MODELING SAPANCA LAKE WITH ONE AND TWO LAYER PAMOLARE MODEL FOR EVALUATION OF WATER QUALITY

by

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B.S., in C.E., Boğaziçi University, 2006

Submitted to the Institute for Graduate Studies in

Science and Engineering in partial fulfillment of

the requirements for the degree of

Master of Science

Graduate Program in Civil Engineering

Boğaziçi University

2009

ACKNOWLEDGEMENTS

First, I would like to express my sincere gratitude to my thesis supervisor, Assoc. Prof. Atilla Akkoyunlu for his guidance, support and encouragement throughout the preparation of this thesis. Without his sympathy, patience and guidance, the accomplishment would be impossible.

I extend my sincere thanks to Assoc. Prof. Ali Fuat Aydın and Dr. Ali Ertürk for their kind and supportive attitude to me and showing high interests and valuable advices to my thesis, also for the courses they gave me in my graduate education.

I want to convey special thanks to Mümin Barış, Yakup Karaaslan who spent their invaluable time and energy with me also my friends, Muhammed Ernur Akıner, Yusuf Eşidir, Murat Cenk Erdurak, Ayşe Aydın, Mehmet Ülker, Umut Karacadağlı, Emin Çiftçi, Abdurrahman Ufuk Şahin and Reza Chowdhury who encourage me during my thesis study.

Lastly, I would like to thank my sister, Hanife Rahmanlar and brother, İsa Rahmanlar and nephew, Ensar Rahmanlar for the endless support, patience and understanding along this period.

ABSTRACT

MODELING SAPANCA LAKE WITH ONE AND TWO LAYER PAMOLARE MODEL FOR EVALUATION OF WATER QUALITY

Lake Sapanca is one of the major water resources supplying drinking water of northwestern Turkey. The determination of water quality of drinkable water resources is so crucial. There are lots of methods to estimate the water quality. In recent years, mathematical models become so popular for investigation of the water quality. In this research, limiting element which is so important for eutrophication is determined by using nitrogen and phosphorus ratio. Beside that, Vollenweider method and probabilistic approaches used to determine trophic character of Lake Sapanca. To see the relation between phosphorus and chlorophyll-a non linear regression is applied. The thermal stratficiation is investigated by using temperature profile of lake then epilimnion and hypolimnion depth is determined. Lastly, dynamic model named as PAMOLARE used for evaluation water quality of Sapanca Lake. PAMOLARE is a model which is estimating future characteristics of lake by using past data and input loads. Two types models were used; namely: 1-Layer PAMOLARE model and 2-Layer PAMOLARE model. 1-Layer Model assumes that lake is well mixed and no stratification occurs in lake. 1-Layer Model makes estimation by using lake morphology and assuming a constant nutrient loading. 2-Layer Model is more complex model. This model separates lake to two layers as hypolimnion and epilimnion. The mathematical formulas are applied differently to two layers. Beside that 2-Layer Model uses daily environmental data and estimates future data by using these past environmental data. In the construction process of model, general behavior of lake was described. Missing data was obtained by curve fitting programs. Solar intensity, epilimnion and hypolimnion layers depth were described by the physical properties of lake. And different results are obtained according to different scenarios.

As a conclusion, water quality of Sapanca Lake is investigated and the PAMOLARE models have been successfully applied to determine future in-lake parameters.

ÖZET

SAPANCA GÖLÜ'NÜN SU KALİTESİNİN DEĞERLENDİRİLMESİ İÇİN TEK VE ÇİFT KATMANLI PAMOLARE MODELİ İLE MODELLENMESİ

Sapanca Gölü Türkiye'nin Kuzeybatısına içme suyu sağlayan önemli su kaynaklarından biridir. İçme suyunun kalitesini belirlemek çok önemlidir. Su kalitesini değerlendirmek için birçok metot vardır. Son yıllarda su kalitesinin araştırılmasında matematiksel modeller çok yaygınlaştı. Bu araştırmada ötrofikasyon için önemli olan sınırlayıcı madde azot fosfor oranı kullanılarak belirlendi. Bunun yanında Sapanca Gölü'nün trofik karakterini belirlemek için Vollenweider metodu ve olasılıklı yaklaşım kullanıldı. Fosfor ve klorofil a arasındaki ilişkiyi görmek için doğrusal olmayan regresyon uygulandı. Termal katmanlaşma gölün sıcaklık profili kullanılarak incelendi daha sonra epilimnion ve hipolimnion derinlikleri belirlendi. Son olarak, PAMOLARE adı verilen dinamik bir model Sapanca Gölü'nün su kalitesinin değerlendirilmesinde kullanıldı. PAMOLARE gölün gelecekteki karakterini geçmiş verileri ve göle giren yükleri kullanarak hesaplayan bir modeldir. İki tip model kullanılmıştır; bunlar ismen :tek tabakalı ve çift tabakalı modellerdir. Tek tabakalı model gölün tam karıştığını ve tabakalaşma olmadığını kabul eder. Tek tabakalı model tahminini gölün morfolojisini kullanarak ve sabit besi yükü kabul ederek yapar. Çift tabakalı model karmaşık bir modeldir. Bu model gölü epilimnion ve hypolimnion olarak iki tabakaya böler. Matematiksel formüller bu iki katmana farklı uygulanır. Bunun yanında çift katmanlı model günlük verileri kullanır ve gelecekteki verileri bu geçmiş verileri kullanarak elde eder. Modelin inşası sürecinde, gölün genel yapısı belirlendi. Eksik veriler curve fitting programlarıyla elde edildi. Güneş ışığı şiddeti, sıcaklık dağılımı gölün fiziksel özelliklerinden belirlendi. Model gölün gelecekteki karakterini tahmin etmek için uygulanmıştır. Ve farklı senaryolar için farklı sonuçlar elde edilmiştir.

Sonuç olarak, Sapanca Gölü'nün su kalitesi incelenmiştir ve PAMOLARE modeli gelecekteki göl içi parametrelerinin belirlenmesinde başarılı bir şekilde uygulanmıştır.

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A	Surface area of each part (hypolimnion, epilimnion)
a	Correction factor of nutrient output due to thermocline formation
C	Dissolved Organics
Cj	Concentrations of j organisms
C_{sed}	Releasable Sediment Dissolved Organics
D	Detritus
DO	Dissolved Oxygen
DO_{sat}	Saturated Dissolved Oxygen
F_j	Changing Rate of Each State Valuable j
F_{MaxZ}	Maximum Growth Rate
F_{mZ}	Half Saturation Constant
f_{Ik}	Light Intensity Affecting Function for M_k
f_{Nk}	Inorganic Nutrient Concentration Affecting Function for Mk
f_{sedC}	Fraction Ratio, Dissolved Organics
f_{sedN}	Fraction Ratio, Nitrogen
f_{sedP}	Fraction Ratio, Phosphorus
f_{Tk}	Temperature Affecting Function for Mk
H	Water Depth of each Part
H_{sed}	Sediment Depth
I	Intensity of Sunlight
$I_{optM\,1}$	Optimum Solar Radaiton for Diatom
$I_{optM\,2}$	Optimum Solar Radaiton for Blue Green Algae
$I_{optM\,3}$	Optimum Solar Radaiton for other phytoplankton
IN	Inflow
J_{day}	Julian day of the observation
K_d	Mixing Rate
K_{DO}	Half Saturation Constant of Dissolved Oxygen
K_L	Reaeration Constant
$K_{nM\,1}$	Half Saturation Constant, N for Diatom

K_{nM2}	Half Saturation Constant, N for Blue-green algae
K_{nM3}	Half Saturation Constant, N for other phytoplankton
K_{pM1}	Half Saturation Constant, P for Diatom
K_{pM2}	Half Saturation Constant, P for Blue-green algae
K_{pM3}	Half Saturation Constant, P for other phytoplankton
k_{dC}	Decomposition Rate of Dissolved Organics
k_{dD}	Decomposition Rate of Detritus
k_{dM1}	Mortality Rate of Diatom
k_{dM2}	Mortality Rate of Blue-green algae
k_{dM3}	Mortality Rate of other phytoplankton
k_{DO}	Oxygen Consumption constant
k_{dZ}	Mortality Rate of zooplankton
k_{srAC}	Release rate, Dissolved Organics for Method a
k_{srAN}	Release rate, Nitrogen for Method a
k_{srAP}	Release rate, Phosphorus for Method a
k_{srC}	Release rate, Dissolved Organics for Method b
k_{srD}	Release rate, floatation of sediment
k_{srN}	Release rate, Nitrogen for Method b
k_{srP}	Release rate, Phosphorus for Method b
L	Lower Layer
M_1	Diatom
M_2	Blue-Green Algae
M_3	Other Phytoplankton
N	Nitrogen
N_{bound}	The ratio of immobilized sedimentated nitrogen.
N_{load}	The nitrogen input to the lake.
N_{rel}	The sediment release rate of nitrogen.
N_{sed}	Releasable Sediment Nitrogen
N_{wat}	Total Nitrogen in the water column.
Of_{day}	Offset for the seasons when mean temperature occurs
P	Phosphorus
P_{bound}	The Ratio of Immobilized Sedimentated Phosphorus.

P_{load}	The Phosphorus input to the Lake.
P_{rel}	The sediment release rate of Phosphorus.
P_{sed}	Releasable Sediment Phosphorus
P_{wat}	Total Phosphorus in the water column.
Q	Inflow rate of each part
Q_C	Circulation flow
Q_{LU}	Flow rate from lower layer to upper layer
Q_{out}	Outflow rate of each Part
Q_{UL}	Flow rate from lower layer to upper layer
q_S	Hydraulic Load
R_1	Growth of Diatom Rate Equation
R_2	Growth of blue-green algae Rate Equation
R_3	Growth of other phytoplankton Rate Equation
R_4	Death of diatom Rate Equation
R_5	Death of blue-green algae Rate Equation
R_6	Death of other phytoplankton Rate Equation
R_7	Grazing of diatom by zooplankton Rate Equation
R_8	Grazing of blue-green algae by zooplankton Rate Equation
R_9	Grazing of other phytoplankton by zooplankton Rate Equation
R_{10}	Death of zooplankton Rate Equation
R_{11}	Decomposition of detritus Rate Equation
R_{12}	Decomposition of dissolved organics Rate Equation
R_{13}	Release of nitrogen from sediment Rate Equation
R_{14}	Release of phosphorus from sediment Rate Equation
R_{15}	Release of dissolved organics from sediment Rate Equation
R_{16}	Release of detritus from sediment Rate Equation
R_{17}	Re-aeration Rate Equation
R_{18}	Oxygen consumption by sediment Rate Equation
$Sedrate$	The mean sedimentation rate
T	Water temperature
T_{mean}	Average Temperature
T_{min}	Minimum Observed Temperature

T_{max}	Maximum Observed Temperature
t	Time
T_w	The mean residence time of the water.
U	Upper layer
V	Volume of each Part
v_{sD}	Sedimentation Velocity
W	Wind Speed
Y_{M1D}	Respiration of Diatom
Y_{M1Z}	Prediction of Diatom
Y_{M2D}	Respiration of Blue-Green Algae
Y_{M2Z}	Prediction of Blue-Green Algae
Y_{M3D}	Respiration of Other Phytoplankton
Y_{M3Z}	Prediction of Other Phytoplankton
Y_{ZD}	Respiration of Zooplankton
Z	Zooplankton
$Z_{optM\,1}$	Optimum temperature for Diatom
$Z_{optM\,2}$	Optimum temperature for Blue-Green Algae
$Z_{optM\,3}$	Optimum temperature for Other Phytoplankton
α	Extinction Coefficientof Sunlight, Algal
ΔH	Water Depth between each Part
ε_0	Extinction Coefficient of Sunlight, Water
γ_{CDO}	DO: Dissolved Organics containing ratio
γ_{CN}	N: COD, Dissolved Organics containing ratio
γ_{CP}	P: COD, Dissolved Organics containing ratio
γ_{DC}	COD: Dry Weigh, Sediment containing ratio
γ_{DN}	N: Dry Weigh, Sediment containing ratio
γ_{DP}	P: Dry Weigh, Sediment containing ratio
γ_{M1D}	Detritus: Diatom containing ratio
γ_{M1DO}	DO: Diatom containing ratio
γ_{M1N}	N: Chl. a, Diatom containing ratio
γ_{M1P}	P: Chl. a, Diatom containing ratio
γ_{M1Z}	Zooplankton: Diatom containing ratio

γ_{M2D}	Detritus: Blue-green algae containing ratio
γ_{M2DO}	DO: Blue-green Algae containing ratio
γ_{M2N}	N: Chl. a, Blue-Green Algae containing ratio
γ_{M2P}	P: Chl. a, Blue-Green Algae containing ratio
γ_{M2Z}	Zooplankton: Blue-Green Algae containing ratio
γ_{M3D}	Detritus: Other Phytoplankton containing ratio
γ_{M3DO}	DO: Other Phytoplankton containing ratio
γ_{M3N}	N: Chl. a, Other Phytoplankton containing ratio
γ_{M3P}	P: Chl. a, Other Phytoplankton containing ratio
γ_{M3Z}	Zooplankton: Other Phytoplankton containing ratio
γ_{ZDO}	DO: Zooplankton containing ratio
γ_{ZN}	N: Dry Weight, Zooplankton containing ratio
γ_{ZP}	P: Dry Weigh, Zooplankton containing ratio
μ_{M1}	Maximum Growth Rate of Diatom
μ_{M2}	Maximum Growth Rate of Blue-Green Algae
μ_{M3}	Maximum Growth Rate of Other Phytoplankton
θ_{C}	Temperature Constant, Decomposition, Dissolved Organics
θ_{D}	Temperature Constant, Decomposition, Detritus
θ_{DO}	Temperature Constant, Decomposition, Dissolved Oxygen
θ_{M1}	Temperature Constant, Diatom
θ_{M2}	Temperature Constant, Blue-Green Algae
θ_{M3}	Temperature Constant, Other Phytoplankton
δ_{h}	Thermocline Constant

ANN	Artificial Neural Networks
BOD	Biochemical Oxygen Demand
BTU	British Thermal Unit
CS	Constant Stoichiometric
DSI	Directorate of State of Hydraulic Works
IBA	Important Bird Areas
NC	Independent Nutrient Cycle
NDHP	Number of days with high primary production
PAMOLARE	Planning and Management of Lakes and Reservoirs focusing on Eutrophication
TEM	Trans-European Motorways
TN	Total Nitrogen
TP	Total Phosphorus

1. INTRODUCTION

Mathematical models have been developed and employed to analyze complex behavior of freshwater systems for various scenarios. The complex nature of lakes, however, often creates difficulties in the application of mathematical models which ultimately requires simplifications of the physical world of the problem (Şahin, 2008). The dynamic models are designed for solving complex nature of lakes. Planning and Management of Lakes and Reservoirs focusing on Eutrophication (PAMOLARE) models are chosen for modeling Sapanca Lake.

In application of model process, general character and behavior of lake is so important. Describing the general behavior of lake (phosphorus loadings and trophic state of lake) Vollenweider approach and possible classification of Lake Sapanca is used.

In the construction of data set, Matlab® curve fitting program is used for regression analysis which was employed between total phosphorus and chlorophyll-a concentration. Thermal Stratification was investigated according to years 1989-1997 and hypolimnion and epilimnion depth is estimated. Solar intensity is predicted according to location of Sapanca Lake. III. Directorate of State Hydraulic works of the period 1989-1997 in lake data and 1986 – 1997 river loads of Sapanca Lake is used for developing model.

After preparation of the data set, PAMOLARE Models was constructed. Firstly, 1-Layer model was investigated. This model is calibrated by the data of 1989-1992 and validated by the data of 1992-1995. Short term estimation is done for future months by input loads. Then more developed 2-Layer PAMOLARE Model was constructed and analyzed. 2-Layer Model was calibrated by the data of 1989-1992 and validated by the data of 1992-1995. According to different input loading scenarios, future phosphorus, nitrogen concentration in hypolimnion and epilimnion in lake was investigated.

2. LAKES AND EUTROPHICATION

2.1. Introduction

Water is a vital component of the Earth ecosystems, redistributing itself through natural cycles, contributing to climate control and the hydrologic cycle. It ignores geographical boundaries, fluctuates in both space and time, and has multiple uses. It is well known that 75% of the earth surface is covered by water. However, less than %1 of this amount is found in lakes. (Figure 2.1) Lakes are inland, standing water bodies having numerous interactive components, and aquatic systems which have inputs, outputs and internal lake process.

Wetlands have always been an important element of the landscape, sustaining a rich biodiversity. People living around them had in the past a close relation to wetlands, depending on them for water, food, materials, transport and focusing important aspects of their social and cultural life on them. Many of the most advanced human civilizations were founded near to wetlands. Therefore managing wetlands especially lake is important (Dinç, 2001).

Water management efforts in Turkey have gained priority in recent years because rapid population growth, urbanization, and industrialization have caused deterioration of the environment. Average annual volume of flow in Turkish rivers is about 187 billion m^3, approximately 0.5% of the total runoff of rivers of the world (Tanik et al., 1998).

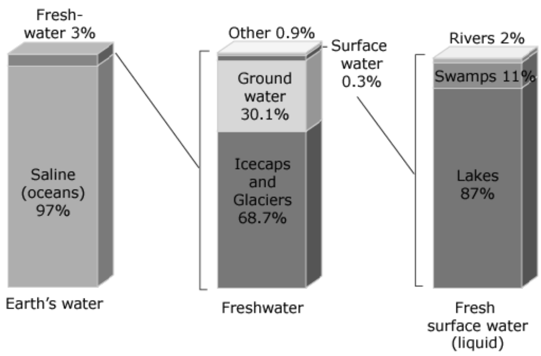


Figure 2.1. Distribution of Earth’s water (Gleick, 1996)

2.2. Trophic Classification of Lakes

Lakes may be classified according to at least three different principles, namely, origin, trophic level, and stratification. The trophic level of a lake can be expressed in terms of several more or less interrelated measurements such as primary productivity, water transparency, chlorophyll-a content, algal volume, concentrations of nutrients and type of community of fish and bottom fauna.

Trophy refers to the quantities of nutrients entering a lake. Higher nutrient loads typically produce higher primary production by phytoplankton and macrophytes (Jørgensen et al., 2005). The terms eutrophic, mesotrophic, and oligotrophic are adjectives commonly used to describe the overall state of fertility or "trophic status" of aquatic ecosystems. These three broad categories delineate a gradient that ranges from nutrient-poor, low-biomass systems (oligotrophic) to nutrient-rich, high-biomass habitats (eutrophic) (Pinckney et al., 2001).

Oligotrophic water bodies (from oligo = poor) receive less nutrients from their drainage basins and therefore, exhibit lower phytoplankton production. As a result, their water is typically very clear. Water bodies with extremely low nutrients loads and levels of primary production are called ultra-oligotrophic (Jørgensen et al., 2005). One typical measure of an oligotrophic lake is that it has lots of oxygen from surface to bottom. Other measures are good water clarity (a deep Secchi disk reading, averaging about 10 meters or 33 feet), few suspended algae, the phytoplankton, which yield low chlorophyll readings (average about 1.7 mg/m^3), and low nutrients, typified by phosphorus (average about 8.0 mg/m^3). Oligotrophic lakes have nice clean water, no weed problems and poor fishing. They are often deep with cold water. They are seldom in populated areas too many people and heavy use tends to eventually shift them out of the oligotrophic category. They are seldom in good agricultural areas; rich soils needed for agriculture do not allow nutrient poor drainage water needed for the oligotrophic lake.

In contrast, eutrophic (from eu = rich) water bodies are rich in nutrients, and have high levels of biological production supported by their high nutrient loads. The water bodies lying between these two nutrient extremes are called mesotrophic. Hypertrophic refers to water bodies extremely rich in nutrients and, therefore, also containing high phytoplankton concentrations. Higher nutrients loads are usually associated with higher loads of organic matter from a lake's drainage basin (i.e., allochthonous organic matter) (Pinckney et al., 2001).

So the oligotrophic and eutrophic lakes are contrast ends of the eutrophic continuum. But human nature has stepped in, and we find that often we say a lake is really a little beyond oligotrophic or it isn't quite eutrophic. After all, as the oligotrophic lake ages, it gradually accumulates nutrients and sediments, and moves toward and eventually into the eutrophic stage. This natural eutrophication process commonly takes thousands of years and involves both the physical filling of the lake and chemical enrichment of the lake water. Cultural eutrophication, which can occur in a human generation or two, involves chemical enrichment of the lake water by human activity in the lake drainage basin.

The mesotrophic lake is intermediate in most characteristics between the oligotrophic and eutrophic stages. Production of the plankton is intermediate so we have some organic sediment accumulating and some loss of oxygen in the lower waters. The oxygen may not be entirely depleted except near the bottom (the relative depth of the lake has a bearing on this). The water is moderately clear with Secchi disk depths and phosphorus and chlorophyll concentrations between those characteristic of oligotrophic and eutrophic lakes. Mesotrophic lakes usually have some scattered weed beds and within these beds the weeds are usually sparse (Akkoyunlu, 2002).

The average values and the range of values for phosphorus and chlorophyll concentrations and Secchi disk depth characteristic of oligotrophic, mesotrophic and eutrophic lakes given in Table 2.1. It is apparent from Table 2.1 that there are no fixed values of phosphorus or chlorophyll concentration or of Secchi disk depth which can be used to differentiate mesotrophic lakes from oligotrophic lakes from eutrophic lakes.

Table 2.1. Trophic Classification of Lakes (Wetzel, 1983)

MEASURED PARAMETER	*Oligotrophic*	*Mesotrophic*	*Eutrophic*
Total Phosphorus (mg/m3) Average	8	26.7	84.4
Range	3.0 - 17.7	10.9 - 95.6	16 – 386
Chlorophyll *a* (mg/m3) Average	1.7	4.7	14.3
Range	0.3 - 4.5	3 – 11	3 – 78
Secchi Disk Depth (m) Average	9.9	4.2	2.45
Range	5.4 - 28.3	1.5 – 8.1	0.8 – 7.0

2.3. Eutrophication Problem

Eutrophication the enrichment of water bodies with plant nutrients, typically nitrogen and phosphorus, and the subsequent effects on water quality and biological structure and function is a process, rather than a state. It represents the aging process of lakes, whereby external or allochthonous sources of nutrients and organic matter of terrestrial origin accumulate in a lake basin, gradually decreasing the depth of the water body, and increasing autochthonous production, to the point that the lake begins to take on a marsh-like character and, ultimately, a terrestrial character. Under natural conditions, this process typically takes place over geological time. However, human influences (The chief sources of enrichment are sewage, artificial fertilizers and agricultural wastes (J.W.G. Lund, 1972)) in a drainage basin can greatly accelerate this enrichment process, rapidly diminishing the utility of a water body, sometimes within only decades. This latter process, termed cultural eutrophication, can be distinguished from natural eutrophication in this way. The former is a consequence of natural lake aging, whereas the latter is a symptom of human-induced imbalances in the biogeochemical cycling of nutritive elements, such as nitrogen and phosphorus (Rast and Thorton, 1996).

The Eutrophication process has some undesirable effects on water quality like taste and odor problems, loss of species diversity, hypolimnetic loss of dissolved oxygen, excessive plant growth (Schnoor, 1995).

The green color of eutrophic lakes makes swimming and boating more unsafe due to increased turbidity. Furthermore, from an aesthetic point of view the chlorophyll concentration should not exceed 100 mg m^{-3}. However, the most critical effect from an ecological viewpoint is the reduced oxygen content of the hypolimnion, caused by the decomposition of dead algae. Eutrophic lakes might show high oxygen concentrations at the surface during the summer, but low oxygen concentrations in the hypolimnion, which may cause fish kill. The zones of deep lakes are shown in Figure 2.2 with a typical oxygen profile (Jørgensen et al., 2003).

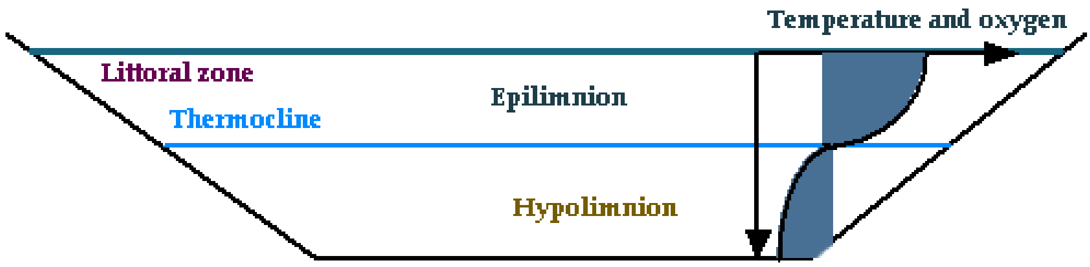


Figure 2.2. Thermal stratification.

About 16-20 elements are necessary for the growth of freshwater plants, as demonstrated in Table A.1, where the relative quantities of essential elements in plant tissue are shown.

The present concern about eutrophication relates to the rapidly increasing amount of phosphorus and nitrogen, which are normally present at relatively low concentrations. Of these two elements, phosphorus is considered the major cause of eutrophication of lakes, as it was formerly the growth-limiting factor for algae in the majority of lakes, but its usage has greatly increased during the last few decades. However, today nitrogen may become limiting to growth in lakes as a result of the tremendous increase in the phosphorus concentration caused by discharge of waste water, which contains relatively more phosphorus than nitrogen. Furthermore, nitrogen accumulates in lakes to a lesser extent than phosphorus and a considerable amount of nitrogen is lost by denitrification (nitrate to N_2) (Akkoyunlu, 2003).

Primary production has been measured in great detail in many great lakes. This process represents the synthesis of organic matter, and can be summarized as follows:

$$Light + 6CO_2 + 6H_2O \leftrightarrow C_6H_{12}O_6 + 6O_2 \tag{2.1}$$

This equation is necessarily an oversimplification of the complex metabolic pathway of photosynthesis, which is dependent on sunlight, temperature and the concentration of nutrient. The composition of phytoplankton is not constant, but to a certain extent reflects the chemical composition of the water. If, for example, the phosphorus concentration is high, the phytoplankton will take up relatively more phosphorus the luxury uptake. Phosphorus cycle is shown in Figure A.1.

Phytoplankton consists mainly of carbon, oxygen, hydrogen, nitrogen, phosphorus, and sulphur and without these elements no algae growth will take place. So each of these elements represents a limiting factor on algae growth. Another side of the problem is the consideration of nutrient sources. It is important to set up mass balances for the most essential nutrients.

This will often reveal that the input of nitrogen from nitrogen-fixing blue green algae, precipitation and tributaries is already contributing too much to the mass balance for any effect to be produced by nitrogen removal from the sewage. On the other hand the mass balance may reveal that most of the phosphorus input (often more than 95%) comes from the sewage, and so demonstrates that it is better management to remove phosphorus from the sewage rather than nitrogen. It is, therefore not important which nutrient is limiting, but which nutrient can most easily be made to limit the algal growth.

These considerations have implied that the eutrophication process can be controlled by a reduction in the nutrient budget. For this purpose a number of eutrophication models have been developed, which take a number of processes into account.

3. MODELING

Mankind has always used models, which are in effect a simplified picture of reality, as a tool to solve problems. The model will never contain all the features of the real system, because, and then it would be the real system itself. However, it is important that the model contains the characteristic features that are essential in the context of the problem to be solved or described. Models have some certain features: They are useful instruments in the survey of complex systems, they can be used to reveal system properties, They reveal weaknesses in our knowledge and can therefore be used to set up research priorities, they are useful in tests of scientific hypotheses, as the model can simulate ecosystem reactions, which can be compared with observations (Jørgensen et al., 2003).

3.1. Types of Models

3.1.1. (Bio-geo-chemical and bio-energetics), Dynamic Models

The model type applies generally differential equations to express the Dynamics (Jørgensen and Bendoricchio, 2001). Change in state variables are expressed as the results of the ingoing minus the outgoing processes and the model is therefore based on the conservation principles. The process equations are based usually on causality; but in principle can also be a result of a statistic analysis of data.

The advantages and disadvantages define so to say the area of application: for description of the state of an ecosystem, when a good data set is available. A developed model may be applied on different ecosystems of the same type, although calibration and validation should always be carried out for each case study. The model will often but not always take many processes and several state variables into account and require therefore in most cases a good data set. The model type has been extensively applied in environmental management as a powerful tool to understand the reactions of ecosystems to pollutants and to set up prognoses.

3.1.2. Static Models

The model type is a bio-geo-chemical or bio-energetic dynamic model where the differential equations are all set to zero to obtain the values of the state variables corresponding to the static situation. This model type will often be used when a static situation is sufficient to give a proper description of an ecological system or to take environmental management decisions. It can often be used beneficial as a first step toward a dynamic model.

3.1.3. Population Dynamic Models

The mathematics of these equation systems is not very interesting from an ecological modelling point of view, where the focus is a realistic description of ecological populations. Population dynamic models may include age structure, which is based on matrix calculations.

This model type is typically used to keep a track on the development of a population. Number of individual is the most applied unit, but it can of course easily be translated into biomass. Effects of toxic substances on the development of populations can be covered by increasing the mortality and decreasing the growth correspondingly. The model type is extensively used in the management of fishery and national parks.

3.1.4. Structurally Dynamic Models

These types of models change the parameters, corresponding to the properties of the biological modeling components, to account for adaptation and changes in species composition. It is possible either to use knowledge or artificial intelligence to describe the changes in the parameters. Most often, however, is used a goal function to find the changes of the parameters. Eco-exergy has most often been used as goal functions in structurally dynamic models. This model type should be applied whenever it is known that structural changes take place. It is also recommended for models that are used in environmental management to make prognoses resulting from major changes in the forcing functions (impacts).

3.1.5. Fuzzy Models

Fuzzy models may either be knowledge-based or data-based. They are useful modelling tools when no data are available only propositions or the data are uncertain. The Mamdani type models are based on a set of linguistic expert formulations, while the Sugemo type applies an optimization procedure. This model should be applied when the data set is fuzzy or only semi-quantitative expert knowledge is available, provided of course that the semi-quantitative results are sufficient for the ecological description or the environmental management.

3.1.6. Artificial Neural Networks

This type of models is able to give relationships between state variables and forcing functions based on a heterogeneous database. It is a black box model and is therefore not based on causality; but it gives in most cases very useful models, that can be applied for prognoses, provided that the model has been based on a sufficient big database, that allows to find the relationships and to test it afterwards on an independent data set.

The advantages and disadvantages of this model type indicate where it would be advantageous to apply artificial neural networks (ANN), namely where ecological descriptions and understandings are required on basis of a heterogeneous database for instance data from several different ecosystems of the same type. It is also often applied beneficially when the database is more homogeneous for instance, when the focus is on a specific ecosystem, although the modeler should seriously consider using bio-geo-chemical dynamic models due to their causality. ANN is, however, faster to use and the time consuming calibration that is needed for bio-geo-chemical models is not needed.

3.1.7. Individual-based Models and Cellular Automata

This model type can be regarded as a reductionist approach, deriving the properties of a system from the properties and interactions among elements of the system. Within the same species the differences are minor and are therefore often neglected in bio-geo-chemical models, but the differences among individuals of the same species may sometimes be important for the ecological reactions. Consequently, a model without the differences among individual may give a completely wrong result.

Cellular automata are systems of cells interacting in a simple way but displaying complex overall behavior. They are usually characterized by a few salient features. Cellular automata form a class of spatio-dynamical models where time, space and states are discrete. Individual-based models are often using the cellular automata approach, although there are individual-based models that are not cellular automata models. Furthermore, there are cellular automata models, that are not individual-based models, but models that should belong to the next type, spatial models. They are treated here as one type, because individual based models are frequently based on cellular automata models.

3.1.8. Spatial Models

As the individual differences may be crucial for the model results, the spatial differences of the forcing functions, of the non-biological state variables and of the biological state variables may be decisive for the model results, too. Furthermore, it may be required to obtain model results that reveal the spatial differences, because they may be needed to understand the ecological reactions or to make a proper environmental management. Models that give the spatial differences must of course also consider the spatial differences in the processes, forcing functions and state variables. It can therefore be concluded that is an urgent need for inclusion of the spatial differences in ecological models.

3.1.9. Ecotoxicological Models

This type of models is designed to solve ecotoxicological research and management problems and perform environmental risk assessment for the application of chemicals.

3.1.10. Stochastic Models

This model type is characterized by an element of randomness. The randomness could be the forcing functions, particularly the climatic forcing functions, or it could be the model parameters. The randomness is in both cases caused by a limitation in our knowledge. We can for instance not know the temperature the 5th of May next year at a given location, but we know how the normal distribution of the temperature has been for instance the last 100 years and can use the normal distribution to represent the temperature on this date. Similarly, many of the parameters in our models are dependent on random forcing functions or on factors that we hardly can include in our model without doing it too complex. A normal distribution of these parameters is known and by the use of a Monte Carlo simulation based on this knowledge, it is possible to consider the randomness (Borsuk et al., 2006). By running the model several times, it becomes possible to obtain the uncertainty of the model results. A stochastic model may be a bio-geo-chemical/bio-energetic model, a spatial model, a structural dynamic model, an individual-based model or a population dynamic model.

3.1.11. Hybrid Models

It is in principle possible to develop hybrid models by combination of any two of the 10 previously listed models; but only very few hybrid models have been developed up to now. It is expected that many more will be developed in the future to combine some of the advantages and eliminate some of the disadvantages of the existing models (Jørgensen, 2008).

Ecological model focuses only on the objects of interest for the considered problem. It would disturb the main objectives of a model to include too many irrelevant details. There are many different ecological models of the same ecosystem, as the model edition is selected according to the model goals.

An ecological model must contain the features that are of interest for the management or scientific problem and that we wish to solve by use of the model. It is a far more complicated matter to capture the main features of importance for an ecological problem. However, intense research during the last few decades has made it possible today to set up workable ecological models.

Complex environmental models are often criticized as being difficult to analyze and poorly identifiable due to their nonlinearities and/or their large number of parameters relative to data availability. Others consider over parameterized models to be useful, especially for predicting system dynamics beyond the conditions for which the model was calibrated (Arhonditsis and Brett, 2005).

3.2. Modeling Elements

Forcing functions, or external variables, which are functions or variables of an external nature that influence the state of the ecosystem are crucial for model. The forcing functions under our control are often called control functions. The control functions in ecotoxicological models are for instance inputs of toxic substances to the ecosystems and in eutrophication models the control functions are inputs of nutrients.

State variables describe the state of the ecosystem. The selection of state variables is crucial to the model structure, but often the choice is obvious. In eutrophication models the state variables will be the concentrations of nutrients and phytoplankton.

Mathematical equations are used to represent the biological, chemical and physical processes. They describe the relationship between the forcing functions and state variables. The same type of process may be found in many different environmental contexts, which implies that the same equations can be used in different models.

Parameters are coefficients in the mathematical representation of processes. They may be considered constant for a specific ecosystem or part of an ecosystem. In causal models the parameter will have a scientific definition.

Universal constants, such as the gas constant and atomic weights, are also used in most models.

Models can be defined as formal expressions of the essential elements of a problem in mathematical terms. The first recognition of the problem is often verbal. The verbal model is difficult to visualize and it is more conveniently translated into a conceptual diagram, which contains the state variables, the forcing functions and how these components are interrelated by mathematical formulations of processes. As it can be seen in Figure A.2 Nitrogen Cycle Conceptual diagram is shown (Jørgensen et al., 2003).

3.3. Modeling Procedure

The first modeling step is definition of the problem and the definition will need to be bound by the constituents of space, time and subsystems. The focal system behavior must be interpreted as a product of dynamic processes, preferably describable by causal relationships. It is difficult to determine the optimum number of subsystems to be included in the model for an acceptable level of accuracy defined by the scope of the model. Due to lack of data it will often become necessary at a later stage to accept a lower number than intended at the start or to provide additional data for improvement of the model. A more complex model contains more parameters and increases the level of uncertainty.

The next step is a formulation of the processes as mathematical equations. Many processes may be described by more than one equation, and it may be of great importance for the results of the final model that the right one is selected for the case under consideration. Once the system of mathematical equations is available; the verification can be carried out.

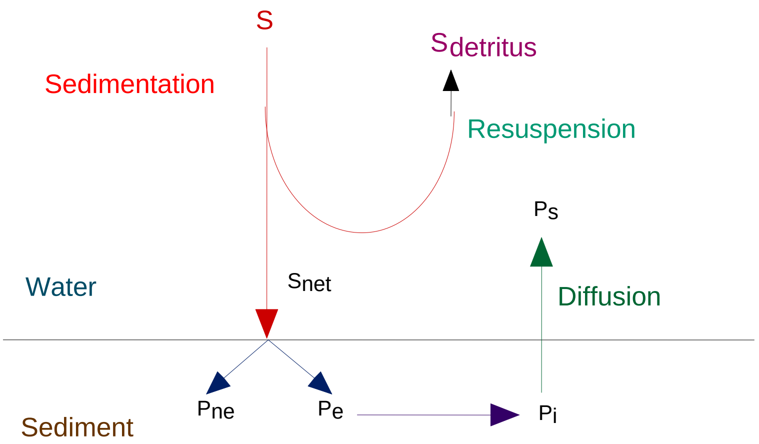


Figure 3.1. Sedimentation Submodel

3.4. Application of Dynamic Models

Ecosystems are dynamic systems and it might therefore be the ultimate goal for a modeler to construct dynamic models of ecosystems. Biogeochemical models attempt to capture the dynamics and cycling of biochemical and geochemical compounds in ecosystems. When models are used as an instrument in pollution control, they must account for the fate and distribution of both pollutants and of nature's own compounds. This will require the application of biogeochemical models, since they focus on the processes and transformation of various compounds in the ecosystem.

The construction of dynamic models requires data, which can elucidate the dynamics of the processes included in the model. Generally, a more comprehensive database is required to build a dynamic model than a static model. Therefore in a data poor situation it might be better to draw up an average situation under different circumstances by use of a static model, than to construct an unreliable dynamic model, which contains uncertainty in the most crucial parameters.

3.5. Eutrophication Models

A lake can be considered as an open system, which exchanges material (waste water, evaporation, precipitation) and energy (evaporation, radiation) with the environment. However, in some great lakes the input of material per year is not able to change the concentration measurably. In such cases the system can be considered as almost closed, which means that it exchanges energy, but not material with the environment.

