that the reduction of TP will be 64.74% as shown in Table 9. After 100 days, the TP concentration was reached  $433.37 \text{ mg.m}^{-3}$  (72.74%) of its initial value (Fig 5).

**Table 10:** Percentages of TP Reduction in the Water Drains and the Calculated Concentrations of TP ( $\text{mg.m}^{-3}$ ) at Different Time Intervals in Lake Manzala

% of TP reduction in all drains	Initial	After 10 days	After 100 days	After 250 days	After 500 Days	After 1000 days	After 3000 days
10%	1590	628.74	509.99	510.07	510.21	510.48	511.59
20%	1590	582.2	457.68	457.77	457.91	458.18	459.28
30%	1590	560.56	433.37	433.45	433.59	433.56	434.95

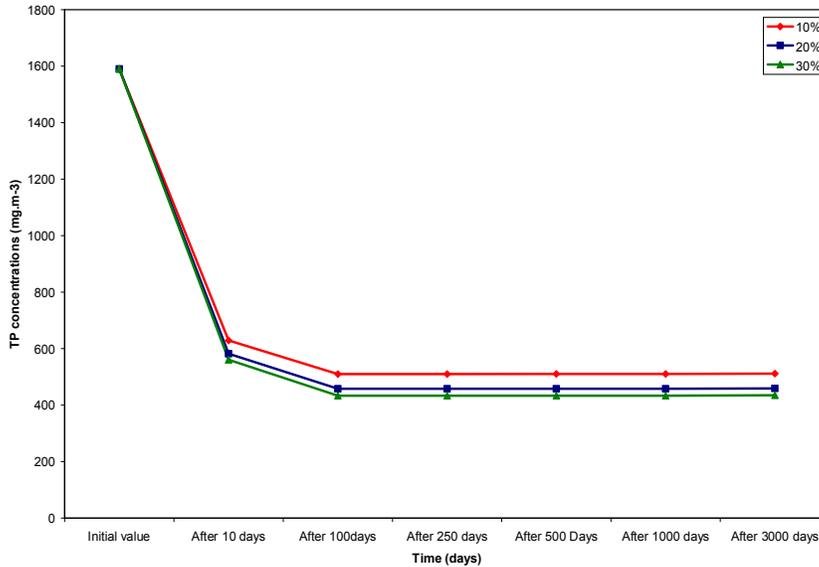
#### 3.4.2. Reduction of TP concentration in internal and external inputs

In this case, there are also multiple alternatives through reduced ratios of TP concentrations in the water column and sediments, whether these ratios constant or variable in each drains. In this study, TP concentration was reduced by 1%, 7% and 10% in the Lake sediments and 10% in each drain water of its initial value  $1590 \text{ mg.m}^{-3}$ . The behavior of  $P_1$  is summarized in Table 11 and exemplified in Fig. 6.

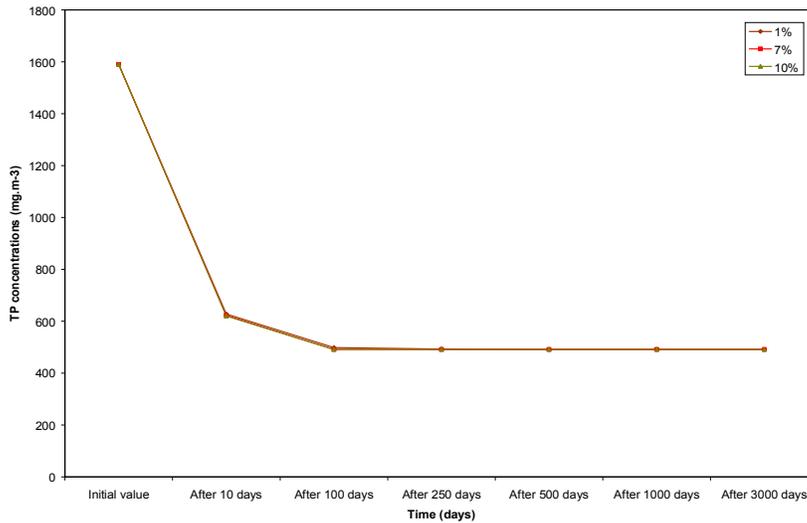
The concept of reducing TP concentrations in the sediments (7%) and drains (10% in each drain) could act as an important solution for fast recovery of the lake condition to reach 40% of TP's initial concentration after 10 days and a maximum of 30% after 100 days (Table 11 and Fig 6). This implies that the response time is highly influenced by the reduction in TP's sediments concentrations. Thus, the lake manifests a substantial improve in 3.3 months. months

**Table 11:** Percentage of TP Reduction in the Sediments With 10% Reduction in the water Drains, as Well as the Calculated Concentrations of TP ( $\text{mg.m}^{-3}$ ) at Different Time Intervals in Lake Manzala.

% of TP reduction in all drains	% of TP reduction in sediments	TP concentrations ( $\text{mg.m}^{-3}$ )						
		Initial	After 10 days	After 100days	After 250 days	After 500 days	After 1000 days	After 3000 days
10%	1%	1590	627.63	498.42	492.84	491.39	491.26	491.26
10%	7%	1590	622.27	491.23	491.21	491.21	491.21	491.21
10%	10%	1590	620.26	491.22	491.21	491.21	491.21	491.21



**Fig. 5:** Total Phosphorous Concentrations ( $\text{mg.m}^{-3}$ ) in Water Column of Lake Manzala as a Result of Different Percent Reductions in Total Phosphorous concentrations of Drains.



**Fig. 6:** Total phosphorous Concentrations ( $\text{mg.m}^{-3}$ ) in Water Column of Lake Manzala Resulting From 10% Reduction in Total Phosphorous of Drains and Different Percent Reductions in Sediments.

#### 4. Conclusion

Lake Manzala has been subjected to huge inputs of terrigenous and anthropogenic nutrients (especially phosphorus and nitrogen compounds) from agricultural runoff, sewage and drains discharges. These conditions have made the lake biologically productive. The major effort to control eutrophication problem of Lake Manzala and its pollution due to industrial and agricultural waste has been directed towards reducing the input of phosphorous.

RTPS is a proposed system which uses DSS tools to control eutrophication problem, a high concentration of phosphorous in the water column and sediments in Lake Manzala. RTPS's components are: Environmental Database, RTP model and user interface. RTP model is targeted towards simulating the mass balance of TP in water and sediments of

Lake Manzala. It utilizes algebraic and differential equation to optimize the ecosystem of Lake Manzala; hence, it is a quantitative model. Also, it depends on time; therefore, it is a dynamic model. Consequently, RTPS is an interactive decision support system to help decision maker to select one of the multiple alternative solutions to reduce TP concentration in Lake Manzala. RTP model can be applied using two control options of scenarios, each scenario have multiple alternatives through ratios of reduced TP concentrations. The first scenario is reduction of TP concentration in water drains and second scenario is reduction of TP concentration in water drains and lake sediments. The decision maker preferred the first scenario by choice 30 % reduction of TP from each drain because it is lower cost and reached about 27% of its initial value after 100 days.

### Acknowledgments

There are no adequate words to thank staff of Rearing lab; Aquaculture Division, NIOF.

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