Several eutrophication models with a wide spectrum of complexity have been developed. As for other models the right complexity of the model is dependent on the available data and the ecosystem. Table 3.1 reviews various eutrophication models.

Table 3.1. Various eutrophication models

Model Name	# of St. Var. Per Layer or Segment	Nutrients	Segments	Dimension (D) or layer (L)	CS or NC*	C and/or V**	Number of Studies
Vollenweider	1	P (N)	1	1L	CS	C+V	many
Imboden	2	P	1	2L, ID	CS	C+V	3
O'Melia	2	P	1	1D	CS	C	1
Larsen	3	P	1	1L	CS	C	1
Lorenzen	2	P	1	1L	CS	C+V	1
Thomann 1	8	P,N,C	1	2L	CS	C+V	1
Thomann 2	10	P,N,C	1	2L	CS	C	1
Thomann 3	15	P,N,C	67	2L	CS	-	1
Chen&Orlob	15	P,N,C	sev.	2L	CS	C	min. 2
Patten	33	P,N,C	1	1L	CS	C	1
Di Toro	7	P,N	7	1L	CS	C+V	1
Biermann	14	P,N,Si	1	1L	NC	C	1
Canale	25	P,N,Si	1	2L	CS	C	1
Jørgensen	17-20	P,N,C,	1	1-2L	NC	C+V	22
Cleaner	40	P,N,C,Si	sev.	sev. L	CS	C	many
Nyholm, Lavsoe	7	P,N	1-3	1-2L	NC	C+V	25
Aster/Melodia	10	P,N,Si	1	2L	CS	C+V	1
Baikal	>16	P,N	10	3L	CS	C+V	1
Chemsee	>14	P,N,C,S	1	profile	CS	C+V	many
Minlake	9	P,N	1	1	CS	C+V	>10
Salmo	17	P,N	1	2L	CS	C+V	16

The table indicates the characteristic features of the models, the number of case studies to which it has been applied and whether the model has been calibrated and validated. CS means constant stoichiometric and NC independent nutrient cycle. C means calibrated and V validated.

Beside that a detailed sediment sub model is very important in eutrophic lakes. As the sediment accumulates nutrients it is important to describe quantitatively the processes determining the mass flows from sediment to water, particularly in shallow lakes, where the sediment may contain the major part of nutrients. An example of sedimentation submodel is shown in Figure 3.1.

4. PAMOLARE MODELS

The PAMOLARE acronym is derived from Planning and Management of Lakes and Reservoirs focusing on Eutrophication. The 1-Layer model consists of a combination of two kinds of models: a causal dynamic model, and a set of associated empirical models. The dynamic model integrates the pools of nitrogen and phosphorus in water and sediment in time as functions of the mass flows. The empirical models are simple regressions made from data of simple physical and chemical characteristics of a number of lakes. The 2-layer model consists of an upper layer of water (corresponding to epilimnion), and a lower layer of water (corresponding to hypolimnion). The water in each layer is assumed to be completely mixed, that is, the water quality in each layer is homogeneous.

4.1. PAMOLARE 1-Layer Model

The dynamic model is a modification of the general model made by Vollenweider (1975). While Vollenweider's model was only concerned with phosphorus, which is the limiting nutrient in most freshwater bodies, Lake Model has included nitrogen as well. The nitrogen and the phosphorus sub models are almost identical. The only difference is the denitrification process included in the nitrogen sub model.
These processes form the two differential equations:

$$\frac{DN_{wat}}{dt} = \frac{(N_{load} - Denit) + N_{rel} \times N_{sed}}{z} - \frac{1 \times N_{wat} \times a}{T_w} - \frac{1}{z} \times SedRate \times N_{wat} \tag{4.1}$$

$$\frac{DN_{sed}}{dt} = SedRate \times N_{wat} \times (1 - N_{Bound}) - N_{rel} \times N_{sed} \tag{4.2}$$

Note that the units for the sediment pools are g/m^2 and mg/l for the water column pools. The denitrification is described by the empirical model (Jensen et al. 1990):

$$Denit = NLoad - 0.34 \times T_w{}^{-0.16} \times z^{0.17} \tag{4.3}$$

Except for the denitrification, the phosphorus submodel is formulated analogous to the nitrogen submodel. The equations are:

$$\frac{DP_{wat}}{dt} = \frac{P_{load} + P_{rel} \times P_{sed}}{z} - \frac{1 \times P_{wat} \times a}{T_w} - \frac{1}{z} \times SedRate \times P_{wat} \quad (4.4)$$

$$\frac{DP_{sed}}{dt} = SedRate \times P_{wat} \times (1 - P_{Bound}) - P_{rel} \times P_{sed} \quad (4.5)$$

The empirical models are a number of relations made from statistical regression analyses (Edmondson, 1986).

$$Chlorophyll \left(\frac{mg}{l}\right) = 0.000073 \times (TP \times 1000)^{1.4} \quad (4.6)$$

$$Zooplankton \left(\frac{mg}{l}\right) = 0.038 \times (TP \times 1000)^{0.64} \quad (4.7)$$

$$Fish \left(\frac{mg}{l}\right) = 0.810 \times (TP \times 1000)^{0.71} \quad (4.8)$$

$$Average\ primary\ production \left(\frac{mg}{l \times day}\right) = {(TP \times 1000 - 79)}/{1000} \quad (4.9)$$

$$Maximum\ primary\ production \left(\frac{mg}{l \times day}\right) = {(TP \times 2000 - 77)}/{1000} \quad (4.10)$$

$$Average\ fish\ yield \left(\frac{mg\ ww}{m^2 \times year}\right) = 7.1 \times TP \quad (4.11)$$

TP is the total phosphorus. Lake model is supplied with an algorithm to decide if phosphorus and/or nitrogen are nutrients limiting the phytoplankton growth. The algorithm is based on the knowledge about the mean internal cell ratios of nutrients in phytoplankton.

The algorithm is based on the following rules:

- If total N >= 10 × total P then P is the limiting nutrient
- If total N <= 5 × total P then N is the limiting nutrient
- If 5 < total N <10 × total P then P and N are limiting algal growth

P-bound can be generally, found from a sediment P- profile. (%15 – 25 of Total Sediment)

N-bound which is more mobile tan P is usually slightly smaller only 10-20%. W_{res} is the retention time

The annual SedRate which is used in the model can be estimated from: Sed Rate (m/y) = SedRate (m/24h) x number of days with high primary production, denoted NDHP. NDHP could be indicated with approximation as: 180 days for latitude 50-65; 210 days for latitude 45-50; 240 days for latitude 30-40 and 300 days for latitude < 30.

P_{rel} and N_{rel} can be estimated from the fact that a lake which has had a constant loading for years would have a balance between the annual transfer of P and N from water to sediment.

"a" is a constant which determines the stratification effect in the model. If we call the average P in the lake for Pa and the concentration in the epilimnion for Pe and the concentration in hypolimnion then "a" becomes:

$$a = (1 - Pe \times \frac{n}{365 \times Pa}) \tag{4.12}$$

Usually, the sediment contains from 3-10 g phosphorus / kg dry matter and 15-60 g N /kg dry matter in the upper active about 5 cm layer. With a dry matter content of 2-8%, it means that the minimum phosphorus and nitrogen expressed as g / m^2 will be:

$$3x50x0.02 = 3g\,\frac{P}{m^2} \tag{4.13}$$

$$15x50x0.02 = 15g\,\frac{N}{m^2} \tag{4.14}$$

4.2. PAMOLARE 2-Layer Model

The vertical distribution of water quality should be considered when describing the water quality in deep lakes and reservoirs where stratification occurs. Because the epilimnion and hypolimnion are rarely mixed in some lakes only limited water is transported through the thermocline during the stratification season. The typical phenomena observed in eutrophic lakes are super-saturation of dissolved oxygen, and depletion of inorganic nutrients and high concentrations of particulate matters in the epilimnion, and depletion of dissolved oxygen and high concentration of inorganic nutrients in the hypolimnion.

4.2.1. State Variables

State variables and transformation paths among state variables are shown in Figure 4.1. The selection and determination of the state variables, which is the first step of the development of a model, is conducted by considering its importance in water quality expression, transformation mechanisms, ecological knowledge and control strategies.

In the standard eutrophication model proposed, two species of nutrients (N, P: inorganic nitrogen and inorganic phosphorus), three groups of phytoplankton (M_1, M_2, M_3: diatom, blue-green algae and the other phytoplankton), zooplankton (Z), detritus (D) and dissolved organics (C), are assumed to be the important components for eutrophication of lakes and reservoirs. Dissolved oxygen (DO) is also included in the model as an important component that strongly affects the transformation mechanisms. The water column is separated into an upper layer, lower layer, and thermocline. All state variables described are determined in each layer.

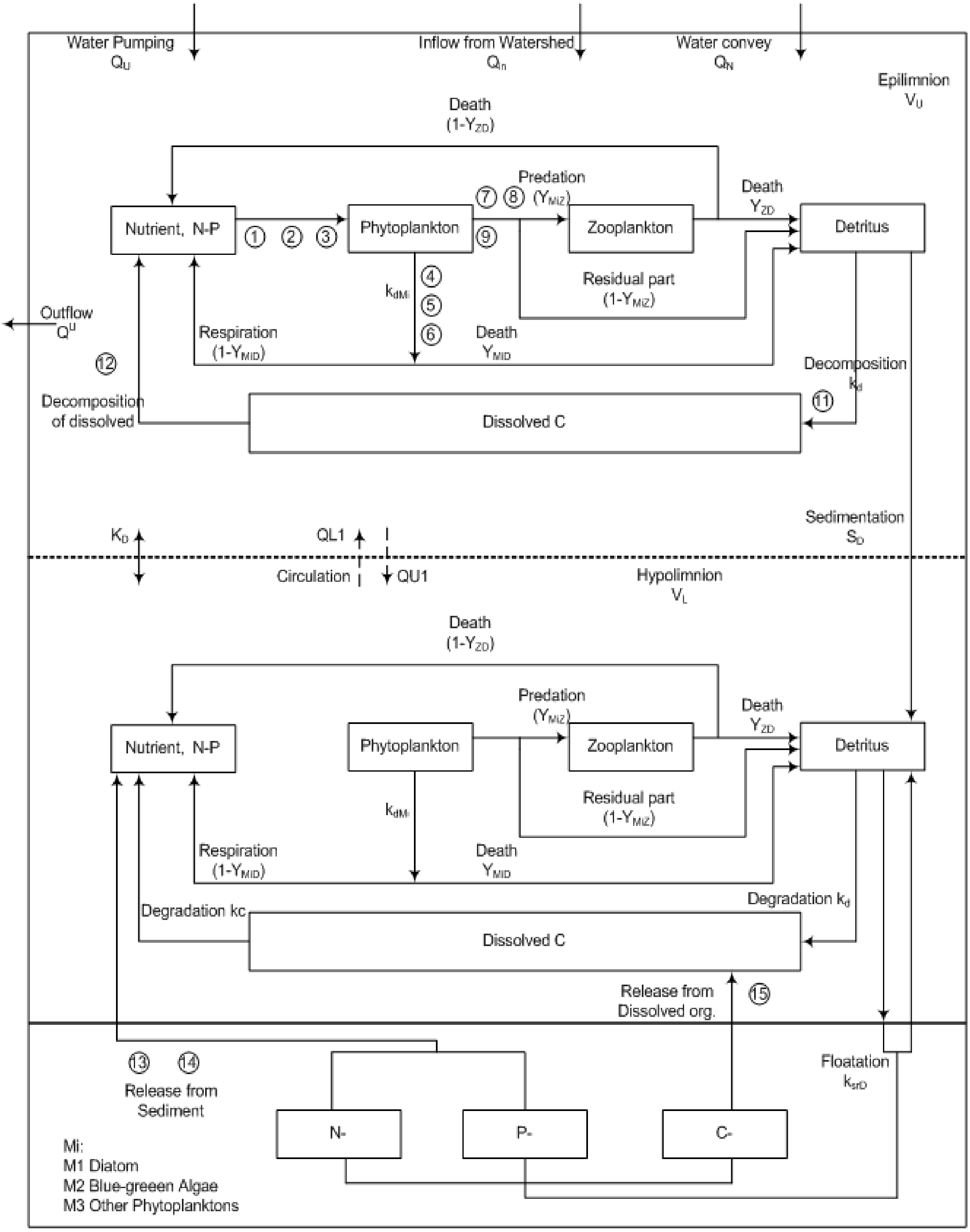


Figure 4.1. State Variables and Transformation Paths

4.2.2. Transformation Paths

Each group of phytoplankton grows by photosynthesis through ingestion of inorganic nitrogen and phosphorus (paths (1), (2) and (3): growth of diatoms, blue-green algae and the other phytoplankton) and self-degrades to detritus and inorganic with oxygen consumption (paths (4), (5) and (6): death of diatoms, blue-green algae and the other phytoplankton). Zooplankton species, which are filter-feeders, grow with predation on phytoplankton by filtration (paths (7), (8) and (9): predation of diatom, blue-green algae and the other phytoplankton) and are self-degraded to detritus and inorganic with oxygen consumption (path (10): death of zooplankton). The residual part of the phytoplankton in filter-feeding predation is directly transformed to detritus. Detritus decreases by sedimentation (Sedimentation rate, v_{SD}) and decomposition to dissolved organics (path (11): decomposition of detritus), which is then degraded to inorganic with oxygen consumption (path (12): decomposition of dissolved organics).

All of these paths occur in the upper layer of water (epilimnion), and all paths, except for the growth of each group of phytoplankton, occur in the lower layer because of the lack in penetration of light. Release of inorganic nitrogen and phosphorus, paths (13) and (14), and dissolved organics, path (15), from sediment, and floatation of sediment, path (16), occur in the lower layer of water. Exchange of each state variable between the upper and lower layers is expressed by the dispersion, K_D. The extent of exchange depends on the stratification, reflected in value of K_D. In the model, circulation may also be incorporated by adding the circulation flow rate between the two layers.

Release rates of inorganic nitrogen and phosphorus and dissolved organics (paths (13), (14) and (15)) can be determined by experiments or a data-fitting method. These rates can be calculated by the material balance in sediment. In this case, releasable sediment nitrogen (N_{sed}), releasable sediment phosphorus (P_{sed}), and releasable sediment organics (C_{sed}) are considered as state variables and increase and decrease associated with sedimentation of detritus, and floatation of sediment. The release rate of inorganic nutrients increases by an order of magnitude during anoxic conditions. Changes in dissolved oxygen occur by re-aeration at the water surface, production and consumption in the water column, and consumption by the sediments.

4.2.3. Equations for Each Path

Equations of each path are summarized in Table B.1 and Table B.2. The growth rate of each group of phytoplankton is affected by water temperature, intensity of solar radiation, and concentration of inorganic nutrients. Therefore, these parameters in this model are expressed by the product of maximum specific growth rate (μ), water temperature affecting function (f_T), light intensity affecting function (f_I), inorganic nutrient concentration affecting function (f_N), and concentration of the associated group of phytoplankton. f_T is expressed by a quadratic-type expression with the value 1.0 at the optimum temperature (T_{opt}) and 0.0 at 0^oC .

Competition in growth among groups of phytoplankton in relation to water temperature can be expressed in this model by adjusting T_{opt} values for each group. Effect of light intensity is an exponential-type function proposed by Di Toro and friends (1971), which can reflect light inhibition when light conditions are above the optimum level. However, as light intensity decreases by penetration through the water column according to Lambert-Beer's Law it should be expressed by the mean depth of the upper layer by combining both equations. Competition in growth among groups of phytoplankton is dependent on the light intensity Iopt values of each group. Michaelis-Menten type equations associated with inorganic nitrogen and phosphorus are applied for f_N. Competition in growth among groups of phytoplankton, which is dependent on the concentrations of inorganic nitrogen and phosphorus, is considered by the values of Michaelis' Constant and maximum specific growth rate of each group.

The death or decomposition rates of plankton, detritus, and dissolved organics are expressed by first order equations and as functions of water temperature and DO concentration. Temperature effect is described by an exponential-type equation with temperature effect coefficients (θ). Michaelis-Menten type equations are applied to describe the effects of DO.

The rates of predation on each group of phytoplankton by zooplankton are expressed by the product of maximum filtration rate, concentrations of phytoplankton and zooplankton, temperature functions, and a grazing preference function.

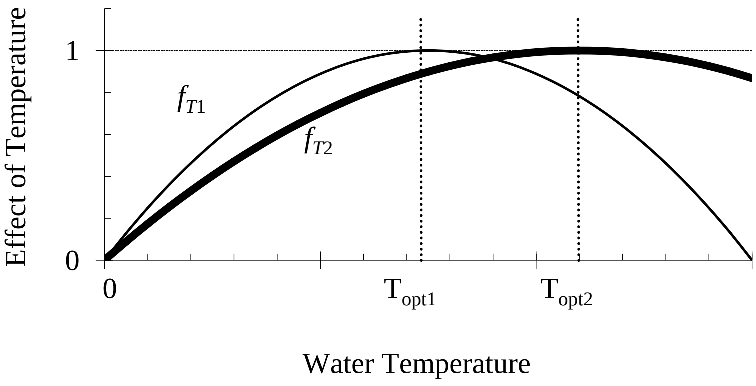


Figure 4.2. Effect of temperature on phytoplankton growth rate

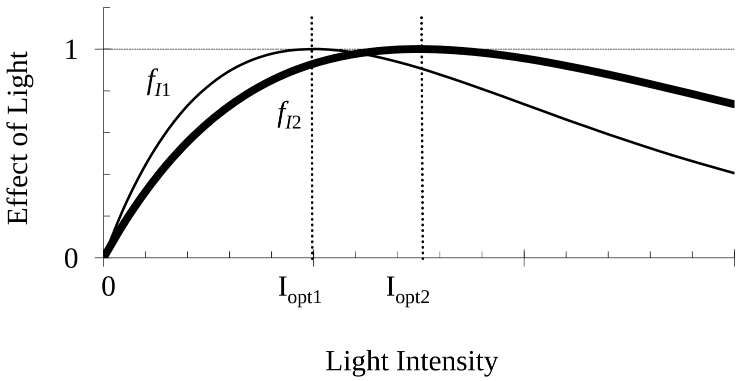


Figure 4.3. Effect of light on phytoplankton growth rate

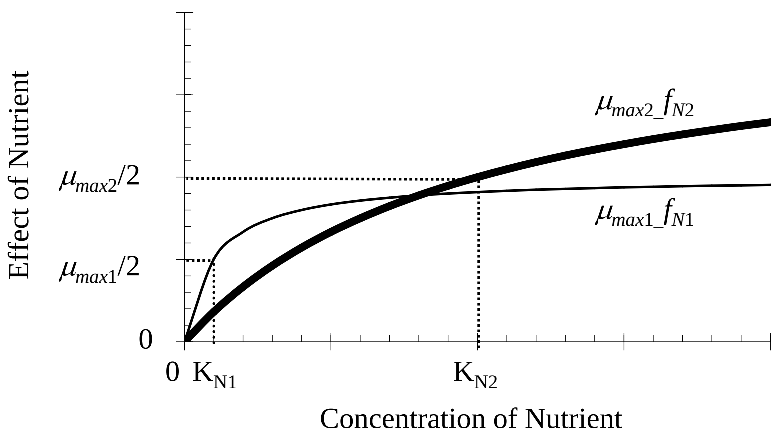


Figure 4.4. Effect of nutrients on phytoplankton growth rate

The release rates of nitrogen, phosphorus, and dissolved organics are generally determined as a rate per unit surface area of sediment (k_{srA}) with dimensions of mg/ (m^2.d) when obtained experimentally or through a data-fitting method. Accordingly, the release rate of each of those materials is expressed by the product of k_{srA} and surface area of sediment divided by the volume of the lower layer. Flotation of sediment is treated similarly.

The release rates of nitrogen, phosphorus, and dissolved organics, are expressed as a first order function of the concentrations the releasable part of each state variable, and corrected for water depth.

Dissolved oxygen concentrations are computed as a function of re-aeration at the water surface, production and consumption in the water column, and consumption at the sediment interface. Re-aeration rate is expressed by the re-aeration rate constant (K_L), which is a function of wind speed (W).

4.2.3. Material Balance Equations

The equation describing the rate of change (F_j) of each state variable (j) is expressed by summation of R_i (+ for production and - for sink) multiplied by the conversion coefficients for correction of dimension. F_j‘s are summarized in Table B.3. F_j of each state variable is obtained by summation of terms written in each column corresponding to each state variable.

The material balance equations that incorporate the flow pattern and loading of nutrients from the watershed in each layer (and sediment) are described by the equation used in the completely-mixed model. They are summarized in Table B.5. They are divided into two (or three) parts: the upper layer, the lower layer, and the sediment. The water depth of each part is stable or variable, depending on the flow rate of each part. When it is variable, it is calculated as shown in Figure B.1, B.2 and Table B.4.

In the upper layer, the material balance equation for each state variable consists of input (inflow rate and concentration) from the watershed, output (flow out) from the layer, the rate of change F_j and the exchange rate between the upper and lower layer. For detritus, the sedimentation rate is also incorporated.

To determine the rate of change in the sediment, release rates of inorganic nutrients and dissolved organics are calculated by the material balance in sediment. Releasable inorganic nitrogen, phosphorus and dissolved organics (N_{sed}, P_{sed} and C_{sed}) are supplied by sedimentation of detritus depending on the ratios and releasable fraction ratios (f_{sedj}). Part of the settled detritus is non-releasable. The ratio is "1-f_{sedj}" and is completely removed from the system. It may be immobilized in the sediment or lost to the lower part of the bottom.

4.2.4. Values Of Constants and Coefficients

The values of constants and coefficients included in this model are summarized in tables Table 4.1 to Table 4.8., which is determined based on stoichiometric consideration, experimental results, literature values and model calibration. Suggested parameter values and standard ranges are shown in the table for reference. Composition ratios do not vary significantly among sites, and should generally not be changed in most cases. Constants that usually have a large effect on simulated results and require calibration are also noted as C in the table.

Table 4.1. Values of constants and coefficients, Containing Ratio

Parameter	*Symbol*	*Condition*	*Value*	*Unit*	*Range*	*JØRGENSEN*	*TSUNO*
Containing Ratio							
P: Chl.a, Diatom	γ_{M1P}		1.3	mgP/mgChl.a		1.3	1.3
P: Chl.a, Blue-green Algae	γ_{M2P}		1.3	mgP/mgChl.a		1.3	1.3
P: Chl.a, Other Phytoplankton	γ_{M3P}		1.3	mgP/mgChl.a		1.3	1.3
P: Dry Weigh, Zooplankton	γ_{ZP}		0.013	mgP/mgDW		0.01	0.013
P: COD, Dissolved Organics	γ_{CP}		0.013	mgP/mgCOD		0.01	0.013
P: Dry Weigh, Sediment	γ_{DP}		0.01	mgP/mgDW			0.01
N: Chl.a, Diatom	γ_{M1N}		10	mgN/mgChl.a		10	10
N: Chl.a, Blue-green Algae	γ_{M2N}		10	mgN/mgChl.a		10	10
N: Chl.a, Other Phytoplankton	γ_{M3N}		10	mgN/mgChl.a		10	10
N: Dry Weight, Zooplankton	γ_{ZN}		0.1	mgN/mgDW		0.077	0.1
N: COD, Dissolved Organics	γ_{CN}		0.1	mgN/mgCOD		0.077	0.1
N: Dry Weigh, Sediment	γ_{DN}		0.1	mgN/mgDW			0.1
COD: Dry Weigh, Sediment	γ_{DC}		1	mgCOD/mgDW			1

Table 4.2. Values of constants and coefficients, Zooplankton and Detritus

Parameter	*Symbol*	*Condition*	*Value*	*Unit*	*Range*	*JØRGENSEN*	*TSUNO*
Zooplankton							
Maximum Growth Rate	F_{maxZ}		0.1	L/(d•mgDW)	0.1-1.0	C	0.1
Half Saturation Constant	F_{mZ}		0.06	mgChl.a/L	0.01-0.1	0.06	0.06
Mortality Rate	k_{dZ}		0.05	1/d	0.01-0.25	0.05	0.05
Temperature Constant	θ_Z		1.02	-	1.01-1.05	1.02	1.02
Detritus							
Sedimentation Velocity	v_{sD}		0.2	m/d	0.02-0.5	C	0.2
Decomposition Rate	k_{dD}		0.04	1/d	0.01-0.5	C	0.04
Temperature Constant, Decomposition	θ_D		1.02	-	1.01-1.05	1.03	1.02

Table 4.3. Values of constants and coefficients, Conversion Coefficients

Parameter	***Symbol***	***Condition***	***Value***	***Unit***	***Range***	***JØRGENSEN***	***TSUNO***
Conversion Coefficient							
DO: Diatom	γ_{M1DO}		100	$mgO_2/mgChl.a$		100	100
DO: Blue-green Algae	γ_{M2DO}		100	$mgO_2/mgChl.a$		100	100
DO: Other Phytoplankton	γ_{M3DO}		100	$mgO_2/mgChl.a$		100	100
DO: Dissolved Organics	γ_{CDO}		1	$mgO_2/mgCOD$		1	1
Zooplankton: Diatom	γ_{M1Z}		100	mgDW/mgChl.a		77	100
Zooplankton: Blue-green Algae	γ_{M2Z}		100	mgDW/mgChl.a		77	100
Zooplankton: Other Phytoplankton	γ_{M3Z}		100	mgDW/mgChl.a		77	100
DO: Zooplankton	γ_{ZDO}		1	$mgO_2/mgDW$		1	1
Detritus: Diatom	γ_{M1D}		100	mgDW/mgChl.a		77	100
Detritus: Blue-green algae	γ_{M2D}		100	mgDW/mgChl.a		77	100
Detritus: Other phytoplankton	γ_{M3D}		100	mgDW/mgChl.a		77	100

Table 4.4. Values of constants and coefficients, Yield Coefficients

Parameter	***Symbol***	***Condition***	***Value***	***Unit***	***Range***	***JØRGENSEN***	***TSUNO***
Yield Coefficient							
Respiration of Diatom	Y_{M1D}		0.6	-		0.6	0.6
Respiration of Blue-green algae	Y_{M2D}		0.6	-		0.6	0.6
Respiration of Other phytoplankton	Y_{M3D}		0.6	-		0.6	0.6
Respiration of Zooplankton	Y_{ZD}		0.65	-		0.65	0.65
Prediction of Diatom	Y_{M1Z}		0.6	-		0.6	0.6
Prediction of Blue-green algae	Y_{M2Z}		0.6	-		0.6	0.6
Prediction of Other phytoplankton	Y_{M3Z}		0.6	-		0.6	0.6

Table 4.5. Values of constants and coefficients, Phytoplanktons

Parameter	***Symbol***	***Condition***	***Value***	***Unit***	***Range***	***JØRGENSEN***	***TSUNO***
Diatom							
Optimum Solar Radiation	I_{optM1}		11.5	MJ/(m^2•d)	10-15	11.5	11.5
Optimum Temperature	T_{optM1}		17	≡}	12-20	17	17
Maximum Growth Rate	μ_{M1}		3	1/d	1-5	C	3
Half Saturation Constant, P	K_{pM1}		0.002	mgP/L	0.001-0.005	0.002	0.002
Half Saturation Constant, N	K_{nM1}		0.025	mgN/L	0.01-0.05	0.025	0.025
Mortality Rate	k_{dM1}		0.11	1/d	0.05-0.4	0.11	0.11
Temperature Constant	θ_{M1}		1.02	-	1.01-1.05	1.02	1.02
Blue-green Algae							
Optimum Solar Radiation	I_{optM2}		13.9	MJ/(m^2•d)			13.9
Optimum Temperature	T_{optM2}		25	≡}			25
Maximum Growth Rate	μ_{M2}		3	1/d			3
Half Saturation Constant, P	K_{pM2}		0.002	mgP/L			0.002
Half Saturation Constant, N	K_{nM2}		0.025	mgN/L			0.025
Mortality Rate	$k_{d\,M2}$		0.11	1/d			0.11
Temperature Constant	θ_{M2}		1.02	-			1.02
Other Phytoplankton							
Optimum Solar Radiation	I_{optM3}		13.9	MJ/(m^2•d)	12-18	13.9	13.9
Optimum Temperature	T_{optM3}		25		16-28	25	25
Maximum Growth Rate	μ_{M3}		3	1/d	1-5	C	3
Half Saturation Constant, P	K_{pM3}		0.002	mgP/L	0.005-0.1	0.01	0.002
Half Saturation Constant, N	K_{nM3}		0.025	mgN/L	0.05-0.4	0.15	0.025
Mortality Rate	$k_{d\,M3}$		0.11	1/d	0.05-0.25	0.11	0.11
Temperature Constant	θ_{M3}		1.02	-	1.01-1.05	1.02	1.02

Table 4.6. Values of constants and coefficients, Dissolved Organics, Floatation of Sediment and Oxygen Consumption Rate by Sediment

Parameter	***Symbol***	***Condition***	***Value***	***Unit***	***Range***	***JØRGENSEN***	***TSUNO***
Dissolved Organic							
Decomposition Rate	k_{dc}		0.04	1/d	0.01-0.5	C	0.04
Temperature Constant, Decomposition	θ_c		1.02	-	1.01-1.05	1.03	1.02
Floatation of Sediment							
Release Rate	k_{srd}	DO<=0.3	20	mgDW/(m^2•d)			20
		DO>0.3	20	mgDW/(m^2•d)			20
Oxygen Consumption Rate by Sediment							
Oxygen Consumption Constant	k_{DO}	DO<0	900	mgO$_2$/(m^2•d)		Table P263	900
		DO=0	0	mgO$_2$/(m^2•d)		0	0
Half Saturation Constant, DO	K_{DO}		0.3	mgO$_2$/L			0.3
Temperature Constant, Decomposition	θ_{DO}		1.02	-			1.02

Table 4.7. Values of constants and coefficients, Extinction of Sunlight

Parameter	***Symbol***	***Condition***	***Value***	***Unit***	***Range***	***JØRGENSEN***	***TSUNO***
Extinction of Sunlight							
Extinction Coefficient, Water	α		16	(1/m)•(m^3/gChl.a)	1-50	16	16
Extinction Coefficient, Algal	ε_0		0.13	1/m	0.12-0.14	0.13	0.13

Table 4.8. Values of constants and coefficients, Release Rate from Sediments for “a” and “b” methods

Parameter	***Symbol***	***Condition***	***Value***	***Unit***	***Range***	***JØRGENSEN***	***TSUNO***
Selection of Release Rate from Sediment							
1: Method (a), 2: Method (b)			1 or 2				
Release Rate from Sediment(a)							
Release Rate, Phosphorus	k_{srAP}	DO<=0.3	6	mgP/(m^2•d)			6
		DO>0.3	0.6	mgP/(m^2•d)			0.6
Release Rate, Nitrogen	k_{srAN}	DO<=0.3	34	mgN/(m^2•d)			34
		DO>0.3	3.4	mgN/(m^2•d)			3.4
Release Rate, Dissolved Organics	k_{srAC}	DO<=0.3	200	mgCOD(m^2•d)			200
		DO>0.3	200	mgCOD/(m^2•d)			200
Release Rate from Sediment(b)							
Fraction Ratio, Phosphorus	f_{sedP}		0.6	-			0.6
Release Rate, Phosphorus	k_{srP}	DO<=0.3	0.05	1/d	0.01-0.5	0.1	0.05
		DO>0.3	0.005	1/d		0.01	0.005
Fraction Ratio, Nitrogen	f_{sedN}		0.7	-			0.7
Release Rate, Nitrogen	k_{srN}	DO<=0.3	0.05	1/d	0.01-0.5	0.1	0.05
		DO>0.3	0.005	1/d		0.01	0.005
Fraction Ratio, Dissolved Organics	f_{sedC}		0.5	-			0.5
Release Rate, Dissolved Organics	k_{srC}	DO<=0.3	0.05	1/d	0.01-0.5	0.1	0.05
		DO>0.3	0.005	1/d		0.01	0.005

5. WORKING AREA-SAPANCA LAKE

Sapanca Lake is located in Marmara Region, which is situated between Izmit Bay and Adapazarı Meadow and runs parallel to Iznik Lake. Lake Sapanca is situated in the Marmara region (Turkey). It has a surface area of 46.8 km^2 and a volume of about $1.0.10^9$ m^3 water. Its catchment area is 209 km^2 and the maximum depth is 52 m. Several streams and ground water entering from the bottom feed the lake. There is only one stream draining the lake (Yalçın and Sevinç, 2001).

Sapanca Lake is a major water resource supplying drinking water as well as water for industrial and agricultural purposes for one of the more industrialized areas of Turkey. Sustainability of its beneficial use is of the great concern. Furthermore the lake is one of the current 97 Important Bird Areas (IBA) of Turkey also meeting the 2nd ,3rd and 4th criteria of Ramsar Convention, that qualify it as a potential Ramsar-Site-wetland of international importance (Davis, 1994).

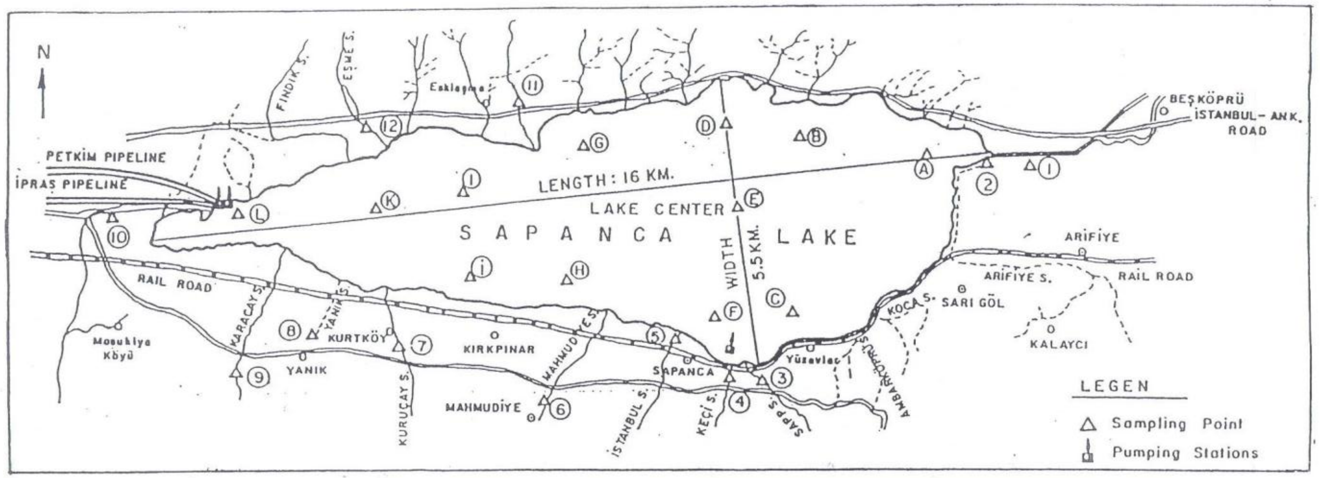
5.1. Morphology of Sapanca Lake

Lake Sapanca is very close to two highly industrialized metropolitan cities, Istanbul and Izmit, supplying water to11 industries and approximately 48,000 people in its cathment area. There are also extensive areas of agriculture and forests in the Lake Sapanca basin. The lake is a potential source of water to Istanbul for future use. As such, it has a vital role in the activities of residential, industrial, and agricultural districts of the area. The basin is surrounded by motorways (TEM, Trans-European Motorways) and a railway connecting Asia to Europe. The total basin area is 311 km^2 of which 40 km^2 is the lake 150 km^2 is forests and meadows. The total agricultural and residental area is about 40% of the basin area. The coastal line of the lake is 39 km long and maximum depth is 50 m. The stratified lake has a volume of about 1 billion m^3. The catchment area covers nine medium size municipalities with a total population of 47,679 people according to the final formal census of 1990. Population increase rates of the basin have increased from 1.5% to 3.5% for the past 20 years, whereas the average population growth rate of Turkey was 2.5%. The total population of the basin is estimated to be over 100,000 in 2030 according to the population increase trend. The basin lies in a transition zone in terms of climatic conditions between the Mediterranean and the Black Sea. It possesses a moderate amount of precipitation, 600–1000 mm/yr. The average annual temperature is 13.5°C, while average annual evaporation is 655 mm. The geology of the region was completed at different periods since Paleontologic Times. It is stressed by the North Anatolian Fault Zone that crosses Turkey and southern part of the lake. There are some plains around the lake surrounded by hills. The hills in the south are higher than those in the north and reach to 4000 m. The lake discharges its water to the Sakarya River through Cark Creek on the eastern end and reaches the Available data shows that the lake has a water quality of class 1 that tends towards class 2, when evaluated according to the classification suggested by Ryding and Rast (1989). There is an abundance of nitrogen in the lake, and phosphorus is the rate-limiting element in it. Hence, nutrients play the most significant part in the fate of the lake quality (Tanik et al., 1998). Morphological charachteristic of Sapanca Lake is summarized in Table 5.1.

Table 5.1. Characteristic values of Sapanca Lake (Dinç, 2001)

Watershed Area	250 km^2
Maximum Length of lake	15 km
Makimum Width of lake	5,5 km
Maximum Depth	52 m
Average Annual Temperature	12^0 C
Average Annual Precipitation	782,5 mm
Relative Humidity	80-85 %
Coldest Month	0^0-6^0 C January
Warmest Month	29^0 C July
Average Water Flow	4,106 m^3/s
Maximum Water Flow	29 m^3/s
Minimum Water Flow	0,005m^3/s
Population Density Around Lake	100 people/km^2
Total Capacity	1325,106 m^3

a)



b)

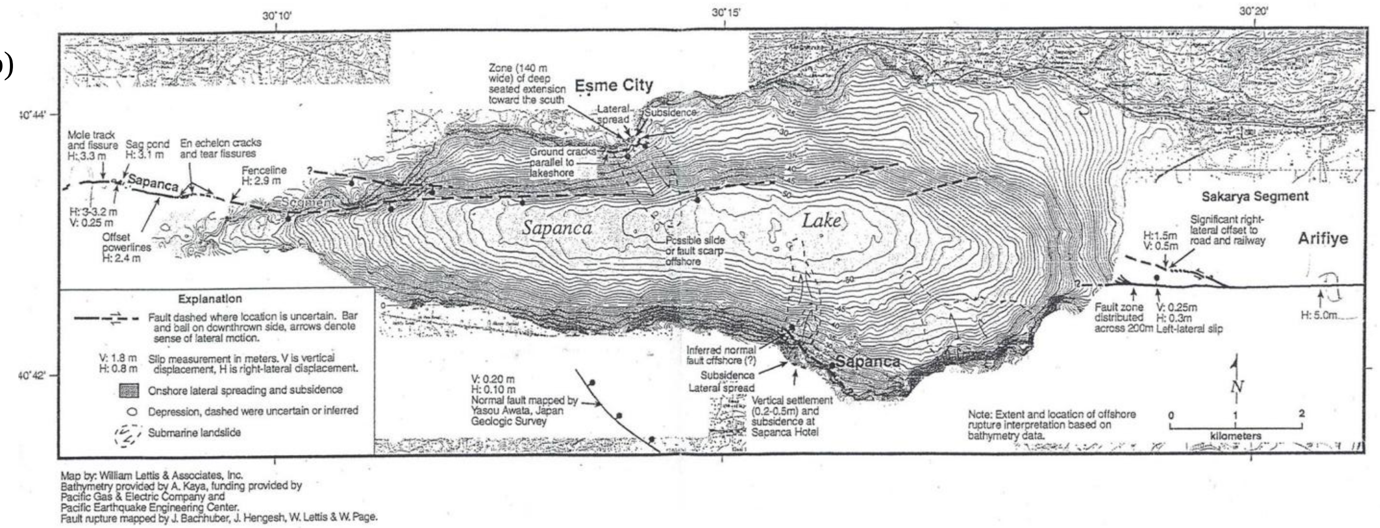


Figure 5.1. Lake Sapanca a) Investigation Stations and b) Batimetric curves

5.2. Environmental Conditions

Temperature values and wind speed is so important for modeling, therefore both of them are investigated separately and shown in Figure 5.2. and Figure 5.3.

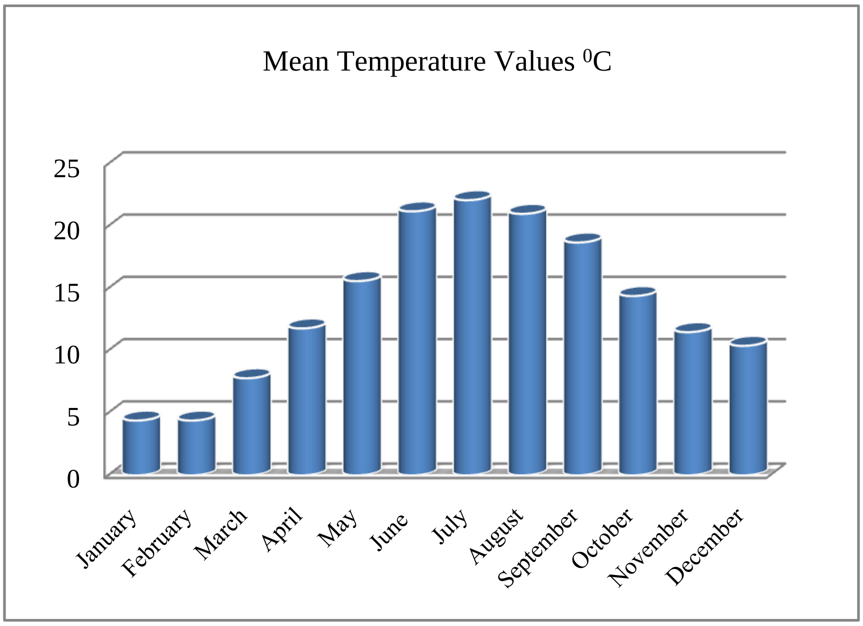


Figure 5.2. Mean temperature values of Sapanca Lake

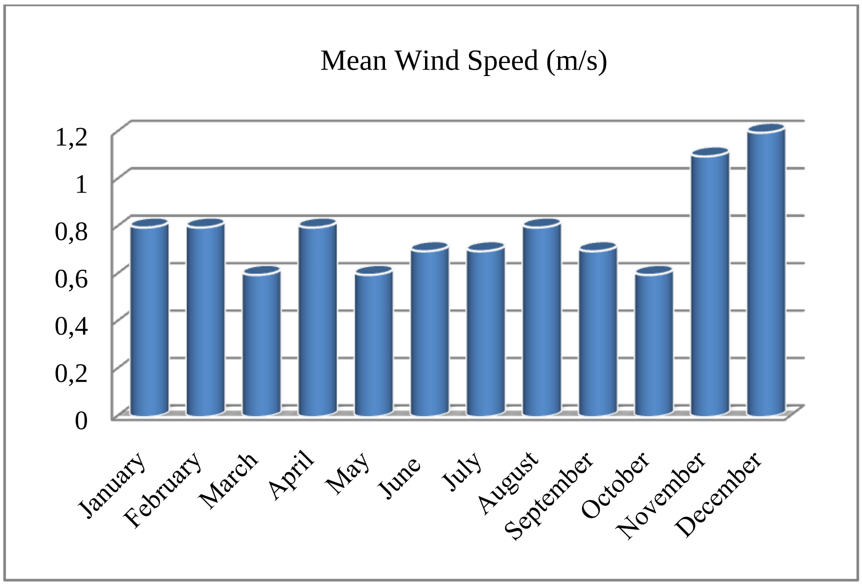


Figure 5.3. Mean wind speed values of Sapanca Lake

5.3. Nutrients in Lake Sapanca

Nutrients play an important role in eutrophication process. In order to gauge how to best prevent eutrophication from occurring, specific sources that contribute to nutrient loading must be identified. In general Phosphorus and Nitrogen is often regarded as the main culprit in cases of eutrophication in lakes subjected to point source pollution from streams. The concentration of algae and the trophic state of lakes correspond well to phosphorus and nitrogen levels in water. Phosphorus (P) was one of the most important nutrients for lake eutrophication.

There are several nutrients, or biogenic elements, necessary for phytoplankton and macrophyte growth. However, their relative quantities necessary for optimal growth are very different. The most abundant nutrients are phosphorus, nitrogen and carbon, which are typically utilized by algae and other autotrophs in a proportion corresponding to their relation in algal cells. This is the basis of the so-called Redfield ratio of carbon to nitrogen to phosphorus (i.e., C: N: P = 106:16:1 by atomic number). If these nutrients are present in a water body in approximately this ratio, the growth of algae is not limited by any of them, but rather depends on the absolute quantities present in the water column. The nutrient, which exhibiting the most deviation in the ratio, is the one that limits algal production. The limiting nutrient in most water bodies is phosphorus, with excess nitrogen typically being present (Jørgensen et al., 2005).

TP and TN concentrations in the water column are derived from measurements of III. Directorate of State of Hydraulic Works from a total of 7 stations at Sapanca Lake within the period of 1989- 1997. Sampling stations are shown in Figure 5.1. NO_2-N mg/l, NH_3-N mg/l, NO_3-N mg/l, Kjeldahl N mg/l, total phosphate-P mg/l and Chlorophyll-a µg/l were measured in these stations (DSI, 2002).

Both models need TP values therefore annual average of total phosphate values derived from the measurements is converted into TP by multiplying total phosphate values with 31/95 to present it P phosphorus.

Similarly, as the Nitrogen in water supposed to be in the models was TN, so TN was calculated as shown below

$$TN\left({}^{mg}/_{l}\right) = NO_2 - N\left({}^{mg}/_{l}\right) + NO_3 - N\left({}^{mg}/_{l}\right) + Kjeldahl\,N\left({}^{mg}/_{l}\right) \quad (5.1)$$

After calculations of TN, TP and chlorophyll-a values they are plotted onto graph and shown in Figure 5.4, Figure 5.5 and Figure 5.6.

5.4. Thermal Stratification

One of the most important steps in the study is the evaluation of stratification status of the lake in stratification periods. Thermal stratification is the main physical process affecting the water quality of lakes. Water quality in lakes and reservoirs is related to temperature and eutrophication rather than to organic material and oxygen deficit. Oxygen-related factors are coupled to temperature and eutrophication.

Systems with long residence times are not significantly affected by the entrance and exit flow effects, the primary factors controlling mixing are wind and temperature. Temperature is simple to measure; it is used as a fundamental parameter. Temperature variation in a lake may be expected over the seasons as shown in Figure5.7 which gives the typical temperature cycle and he relative dispositions of the three zones; epilimnion, thermocline and hypolimnion.

Lakes gain and loose energy through the surface because of shear forces from wind, solar heating, and radiant cooling. In warm weather, vertical convection currents are formed because of differential cooling and heating during the day and night. Gradually, the water at lower levels become significantly cooler and denser than that at the surface, and convective forces are damped out except in a surface layer called the epilimnion, which may extend over a depth of 5 to 15 m. This is where there is greater heat transfer to and from the atmosphere, and constitutes the zone of circulation due to wind mixing. Circulation accounts for the more or less uniform temperature profiles in the epilimnion at any particular time. Temperature can however, vary substantially from season in this zone.

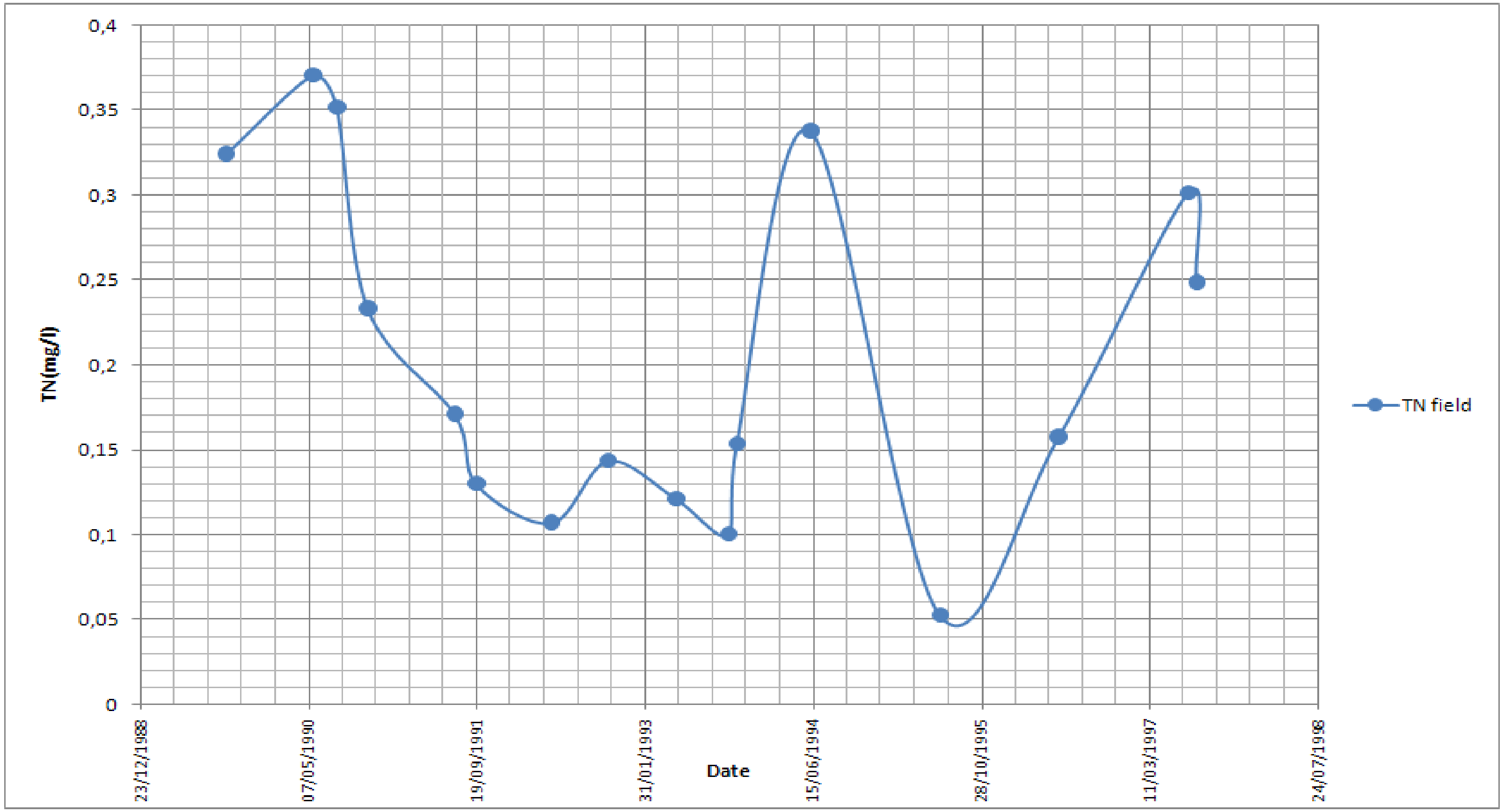


Figure 5.4. Total nitrogen concentration of Lake Sapanca 1988-1997

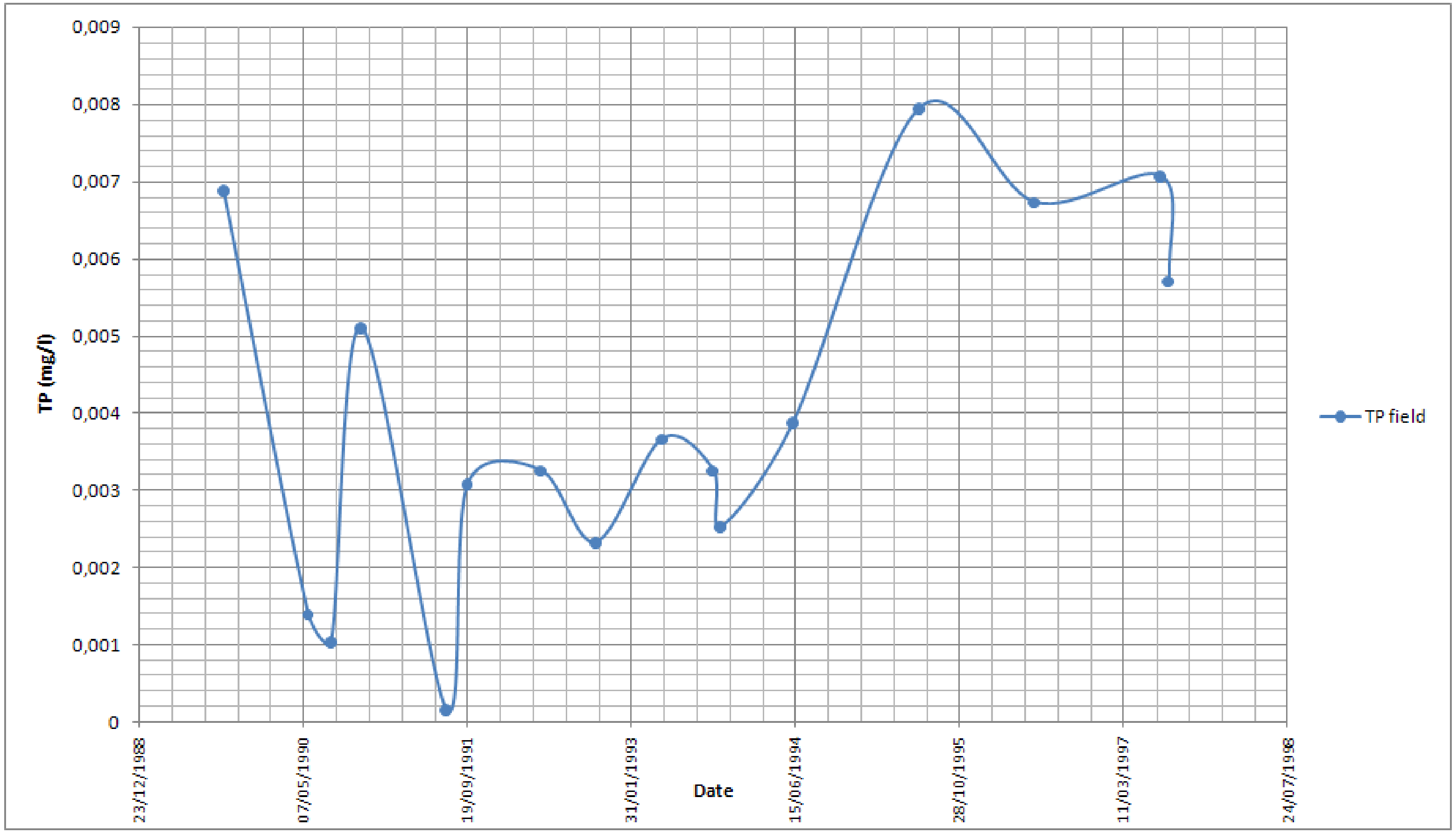


Figure 5.5. Total phosphorus concentration of Lake Sapanca 1988-1997

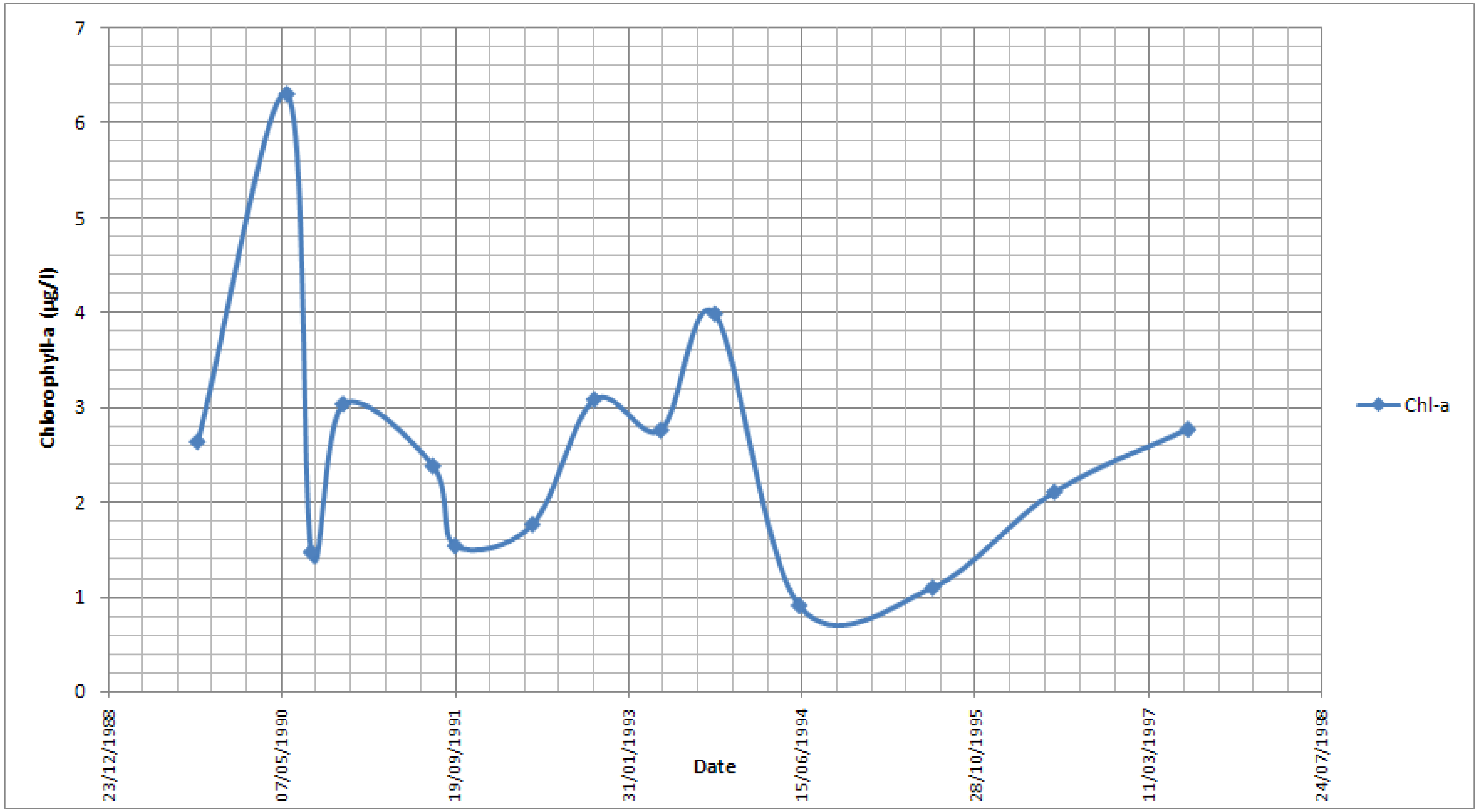


Figure 5.6. Chlorophyll – a concentration of Lake Sapanca 1988-1997

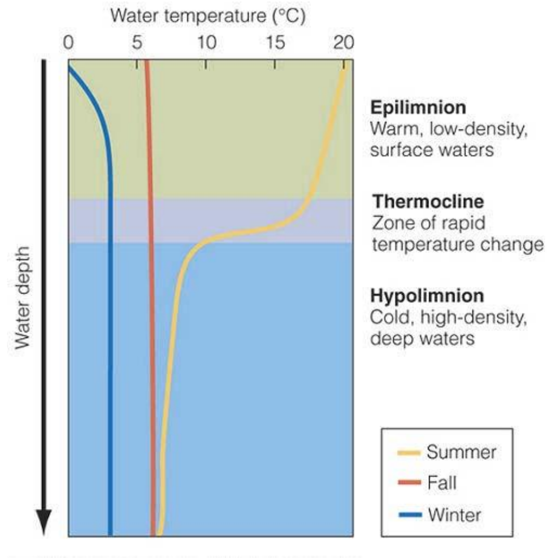


Figure 5.7. Thermal stratification of lake

Although the epilimnion is well mixed, the lower layer, hypolimnion, is weakly mixed and usually has distinct gradients in nutrient and oxygen concentrations. Generally hypolimnions of deep lakes undergo smaller variations in temperature between summer and winter as compared to their epilimnions. Between these layers is the transition zone, thermocline, layer of varying depth having a sharp temperature gradient.

As fall passes, surface water cools, the epilimnion temperatures may approach 4^0 C and its density increases while the hypolimnion temperatures lower than 4^0C. Density of the epilimnion will be greater than that of the hypolimnion, and the system becomes unstable resulting in epilimnion water sink down. Small perturbations, as from wind shear, result in a turnover of the lake contents, and for a period the lake is completely mixed. After mixing the entire contents of the lake will be less than 4^0C, and the lake will re-stratify with the colder and lighter water near the surface. Surface freezing may occur in winter after this fall turnover. A spring turnover also occurs as the water gets warmer on the surface, the maximum density develops as temperatures in epilimnion approach 4^0C, and instability develops. But as summer comes, stratification takes place again, resulting in stagnation. In fact, within the hypolimnion there is not likely to be any substantial vertical circulation of water because of more or less uniform density within this zone. For this reason, the hypolimnion is often referred to as the stagnation zone.

Turnover affects the water quality in a lake in two ways: (a) by changes in nutrient and temperature distribution and (b) by movement of bottom materials throughout the volume Quite often, nutrient materials accumulate in the lower depths, either as sediment or because biological activity is lower. When these materials are brought to the surface, eutrophication rates are increased due to sunlight and higher temperatures. As a deep lake, thermal stratification is expected in Lake Sapanca. Bearing these crucial effects of thermal stratification in mind, temperature profiles were formed to see the periods of stratification and de-stratification. Station E is selected as an example to show temperature changes in Lake Sapanca (Figure 5.8, 5.9 and 5.10).

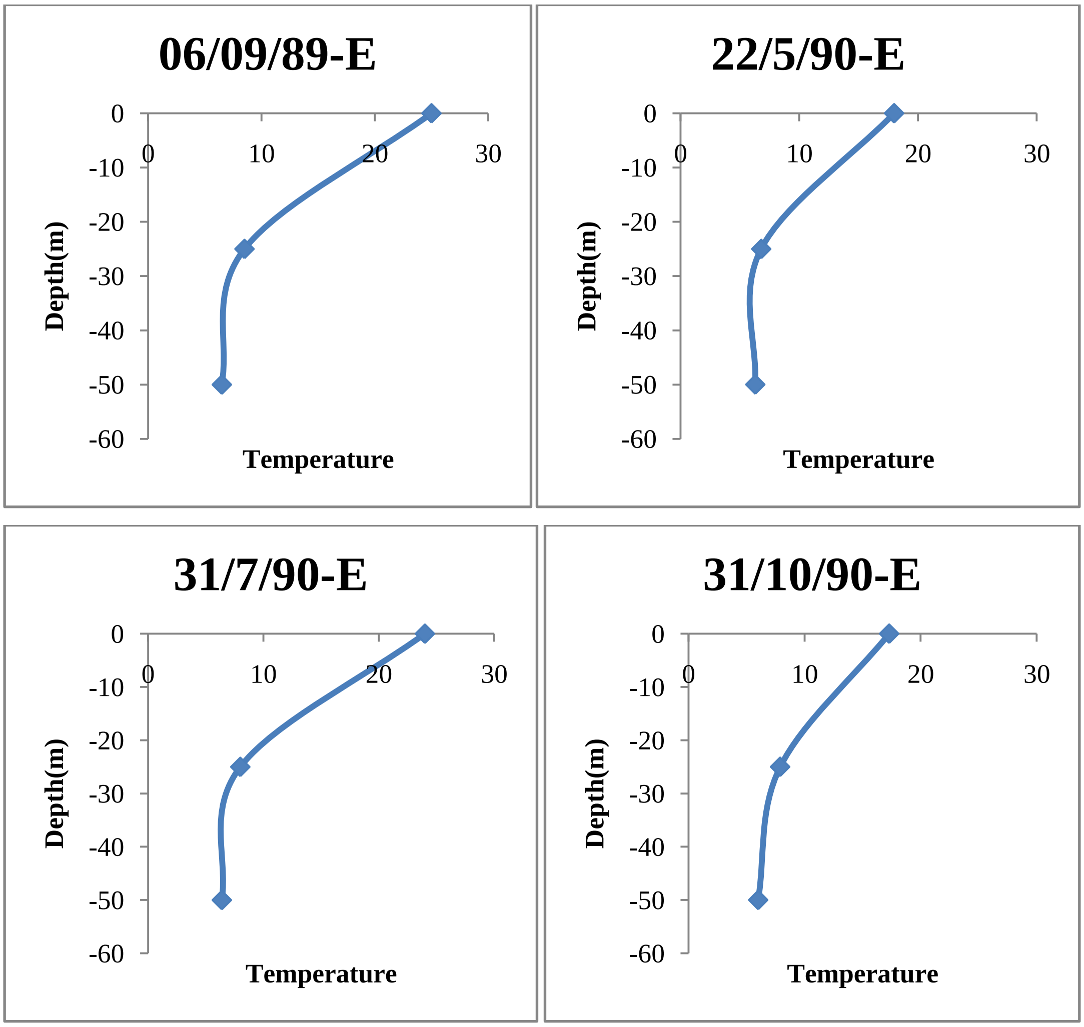


Figure 5.8. Temperature changes in station E between years 1989-1990

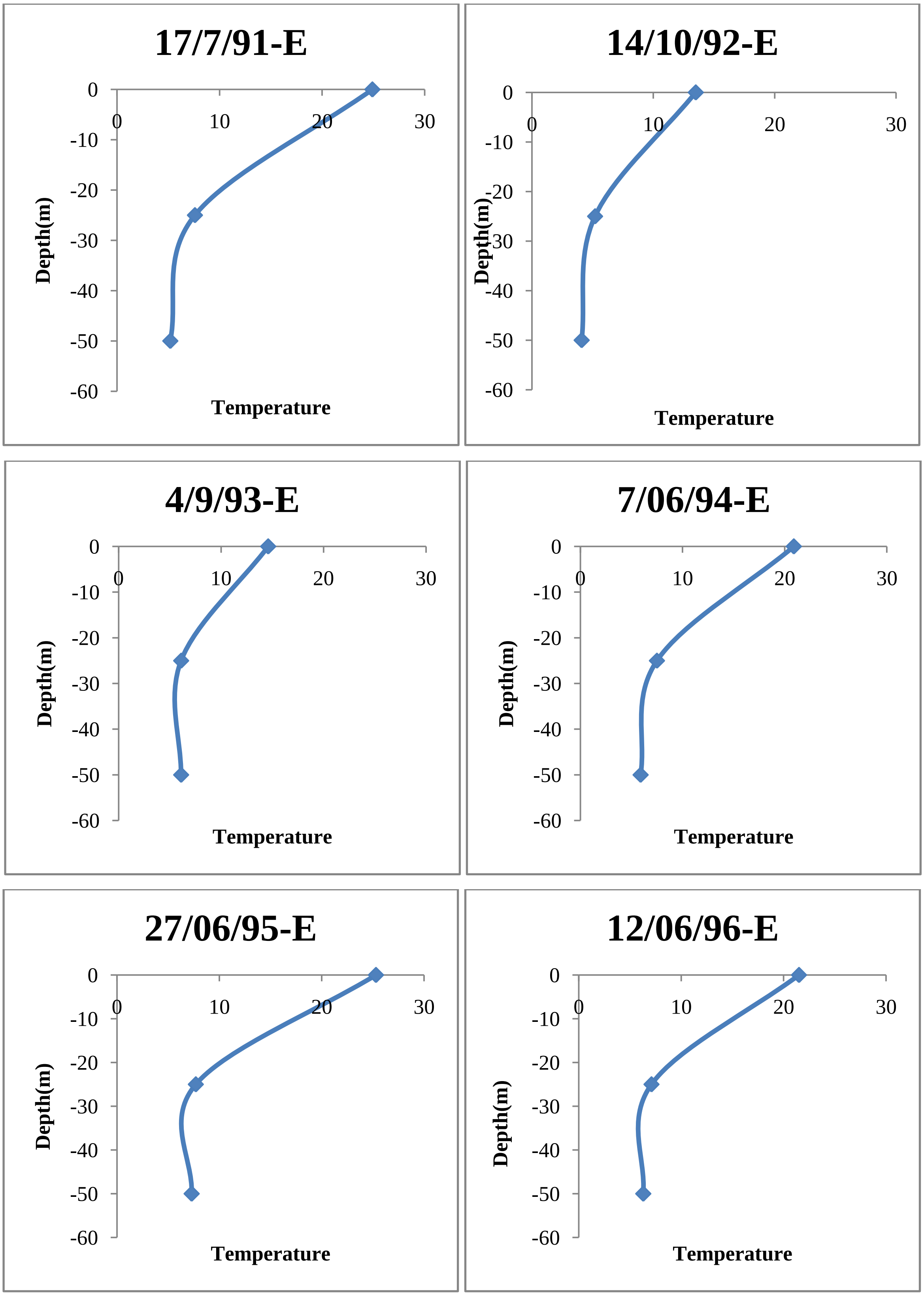


Figure 5.9. Temperature changes in station E between years 1991-1996

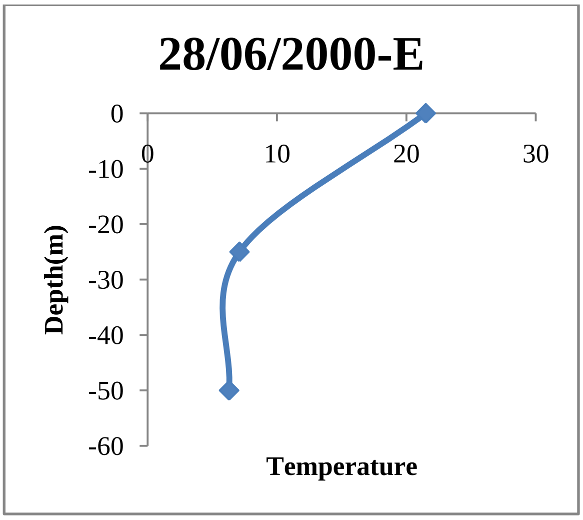


Figure 5.10. Temperature changes in station E in year 2000

With help of these temperature profiles, the lake volume is divided into three zones, the epilimnion, the thermocline, and the hypolimnion in stratification periods. In mixing periods the volume is considered as a whole. Depending on the available data for temperature, the stratification in Lake Sapanca begins in April, epilimnion gets warmer from May to June, stratification is solid and stable from July to the end of August, epilimnion starts to get colder in September, this cooling proceeds in October and the thermocline is pushed downwards until it is broken in November. According to these observations, epilimnion is accepted as the volume beginning from the surface of the lake to the mean depth where the temperature gradient is below than 1^0C per meter depth. Epilimnion volume roughly ends at the mean depth of 8m from the surface, ranging from 4 to 12 m in different months. In the same manner, hypolimnion is accepted as the volume beginning from the bottom to the mean depth the temperature gradient is below than 1^0C per meter depth. Hypolimnion volume roughly ends at the mean depth of 22 m from the surface, ranging from 20 to 30 m in different months. The remaining volume is accepted as the thermocline (between 8 and 22 depths) having a temperature gradient over 1^0C per meter depth. In PAMOLARE models, lake is considered as two layers: hypolimnion and epilimnion. Therefore epilimnion depth is assumed as 18.82 m for PAMOLARE calculations (Baltaoğlu, 1990).

6. TROPHIC STATUS OF SAPANCA LAKE

6.1. Limiting Nutrient in Sapanca Lake

Excess nutrient inputs can stimulate algal blooms leading to decreases in light penetration and hypolimnion oxygen levels, decreases in lake aesthetics and shifts to algal taxa (i.e. cyanobacteria) that are associated with objectionable taste and odor events. Therefore, determining which nutrients limit phytoplankton growth is an important step in the development of effective lake and watershed management strategies (Palsson and Graneli, 2004).

Aquatic plants (phytoplankton, macroalgae and macrophytes) absorb nutrients in specific proportions during photosynthesis and growth. C: N: P = 106:16:1—this is referred to as the Redfield atomic ratio and it is regarded as the ideal balance between these nutrients for algal production (Downing and McCauley, 1992). The proportions and amounts of nutrients absorbed by aquatic plants from water vary between species; however, the overall average composition of aquatic plant tissue is $C_{106}H_{263}O_{110}N_{16}P$ in addition to other trace elements. A general equation for photosynthesis in unpolluted waters is as follows:

The proportions and amounts of nutrients absorbed by aquatic plants from water vary between species; however, the overall average composition of aquatic plant tissue is $C_{106}H_{263}O_{110}N_{16}P$ in addition to other trace elements. A general equation for photosynthesis in unpolluted waters is as follows:

$$106CO_2 + 16NO_3^- + HPO_4^{-2} + 122H_2O + 18H^+ \\ \rightarrow (CH_2O)_{106} + (NH_3)_{16} + (H_3PO_4) + 138O_2 \qquad (6.1)$$

N and P are the nutrients that are commonly referred to as being potentially limiting in estuarine and coastal waters. In general, the limiting nutrient for plant growth in freshwater ecosystems is usually attributed to P; whereas in coastal waters the limiting nutrient is often attributed to N; however this is not necessarily the case in all circumstances (Neill, 2005).

Both Japanese and Swedish work found that between TN: TP ratios by weight of 10-17, P or N or both limited growth, but that higher ratio denoted a P deficiency (Kalff, 1983).

- When the TN/TP ratio is less than 10, a lake is nitrogen-limited;
- When the TN/TP ratio is between 10 and 17, there appears to be a gray area (nitrogen or phosphorus could be limiting);
- When the TN/TP ratio is greater than 17, a lake is phosphorus-limited.

After mean TP and TN values are calculated according to 1989-1997 years. TP: TN ratio of Sapanca Lake is calculated and plotted in the figure 6.1. It can be seen that except years 1995, in all years generally P or both of them is limiting nutrient for Sapanca Lake. If the limiting nutrient in a water body is exhausted, the population of algae stops expanding.

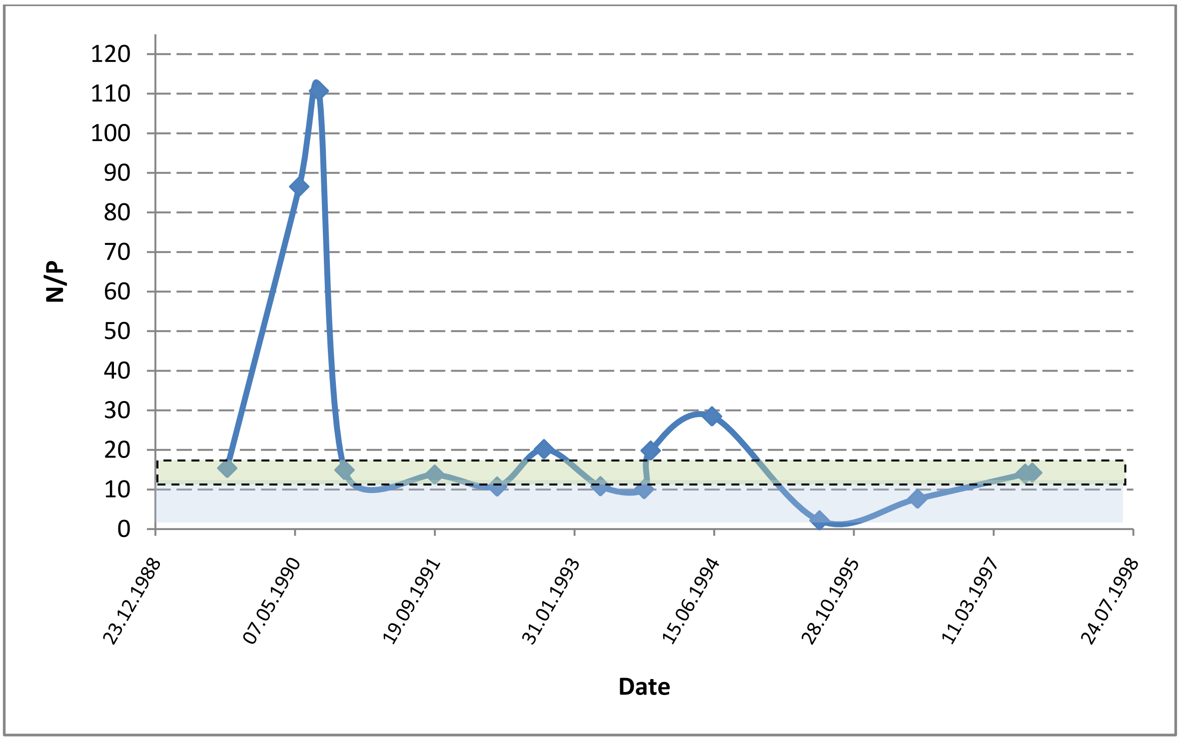


Figure 6.1. N/P ratio of Sapanca Lake

6.2. Nutrient Loads of Sapanca Lake

There are nine streams which bring phosphorus and nitrogen loads to Sapanca Lake. Balıkhane, Arifiye, İstanbul, Karaçay, Keçi, Kuruçay, Mahmudiye, Sarp Deresi, Maden streams' inflow data is obtained from DSI (2007) and flow of these streams are shown in Figure 6.2.

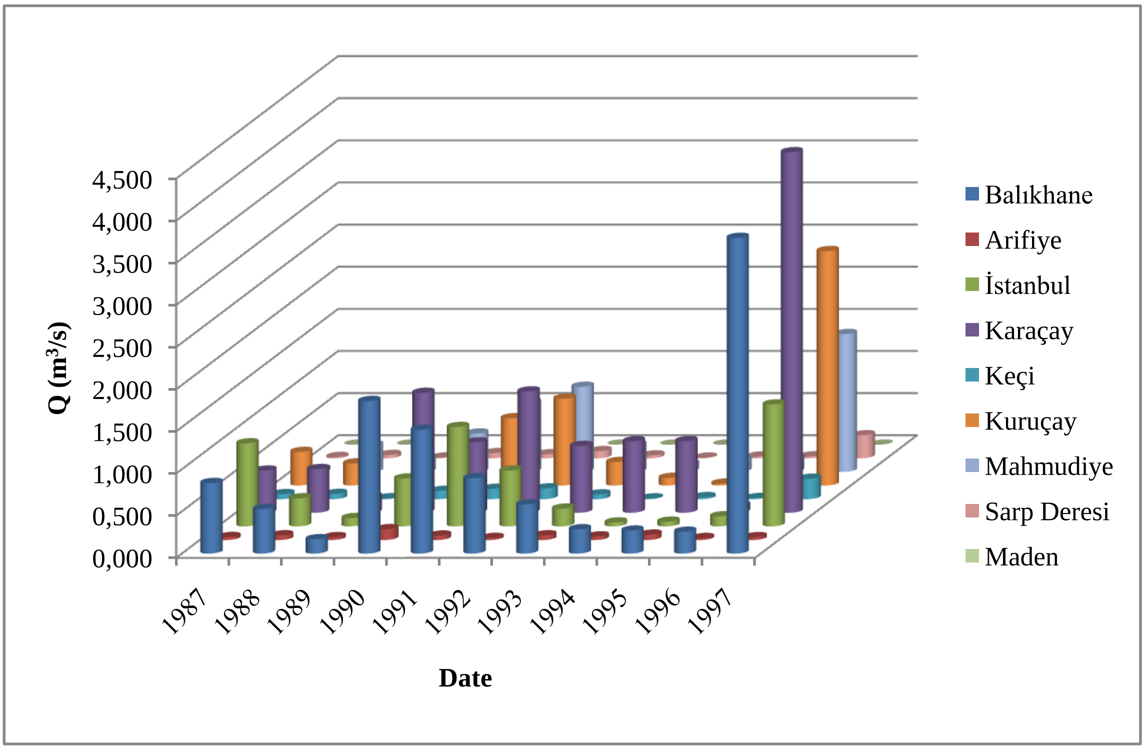


Figure 6.2. Annual flow rates of streams

6.2.1. Nitrogen Load

Nitrogen load of Sapanca Lake is calculated by using inflow nitrogen concentrations. Nitrogen loads are shown in Figure 6.3. and formula of nitrogen load is shown below.

$$Total\ Nitrogen\ Inflow = \sum \begin{matrix} Average\ Flow\ Rate\ of\ Streams\ \times \\ Average\ concentration\ of\ Streams \end{matrix} \tag{6.2}$$

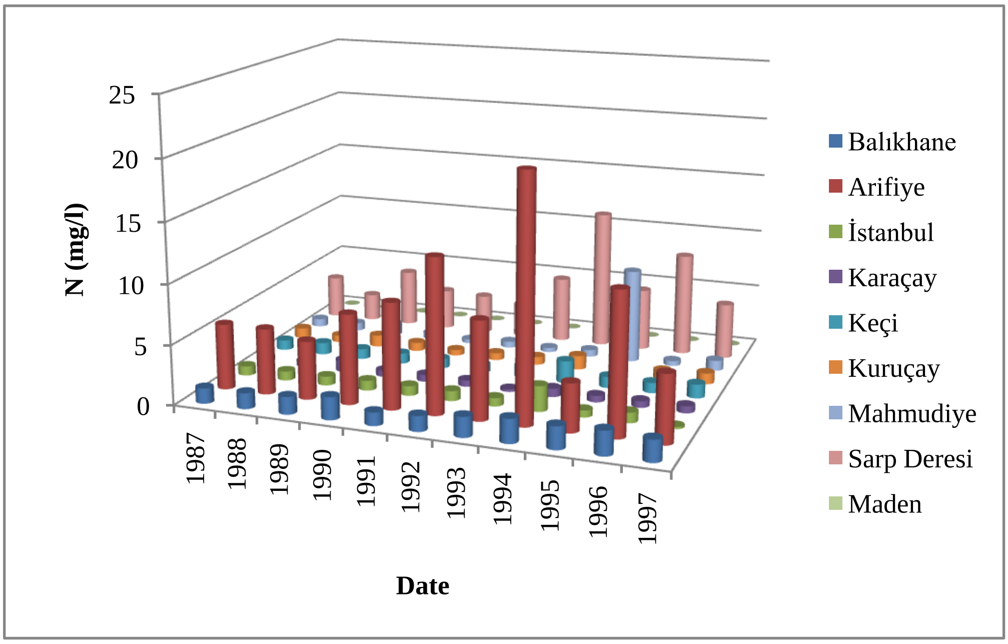


Figure 6.3. Mean nitrogen concentrations of streams

Average concentrations and flow rates are calculated according to years 1989-1997. Nitrogen loads are shown in Table 6.1.

$$Total\ Nitrogen\ Inflow = \begin{pmatrix} 0.987 \times 1.621 + 0.049 \times 8.636 + 0.518 \times 0.844 \\ +1.068 \times 0.577 + 0.074 \times 0.995 + 0.565 \times 0.759 \\ +0.470 \times 1.261 + 0.056 \times 5.119 \end{pmatrix}$$

$$\times \frac{mg}{l} \times \frac{m^3}{sec} \times \frac{10^3 l}{m^3} \times \frac{kg}{10^6 mg} \times \frac{86400\,sec}{day} \times \frac{365\,day}{year} \tag{6.3}$$

$$Total\ Nitrogen\ Inflow = 125852\,\frac{kg}{year} \tag{6.4}$$

$$Total\ Nitrogen\ Load = 125852\,\frac{kg}{year} \times \frac{10^3 g}{kg} \times \frac{1}{46{,}8 \times 10^6 \times m^2} = 2.689\,\frac{g}{m^2 \times year}$$

(6.5)

Table 6.1. Nitrogen Loads Of Sapanca Lake Between 1987- 1997

Year	Balıkhane mg/L*m^3/s	Arifiye mg/L*m^3/s	İstanbul mg/L*m^3/s	Karaçay mg/L*m^3/s	Keçi mg/L*m^3/s	Kuruçay (mg/L*m^3/s)	Mahmudiye (mg/L*m^3/s)	Sarp (mg/L*m^3/s)	Total N (kg/year)
1987	1.0723	0.1928	0.7791	0.2928	0.0500	0.3411	0.0201	0.0525	86,484
1988	0.7025	0.3030	0.2571	0.2438	0.0620	0.1518	0.2104	0.0904	62,405
1989	0.2497	0.1620	0.0744	0.1890	0.0087	0.0264	0.1625	0.0434	28,285
1990	3.4420	0.9627	0.4760	0.7425	0.0858	0.3131	0.2371	0.2093	199,746
1991	1.6287	0.4609	0.9632	0.4804	0.0998	0.3842	0.2643	0.1555	137,012
1992	1.1548	0.3090	0.5534	0.7682	0.0883	0.6259	0.5330	0.2434	132,041
1993	0.9865	0.4512	0.1468	0.1671	0.0547	0.1897	0.1179	0.1868	71,046
1994	0.5783	0.8495	0.0985	0.6042	0.0159	0.1059	0.0534	0.0881	73,919
1995	0.5160	0.2534	0.0320	0.4667	0.0218	0.0130	1.2008	0.1056	80,575
1996	0.5271	0.2704	0.1033	0.0442	0.0113	0.0767	0.0729	0.1955	40,182
1997	6.8036	0.1875	0.2524	2.5155	0.2824	2.5678	1.4114	1.2870	472,687
Average	1.6056	0.4002	0.3397	0.5922	0.0710	0.4360	0.3894	0.2416	125,853

6.2.2. Phosphorus Load

Vollenweider (Vollenweider, 1975) developed a model describing a relationship between P load to a water body and the quotient of the mean depth and hydraulic residence time. Equations representing permissible and excessive phosphorus loadings are as follows:

$$Lp(P) = 100 + 10\left(\frac{z}{Tw}\right) \tag{6.6}$$

$$Le(P) = 200 + 20\left(\frac{z}{Tw}\right) \tag{6.7}$$

$q_s = Hydraulic\ Load$

$z = Average\ Depth$

$T_w = Water\ residence\ time$

$$q_s = \frac{Outflow\ \ water}{Average\ \ Area\ of\ Lake} \tag{6.8}$$

$$T_w = \frac{Average\ \ Lake\ Volume}{Outflow\ \ Water} \tag{6.9}$$

$$Total\ Outflow = 2{,}90\frac{m^3}{s}x\frac{86400sec}{day}x\frac{365day}{year} + 25{,}6x10^6\frac{m^3}{year} + 54{,}95x10^6\frac{m^3}{year}$$
$$= 172{,}023 \times 10^6\, m^3/year \tag{6.10}$$

Average evaporation rate according to Kurtkoy datas = 16, 4 x 10^6 m^3/year (DSI, 1984)

$$Total\ Outflow = 172{,}037 + 16{,}4 = 188{,}437 \times 10^6\ \mathrm{m}^3/\mathrm{year} \tag{6.11}$$

$$q_s = \frac{188{,}437\mathrm{x}\ 10^6\ \ \mathrm{m}^3/\mathrm{year}}{46{,}8\mathrm{x}\ 10^6\ \ \mathrm{m}^2} = 4{,}02\ m/year \tag{6.12}$$

$$T_w = \frac{1218\mathrm{x}\ 10^6\ \ \mathrm{m3}}{188{,}437\mathrm{x}\ 10^6\ \ \mathrm{m3/year}} = 6{,}46\ year \tag{6.13}$$

$$z = q_s x T_w = 26{,}02meters \tag{6.14}$$

$$Lp(P) = 100 + 10(4{,}02) = 140{,}2mg\ P/m^2year \tag{6.15}$$

$$Le(P) = 200 + 20(4{,}02) = 280{,}4mg\ P/m^2year \tag{6.16}$$

For calculation of the phosphorus load, DSI data were used. (Figure 6.4) Phosphorus concentrations are obtained by using o-PO_4 data. Annual phosphorus loads are shown in Table 6.2.

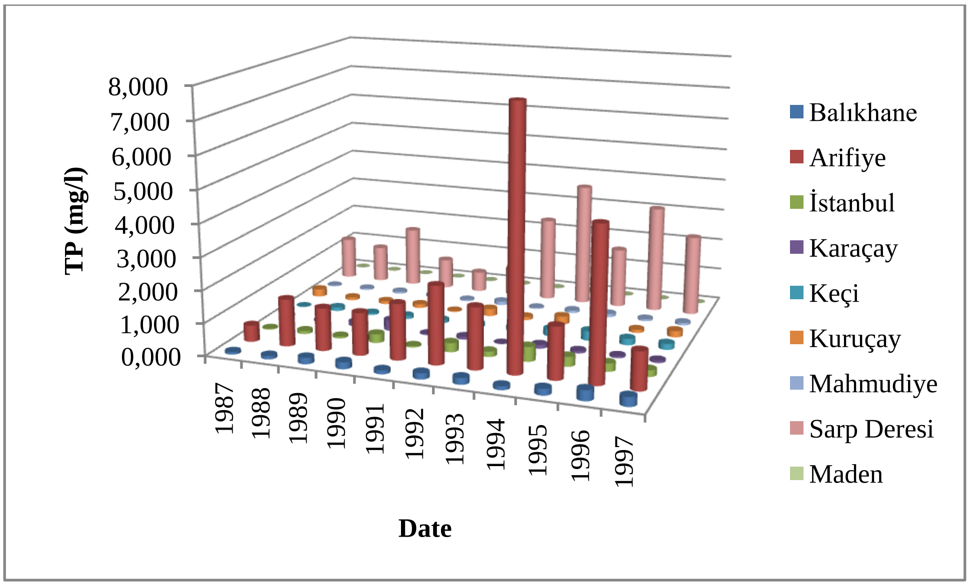


Figure 6.4. Mean total phosphorus concentration of streams.

$$Total\ o - PO_4 - P\ Inflow = \sum Flow\ of\ streams\ x\ concentration\ of\ streams \quad (6.17)$$

$$Total\ Phosphorus\ Inflow$$
$$= 0.987 \times 0.182 + 0.049 \times 2.357 + 0.518 \times 0.196 + 1.068 \times 0.092$$
$$+0.074 \times 0.141 + 0.565 \times 0.167 + 0.470 \times 0.060 + 0.056 \times 1.906 \quad (6.18)$$

$$\times \frac{mg}{l} \times \frac{m^3}{sec} \times \frac{10^3 l}{m^3} \times \frac{kg}{10^6 mg} \times \frac{86400 sec}{day} \times \frac{365 day}{year}$$

$$Total\ Phosphorus\ Inflow = 23141 \frac{kg}{year} \quad (6.19)$$

$$Total\ Phosphorus\ Load\ in\ Lake = \frac{\frac{23141\ kg}{year} x \frac{10^6 mg}{kg}}{46,8x10^6 m^2} = \frac{494,49 mg}{m^2} year \quad (6.20)$$

Table 6.2. Annual phosphorus loads of streams in 1989-1997.

Year	Balıkhane mg/L*m^3/s	Arifiye mg/L*m^3/s	İstanbul mg/L*m^3/s	Karaçay mg/L*m^3/s	Keçi mg/L*m^3/s	Kuruçay (mg/L*m^3/s)	Mahmudiye (mg/L*m^3/s)	Sarp (mg/L*m^3/s)	Total P (kg/year)
1987	0.0628	0.0179	0.0296	0.0383	0.0009	0.0965	0.0009	0.0193	8,391
1988	0.0554	0.0803	0.0324	0.0259	0.0072	0.0242	0.0157	0.0445	9,003
1989	0.0332	0.0438	0.0059	0.0246	0.0006	0.0025	0.0109	0.0168	4,360
1990	0.3802	0.1681	0.1534	0.4694	0.0102	0.0514	0.0273	0.0575	41,546
1991	0.1688	0.0897	0.0531	0.0250	0.0123	0.0239	0.0370	0.0302	13,874
1992	0.1655	0.0576	0.1887	0.1151	0.0146	0.2368	0.1161	0.0744	30,549
1993	0.1164	0.1042	0.0347	0.0079	0.0076	0.0292	0.0128	0.0881	12,643
1994	0.0331	0.3305	0.0209	0.0976	0.0018	0.0225	0.0074	0.0288	17,115
1995	0.0546	0.1008	0.0165	0.0594	0.0069	0.0081	0.0151	0.0374	9,424
1996	0.0829	0.1073	0.0296	0.0047	0.0026	0.0106	0.0112	0.0750	10,215
1997	1.0678	0.0389	0.2893	0.2781	0.0447	0.5564	0.1308	0.6840	97,442
Average	0.2019	0.1036	0.0776	0.1042	0.0099	0.0966	0.0350	0.1051	23,142

Acceptable and excessive limits are determined in (6.16) and (6.17). According to Vollenweider, lakes that have combinations of phosphorus loading and flushing rate such that they plot below the permissible loading line are classified as oligotrophic and those plot above excessive line are classified as eutrophic. Between these two lines are called mesotrophic. By placing the average phosphorus in Sapanca Lake on to the graph, it is seen that Sapanca Lake is in the eutrophic region in Figure 6.5.

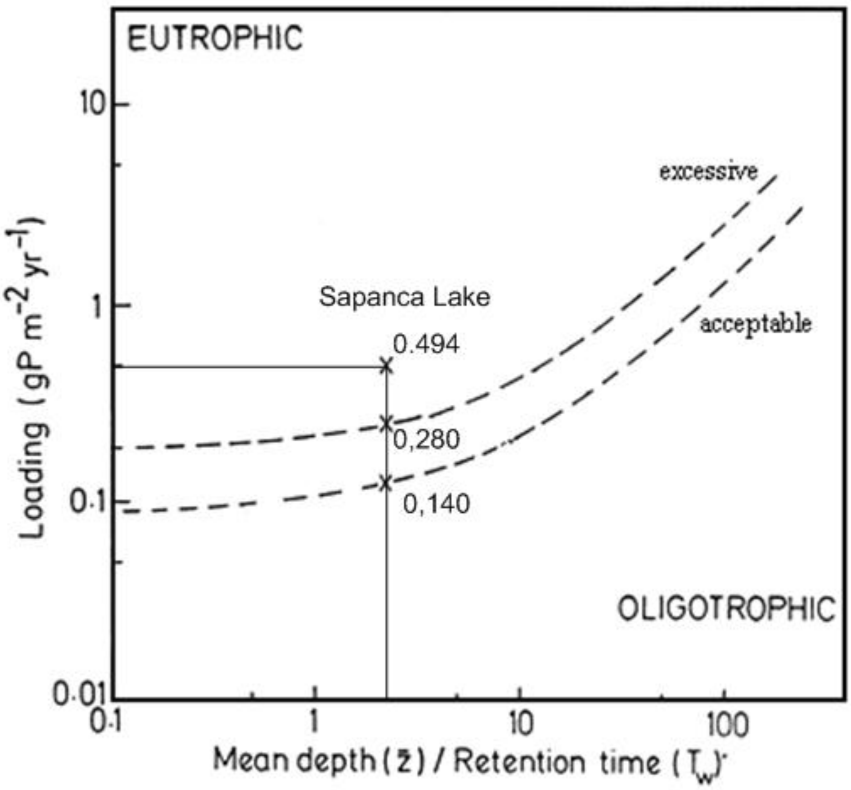


Figure 6.5. Application of Vollenweider model to Lake Sapanca

6.2.3. Probabilistic Approach

Lakes and reservoirs can be broadly classed as ultra-oligotrophic, oligotrophic, mesotrophic, eutrophic or hypereutrophic depending on concentration of nutrients in the body of water and/or based on ecological manifestations of the nutrient loading. Strict boundaries for these groupings are often difficult to apply because of regional variations in ranges of limnological parameters and because of lakes falling in different categories depending on the criterion used. One solution to these ambiguities is to designate a range of values for a particular degree of eutrophication as a statistical distribution. Figure illustrates a set of statistical distributions for three criteria for degree of eutrophication: total phosphorus concentration, mean chlorophyll concentration and mean Secchi disk visibility.

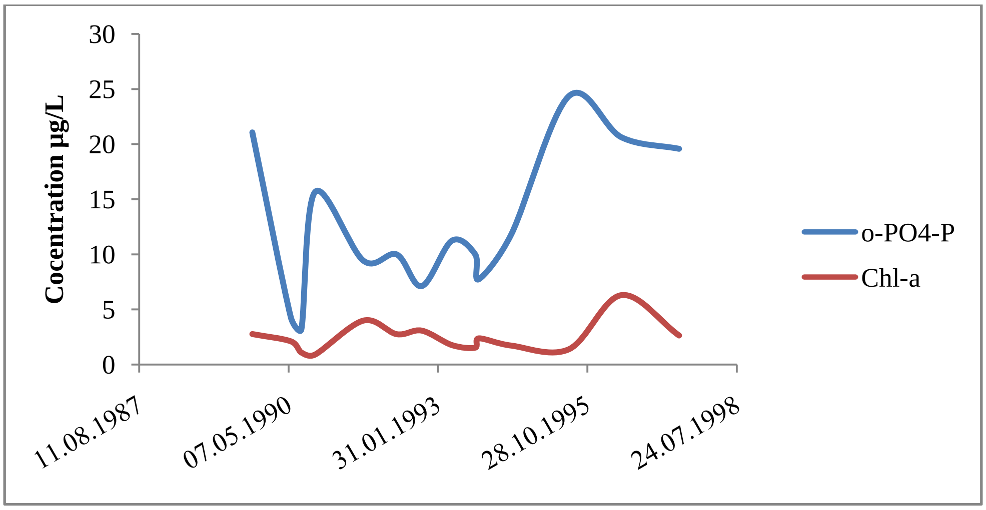


Figure 6.6. Average Phosphorus and Chlorophyll-a values between 1989-1997 in Lake Sapanca

Average total phosphorus is calculated from Figure 6.6 as 12.58 µg/l and average chlorophyll-a is 2.46 µg/l. Secchi Disc depth is related with Chlorophyll-a (Henderson, 1979).

$$SD = \frac{8.7}{(1 + 0.47 \times Chl - a)} \tag{6.21}$$

$$SD = \frac{8.7}{(1 + 0.47 \times 2.46)} = 4.03m \tag{6.22}$$

According to probabilistic classification(OECD,1982) for total phosphorus (Figure 6.7.), possibility of that Sapanca Lake is oligotrophic 46%, mesotrophic 44% and eutrophic10%. Chlorophyll-a classification (Figure 6.8.) ; probabilities are 50% oligotrophic, 40% mesotrophic and 10% eutrophic. Secchi disc classification (Figure 6.9.); probabilities are 13% oligotrophic, 49% mesotrophic and 38% eutrophic.

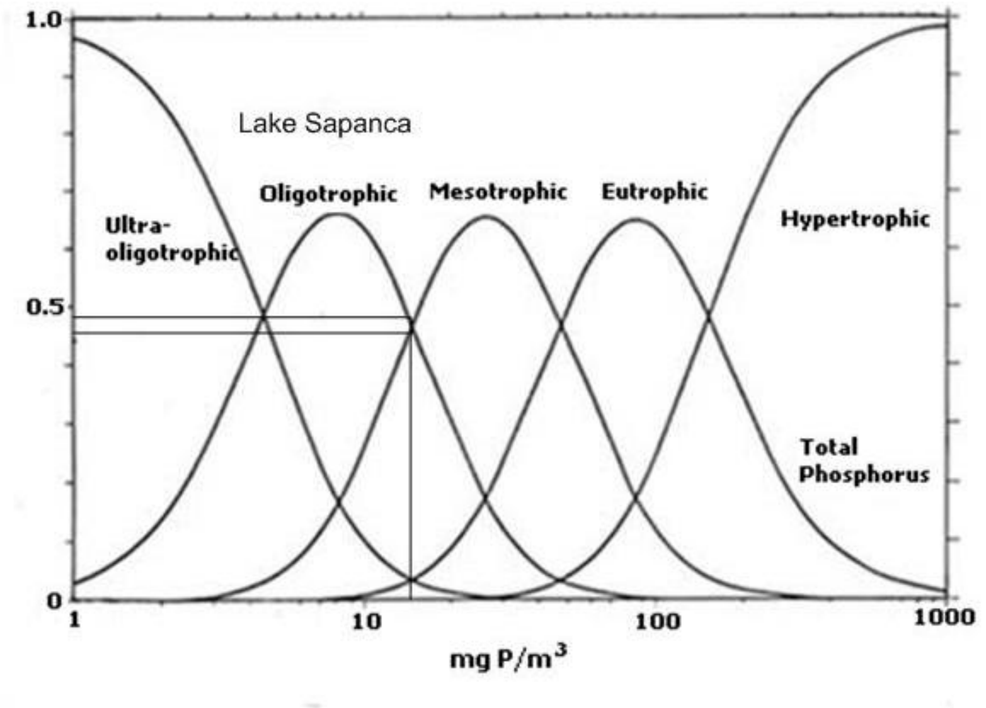


Figure 6.7. Probabilistic Classification for mean phosphorus loading

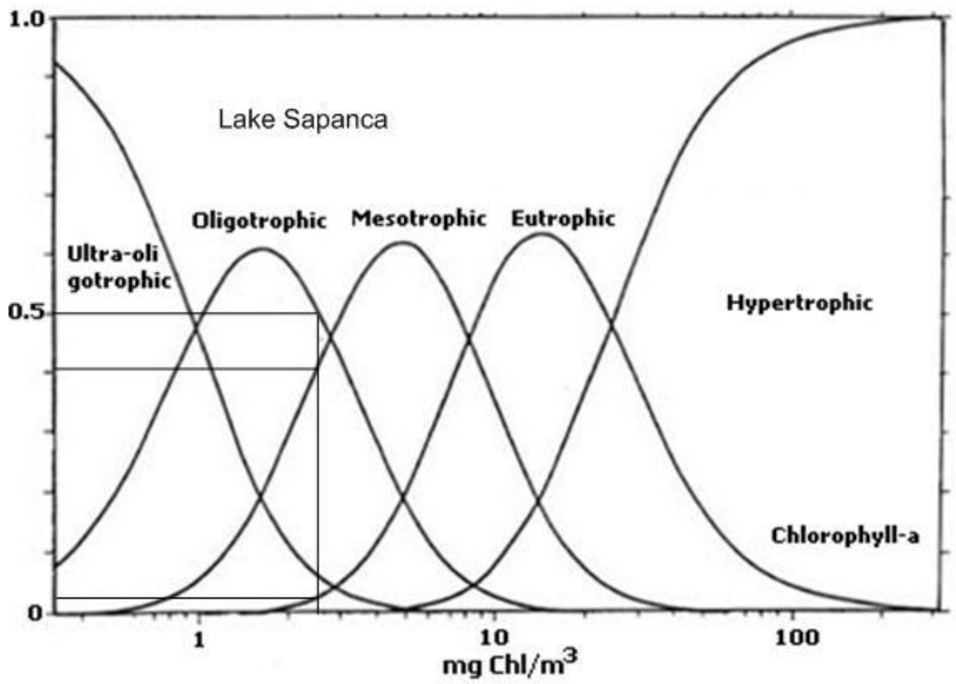


Figure 6.8. Probabilistic Classification for chlorophyll-a

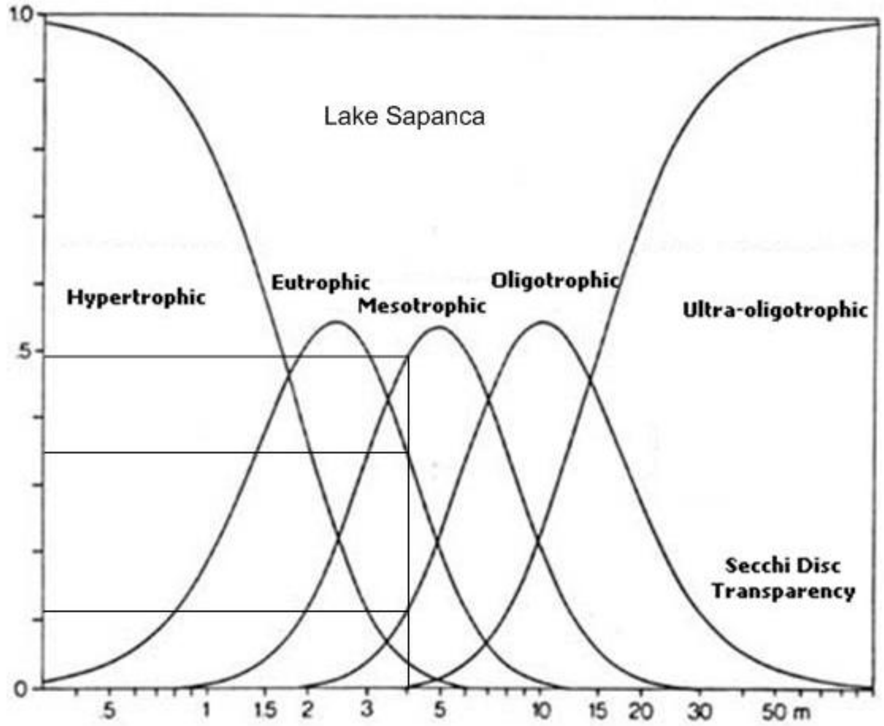


Figure 6.9. Probabilistic Classification for secchi depth.

7. APPLICATION OF PAMOLARE MODELS

7.1. PAMOLARE 1-Layer Model

1-Layer PAMOLARE model can be applied only when thermal stratification did not appear in deep lakes. Therefore this model is used only certain times of lake profile. Generally in Sapanca Lake, thermal stratification can be seen between 6th and 8th months of year. Rest months no certain stratification is seen therefore lake is assumed fully mixed. Therefore rest months data are used for modeling.

7.1.1. Inputs

When the sediment has a high content of organic matter it binds usually more nitrogen than phosphorus but has low dry matter content. It means a reasonable figure in this case would be 10gP/m^2 and 50 gN/m^2 (Jørgensen et al., 2003). Therefore in the model Nsed will be 50 gN/m^2 and Psed will be 10. gP/m^2. According to model Nrel and P rel are related with Nsed and Psed, therefore after calibrations and tuning right values can be found.

According to model, Generally P- bound changes between 15 - 20% and N-bound changes 10-20 % (Jørgensen et al., 2003). But in some cases P and N bound can exceed these limits; therefore they had to be calibrated according to Lake data.

Phosphorus load obtained from stream loads average=0,494 g/ m^2/year from (6.20) and nitrogen load again obtained with same method = 2,689 g/ m^2/year from (6.5).

Sapanca Lake is locating between 30 -40 latitudes. Therefore number of days with high primary production is 240 days (Jørgensen et al., 2003). Sedimentation rate is calculated as:

$$Sed_{rate} = 0.5 \frac{m}{year} \times 240 days = 120 \tag{7.1}$$

Water residence time is calculated as 6.46 year from (6.13) and mean depth is calculated as 26.02 meter (6.14). In this case no thermal stratification is assumed therefore our constant “a”=1. And denitrification is calculated from (4.3) and found (7.2) but PAMOLARE does not allow entering a higher value therefore “Denit” is assumed as “0.9”.

$$Denit = 2{,}689 - 0.34 \times 6.46^{-0.16} \times 26.02^{0.17} = 2.25 \tag{7.2}$$

Model calibrated according to the 1989- 1992 data and verified according to 1992-1995 data. Comparisons are shown in Figure 7.1 and 7.2. Calibrated values are shown in Table 7.1. Input values are shown in table 7.2.

Table 7.1. 1-Layer PAMOLARE Model Calibrated Model Parameters

Parameters	Unit	Range	Initial Values	Calibrated Values
Sed Rate	m/year	48-120	100	120
P sediment	g/m^2	3-50	3	10
P bound		-	0,15	0.2
P release	/year	needs calibration	8	0,005
Nsediment	g/m^2	15-300	50	50
Nbound		-	0.15	0.790
Nrelease	/year	needs calibration	7.5	0.950

Table 7.2. Input values of 1- Layer PAMOLARE model

Phosphorus and Nitrogen				
Phosphorus		Nitrogen		unit
P Water	0.0068	N Water	0.320	mg/L
P Sediment	10.00	N Sediment	50.00	g/m^2
P Loading	0.4940	N Loading	2.690	g/m^2/year
P Release	0.0050	N Release	0.950	g/year
P Bound	0.0030	N Bound	0.790	
		Denitrification	0.900	

Morphology		unit
Lake Depth	26.02	m
Residence Time	6.46	year
Sedimentation time	120	m/year
a	1	

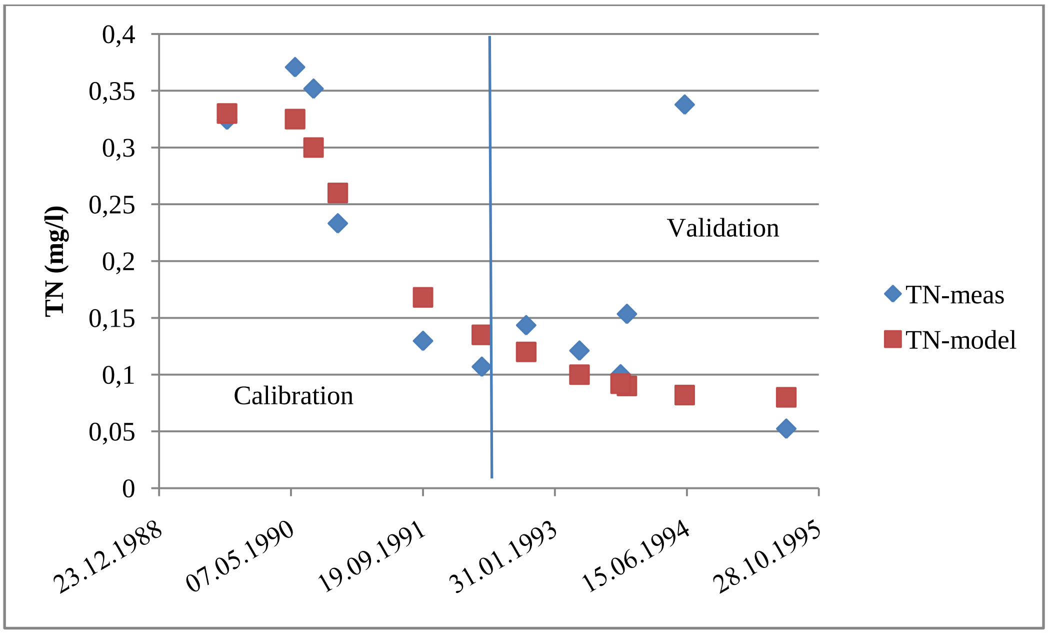


Figure 7.1. Comparison with model TN and measured TN

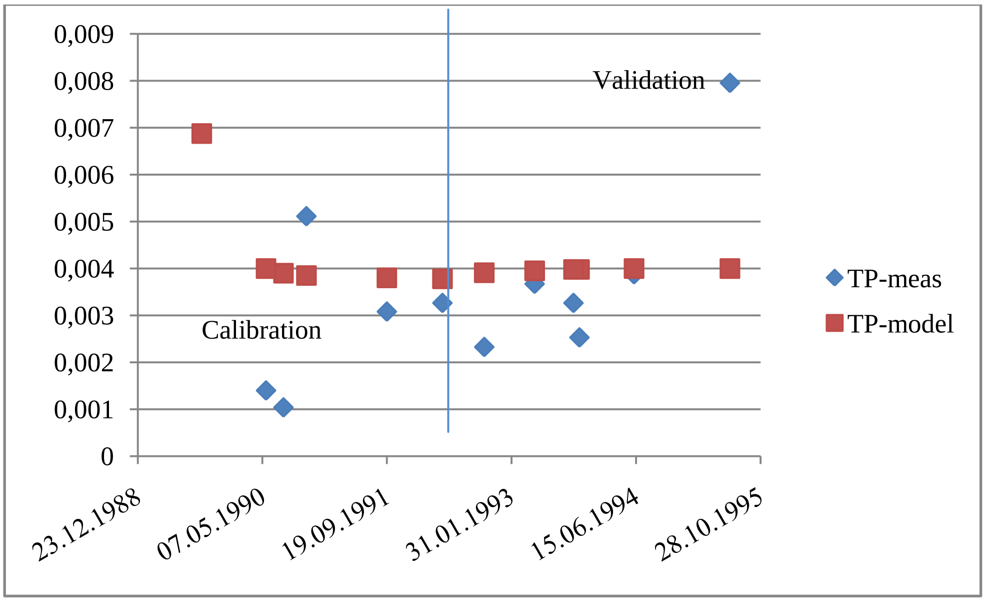


Figure 7.2. Comparison with model TP and measured TP

7.1.2. Discussion and Results

1-Layer Model is a simple model which directly relates organisms with total phosphorus. The model does not take account lake conditions like temperature, solar intensity. Shortly 1-Layer Model generalizes lake structure therefore this model is applicable if data are not adequate. Using complex model would be problem if data are not adequate.

Sapanca is not shallow lake therefore thermal stratification appears on summer terms especially 6th and 8th months of year. In mixing periods the volume is considered as a whole. Depending on the available data for temperature stratification is solid and stable from June to the end of August. So rest of months this model can be applicable for short term estimation. For long term using this model may result to wrong predictions. Model is simulated for 5 years to see the general behavior of model (However, just first four months are acceptable values because after fifth month thermal stratification occurs and also model has to run after thermal stratification) with initial nitrogen 0.32 mg/L and initial phosphorus 0.0068 (Average value of lake data is assumed as 2009 year data). For 4 month period Nitrogen value is 0.37 mg/l, phosphorus value is 0.005 mg/l and other results can be obtained from graphs. Total phosphorus, nitrogen, fish, chlorophyll, zooplankton, secchi depth results are shown in Figure 7.3, 7.4 and 7.5 the other results are shown in Figure C.1. Beside that output of program is shown in Table C.1 and C.2.

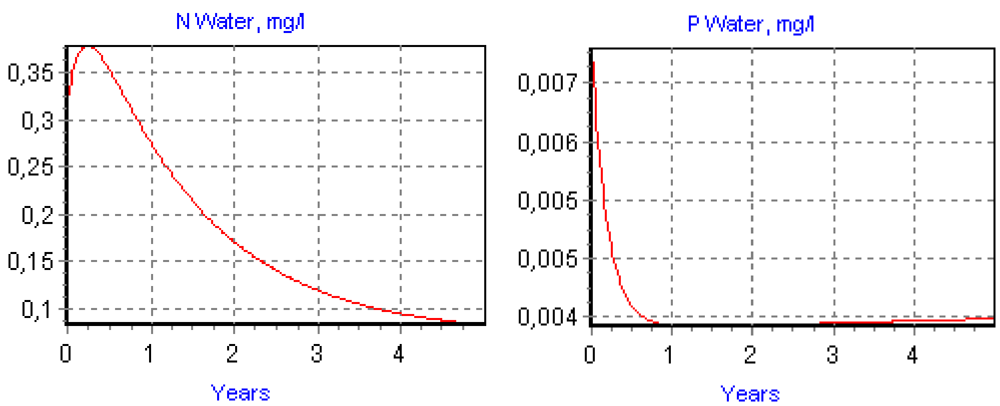


Figure 7.3. Model predictions for nitrogen and phosphorus in lake

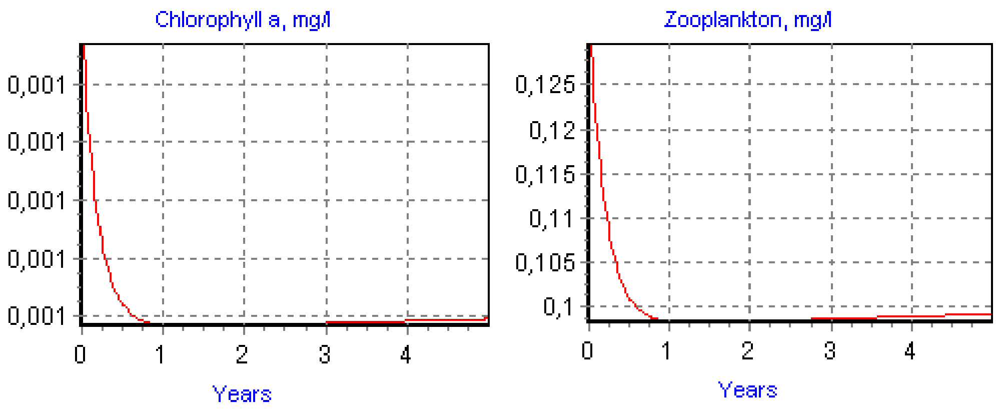


Figure 7.4. Model predictions for chlorophyll and zooplankton in lake

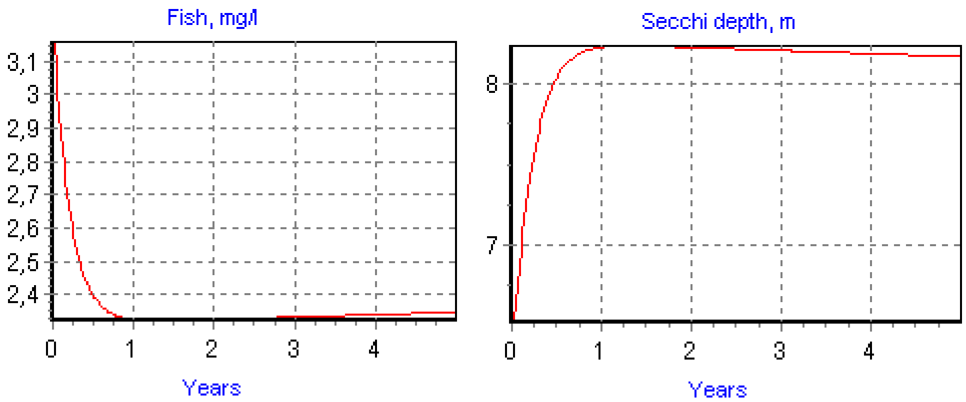


Figure 7.5. Model predictions for fish and secchi depth in lake

According to Figure 7.1, it can be seen that nitrogen values are so close to estimated values,(although model was used for short term it gave close values for long term) but same thing not exist for phosphorus and chlorophyll-a values. This may be stem from wrong regression selection of the model because Swedish lake profiles are not same with Sapanca Lake’s profile. Besides, model neglects phytoplankton’s effect on chlorophyll and phosphorus.

To sum up, PAMOLARE 1 layer model is a good model to estimate short term values of phosphorus and nitrogen with less data. This model provides understanding general behavior of lake. But using this model for estimation fish or chlorophyll in lake may cause wrong predictions.

7.2. PAMOLARE 2-Layer Model

In PAMOLARE 2-Layer Model lake is considered as two parts. The epilimnion and hypolimnion are rarely mixed in lake therefore only limited water is transported through the thermocline during the stratification season. Lake was modeled according to epilimnion and hypolimnion borders with daily environmental data.

7.2.1. Inputs

7.2.1.1. Morphology. Lake volume, area and depth were determined by Table 7.3. Using Figure 5.1 and Table 7.3, Sapanca Lake volume is modelled with AutoCAD and shown in Figure 7.6 to create a basic idea about lake morphology.

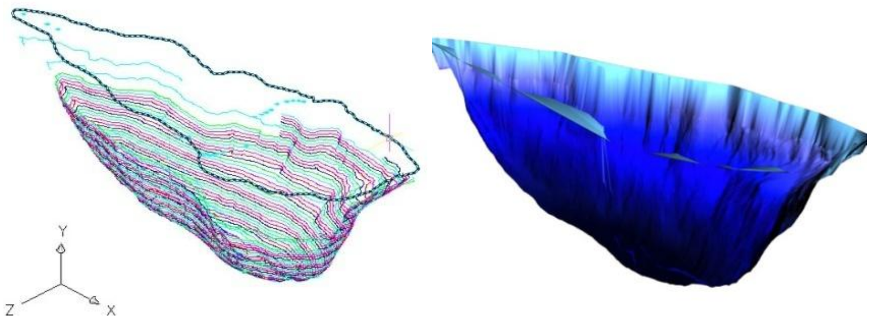


Figure 7.6. 3-D Model Of Sapanca Lake

Table 7.3. Relation of height with area and volume (DSI, 1984)

Height(m)	Volume(m^3)	Area(m^2)
-20	-	0
-18,18	0	0,265
-16,18	7	4,6
-15	13	5,15
-10	47	7,9
-5	95	11,2
0	164	15,1
2	200	17,7
-3	218	19,8
4	240	21,15
5	263	22,1
10	384	26
15	518	29,2
20	676	32,7

Height(m)	Volume(m^3)	Area(m^2)
25	846	37
29,5	1035	41,55
29,9	1051	41,9
30	1054	42,1
30,7	1086	42,9
31	1100	43,2
31,29	1112	43,59
31,5	1120	43,85
31,9	1136	44,35
32	1140	44,4
32,5	1162	45,05
33	1183	45,65
33,5	1204	46,3
33,82	1218	46,8

In section 5.4 thermal stratification is expressed and epilimnion depth is assumed as 18.82 for Sapanca Lake model. PAMOLARE model uses epilimnion volume and hypolimnion for estimations. But model inputs are surface area and mean water depth. Model finds volume by multiplying these inputs. Therefore firstly Sapanca Lake volume is divided according to 18.82 m depth. After that volume of hypolimnion and epilimnion is calculated from Table 7.3. As seen from Figure 7.7 middle area of each layer is selected. Then each volume is divided to these layers to find mean depth.

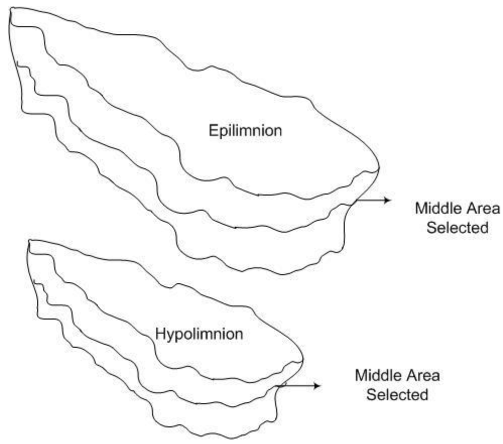


Figure 7.7. Calculation of hypolimnion and epilimnion volume

Circulation flow is an artificial flow for calibrating the concentrations. The mixing rate, K_d, is assumed to be 7 for lakes with a mean depth less than 50 m and equal to 1.9 times ΔH, the distance between the center of the upper and lower layers, in meters, for lakes with a mean depth greater than 50 m (Jørgensen et al., 2003). Our lake's depth is 53 m and it is so close to 50 m, so mixing rate is assumed as 7. And sediment depth is generally set at a value around 5-10 cm.

Table 7.4. Morphology Input of Lake

	Epilimnion	Hypolimnion
Mean Water Depth(m)	20.62	32.68
Surface Area(m^2)	37,200,000	13,800,000
Circulation Flow, (m^3/d)	0	0
Mixing rate T<=20^{0}C	7	0
Mixing rate T>20^{0}C	0	0
	Sediment Depth	0.05

7.2.1.2. Initial Values. Initial values are taken from DSI in lake data. For calibration and validation 1989 and 1992 year data is used respectively. Initial value of 1989 year is shown in Table 7.5 as an example.

Table 7.5. Sample Initial Values (for year 1989)

	Epilimnion	Hypolimnion
TP(mg P/L)	0.00707	0.006526
TN(mg N/L)	0.346462	0.399786
T (^{0}C)	21.85118	9.95
DO(mg O_2/L)	8.701236	4.352611
Diatom(mg/L)	0.001656	0.000532
Blue-GreenAlgae(mg/L)	0.000552	0.000177
Other Phytoplankton (mg/L)	0.000552	0.000177
Detritus (mg / L)	1.184	1.184
Dissolved Organics (mg / L)	0.623158	0.623158
Zooplankton (mg/L)	0.132868	0.126232
Phosphorus in Sediment (mg P/L-sed)	0	10
Nitrogen in Sediment (mg N/L-sed)	0	50
Dissolved Organics in Sediment (mg C/L-sed)	0	70

When the sediment has a high content of organic matter it binds usually more nitrogen than phosphorus but has low dry matter content. It means a reasonable figure in this case would be 10gP/m^2 and 50gN/m^2 (Jørgensen et al., 2003). Organic matter content is 7 times larger than Psed values, and according to Jørgensen 10gP/m^2 and 50 gN/m^2 for eutrophic lakes 70gC/m^2

Water content values of sediment samples from Sapanca Lake vary from 60.35% to 98.62% by weight (1.38% - 39.65% dry matter content), the average being 89.59% (10.41% dry matter content). It is found that the maximum and minimum values of organic matter content of the sediment samples of Sapanca Lake is 12.13% and 3.81%, the average values being 6.45% (Bakan, 1995). Table 4.8 is used for determining sediment content.

7.2.1.3. Inflow and Outflow Rates. Average inflow and outflow rates of streams are applied in PAMOLARE model. Inflow rates of streams for year 1992 are shown in Table 7.6. Flow distributions for years and months are shown in Figure D.1.

Table 7.6. Inflow rates of streams in Sapanca watershed (Öktem, 1996)

Months	**İstanbul,Sarp, Keçi,Arifiye**	**Karaçay,Yanık**	**Mahmudiye**	**Kurt, Kuruçay**	**Balıkhane**	**Maden, eşme**	**Total (m^3/sec)**
1	0,358	0,575	0,507	0,546	1,044	0,378	3,408
2	0,55	0,883	0,779	0,838	1,604	0,581	5,235
3	0,789	1,267	1,118	1,203	2,302	0,833	7,512
4	0,329	0,528	0,466	0,502	0,96	0,347	3,132
5	0,139	0,223	0,197	0,212	0,406	0,147	1,324
6	0,659	1,057	0,932	1,004	1,92	0,695	6,267
7	0,651	1,045	0,922	0,993	1,899	0,687	6,197
8	0,001	0,02	0,001	0,002	0,004	0,001	0,029
9	0,174	0,28	0,247	0,266	0,509	0,184	1,66
10	0,08	0,128	0,113	0,122	0,233	0,084	0,76
11	0,434	0,696	0,614	0,661	1,265	0,458	4,128
12	0,851	1,365	1,204	1,296	2,48	0,898	8,094

7.2.1.4. Temperature and Solar Intensity. Temperature data is obtained from Cark Stream data which is shown in Table D.3. For obtaining daily data PAMOLARE program uses sinus functions. Sinus function is shown in (7.3) and result of separation is shown in Figure 7.15. Formula assumes that when a "T" value is smaller than "0", then "T" equals to "0" (Jørgensen et al., 2003).

$$T = T_{mean} + \left(\frac{T_{min} + T_{max}}{2}\right) \times sin\left(2 \times \pi \times \frac{J_{day} + Of_{day}}{365}\right) \qquad (7.3)$$

Where

J_{day}: Julian day of the observation:

Of_{day}: Offset for the seasons when mean temperature occurs (approx. 90-120 days for lakes in northern hemisphere, and 270-300 days in southern hemisphere).

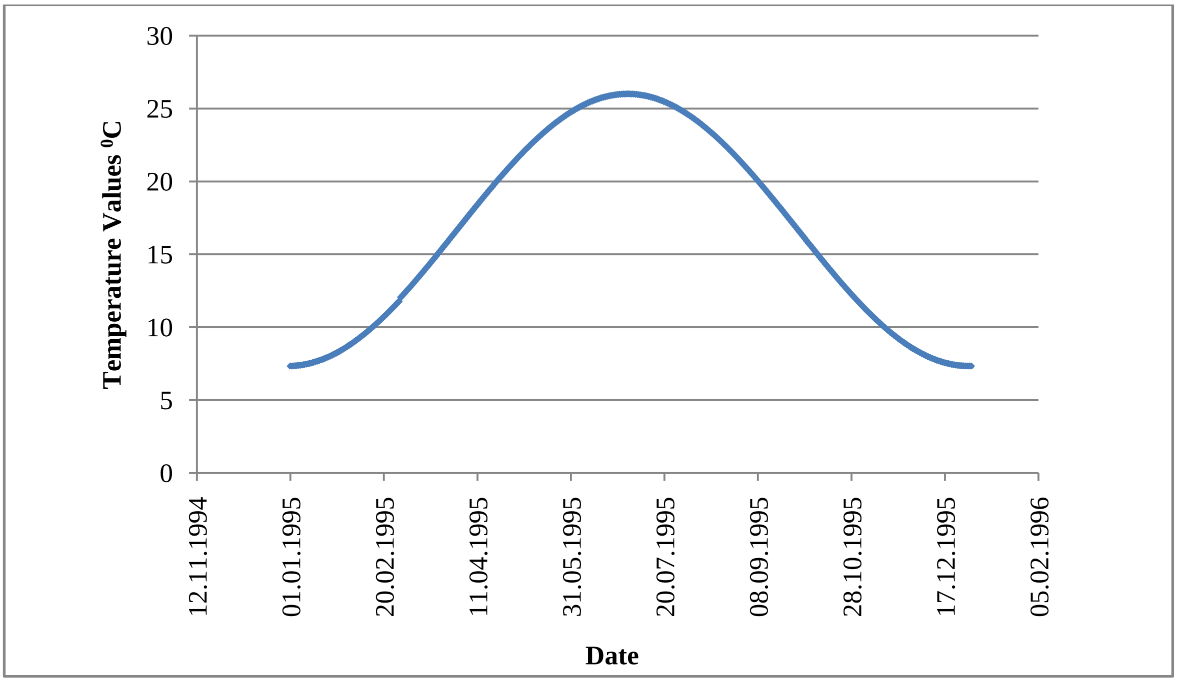


Figure 7.8. Temperature distribution of Sapanca Lake with sinus function

Annual average wind speed is shown in Figure 5.3. And applied to days assuming that whole days of the month, wind speed was not change.

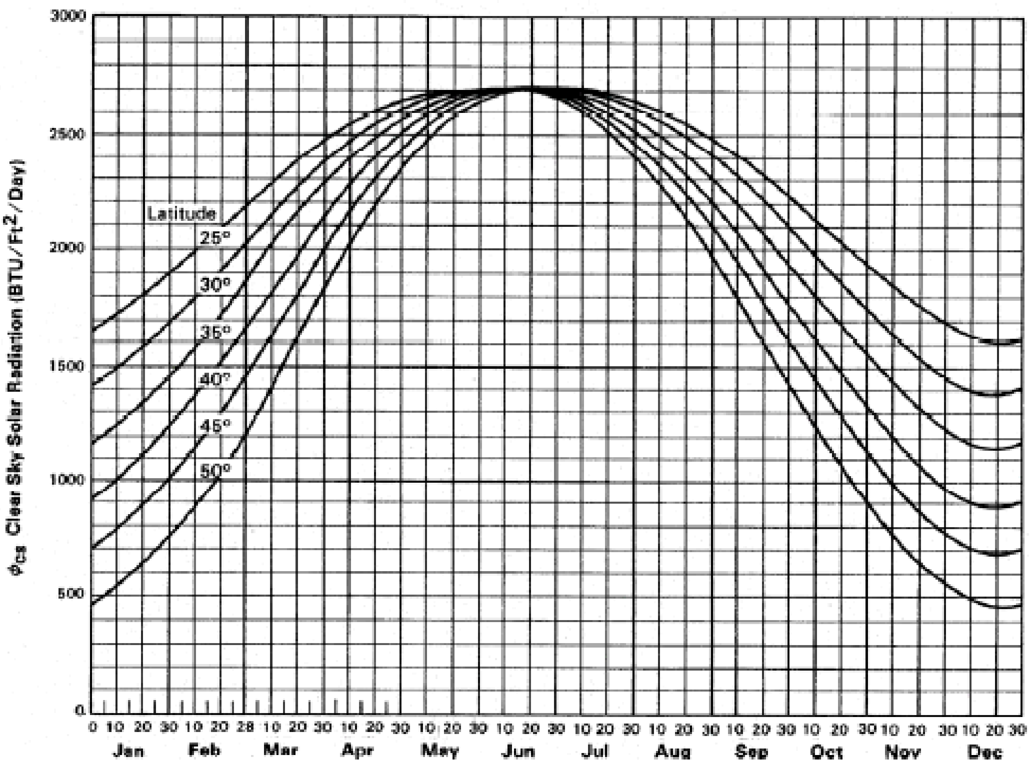


Figure 7.9. Solar intensity with respect to Latitudes (Hamon et al., 1954)

Daily solar intensity rates of Sapanca Lake were not measured, therefore Solar intensity and Latitude graph (Figure 7.9) is used. Sapanca Lake is locating at the 30° latitude, from the figure, it can be seen solar intensity in February is about 1900 BTU/ft^2/day. All the daily solar radiation inputs were read from graph and used as input for model. Solar radiation unit is Mj/m^2/day in model, therefore unit conversations applied, and February values are shown below:

$$1\,BTU \; = \; 0.001055009\,Mj \tag{7.4}$$

$$1900\,\frac{BTU}{ft^2}/day = \; 2.0045\;\frac{Mj}{ft^2}/day \tag{7.5}$$

$$1\,ft^2 \; = \; 0.0929m^2 \tag{7.6}$$

$$2.0045\;\frac{Mj}{ft^2}/day = \; 21.57\;\frac{Mj}{m^2}/day \tag{7.7}$$

7.2.1.5. Chlorophyll-a and Phytoplankton. Chlorophyll-a is so important for eutrophication modeling, it is used in form of phytoplankton, diatoms and blue green algae. For estimation of some chlorophyll-a data's some regression methods are used.

Edmondson's Statistical illustrated the relationship between chlorophyll-a concentration and the total phosphorus concentration.

$$Chlorophyll\;(mg/l) = \; 0.000073 \; \times \; (TP \; \times \; 1000)^{1.4} \tag{7.8}$$

Dillon and Rigler (1974) make some suggestions and find that Chlorophyll-a and total phosphorus relation

$$Chl - a(mg/l) \; = \; 0.0731 \times \; TP^{1.499} \tag{7.9}$$

And OECD (1982) derived another equation

$$Chl - a \; = \; 0{,}28 \times TP^{0.96} \tag{7.10}$$

These regressions are designed according to the European Lakes, but Sapanca Lake has different characteristics, therefore another regression model is designed from Sapanca Lake's data of 1989- 1997 years (14 years data). Some data's are eliminated until to reach a suitable correlation as shown in formula and R square is 0.72. Chlorophyll-a versus total phosphorus graph is shown in Figure 7.10.

$$Chl - a \; = \; 1{,}4803 \times TP^{0.5485} \tag{7.11}$$

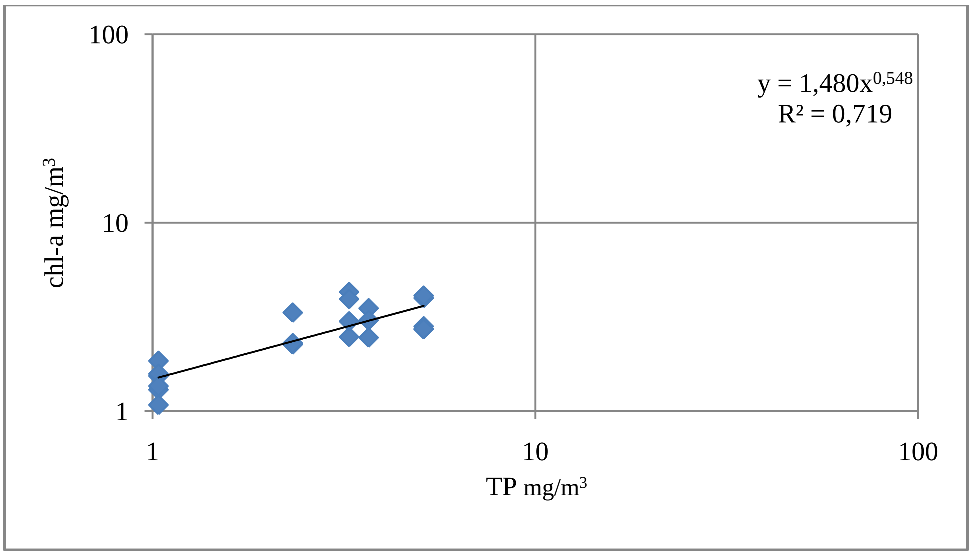


Figure 7.10. Regression of Chlorophyll-a values with TP values

Table 7.7. Comparison of regression models

Date	Measured Chl-a (µg/L)	Sapanca Regression (µg/L)	Edmonson (µg/L)	Dillon Rigler (µg/L)	OECD (µg/L)
06/09/1989	2,64	4,04	1,09	1,32	1,78
22/05/1990	6,3	1,69	0,12	0,12	0,39
31/07/1990	1,4	1,43	0,08	0,08	0,29
31/10/1990	1,72	3,43	0,72	0,84	1,34
17/07/1991	2,38	0,52	0,01	0	0,05
19/09/1991	1,54	2,60	0,35	0,39	0,82
29/04/1992	1,77	2,68	0,38	0,43	0,87
14/10/1992	3,08	2,23	0,24	0,26	0,63
04/05/1993	2,76	2,86	0,45	0,51	0,98
07/10/1993	3,99	2,68	0,38	0,43	0,87
07/06/1994	0,91	2,95	0,49	0,56	1,03
27/06/1995	1,1	4,37	1,33	1,64	2,05
12/06/1996	2,11	3,99	1,05	1,27	1,75
02/07/1997	2,77	4,10	1,13	1,37	1,83

Chlorophyll-a estimated values are compared with measured data (Table 7.7). Sapanca Regression is more accurate than other analyses. This regression is applicable, but in some years chlorophyll values are so different from real values.

After that, a model is designed according to Sapanca Lake data by using Matlab® program. Fitting curve is shown in Figure 7.18. This model's main advantage is fitting chlorophyll-a values according to mean total phosphorus values without eliminating data. Model uses fifth order Fourier series to obtain missing data (7.12). That is nearly an exact correlation with R square 0.91.

$$Chl - a =$$
$$1.746 + 1.131 \times cos(TP \times 0.7309) + 1.42 \times sin(TP \times 0.7309) -$$
$$1.496 \times cos(2 \times TP \times 0.7309) + 0.1837 \times sin(2 \times TP \times 0.7309) -$$
$$0.313 \times cos(3 \times TP \times 0.7309) - 0.6921 \times sin(3 \times TP \times 0.7309) -$$
$$0.2792 \times cos(4 \times TP \times 0.7309) - 1.256 \times sin(4 \times TP \times 0.7309) +$$
$$2.251 \times cos(5 \times TP \times 0.7309) + 0.4443 \times sin(5 \times TP \times 0.7309) \quad (7.12)$$

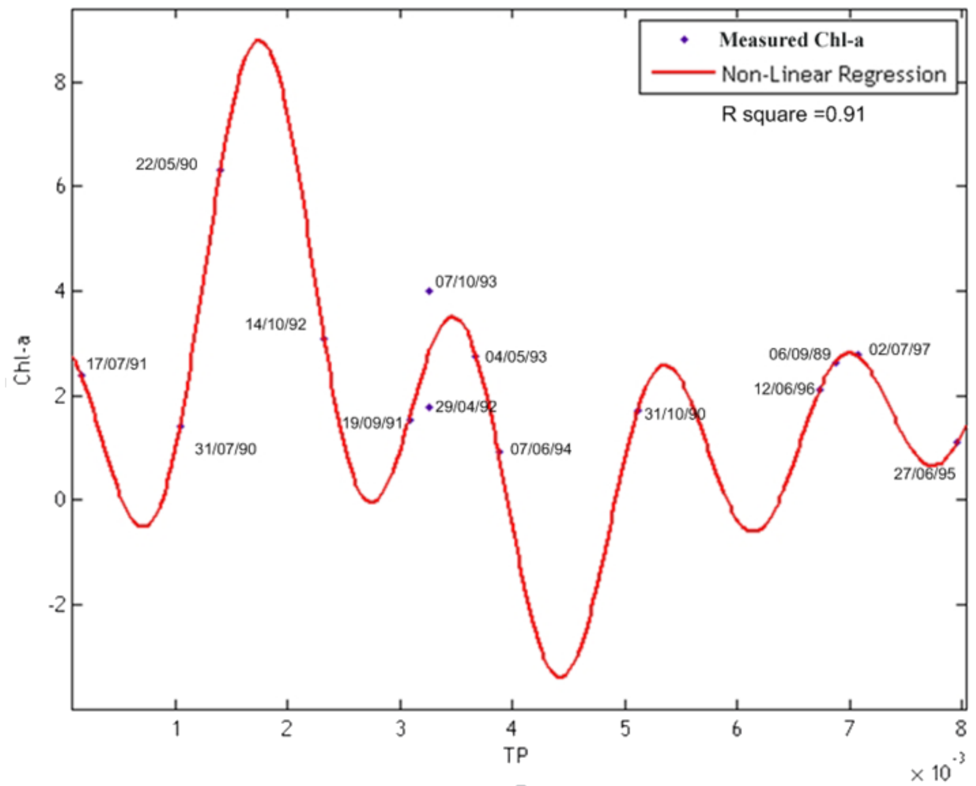


Figure 7.11. Estimation of chlorophyll-a values by total phosphorus values using Matlab

Model uses phytoplankton types' chlorophyll-a contents. Phytoplankton inputs are separated to three main groups namely: blue green algae, diatoms and other phytoplankton. Total chlorophyll-a obtained by non linear regression. Phytoplankton types of Sapanca Lake between 1995 and 1997 years are listed in Table D.1. Blue green algae species in Sapanca Lake are cyanophyceae and clorophyceae. Diatom specie in Sapanca Lake is diatomea and other phytoplankton types are dinophyceae, chrysophyceae, xanthophyceae and euglenophyceae. There is a direct relation with chlorophyll-a values and phytoplankton amount (Akbulut, 2003). From the amount of phytoplankton each species percentage are calculated (Table D.2.) and these ratios are multiplied by total chlorophyll-a values to explain phytoplankton as chlorophyll-a to use in model.

7.2.1.6. Zooplankton, Detritus and Dissolved Organics. Zooplankton is assumed from literature. The empirical models are a number of relations made from statistical regression analyses (Edmondson, 1986). And a correlation obtained between BOD, Detritus and Dissolved Organics from literature (Clough and Park, 2005).

$$Zooplankton\,(mg/l) = 0.038 \times (TP \times 1000)^{0.64} \tag{7.13}$$

$$Detritus = BOD \times 0.74 \tag{7.14}$$

$$Detritus = Dissolved\,Organics \times 1.9 \tag{7.15}$$

7.2.2. Applied Scenarios and Methods

PAMOLARE program uses daily data for modeling. D.S.İ. collected in-lake data and streams data at a certain time of years. Number of data is limited due to this reason. Adasu and D.S.I. believes that Cark Stream is an important stream and due to that they collect monthly data of Cark Stream (Table D.3.). Cark stream has 10 times more data than other streams and lake. Cark Stream's total phosphorus, total nitrogen, BOD5, temperature, dissolved oxygen values are shown graphically in Figures 7.13, 7.14, 7.15, 7.16, 7.17. Cark stream is an outflow stream of Lake Sapanca which can show same characteristics of lake therefore in some cases Cark stream can be used for missing data. (Temperature, Solar intensity, BOD, etc.). Also when input load increases the effect of this increase can be seen in Cark Stream. For minimizing uncertainty, year 1995 – 1997 data are selected for modeling.

Due to the missing data, some assumptions are made to construct the model data. Each assumption's scenarios were investigated. First assumption is taking average of monthly loads to characterize annual loading of lake. Second assumption is applying the cark stream trend to estimate missing data.

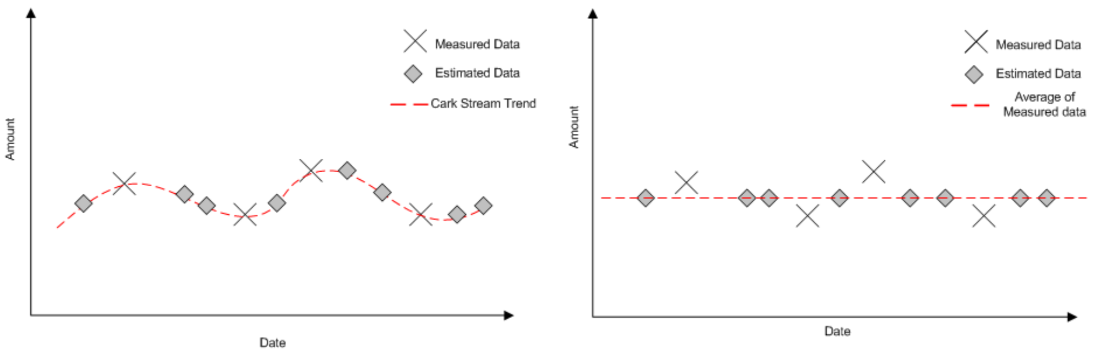


Figure 7.12. Comparison of missing data assumptions.

Model needs phytoplankton loading from streams but no such information is available. Therefore, one assumption is the streams have no phytoplankton load into lake. Other assumption is rivers load may behave as Lake Sapanca, therefore phytoplankton load was estimated from chlorophyll-a amount and applied to the model.

And lastly according to assumptions, future estimation is constructed. No such information about year 2009 is obtained. Therefore 2009 year data is assumed as same as average of data. For first scenario, if loading continues as same as past data. Load is doubled in second scenario and load is halved in third scenario. Each scenario is applied for each assumption; lastly 12 results are obtained shown in Figure 7.18.

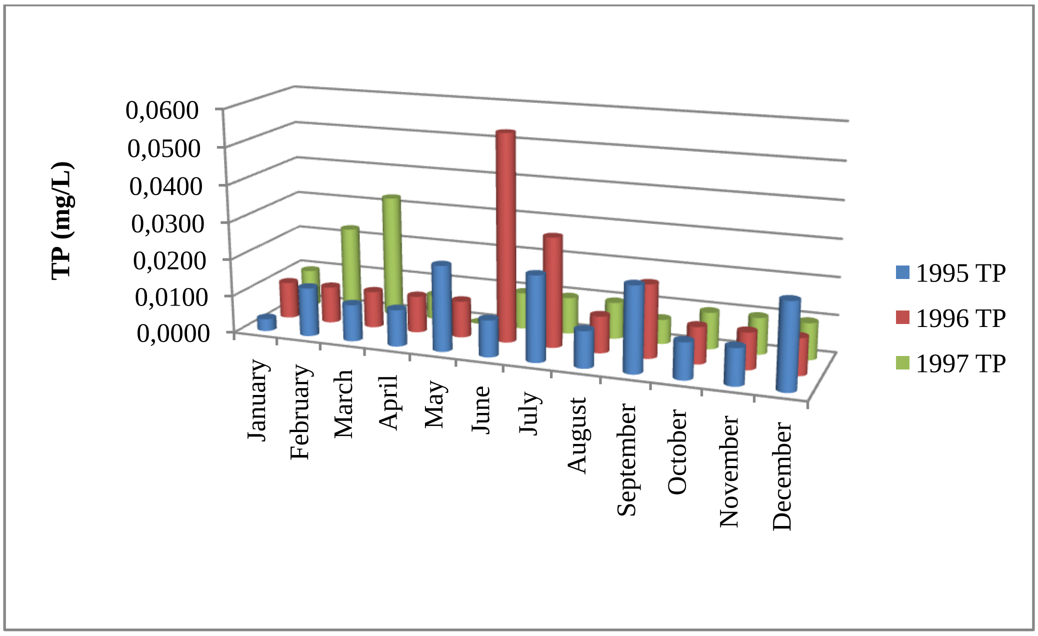


Figure 7.13. TP values in Cark Stream between years 1995-1997

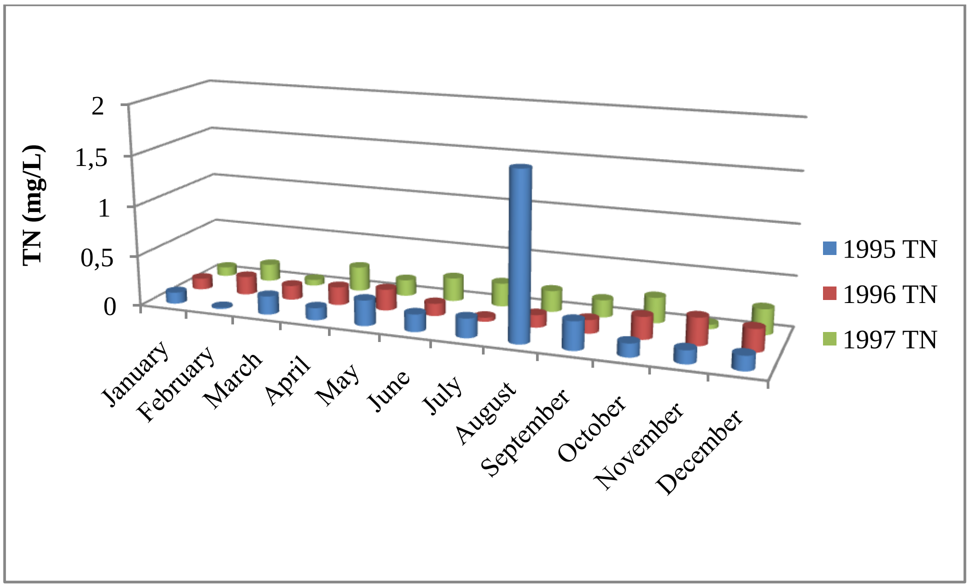


Figure 7.14. TN values in Cark Stream between years 1995-1997

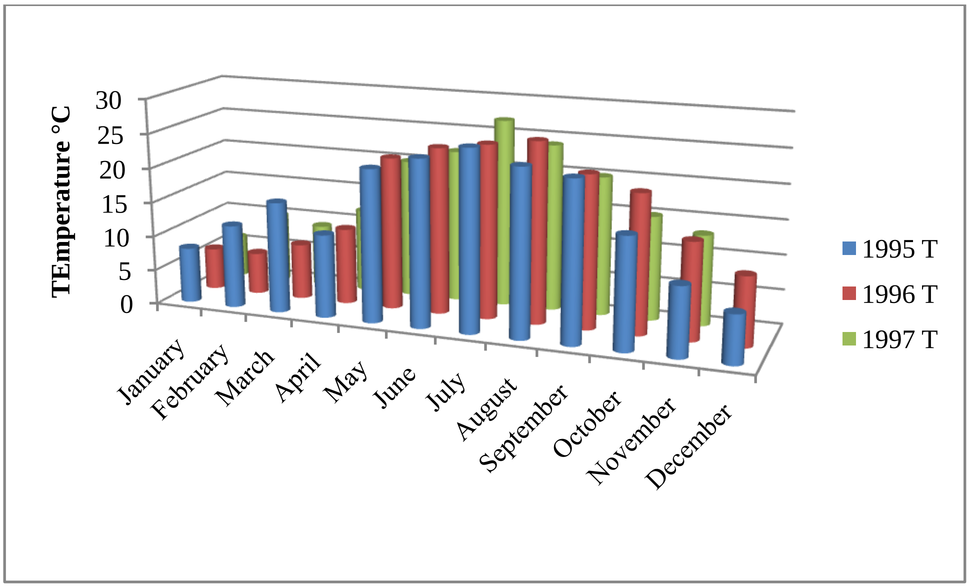


Figure 7.15. Temperature values in Cark Stream between years 1995-1997

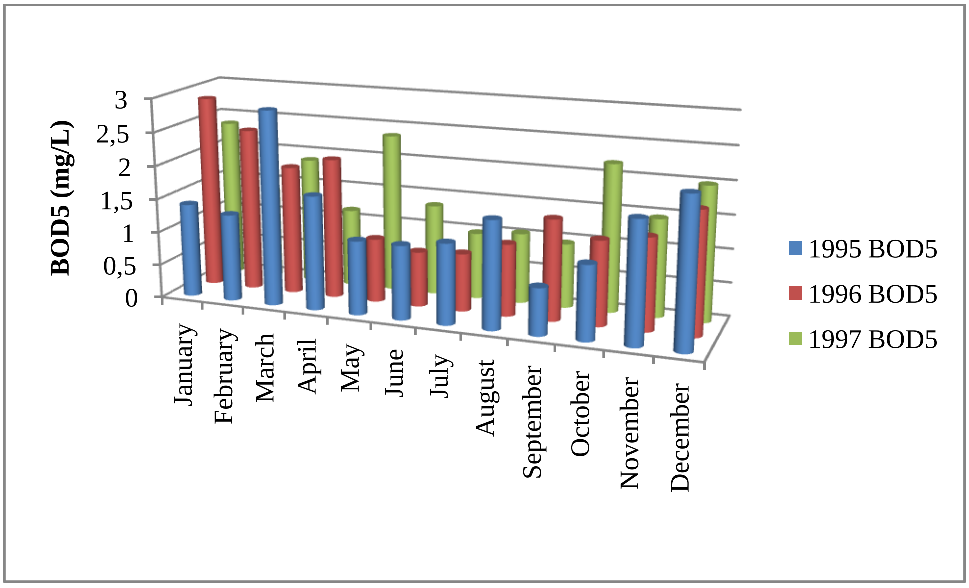


Figure 7.16. BOD5 values in Cark Stream between years 1995-1997

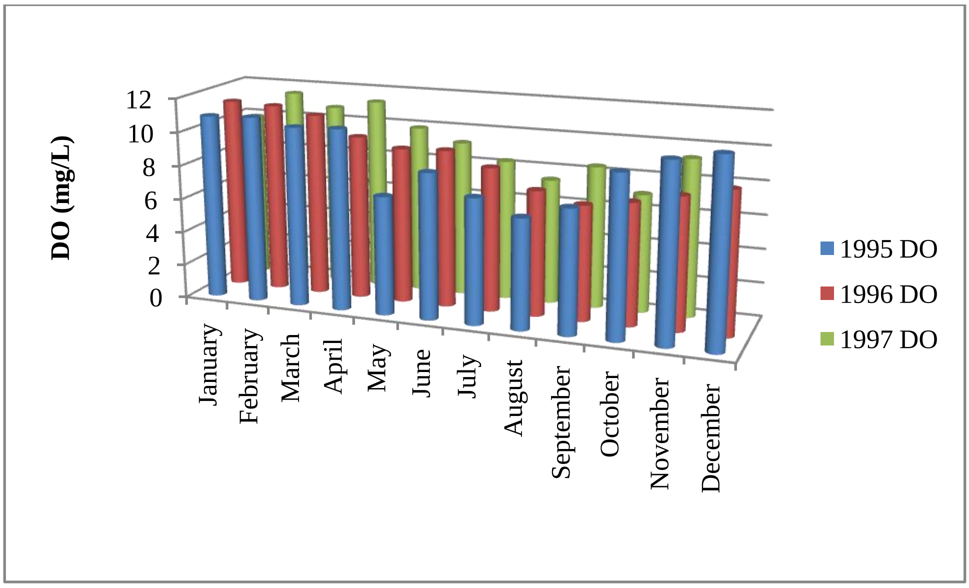


Figure 7.17. Dissolved Oxygen values in Cark Stream between years 1995-1997

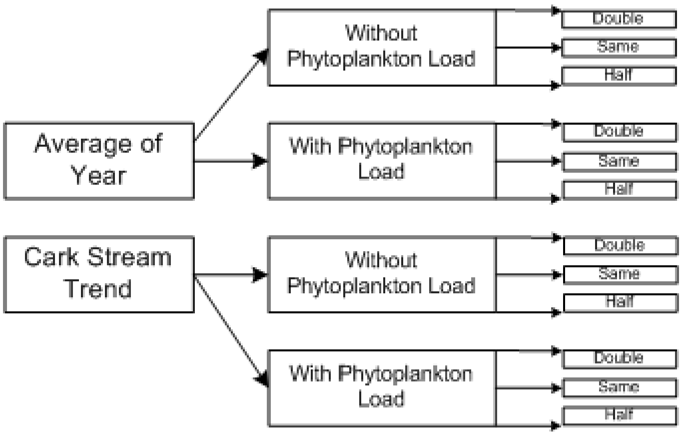


Figure 7.18. Applied Methods and Scenarios

7.2.3. Calibration and Validation

1989- 1992 year data is used for calibration method. 1992-1995 year data is used for validation method. In calibration, mean nitrogen and phosphorus of hypolimnion and epilimnion values used. The initial and calibrated data are shown in Table 7.8. And matching with measured data is shown in Figure 7.19 and 7.20. After calibrating, for validation no changes added. This calibration and validation step also exists in all assumptions.

Table 7.8. Calibrated data of PAMOLARE program

		Symbol	unit	Range	Initial	Calibrated
Dissolved Organic	Decomposition Rate	$\kappa_{\delta X}$	1/d	0.01-0.5	0.1	0.04
Detritus	Sedimentation Velocity	ϖ_{sD}	m/d	0.02-0.5	0.5	0.5
	Decomposition Rate	κ_{dD}	L/(d•mgDW)	0.01-0.5	0.5	0.01
Zooplankton	Maximum Growth Rate	$\Phi_{\mu Z}$	1/d	0.1-1.0	1	0.1
Other Phytoplankton	Maximum Growth Rate	μ_{M1}	1/d	1.0-5.0	1.5	1
Diatom	Maximum Growth Rate	μ_{M1}	1/d	1.0-5.0	1	3

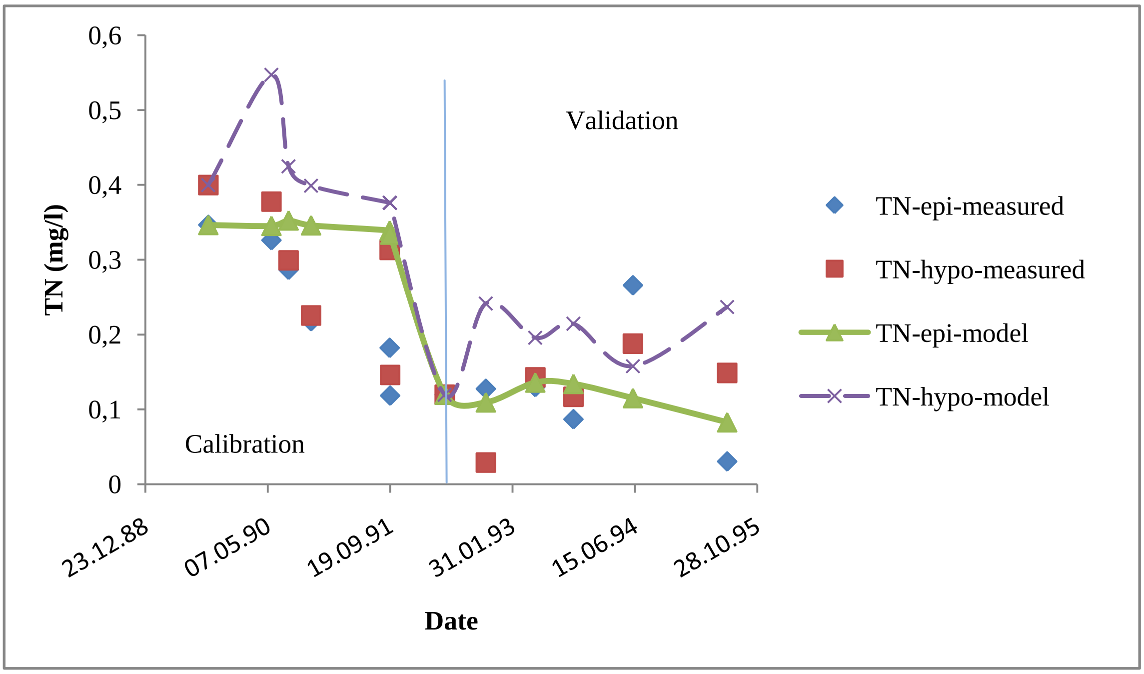


Figure 7.19. Calibration and validation of TN values

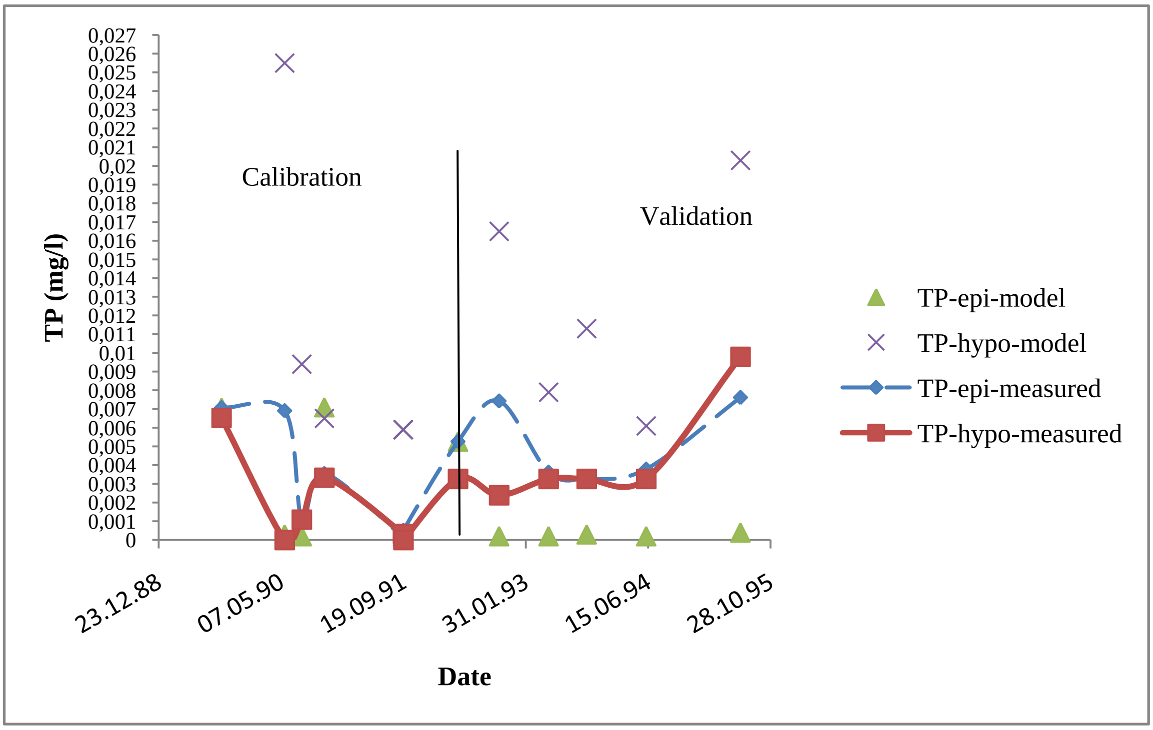


Figure 7.20. Calibration and validation of TP values

7.2.4. Results and Discussions

Initial data is selected from average data of all years because no exact data of year 2009 is available. Model uses daily environmental data input for estimating the future. And for decreasing uncertainty three year past data used. Therefore model can make three years estimation.

Table 7.9. Initial Values for year 2009

	Epilimnion	Hypolimnion
TP(mg/L)	0.00445	0.004472
TN(mg/L)	0.19137	0.225611
T(^{0}C)	16.90	8.44
DO(mg/L)	10.34	6.77
Diatom(mg/L)	0.001296	0.0001542
Blue-GreenAlgae (mg/L)	0.000432	0.000514
Other Phytoplankton (mg/L)	0.000432	0.000514
Detritus (mg/L)	0.919	0.919
Dissolved Organics (mg/L)	0.484	0.484
Zooplankton (mg/L)	0.093	0.0867

From 4 assumptions and 3 scenarios, 12 results are obtained and shown in figures. Also all results are investigated respectively, beside that some comparisons were done.

Generally in all results, it can be seen that phosphorus is always limiting element in the model. And it is obvious that temperature is main factor in eutrophication process. When the temperature reaches highest value in year, phosphorus and nitrogen amounts reach peak values. This stems from the death of organisms and decomposition of dissolved organics and all of these are related with effect of temperature.

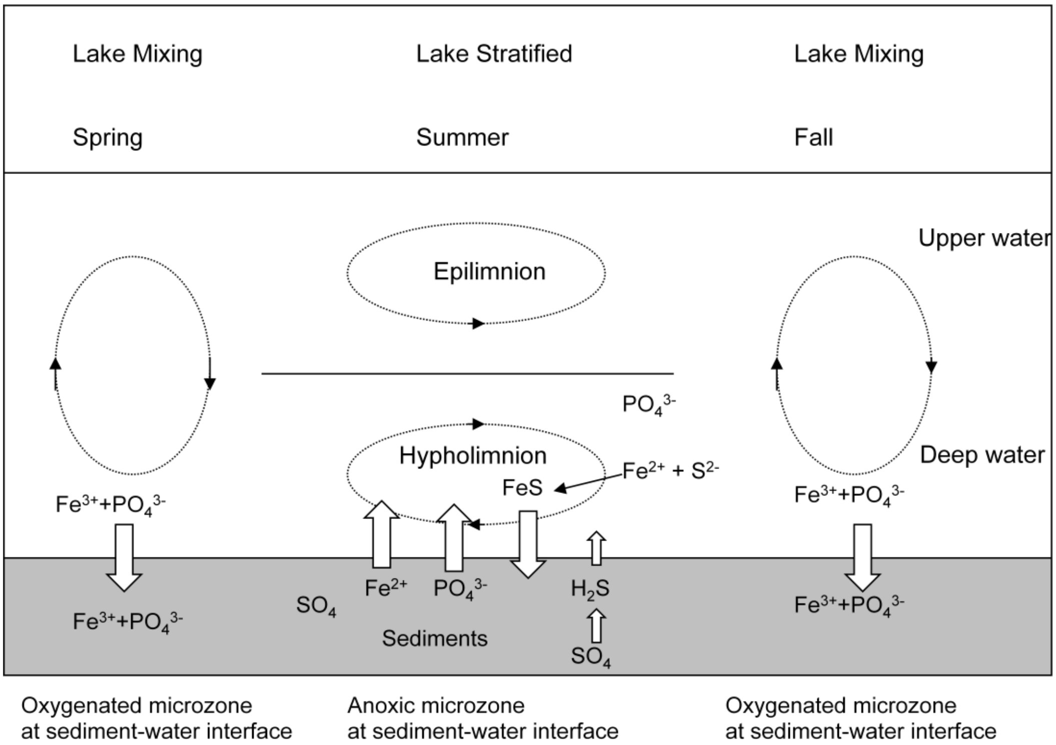


Figure 7.21. The interaction of iron, sulfur and phosphorus in eutrophic lakes (Horne and Goldman, 1994)

In spring term the phosphorus passes through the sediment and phosphorus concentration of hypolimnion decreases. In summer term opposite reaction occurs and phosphorus concentration in hypolimnion increases. The result of the model is consistent with expected lake character (Horne and Goldman, 1994). From Figure 8.2 it can be seen that between 150-240 days which refers the summer term, the phosphorus concentration increases.In fall term, the concentration decreases rapidly up to next year summer term as expected.

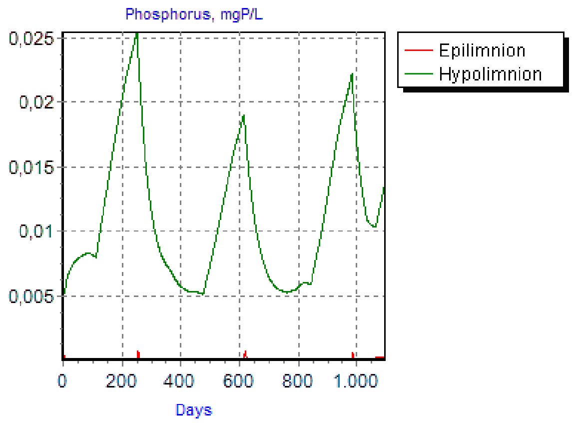


Figure 7.22. Phosphorus concentration

Always hypolimnion concentration is higher than epilimnion due to release of nitrogen and phosphorus from sediment and beside that growth of phytoplanktons (which utilizes nutrients) occurs in epilimnion layer. In general, due to the concentration of limiting element in epilimnion the concentration of phytoplankton decreases.

When the limiting element (phosphorus) in the epilimnion reaches the peak point, with same tendency the phytoplankton concentration reaches top point. Zooplankton and phytoplankton amount has a direct relation. From nutrient chain, zooplankton concentration increases by grazing of phytoplanktons.

Dissolved oxygen amount of epilimnion is generally higher than hypolimnion as expected due to the reaeration and photosynthesis in epilimnion and the oxygen consumption by sediment. Dissolved Oxygen drops to minimum level when the BOD reaches high level. As expected when the oxygen producers (phytoplanktons), concentration decreases the dissolved oxygen concentration decreases. This proves that the result is logical.

Dissolved organics are related with release of dissolved organics from sediment, decomposition of detritus and dissolved organics. And its trends look like phytoplanktons and detritus trend. Detritus decreases when the amount of the living organisms decreases. If living organisms amount increases detritus also increases parallelly.

Sapanca Lake Watershed data is measured by general directorate state hydraulic works. They observed data at certain time of year. Therefore all months of year were not constructed and missing data arises. To get a general character of lake, average data of streams were applied to model.

Two assumptions were made in this research. One of them is neglecting phytoplankton loads of streams and the other is assuming streams phytoplankton consantration similar to lake and modeled according to lake profile.

Model results have same tendency for each year. This shows that the model is working coherently. When the loads were doubled or halved, tendency of curves did not change. If same loading continues, according to Wetzel (1983), Phosphorus concentration of the lake is so close to mesotrophic Lake. However, if the load is doubled, lake character shifts to eutrophic condition.

Phytoplankton load is estimated from non linear regression of chlorophyll and phosphorus. The concentration of phytoplankton is so low, thus phytoplankton load make small differences in results. The difference only can be seen in the diatom, blue green algae concentrations. In other graphs no obvious effect can be observed.

For modified data, cark stream tendency was taken into account. Therefore, fluctuations occur in concentration of nutrients. Also in recent year the concentration of nitrogen decreases due to the concentration trend of Cark Stream. The figures and output tables are listed below. Some output tables are attached to appendices.

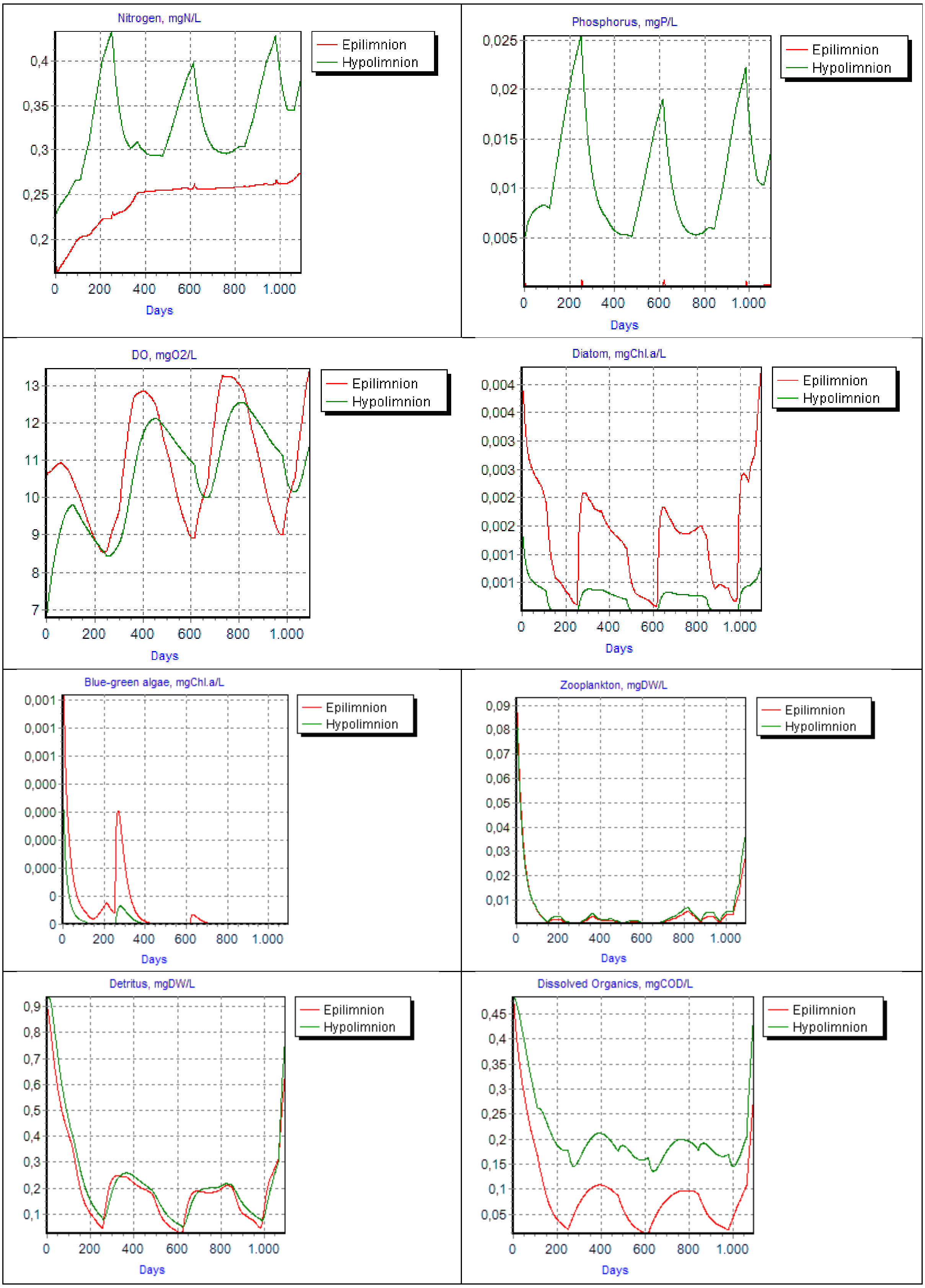


Figure 7.23. Future estimation for average daily load if load continues same neglecting phytoplankton load

Table 7.10. Output table for average daily load if load continues same neglecting phytoplankton load

18-01-09, 00:18:25

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion
Nitrogen	0.1914	0.2256 mgN/L
Phosphorus	0.0045	0.0045 mgP/L
Diatom	0.0013	0.0016 mgChl.a/L
Blue-green algae	0.0004	0.0005 mgChl.a/L
Other phytoplankton	0.0004	0.0005 mgChl.a/L
Zooplankton	0.0935	0.0867 mgDW/L
Detritus	0.9197	0.9197 mgDW/L
Dissolved Organics	0.4841	0.4841 mgCOD/L
DO	10.3489	6.7787 mgO2/L
Nitrogen in Sediment	0.0000	50.0000 mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000 mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000 mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion
Nitrogen	0.2747	0.3802 mgN/L
Phosphorus	0.0003	0.0137 mgP/L
Diatom	0.0043	0.0008 mgChl.a/L
Blue-green algae	0.0000	0.0000 mgChl.a/L
Other phytoplankton	0.0000	0.0000 mgChl.a/L
Zooplankton	0.0281	0.0367 mgDW/L
Detritus	0.6487	0.7833 mgDW/L
Dissolved Organics	0.2817	0.4434 mgCOD/L
DO	13.4510	11.4194 mgO2/L
Nitrogen in Sediment	0.0000	50.0000 mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000 mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000 mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

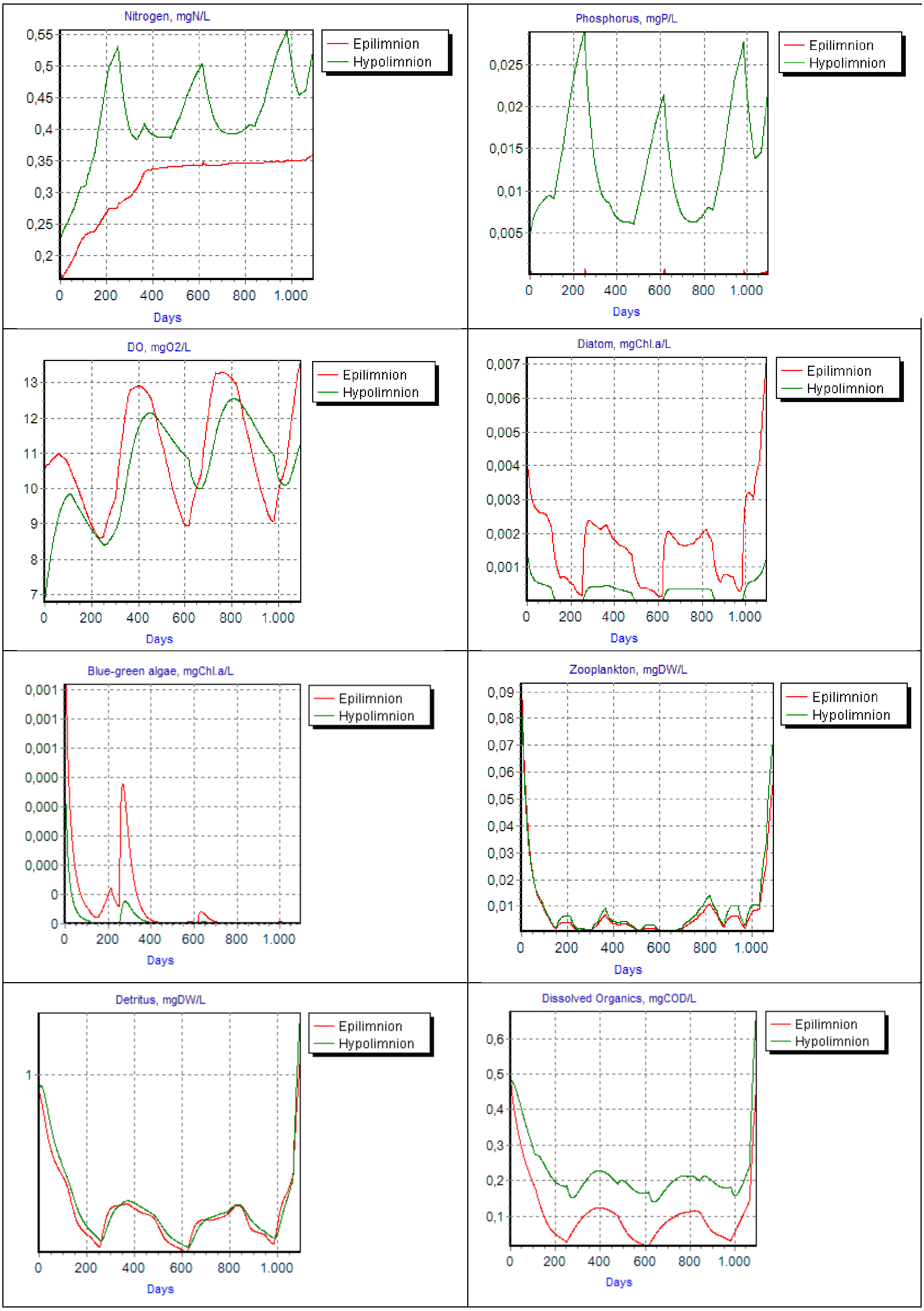


Figure 7.24. Future estimation for average daily load if load is doubled neglecting phytoplankton load

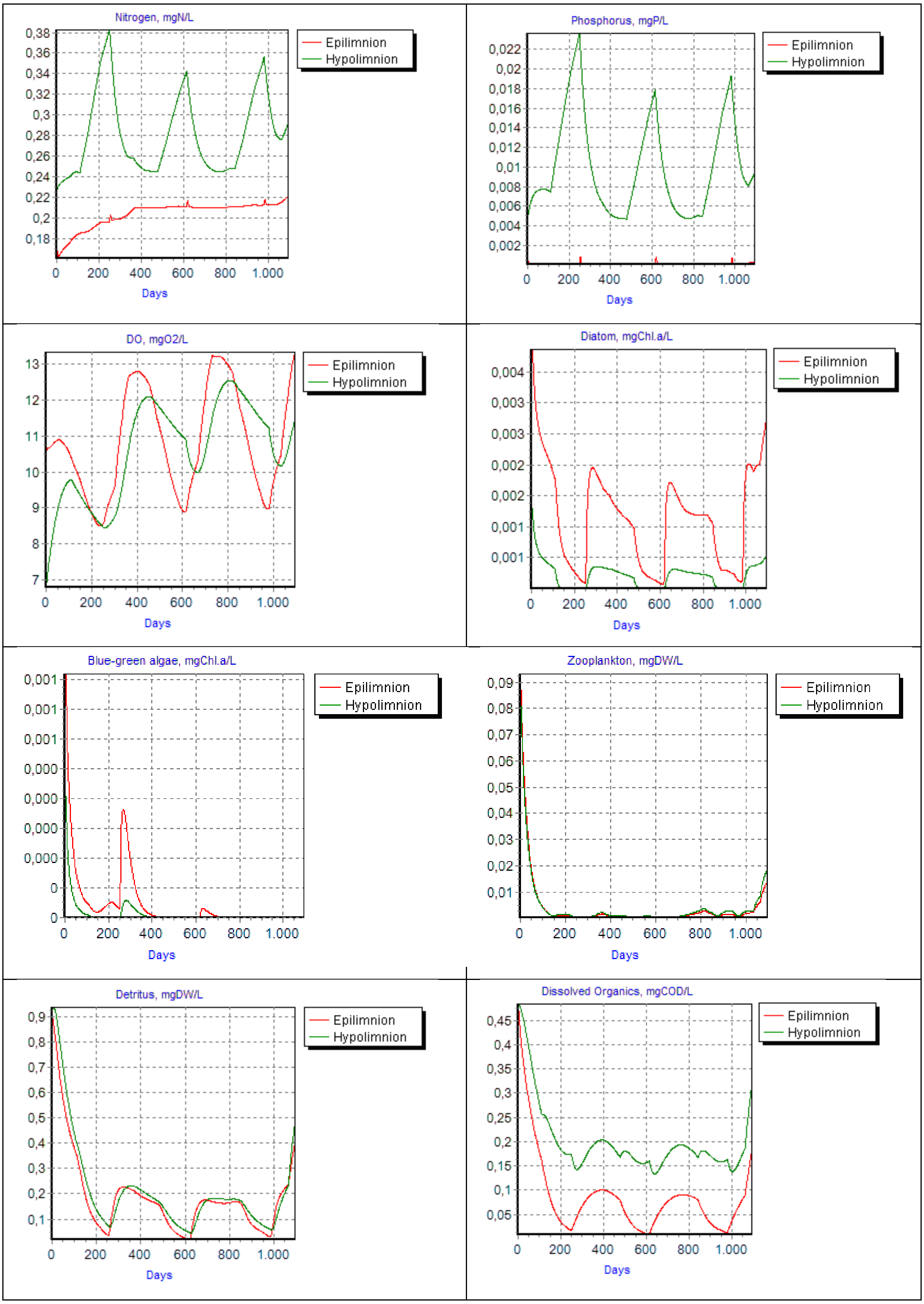


Figure 7.25. Future estimation for average daily load if load is halved neglecting phytoplankton load

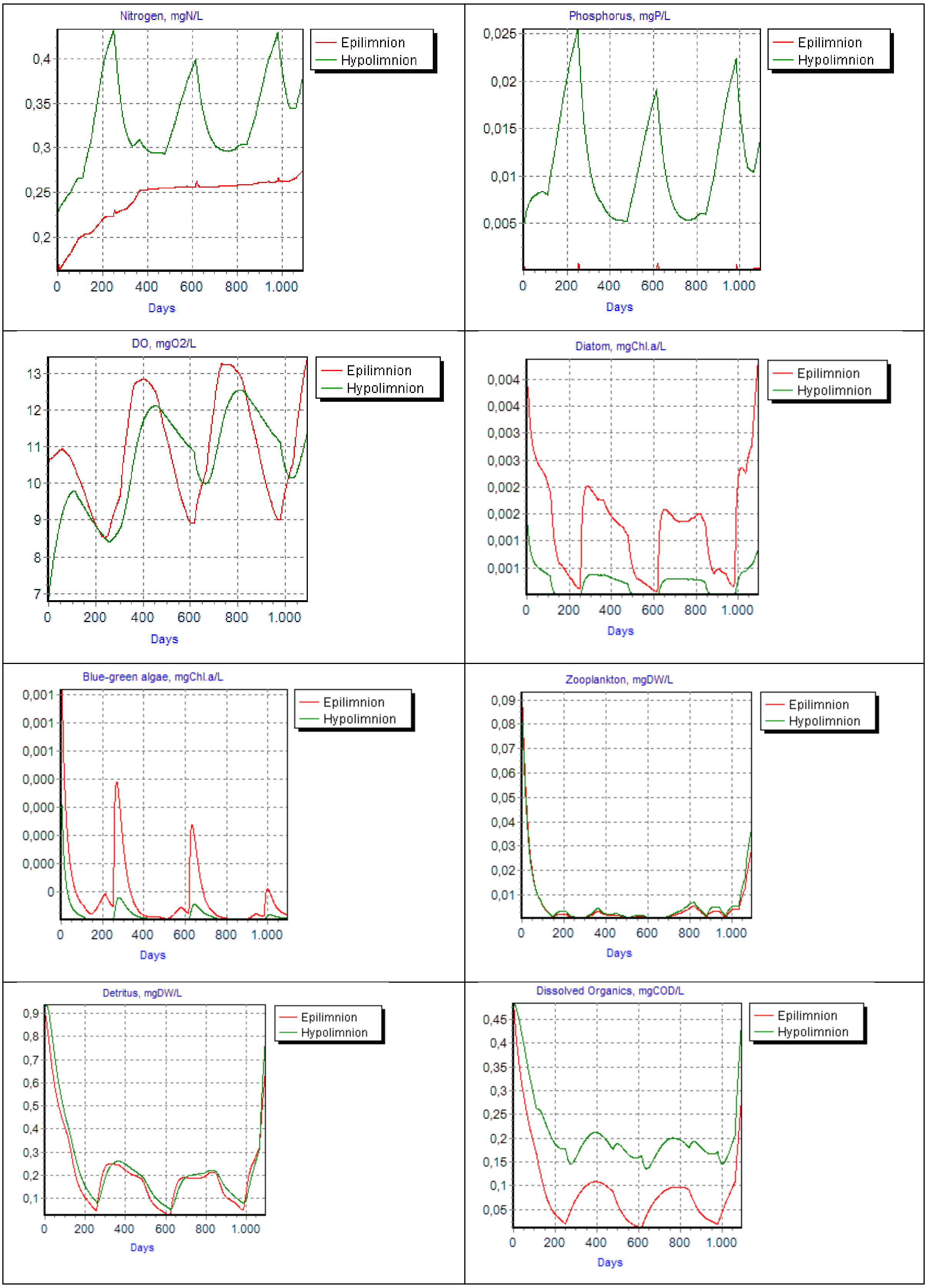


Figure 7.26. Future estimation for average daily load if load continues same with phytoplankton load

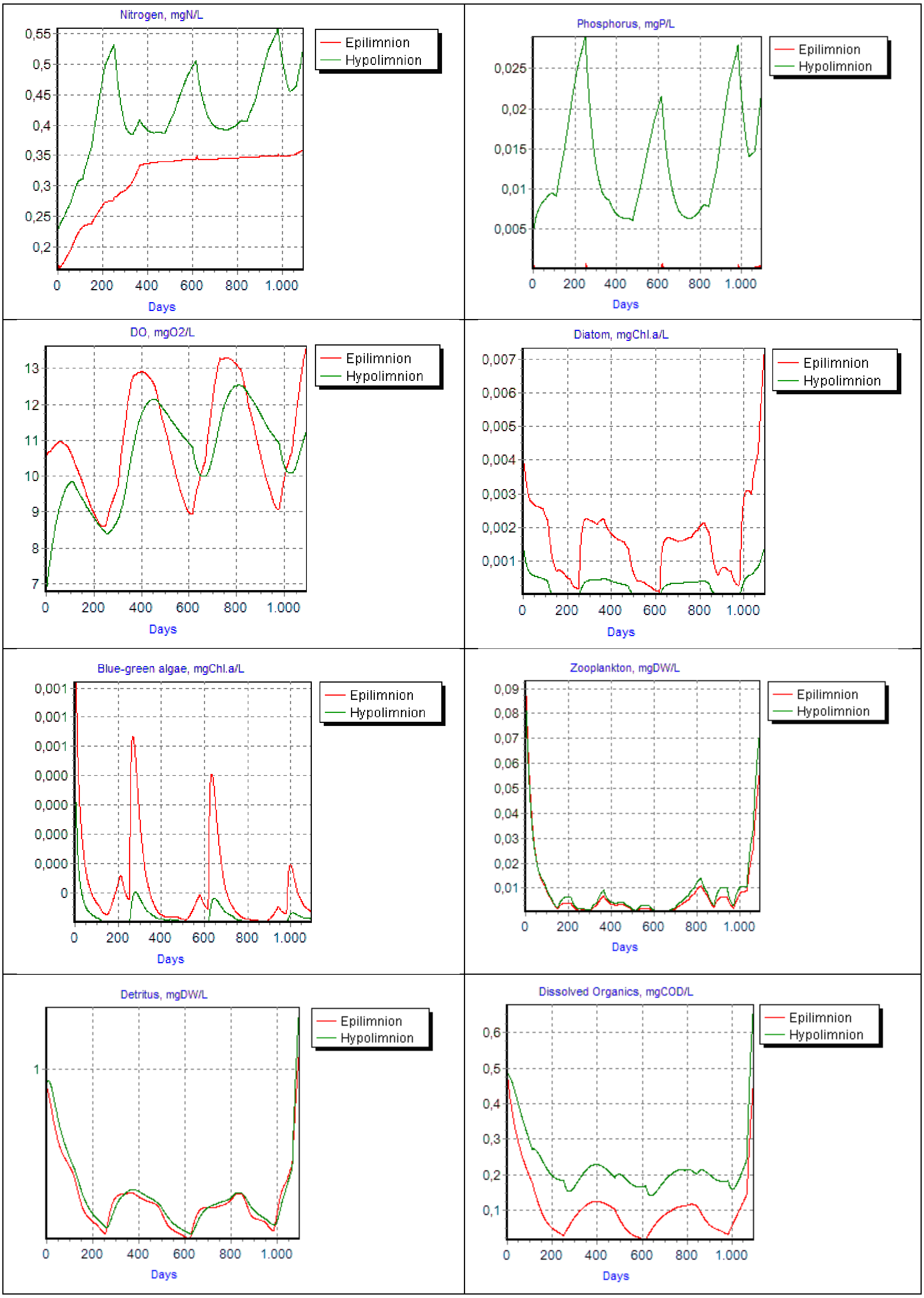


Figure 7.27. Future estimation for average daily load if load is doubled with phytoplankton load

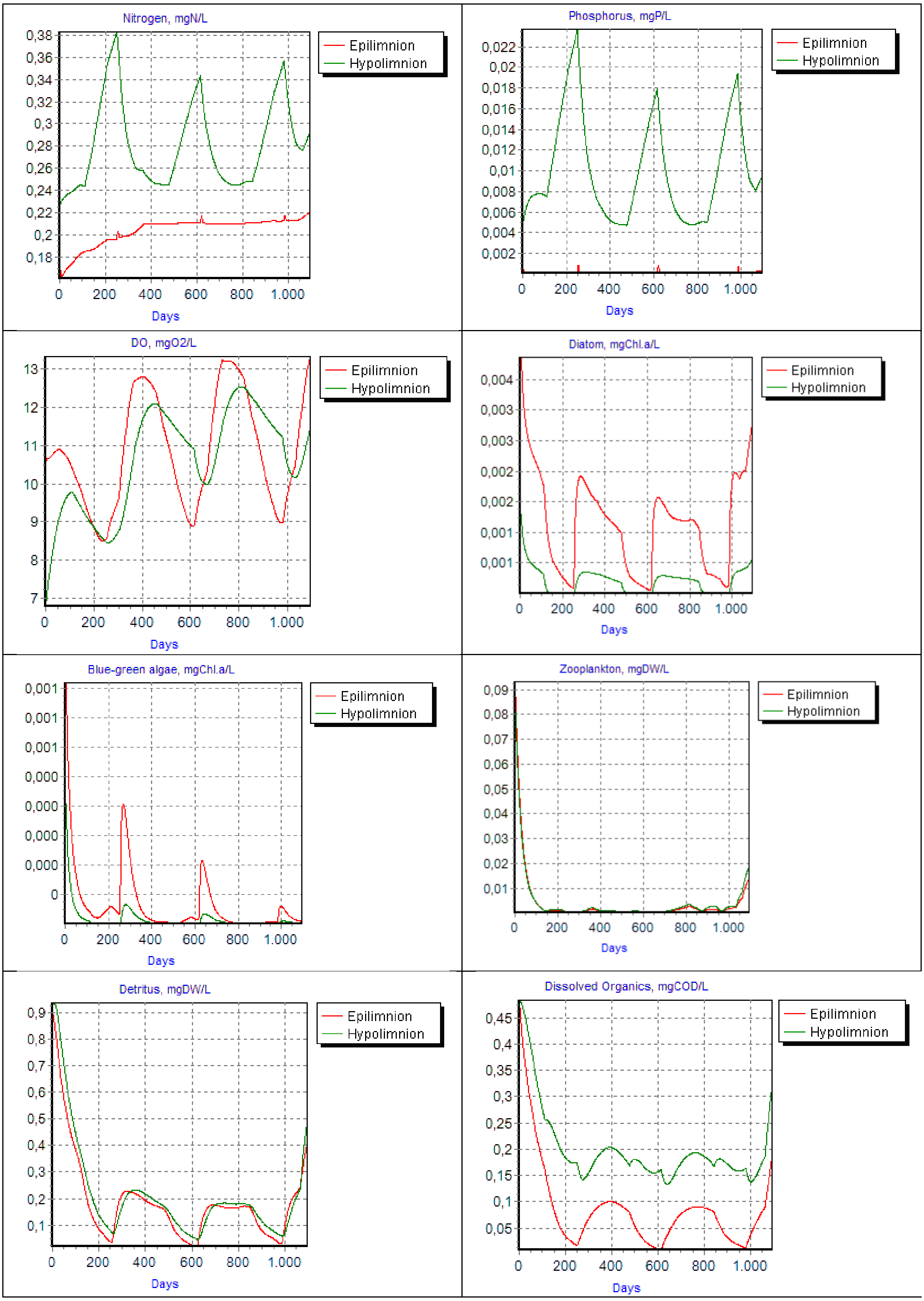


Figure 7.28. Future estimation for average daily load if load is halved with phytoplankton load

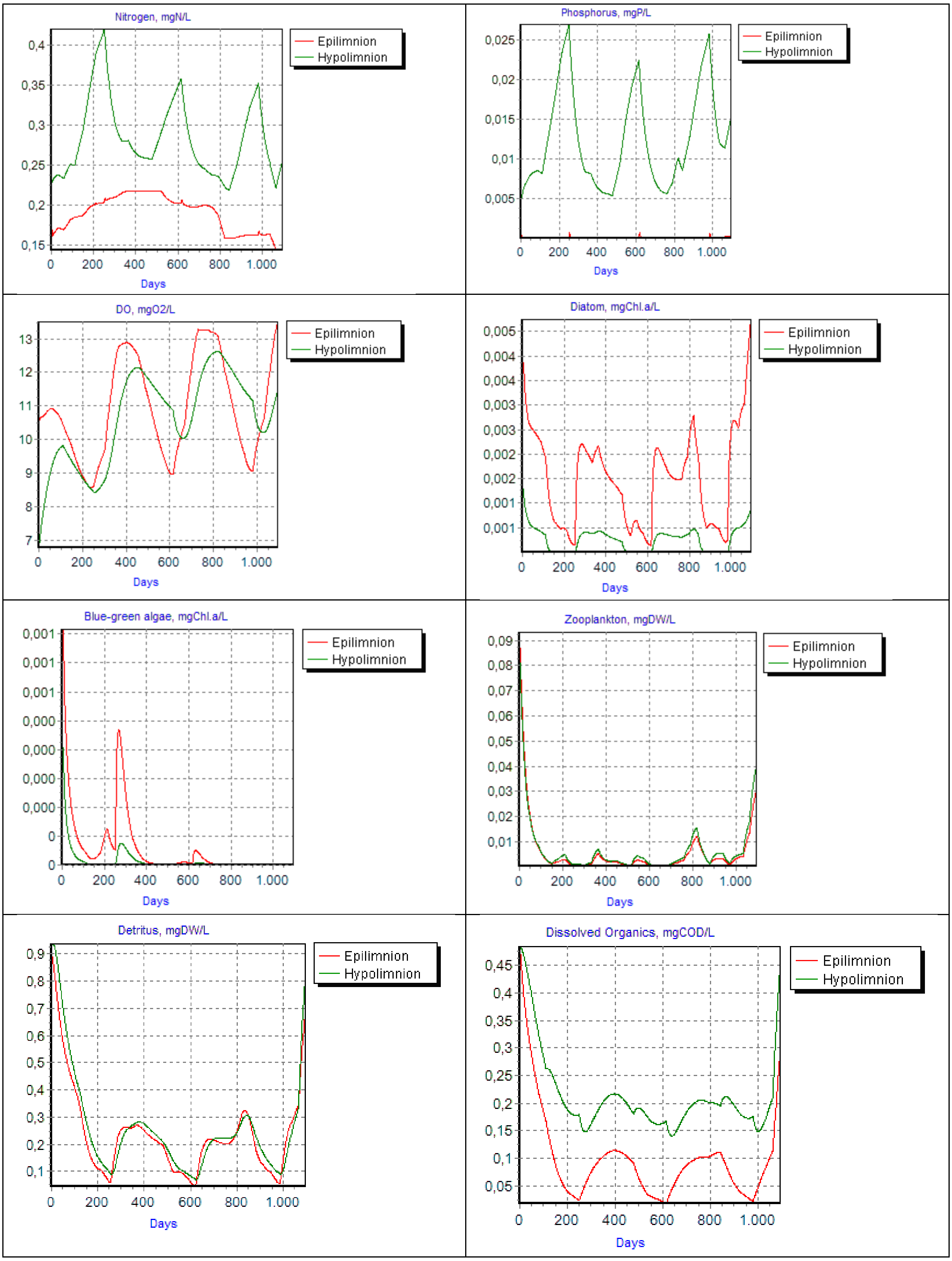


Figure 7.29. Future estimation for modified daily load if load continues same neglecting phytoplankton load

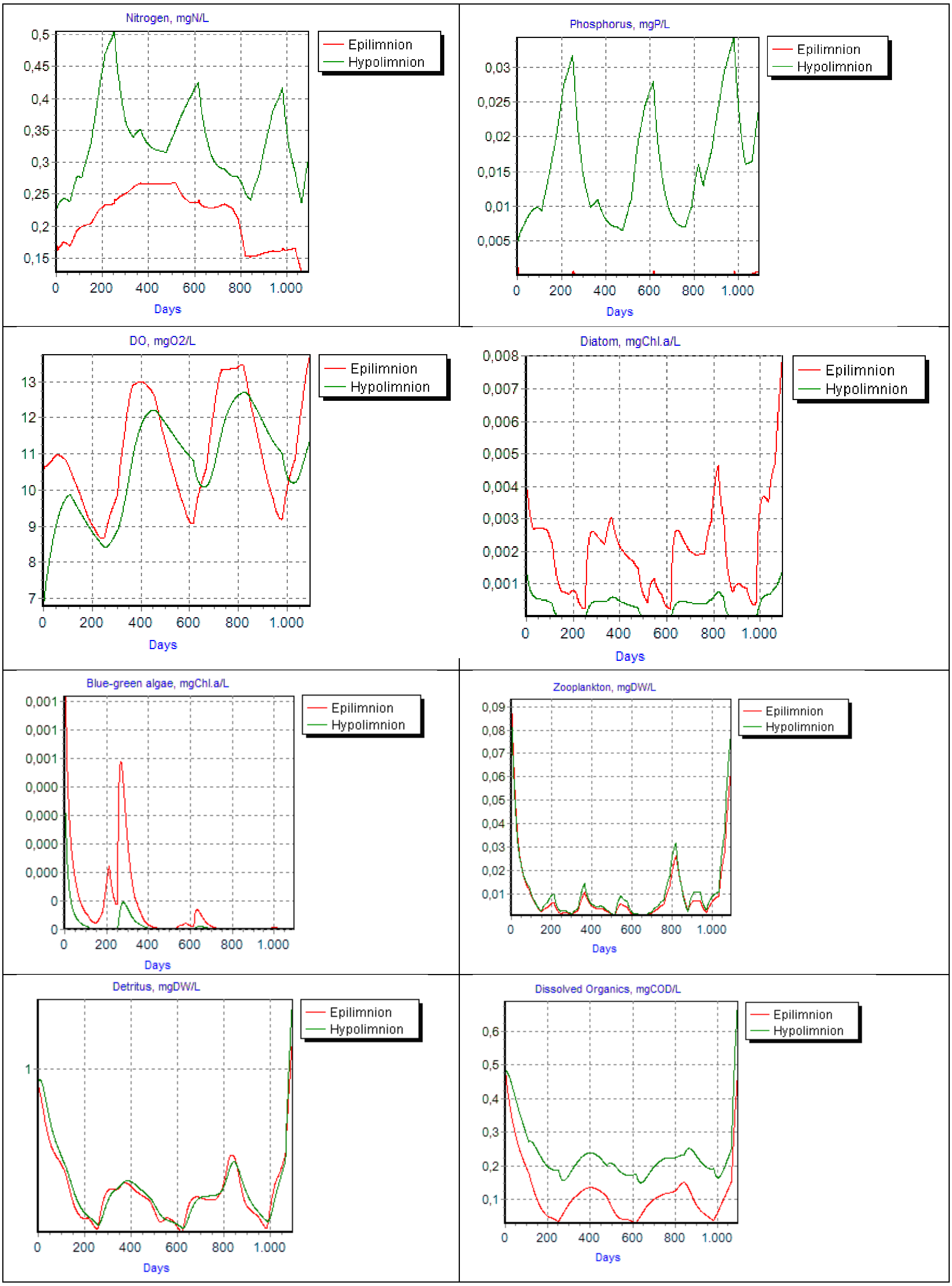


Figure 7.30. Future estimation for modified daily load if load is doubled neglecting phytoplankton load

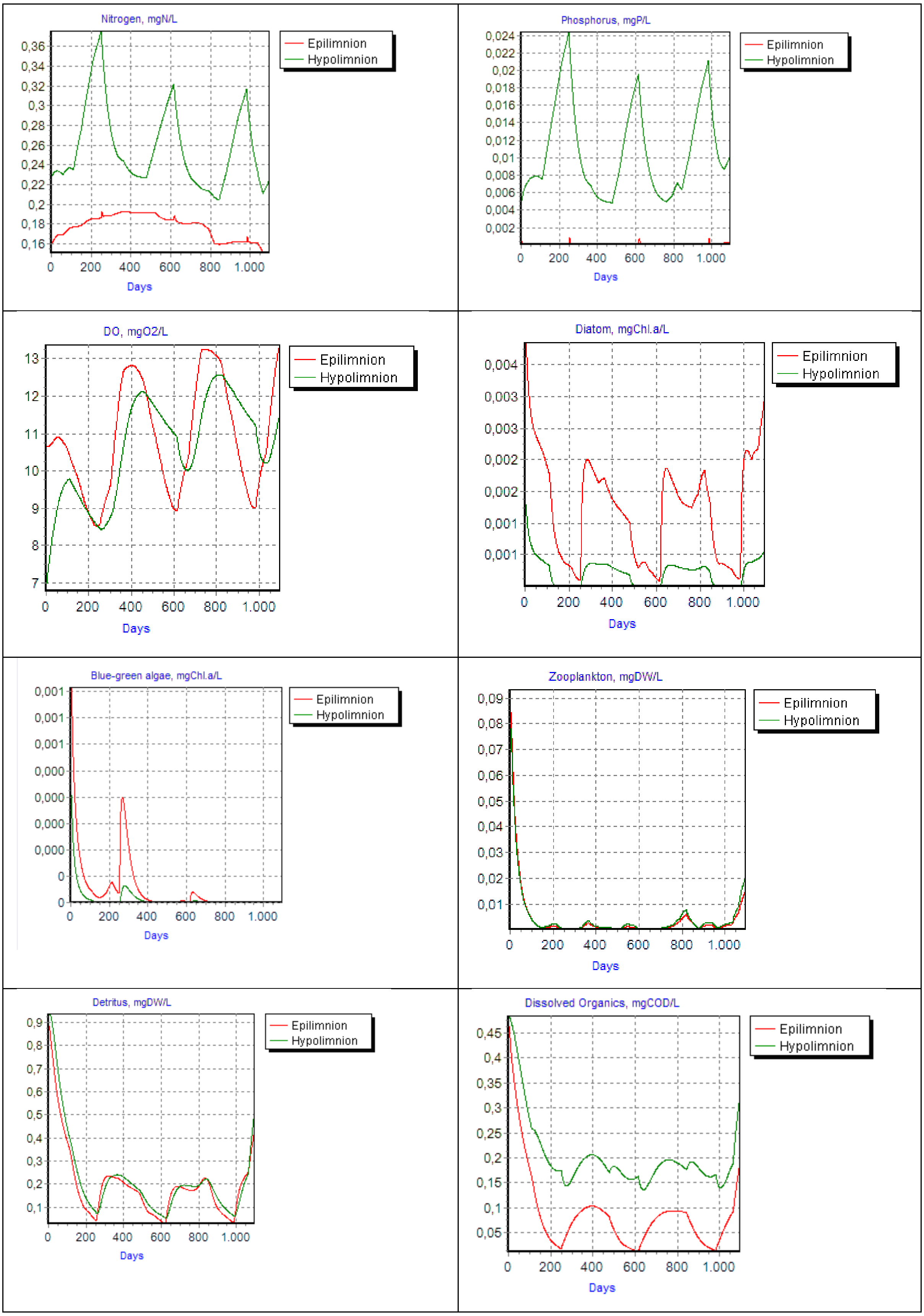


Figure 7.31. Future estimation for modified daily load if load is halved neglecting phytoplankton load

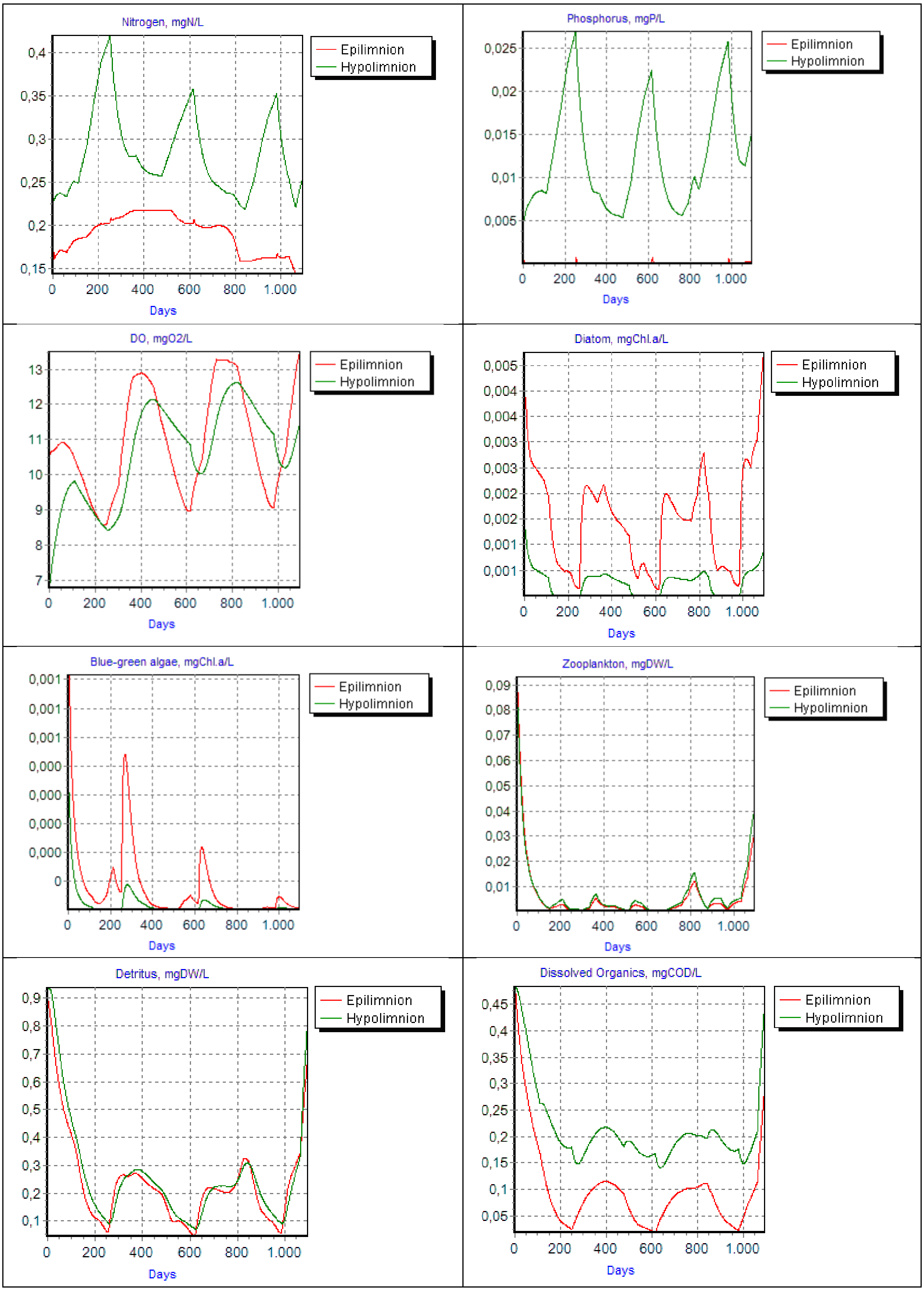


Figure 7.32. Future estimation for modified daily load if load continues same with phytoplankton load

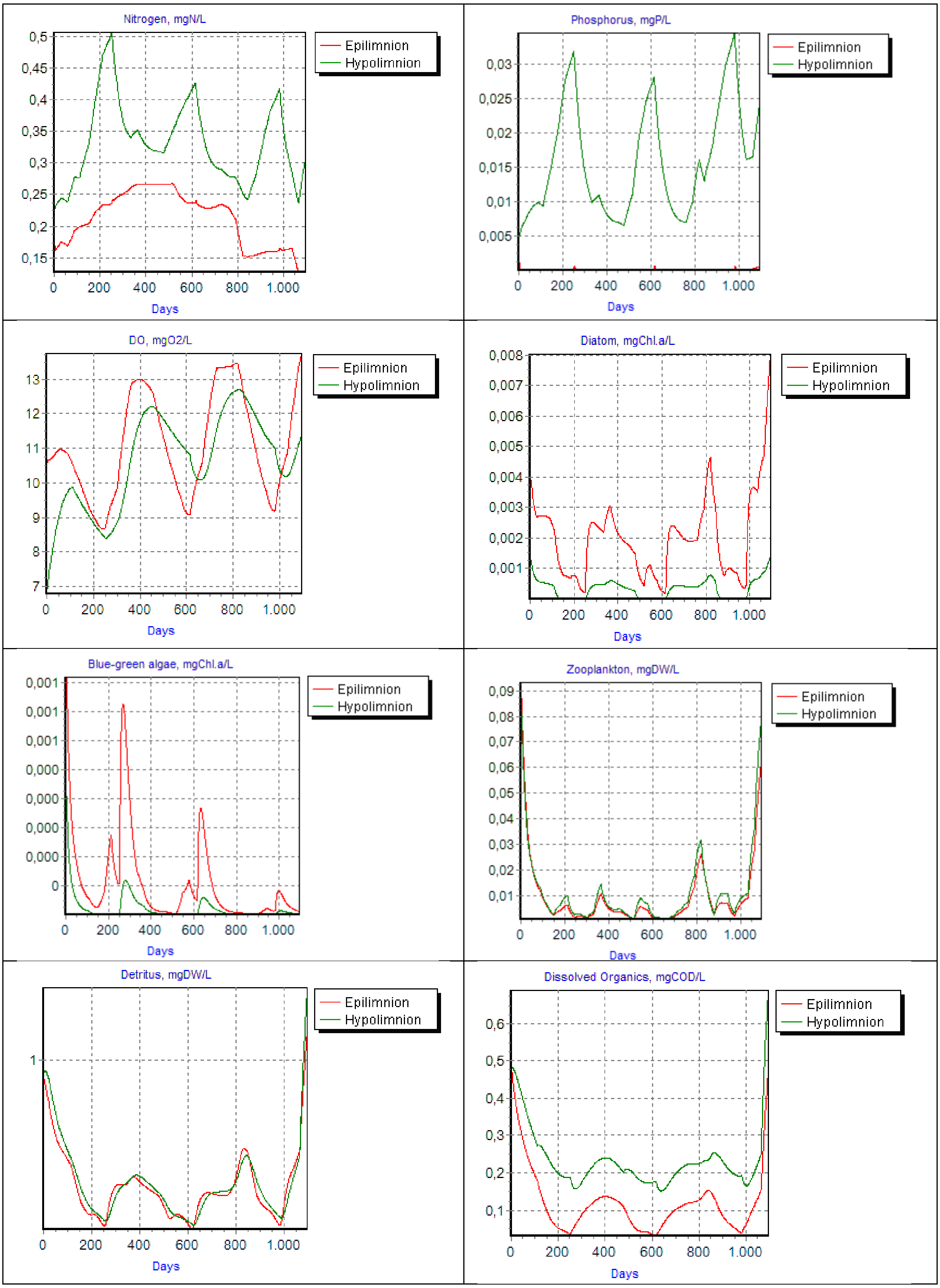


Figure 7.33. Future estimation for modified daily load if load is doubled with phytoplankton load

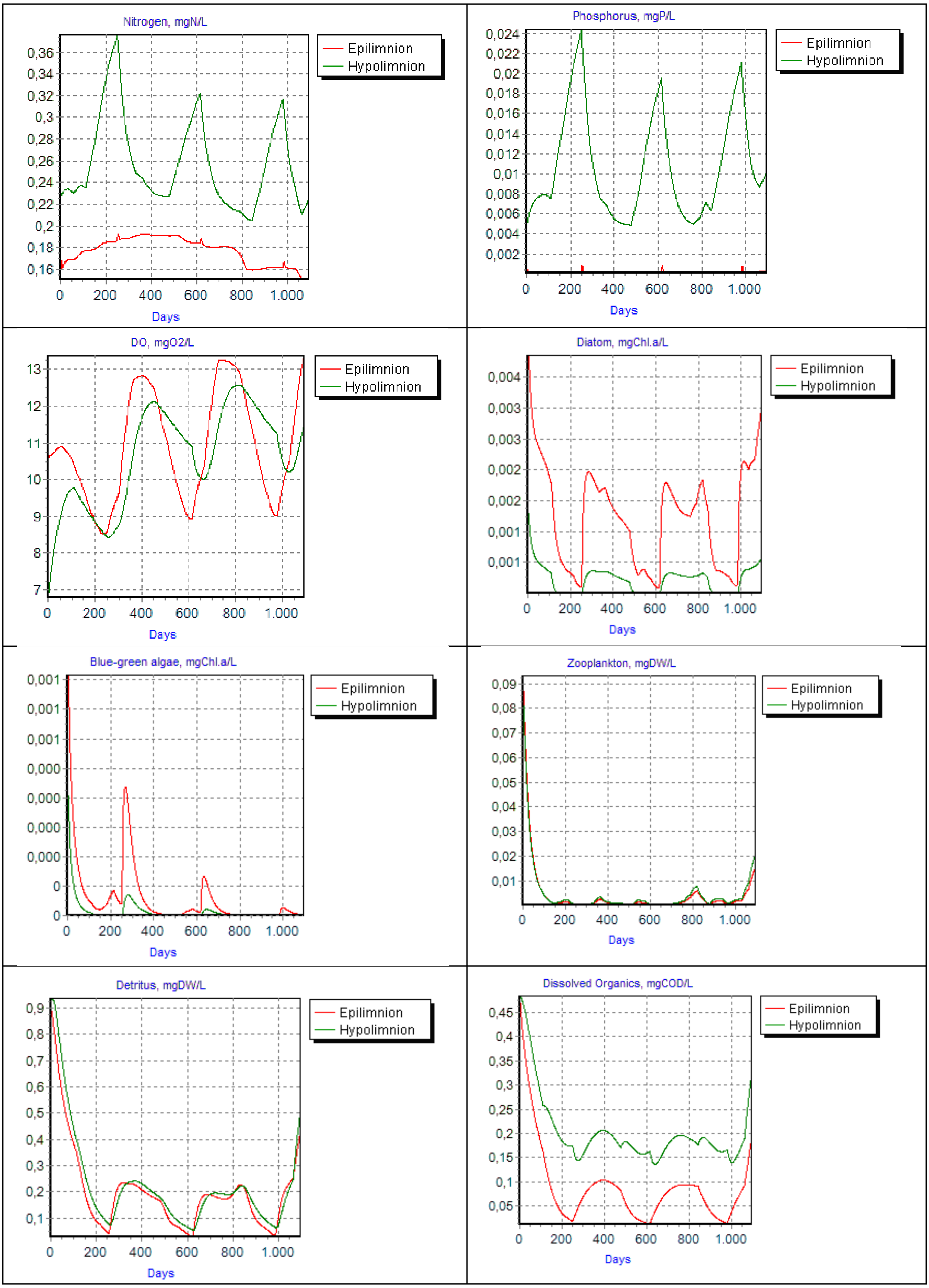


Figure 7.34. Future estimation for modified daily load if load is halved with phytoplankton load

8. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Lakes are generally subjected to wastewater discharges from various sources. Certain chemicals, such as nitrogen, phosphorus and carbon, in the right concentrations can distort and disrupt aquatic ecosystems by overfeeding. Eutrophication of inland bodies of water has become synonymous with the deterioration of water quality, which interferes with most of the beneficial uses of waters. Eutrophication is the consequence of a lake's nutrient enrichment (Akkoyunlu and İleri, 2003). In recent years, this problem has been increasingly acute due to the discharge of nutrients. The principal sources of nutrient inputs are municipal wastes, industrial wastes, agricultural runoff and atmospheric fallout. Lake Sapanca, which is located in the northern part of Marmara region of Turkey, is the subject of this paper. In this study, the eutrophication of the lake was evaluated and modeled with 1- Layer and 2- Layer Pamolare models.

Average annual concentration of nitrogen, phosphorus and chlorophyll-a in Sapanca Lake is computed and shown in Figures 5.4, 5.5 and 5.6. Utilizing nitrogen and phosphorus concentration TN : TP ratio was investigated. Generally, phosphorus or both nitrogen and phosphorus is limiting nutrient for Sapanca Lake (Figure 6.1). From average chlorophyll concentration of lake secchi disc depth is determined (Henderson, 1979). From probabilistic classification (OECD, 1982) for phosphorus, Sapanca Lake is oligotrophic %46, mesotrophic 44% and eutrophic10%. For Chlorophyll-a classification (Figure 6.8) ; probabilities are 50% oligotrophic, 40% mesotrophic and 10% eutrophic. Secchi disc classification (Figure 6.9); probabilities are 13% oligotrophic, 49% mesotrophic and 38% eutrophic.

Average annual flow, nitrogen and phosphorus concentration of streams in Sapanca watershed is calculated from DSI (2007). By using inflow and concentrations Table 6.1 and Table 6.2 which show the annual nitrogen and phosphorus load of Sapanca Lake is constructed. And average phosphorus load is applied to Vollenweider (1975) graph to determine the trophic status of Lake Sapanca. It was observed that Sapanca Lake is in the eutrophic region in Figure 6.5.

1-Layer PAMOLARE model is calibrated with 1989-1992 year and validated with 1992- 1995 years. Model shows that nutrient concentrations of lake tend to decrease if the nitrogen and phosphorus loading to Sapanca Lake continues as average of 1989-1997 years. But this model is designed for lakes which are not stratified. Therefore this model is applicable for short-term when the stratification does not occur. However, the model's estimation for nitrogen is consistent with measured nitrogen concentration. For future 4 month prediction: estimated nitrogen value is 0,37 mg/l and estimated phosphorus value is 0,005 mg/l. Main aim of the model is to obtain a general overview about the response of lake in case of low data availability.

2-Layer Model is more complex model than 1-Layer Model. Before 2-Layer Model was constructed, by using bathymetric curves, morphological data of Sapanca Lake and DSI temperature data; epilimnion and hypolimnion depth of Sapanca Lake is determined and epilimnion depth is assumed as 18.82 m.

In the construction of data set, Matlab® curve fitting program is used for regression analysis which was employed between total phosphorus and chlorophyll-a concentration with R square 0.91. For daily environmental data which is the crucial part of the 2-Layer Pamolare Model average monthly temperature values of Lake Sapanca are converted to daily temperature data by using distribution formula. Solar intensity of Sapanca Lake is computed from latitudes (Hamon, et al., 1954). The rest of unknown data is calculated from literature search.

Some assumptions are made to construct the daily environmental data due to the missing data. First assumption is taking average of monthly loads to characterize annual loading of lake. Second assumption is applying the cark stream trend to estimate missing data. Also two more assumptions are created in these assumptions because the model needs phytoplankton loading from streams but no such information is available. Therefore, one assumption is the streams have no phytoplankton load into lake. And other assumption is rivers load may behave as Lake Sapanca, therefore phytoplankton load was estimated from chlorophyll-a amount and applied to the model.

According to assumptions, future estimation is constructed. No such information about year 2009 is obtained. Therefore 2009 year data is assumed as same as average of data. 2-Layer Model is calibrated according to years 1989-1992 and validated according to 1992-1995 years. For first scenario, if loading continues as same as past data. Load is doubled in second scenario and load is halved in third scenario. Each scenario is applied for each assumption; lastly 12 results are obtained.

According to the pamolare models, results indicated that Lake Sapanca has not yet reached the eutrophic stage. The conditions show that it is between the mesotrophic and eutrophic levels (Wetzel, 1983). However if load is doubled, lake becomes closer to eutrophic level. Model results have same tendency for each year. This shows that the model is working coherently. When the loads were doubled or halved, tendency of curves did not change.

In modeling step, some limitations of two layer model were observed. One of them is the position of the thermocline can not be determined using the current package. Therefore thermocline is determined by using past data. The inflow and ouflow of streams are not equal in reality but the inflow and outflow volumes should remain equal throughout the calculations of model. Further the user has no control within the structure of the model. Also program do not accept the data out of boundaries despite the data is determined by program.

Graphical outputs can not be saved or modified. Real measurement results can not be added to graphical outputs for comparison in validation and calibration step. Also the graphs styles are not suitable for using in articles. Therefore additional programs have to be used to get graphs from model.

Another disadvantage of the program is output format. Differently from 1-Layer model, 2-Layer Model gives result for just one day in text format. Model does not give results as table thus for making comparisons at certain times, user has to run model several times.

Also another problem that faced during model construction is saving models. Program can not recognize the saved document of another computer. Program has to import data separately (as morphology, environmental data, etc.) from user.

2-Layer Model can not estimate the future data if input data is limited. For example if daily data is only for 5 years, model can make 5 year prediction. If 6 year prediction wanted from user model starts to reply the last data for whole year.

Beside that there are also limitations due to data. Although data of year 2000 was available, due to lack of previous water quality constituents, such as Kjeldahl-N, these data could not be used. Instead total nitrogen values were measured, however, there was an extraordinary difference between averages of total nitrogen calculated for the previous years and this was illogical when it is checked with the other nutrient concentrations, this data is regarded. Although river measurements was available for years after 1997, due to sharp decrease in number of sampling stations, these data could not be used in loading calculations. And due to same reason, 1995 - 1997 year environmental data is used to decrease uncertainty.

The number of station points in streams and lake is limited. Station point determines the character of streams, therefore increasing the number of station points provide more exact results. Beside that data was collected at certain time like one day of a month. But this day may not show the character of the whole month. Model can give more suitable results if online monitoring system is used. Thanks to online monitoring daily data even hourly data can be constructed.

DSI defines parameters that are observed in lake and streams according to their needs. Chlorophyll-a, zooplankton, phytoplankton, detritus and dissolved organics parameters are not measured directly from lake. They were calculated from regression calculations and literature. These values are to be known estimated. Due to that in some cases model predictions are not so close to real values.

According to model simulations, for the moment an urgent remedation is not necessary, except lowering phosphorus loading into the lake. May be some nutrient loading prevention methods that can be recommended here : use of permeable sewers and catch basins, detention basins for the urban runoff; developing vegetative buffer strips adjacent to water courses to remove up the sediment load and associated nutrient loading, eliminating excessive fertilization of agricultural non-point sources, and wetland treatment for both urban runoff and agricultural drainage waters by routing the flow through an area of vegetation in a controlled manner to remove nutrients, metals and solids; as well as use of land treatment practices following conventional treatment of point sources to remove nutrients.

APPENDIX A: Modeling documents

Table A.1 Average water plant composition on wet basis

Element	Plant content (%)	Element	Plant content (%)
Oxygen	80.5	Chlorine	0.06
Hydrogen	9.7	Sodium	0.04
Carbon	6.5	Iron	0.02
Silicon	1.3	Boron	0.001
Nitrogen	0.7	Zinc	0.0003
Calcium	0.4	Phosphorus	0.08
Potassium	0.3	Magnesium	0.07
Sulphur	0.06	Copper	0.0001
Manganese	0.0007	Cobalt	0.000002
Molybdenum	0.00005		

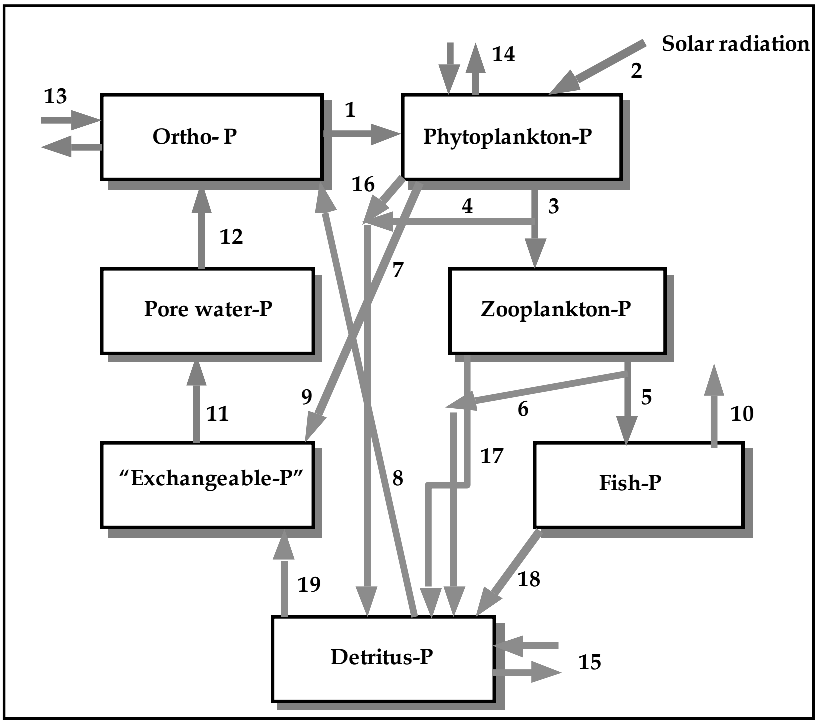


Figure A.1. The phosphorus cycle*

*Phosphorus cycle processes are: (1) Uptake of phosphorus by algae, (2) Photosynthesis, (3) Grazing with loss of undigested matter, (4), (5) is predation with loss of undigested material, (6), (7) and (9) Settling of phytoplankton (8) Mineralization, (10) Fishery (11) Mineralization of phosphorous organic compounds in the sediment, (12) Diffusion of pore water P (13) (14) and (15) are inputs/outputs, (16), (17) and (18) represent mortalities and (19) is settling of detritus.

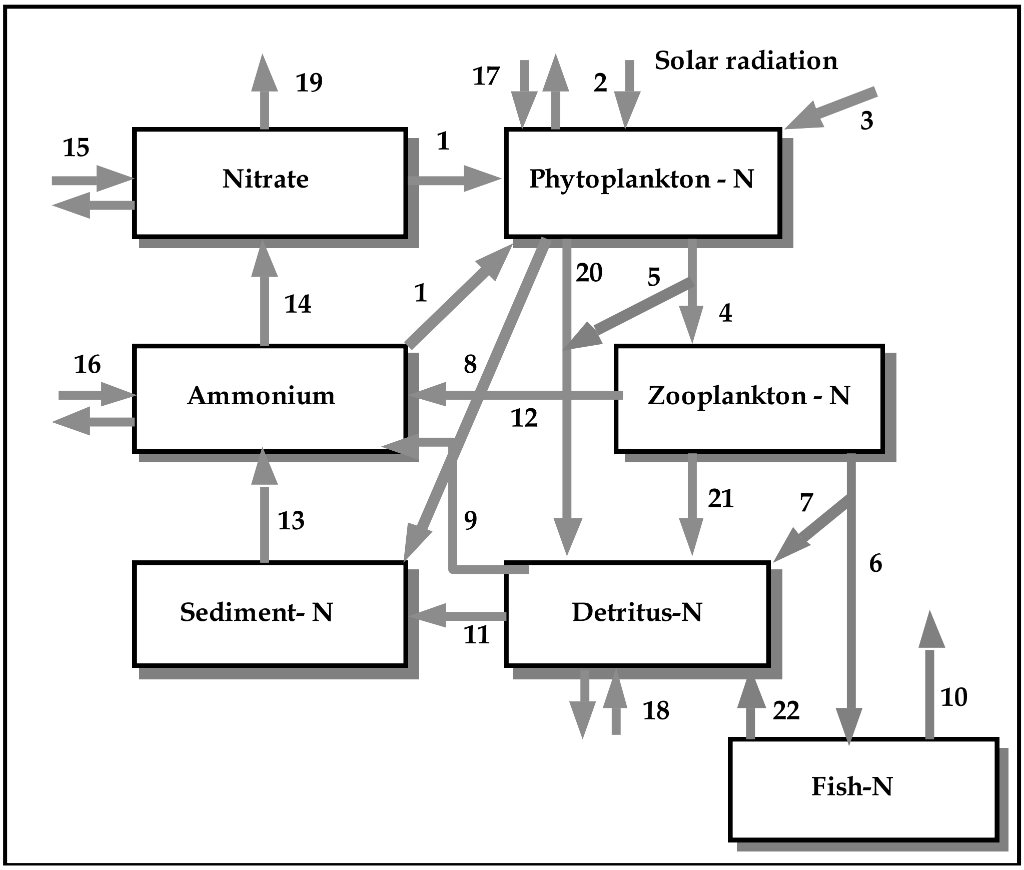


Figure A.2. The conceptual diagram of a nitrogen cycle in an aquatic ecosystem*

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*The nitrogen cycle processes are: 1) uptake of nitrate and ammonium by algae; 2) photosynthesis; 3) nitrogen fixation; 4) grazing with loss of undigested matter; 5), 6) and 7) are predation and loss of undigested matter; 8) settling of algae; 9) mineralization 10) fishery 11) settling of detritus 12) excretion of ammonium from zooplankton; 13) release of nitrogen from the sediment; 14) nitrification; 15),16) 17) and 18) are inputs/outputs; and 19) denitrification 20) 21) and 22) mortality of phytoplankton, zooplankton and fish

APPENDIX B: PAMOLARE 2-Layer Model Equations

Table B.1. Rate equation of each process

Process	Equation	
1. Growth of diatom [mgChl.a/(L·day)]	$R_1 = \mu_{M1} \times f_{T1} \times f_{I1} \times f_{N1} \times M_1$	
2. Growth of blue-green algae [mgChl.a/(L·day)]	$R_2 = \mu_{M2} \times f_{T2} \times f_{I2} \times f_{N2} \times M_2$	
3. Growth of other phytoplankton [mgChl.a/(L·day)]	$R_3 = \mu_{M3} \times f_{T3} \times f_{I3} \times f_{N3} \times M_3$	
4. Death of diatom [mgChl.a/(L·day)]	$R_4 = k_{dM1} \theta_{M1}{}^{(T-20)} \dfrac{DO}{K_{DO} + DO} M_1$	
5. Death of blue-green algae [mgChl.a/(L·day)]	$R_5 = k_{dM2} \theta_{M2}{}^{(T-20)} \dfrac{DO}{K_{DO} + DO} M_2$	
6. Death of other phytoplankton [mgChl.a/(L·day)]	$R_6 = k_{dM3} \theta_{M3}{}^{(T-20)} \dfrac{DO}{K_{DO} + DO} M_3$	
7. Grazing of diatom by zoopl. [mgChl.a/(L·day)]	$R_7 = F_{\max Z} \dfrac{T}{20} \dfrac{K_{mZ}}{K_{mZ} + (M_1 + M_2 + M_3)} M_1 Z$	
8. Grazing of blue-green algae by zoopl. [mgChl.a/(L·day)]	$R_8 = F_{\max Z} \dfrac{T}{20} \dfrac{K_{mZ}}{K_{mZ} + (M_1 + M_2 + M_3)} M_2 Z$	
9. Grazing of other phytoplankton by zoopl. [mgChl.a/(L·day)]	$R_9 = F_{\max Z} \dfrac{T}{20} \dfrac{K_{mZ}}{K_{mZ} + (M_1 + M_2 + M_3)} M_3 Z$	
10. Death of zoopl. [mgDW/(L·day)]	$R_{10} = k_{dZ} \theta_Z{}^{(T-20)} \dfrac{DO}{K_{DO} + DO} Z$	
11. Decomposition of detritus [mgDW/(L·day)]	$R_{11} = k_{dD} \theta_D{}^{(T-20)} D$	
12. Decomposition of dissolved organics [mgCOD/(L·day)]	$R_{12} = k_{dC} \theta_C{}^{(T-20)} \dfrac{DO}{K_{DO} + DO} C$	
13. Release of nitrogen from sediment [mgN/(L·day)]	model(a) $R_{13a} = k_{srAN} \dfrac{A}{1000 V_L}$	model(b) $R_{13b} = k_{srN} N_{sed} \dfrac{H_{sed}}{H}$
14. Release of phosphorus from sediment [mgP/(L·day)]	model(a) $R_{14a} = k_{srAP} \dfrac{A}{1000 V_L}$	model(b) $R_{14b} = k_{srP} P_{sed} \dfrac{H_{sed}}{H}$
15. Release of dissolved organics from sediment [mgCOD/(L·day)]	model(a) $R_{15a} = k_{srAC} \dfrac{A}{1000 V_L}$	model(b) $R_{15b} = k_{srC} C_{sed} \dfrac{H_{sed}}{H}$
16. Release of detritus from sediment [mgDW/(L·day)]	$R_{16} = k_{srD} \dfrac{A}{1000 V_L}$	

Table B.1. Rate equation of each process continued

Process	Equation
17. Re-aeration [$mgO_2/(L\cdot day)$]	$R_{17} = k_L \dfrac{A(DO_{sat} - DO)}{V_L}$
18. Oxygen consumption by sediment [$mgO_2/(L\cdot day)$]	$R_{18} = k_{DO}\theta_{DO}^{(T-20)} \dfrac{A}{1000V_L}$

Table B.2. Rate equation of each process (affecting functions)

Effect of water temperature $f_{Tk}\ (k = 1, 2, 3)$ [-]	$f_{Tk} = -\dfrac{(T - T_{optMk})^2}{T_{optMk}^{\ 2}} + 1$
Effect of Solar radiation $f_{Ik}\ (k = 1, 2, 3)$ [-]	$f_{Ik} = \dfrac{e}{\varepsilon h}\left[\exp\left\{-\dfrac{I}{I_{optMk}}\exp(-\varepsilon h)\right\} - \exp(-\dfrac{I}{I_{optMk}})\right]$
Effect of nutrients $f_{Nk}\ (k = 1, 2, 3)$ [-]	$f_{Nk} = \dfrac{N}{K_{NMk} + N}\dfrac{P}{K_{PMk} + P}$
Re-aeration rate constant [m/day]	$K_L = \max(0.04, 0.782\sqrt{W} - 0.317W + 0.0372W^2)$
Saturated Dissolved Oxygen [mgO_2/L]	$DO_{sat} = 16.5 - \dfrac{8.0}{22.0}T$

Table B.3. Material balance equations

		Nitrogen	Phosphorus	Diatom	Blue-green algae	Other phytoplankton	Zooplankton
		C1	C2	C3	C4	C5	C6
		mgN/L	mgP/L	mgChl.a/L	mgChl.a/L	mgChl.a/L	mgDW/L
R1	mgChl.a/(L·d)	- R(1) * γ_{M1N} ($)	- R(1) * γ_{M1P} ($)	R(1) ($)			
R2	mgChl.a/(L·d)	- R(2) * γ_{M2N} ($)	- R(2) * γ_{M2P} ($)		R(2) ($)		
R3	mgChl.a/(L·d)	- R(3) * γ_{M3N} ($)	- R(3) * γ_{M3P} ($)			R(3) ($)	
R4	mgChl.a/(L·d)	R(4) * (1 - Y_{M1D}) * γ_{M1N}	R(4) * (1 - Y_{M1D}) * γ_{M1P}	- R(4)			
R5	mgChl.a/(L·d)	R(5) * (1 - Y_{M2D}) * γ_{M2N}	R(5) * (1 - Y_{M2D}) * γ_{M2P}		- R(5)		
R6	mgChl.a/(L·d)	R(6) * (1 - Y_{M3D}) * γ_{M3N}	R(6) * (1 - Y_{M3D}) * γ_{M3P}			- R(6)	
R7	mgChl.a/(L·d)			- R(7)			R(7) * Y_{M1Z} * γ_{M1Z}
R8	mgChl.a/(L·d)				- R(8)		R(8) * Y_{M2Z} * γ_{M2Z}
R9	mgChl.a/(L·d)					- R(9)	R(9) * Y_{M3Z} * γ_{M3Z}
R10	MgDW/(L·d)	R(10) * (1 - Y_{ZD}) * γ_{ZN}	R(10) * (1 - Y_{ZD}) * γ_{ZP}				- R(10)
R11	MgDW/(L·d)						
R12	MgDW/(L·d)	R(12) * γ_{CN}	R(12) * γ_{CP}				
R13	mgN/(L·d)	R(13) ($$)					
R14	mgP/(L·d)		R(14) ($$)				
R15	MgDW/(L·d)						
R16	MgDW/(L·d)						
R17	mgO_2/(L·d)						
R18	mgO_2/(L·d)						

($): only in the upper layer water cell;

($$): only in the lower layer water cell

Table B.3. Material balance equations continued

		Detritus	Dissolved Organics	DO	Releasable Sediment Nitrogen	Releasable Sediment Phosphorus	Releasable Sediment Dissolved Organics
		C7	C8	C9	C10*	C11*	C12*
		mgDW/L	mgCOD/L	mgO_2/L	mgN/L-sed	mgP/L-sed	mgC/L-sed
R1	mgChl.a/(L·d)			$R(1) * \gamma_{M1DO}$			
R2	mgChl.a/(L·d)			$R(2) * \gamma_{M2DO}$			
R3	mgChl.a/(L·d)			$R(3) * \gamma_{M3DO}$			
R4	mgChl.a/(L·d)	$R(4) * Y_{M1D} * \gamma_{M1D}$		$- R(4) * (1 - Y_{M1D}) * \gamma_{M1DO}$			
R5	mgChl.a/(L·d)	$R(5) * Y_{M2D} * \gamma_{M2D}$		$- R(5) * (1 - Y_{M2D}) * \gamma_{M2DO}$			
R6	mgChl.a/(L·d)	$R(6) * Y_{M3D} * \gamma_{M3D}$		$- R(6) * (1 - Y_{M3D}) * \gamma_{M3DO}$			
R7	mgChl.a/(L·d)	$R(7) * (1 - Y_{M1Z}) * \gamma_{M1D}$					
R8	mgChl.a/(L·d)	$R(8) * (1 - Y_{M2Z}) * \gamma_{M2D}$					
R9	mgChl.a/(L·d)	$R(9) * (1 - Y_{M3Z}) * \gamma_{M3D}$					
R10	MgDW/(L·d)	$R(10) * Y_{ZD}$		$- R(10) * (1 - Y_{ZD}) * \gamma_{ZDO}$			
R11	MgDW/(L·d)	- R(11)	$R(11)*1/\gamma_{DC}$				
R12	MgDW/(L·d)		$- R(12) *1/\gamma_{DC}$	$- R(12) * \gamma_{CDO}$			
R13	mgN/(L·d)				$- R(13)b * H / H_{sed}$		
R14	mgP/(L·d)					- R(14)b * H / Hsed	
R15	MgDW/(L·d)		$R(15))*1/\gamma_{DC}$ ($$)				$- R(15)b * H / H_{sed}$
R16	MgDW/(L·d)	R(16) ($$)			$- R(16) * H / H_{sed} * \gamma_{DN}$	$- R(16) * H / Hsed * \gamma DP$	$- R(16) * H / H_{sed} * \gamma_{DC}$
R17	$mgO_2/(L·d)$			R (17) ($)			
R18	$mgO_2/(L·d)$			- R (18) ($$)			

*: Column 10, 11, 12 are for the case in which release rates of inorganic nitrogen, phosphorus and dissolved organics are calculated by the material balance in sediment (model(b))

($): only in the upper layer water cell;

($$): only in the lower layer water cell

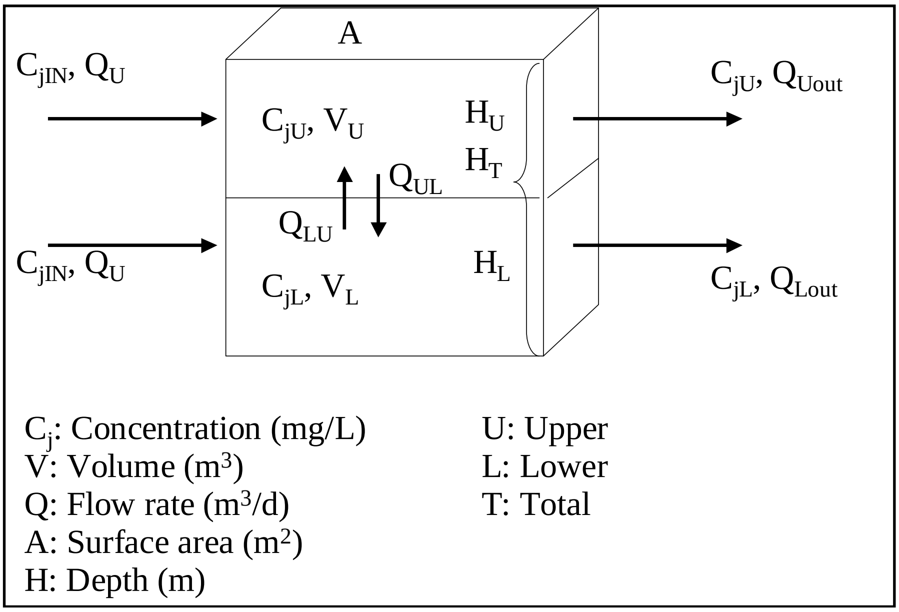

Figure B.1. Material balance equations

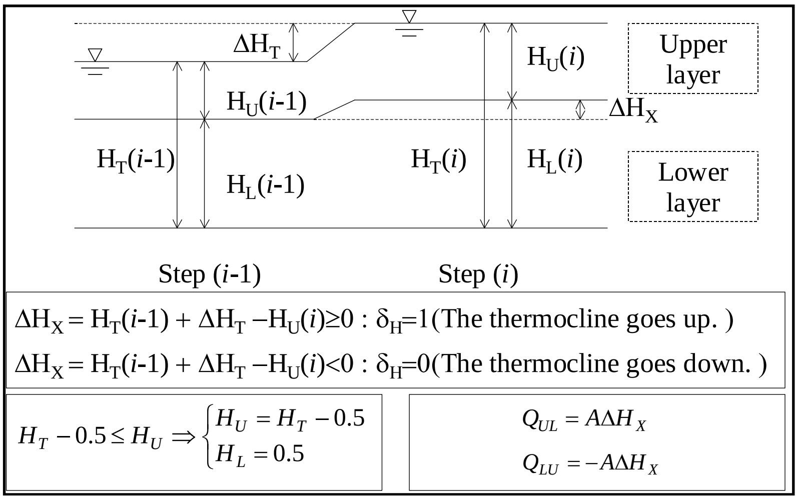

Figure B.2. Variable depth in calculation

Table B.4. Material balance equations- variable depth in calculation

Minimum depth of the lower layer is 0.5 m.
$\frac{d(VC_j)}{dt} = Q_{IN}C_{jIN} - Q_{OUT}C_j \pm \langle Q_{UL}\ or\ Q_{LU}\rangle\langle C_{jU}\ or\ C_{jL}\rangle + F_j$
$\frac{d(VC_j)}{dt} = A\left\{C_j\frac{dH}{dt} + h\frac{dC_j}{dt}\right\}$

Table B.5. Material balance equations

Upper layer

$$\frac{dC_{jU}}{dt} = \frac{Q_U C_{jIN} - Q_{Uout} C_{jU} - \delta_h Q_{UL} C_{jU} + (1-\delta_h) Q_{LU} C_{jL}}{V_U} + F_{j_U} - \frac{K_d A}{\Delta H V_U}(C_{jU} - C_{jL}) - \frac{C_{jU}}{H_U}\frac{dH_U}{dt}$$

$$\frac{dD_U}{dt} = \frac{Q_U D_{IN} - Q_{Uout} D_U - \delta_h Q_{UL} D_U + (1-\delta_h) Q_{LU} D_L}{V_U} + F_{j_U} - \frac{v_{sD} D_U}{H_U} - \frac{K_d A}{\Delta H V_U}(D_U - D_L) - \frac{D_U}{H_U}\frac{dH_U}{dt}$$

j=N, P, M_1, M_2, M_3, Z, C, DO, Cj =Concentrations of j,

D=Concentrations of detritus

F_j: Rate of change of j

U: Upper layer, L: Lower layer

Lower layer

$$\frac{dC_{jL}}{dt} = \frac{Q_L C_{jIN} - Q_{Lout} C_{jL} + \delta_h Q_{UL} C_{jU} - (1-\delta_h) Q_{LU} C_{jL}}{V_U} + F_{j_L} + \frac{K_d A}{\Delta H V_U}(C_{jU} - C_{jL}) - \frac{C_{jL}}{H_L}\frac{dH_L}{dt}$$

$$\frac{dD_L}{dt} = \frac{Q_L D_{IN} - Q_{Lout} D_L + \delta_h Q_{UL} D_U - (1-\delta_h) Q_{LU} D_L}{V_U} + F_{j_L} + \frac{v_{sD} D_U}{H_L} - \frac{v_{sD} D_L}{H_L} + \frac{K_d A}{\Delta H V_U}(D_U - D_L) - \frac{D_L}{H_L}$$

j=N, P, M_1, M_2, M_3, Z, C, DO , Cj =Concentrations of j,

D=Concentrations of detritus

F_j: Rate of change of j

U: Upper layer, L: Lower layer

Sediment Part

$$\frac{dC_{jS}}{dt} = F_{jS} + \frac{v_{sD} D_L}{H_{sed}} \gamma_{D\,j} f_{sed\,j}$$

j=N_{sed}, P_{sed}, C_{sed}, Cj =Concentrations of j,

F_j: Rate of change of j

U: Upper layer , L: Lower layer

δ_h =1: When the thermocline goes up.

δ_h =0: When the thermocline goes down.

APPENDIX C: PAMOLARE 1-Layer Model Outputs

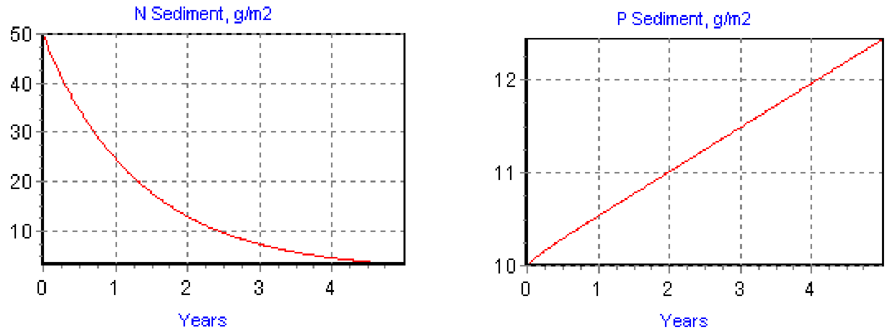

Figure C.1. 1-Layer Model predictions for N sediment and P sediment

Table C.1. PAMOLARE 1- Layer Model outputs-summary

```
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Simulation for :
---------------------------------------------------------------
Simulated period                                      5.0 year(s)
Printing step                                       0.010 year
Integration step                                    0.020 year

Physical data
  Lake depth                                         26.02 m
  Water residence time                                6.46 year(s)
  Sedimentation constant                            120.00 m/year
  Reduction of nutrient outflow
   due to thermocline                                 0.00

Nitrogen data
  Initial value of nitrogen in water                  0.320 mg/l
  Initial value of nitrogen in sediment              50.000 g/m2
  Nitrogen loading                                    2.690 g/m2/year
  Sediment release of nitrogen                        0.950 /year
  Fraction of nitrogen bound in sediment              0.790

Phosphorus data
  Initial value of phosphorus in water                0.007 mg/l
  Initial value of phosphorus in sediment            10.000 g/m2
  Phosphorus loading                                  0.494 g/m2/year
  Sediment release of phosphorus                      0.005 /year
  Fraction of phosphorus bound in sediment            0.150
```

Table C.2. PAMOLARE 1- Layer Model outputs-step by step

Time	Water	Sediment	Water	Sediment	Lim	Chla	Secchi	Zoopl.	Fish	Av	Av. Fish
	N	N	P	P	nut		depth			prim	yield
Years	mg/l	g/m2	mg/l	g/m2		mg/l	m	mg/l	mg/l	g/l/	
-------	---------	-----------	---------	---------	------	------	-------	-------	---------	----	-----
0.0	0.33	49.21	0.01	10.01	P	0.00	6.64	0.13	3.08	0.05	0.05
0.0	0.34	48.44	0.01	10.03	P	0.00	6.75	0.12	3.01	0.05	0.05
0.1	0.35	47.69	0.01	10.04	P	0.00	6.86	0.12	2.95	0.05	0.04
0.1	0.36	46.96	0.01	10.05	P	0.00	6.97	0.12	2.89	0.04	0.04
0.1	0.36	46.25	0.01	10.06	P	0.00	7.07	0.12	2.84	0.04	0.04
0.1	0.37	45.56	0.01	10.07	P	0.00	7.16	0.12	2.79	0.04	0.04
0.1	0.37	44.87	0.01	10.08	P	0.00	7.25	0.11	2.75	0.03	0.04
0.2	0.37	44.21	0.01	10.09	P	0.00	7.33	0.11	2.71	0.03	0.04
0.2	0.38	43.56	0.01	10.10	P	0.00	7.40	0.11	2.67	0.03	0.04
0.2	0.38	42.92	0.01	10.11	P	0.00	7.47	0.11	2.64	0.03	0.04
0.2	0.38	42.29	0.01	10.12	P	0.00	7.54	0.11	2.61	0.03	0.04
0.2	0.38	41.68	0.01	10.13	P	0.00	7.60	0.11	2.58	0.03	0.04
0.3	0.38	41.08	0.01	10.14	P	0.00	7.65	0.11	2.56	0.02	0.04
0.3	0.38	40.49	0.00	10.15	P	0.00	7.71	0.11	2.53	0.02	0.04
0.3	0.38	39.91	0.00	10.16	P	0.00	7.75	0.11	2.51	0.02	0.03
0.3	0.37	39.34	0.00	10.17	P	0.00	7.80	0.10	2.49	0.02	0.03
0.3	0.37	38.78	0.00	10.18	P	0.00	7.84	0.10	2.48	0.02	0.03
0.4	0.37	38.23	0.00	10.19	P	0.00	7.87	0.10	2.46	0.02	0.03
0.4	0.37	37.69	0.00	10.19	P	0.00	7.91	0.10	2.45	0.02	0.03
0.4	0.37	37.16	0.00	10.20	P	0.00	7.94	0.10	2.44	0.02	0.03
0.4	0.36	36.64	0.00	10.21	P	0.00	7.97	0.10	2.43	0.02	0.03
0.4	0.36	36.13	0.00	10.22	P	0.00	7.99	0.10	2.41	0.02	0.03
0.5	0.36	35.62	0.00	10.23	P	0.00	8.01	0.10	2.41	0.02	0.03
0.5	0.36	35.13	0.00	10.24	P	0.00	8.04	0.10	2.40	0.02	0.03
0.5	0.35	34.64	0.00	10.25	P	0.00	8.06	0.10	2.39	0.01	0.03
0.5	0.35	34.16	0.00	10.25	P	0.00	8.07	0.10	2.38	0.01	0.03
0.5	0.35	33.69	0.00	10.26	P	0.00	8.09	0.10	2.38	0.01	0.03
0.6	0.34	33.22	0.00	10.27	P	0.00	8.10	0.10	2.37	0.01	0.03
0.6	0.34	32.77	0.00	10.28	P	0.00	8.12	0.10	2.37	0.01	0.03
0.6	0.34	32.31	0.00	10.29	P	0.00	8.13	0.10	2.36	0.01	0.03
0.6	0.33	31.87	0.00	10.30	P	0.00	8.14	0.10	2.36	0.01	0.03
0.6	0.33	31.43	0.00	10.30	P	0.00	8.15	0.10	2.35	0.01	0.03
0.7	0.33	31.00	0.00	10.31	P	0.00	8.16	0.10	2.35	0.01	0.03
0.7	0.32	30.58	0.00	10.32	P	0.00	8.17	0.10	2.35	0.01	0.03

APPENDIX D: PAMOLARE 2-Layer Model Input Data

Table D.1. Phytoplankton numbers in Lake Sapanca

		1997				1996				1995			
		B-1	E-2	F-3	L-4	B-1	E-2	F-3	L-4	B-1	E-2	F-3	L-4
CYANOPHYCEAE	Microsystis	550	380	290	180	26600	7100	12000	19000	330	360	160	840
	Aphanizomenon	70	30	230	1840	600	6800	7200	4900	150	360	150	260
	Anabaena	200	260	130	2960	300	1200	1100	200	20	20	20	20
	Chroococcus	0	10	0	0	100	100	100	0	10	10	10	10
	Oscillatoria	70	40	7000	21000	3100	33200	370000	49000	0	0	0	10
CHLOROPHYCEAE	Coelastrum	80	110	60	1500	400	200	200	2000	60	20	30	400
	Oocystsis	30	90	100	1300	1800	1100	400	2500	140	540	80	300
	Ankistrodesmus	60	200	100	11000	700	18200	85000	7600	0	0	0	0
	Zygnema	40	70	110	640	500	500	300	300	20	0	10	20
	Chlamydomonas	0	0	0	0	700	600	100	200	10	0	0	30
	Volvox	0	0	0	0	400	600	300	600	10	20	0	30
	Eastrum	0	0	0	0	100	200	200	5100	0	0	0	0
DIATOMEA	Synedra	12330	11600	12780	30000	470000	390000	210000	100000	33160	25060	18590	6420
	Fragilaria	670	1600	530	1100	3000	1100	3000	1700	20	20	170	80
	Meridion	0	0	0	40	0	0	0	100	0	0	0	0
	Cylotella	90	220	80	600	900	1900	600	300	270	480	130	360
	Asterionella	1810	7050	9730	4500	42600	6400	10100	6900	0	0	0	0
	Pinnularia	10	20	50	60	100	300	0	200	0	0	0	0
	Navicula	0	30	20	60	100	200	300	400	10	30	20	10
	Nitzschia	0	20	10	40	0	400	200	1000	50	20	10	0
	Cymbella	0	0	10	60	100	100	100	100	10	0	0	0
	Tabellaria	0	0	0	0	100	300	100	400	100	60	50	150
OTHER PHYTOPLANKTONS: (DINOPHYCEAE, CHRYSOPHYCAE, XANTOPHYCAE,EUGLENOPHYCEAE	Ceratium	400	1020	8070	1640	3900	7500	1700	3300	20	20	20	70
	Peridinium	360	360	170	820	800	200	1500	5600	180	120	160	100
	Dinobyron	2340	790	500	200	2500	220	1300	500	9630	10650	5340	9870
	Mallomonas	0	0	0	0	100	20	100	200	10	0	0	110
	Botrydiopsis	440	50	30	140	0	10	100	200	20	0	10	300
	Trachelomonas	10	140	130	560	600	80	300	1400	10	10	20	210
	Euglena	0	0	0	0	0	10	0	60	70	60	40	180

Table D.2. Phytoplankton ratios in Lake Sapanca

	1997				1996				1995			
	Diatom	Blue Green	Other	Total	Diatom	Blue Green	Other	Total	Diatom	Blue Green	Other	Total
Number	23780	12683	4543	41005	313275	168425	8033	489733	21320	1115	9220	31655
Ratio	0,58	0,309	0,111	1	0,6397	0,3439	0,0164	1	0,674	0,035	0,291	1

Table D.3. Cark Stream data used for trend

Year	Parameters	Unit	January	February	March	April	May	June	July	August	September	October	November
1995	TP	mg/L	0,003	0,013	0,01	0,01	0,023	0,01	0,023	0,01	0,0228	0,01	0,01
1996	TP	mg/L	0,01	0,01	0,01	0,01	0,01	0,056	0,029	0,01	0,0196	0,01	0,01
1997	TP	mg/L	0,01	0,023	0,033	0,007	0	0,01	0,01	0,01	0,0065	0,01	0,01
1995	TN	mg/L	0,113	0,013	0,182	0,121	0,253	0,172	0,19	1,634	0,28	0,132	0,13
1996	TN	mg/L	0,112	0,182	0,141	0,18	0,21	0,123	0,04	0,123	0,133	0,221	0,271
1997	TN	mg/L	0,091	0,171	0,06	0,243	0,161	0,233	0,232	0,21	0,172	0,252	0,043
1995	T	°C	8	12	16	12	22	24	26	24	23	16	10
1996	T	°C	6	6	8	11	22	24	25	26	22	20	14
1997	T	°C	6	10	9	12	20	22	27	24	20	15	13
1995	BOD5	mg/L	1,4	1,3	2,9	1,7	1,1	1,1	1,2	1,6	0,7	1,1	1,8
1996	BOD5	mg/L	2,87	2,43	1,92	2,09	0,95	0,82	0,86	1,07	1,5	1,26	1,37
1997	BOD5	mg/L	2,37	1,37	1,89	1,16	2,36	1,35	0,99	1,05	0,96	2,2	1,46
1995	DO	mg O2/l	10,9	11	10,6	10,7	7	8,6	7,4	6,5	7,3	9,5	10,4
1996	DO	mg O2/l	11,3	11,2	10,8	9,7	9,2	9,3	8,5	7,4	6,8	7,2	7,8
1997	DO	mg O2/l	9,9	11,5	10,8	11,3	9,9	9,2	8,3	7,4	8,4	7	9,3

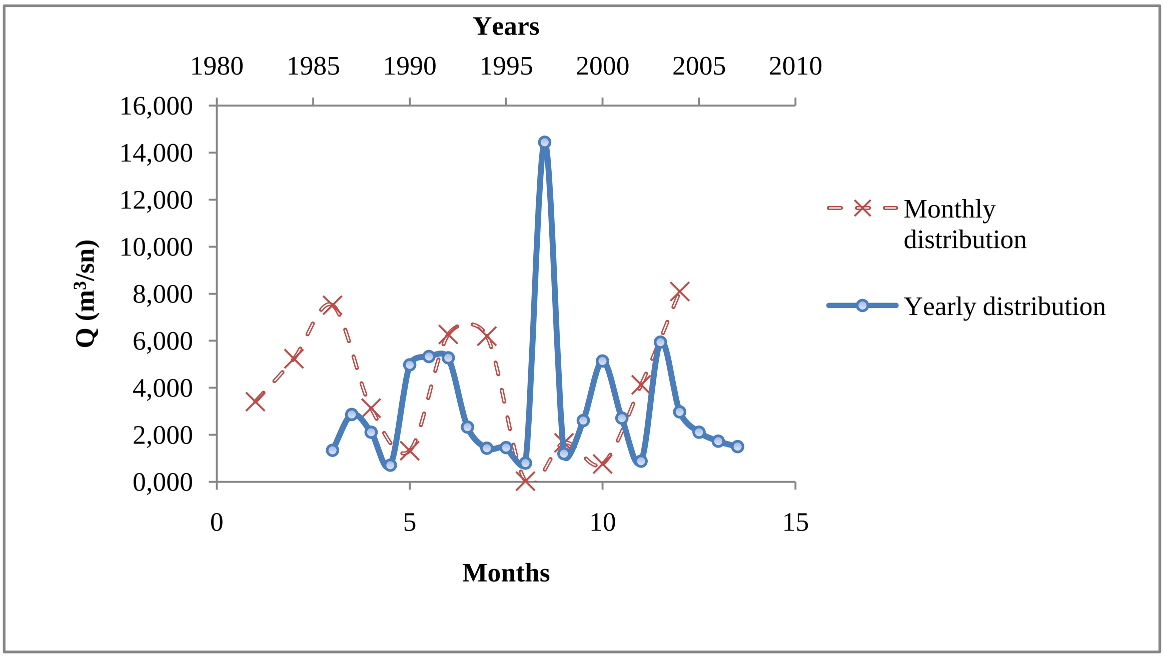

Figure D.1. Monthly and yearly distribution of average flow

APPENDIX E: PAMOLARE 2-Layer Model Outputs

Table E.1. Model output using average daily load, neglecting phytoplankton with doubling existing load

18-01-09, 00:14:39

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.3589	0.5234	mgN/L
Phosphorus	0.0004	0.0216	mgP/L
Diatom	0.0072	0.0013	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0570	0.0717	mgDW/L
Detritus	1.1058	1.3402	mgDW/L
Dissolved Organics	0.4681	0.6810	mgCOD/L
DO	13.6419	11.2988	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.1	million m^3

Table E.2. Model output using average daily load, neglecting phytoplankton with halving existing load

18-01-09, 00:12:21

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.2207	0.2921	mgN/L
Phosphorus	0.0003	0.0094	mgP/L
Diatom	0.0027	0.0005	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0139	0.0186	mgDW/L
Detritus	0.4046	0.4819	mgDW/L
Dissolved Organics	0.1831	0.3160	mgCOD/L
DO	13.3474	11.4840	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

Table E.3. Model output using average daily load, modified phytoplankton with same existing load

18-01-09, 002031

SIMULATION FOR CProgram FilesILECPamolare30Averagein.lk2

Simulated period   1095 days
Integration step   0.10 days

(Daily results are saved in the file CProgram FilesILECPamolare30Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgNL
Phosphorus	0.0045	0.0045	mgPL
Diatom	0.0013	0.0016	mgChl.aL
Blue-green algae	0.0004	0.0005	mgChl.aL
Other phytoplankton	0.0004	0.0005	mgChl.aL
Zooplankton	0.0935	0.0867	mgDWL
Detritus	0.9197	0.9197	mgDWL
Dissolved Organics	0.4841	0.4841	mgCODL
DO	10.3489	6.7787	mgO2L
Nitrogen in Sediment	0.0000	50.0000	mgNL-sed
Phosphorus in Sediment	0.0000	10.0000	mgPL-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgCL-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.2747	0.3811	mgNL
Phosphorus	0.0003	0.0139	mgPL
Diatom	0.0044	0.0009	mgChl.aL
Blue-green algae	0.0000	0.0000	mgChl.aL
Other phytoplankton	0.0000	0.0000	mgChl.aL
Zooplankton	0.0281	0.0368	mgDWL
Detritus	0.6576	0.7944	mgDWL
Dissolved Organics	0.2831	0.4449	mgCODL
DO	13.4506	11.4092	mgO2L
Nitrogen in Sediment	0.0000	50.0000	mgNL-sed
Phosphorus in Sediment	0.0000	10.0000	mgPL-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgCL-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

Table E.4. Model output using average daily load, modified phytoplankton with doubling existing load

18-01-09, 00:22:37

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.3590	0.5252	mgN/L
Phosphorus	0.0004	0.0218	mgP/L
Diatom	0.0074	0.0014	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0001	mgChl.a/L
Zooplankton	0.0573	0.0720	mgDW/L
Detritus	1.1226	1.3610	mgDW/L
Dissolved Organics	0.4706	0.6838	mgCOD/L
DO	13.6412	11.2804	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.1	million m^3

Table E.5. Model output using average daily load, modified phytoplankton with halving existing load

18-01-09, 00:24:38

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.2207	0.2926	mgN/L
Phosphorus	0.0003	0.0095	mgP/L
Diatom	0.0028	0.0006	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0139	0.0186	mgDW/L
Detritus	0.4092	0.4877	mgDW/L
Dissolved Organics	0.1838	0.3168	mgCOD/L
DO	13.3472	11.4787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

Table E.6. Model output using modified daily load, neglecting phytoplankton with same existing load

17-01-09, 23:58:03

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.1435	0.2537	mgN/L
Phosphorus	0.0004	0.0151	mgP/L
Diatom	0.0048	0.0009	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0306	0.0399	mgDW/L
Detritus	0.6888	0.8170	mgDW/L
Dissolved Organics	0.2890	0.4500	mgCOD/L
DO	13.5148	11.4671	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

Table E.7. Model output using modified daily load, neglecting phytoplankton with doubling existing load

18-01-09, 00:00:30

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.1281	0.3058	mgN/L
Phosphorus	0.0005	0.0241	mgP/L
Diatom	0.0080	0.0014	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0626	0.0780	mgDW/L
Detritus	1.1784	1.3993	mgDW/L
Dissolved Organics	0.4809	0.6923	mgCOD/L
DO	13.7590	11.3808	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.1	million m^3

Table E.8. Model output using modified daily load, neglecting phytoplankton with halving existing load

17-01-09, 23:54:20

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.1507	0.2239	mgN/L
Phosphorus	0.0003	0.0101	mgP/L
Diatom	0.0030	0.0006	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0151	0.0201	mgDW/L
Detritus	0.4257	0.4999	mgDW/L
Dissolved Organics	0.1870	0.3196	mgCOD/L
DO	13.3807	11.5098	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

Table E.9. Model output using modified daily load, with phytoplankton with same existing load

18-01-09, 00:04:49

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.1435	0.2539	mgN/L
Phosphorus	0.0004	0.0151	mgP/L
Diatom	0.0048	0.0009	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0306	0.0399	mgDW/L
Detritus	0.6900	0.8184	mgDW/L
Dissolved Organics	0.2894	0.4504	mgCOD/L
DO	13.5146	11.4654	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

Table E.10. Model output using modified daily load, with phytoplankton with doubling existing load

18-01-09, 00:09:38

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.1281	0.3060	mgN/L
Phosphorus	0.0005	0.0242	mgP/L
Diatom	0.0081	0.0014	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0626	0.0781	mgDW/L
Detritus	1.1805	1.4017	mgDW/L
Dissolved Organics	0.4815	0.6930	mgCOD/L
DO	13.7588	11.3779	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.1	million m^3

Table E.11. Model output using modified daily load, with phytoplankton with halving existing load

18-01-09, 00:07:22

SIMULATION FOR : C:\Program Files\ILEC\Pamolare30\Averagein.lk2

Simulated period 1095 days
Integration step 0.10 days

(Daily results are saved in the file: C:\Program Files\ILEC\Pamolare30\Averagein_dailyResults.csv)

STATE VARIABLES, initial values

	Epilimnion	Hypolimnion	
Nitrogen	0.1914	0.2256	mgN/L
Phosphorus	0.0045	0.0045	mgP/L
Diatom	0.0013	0.0016	mgChl.a/L
Blue-green algae	0.0004	0.0005	mgChl.a/L
Other phytoplankton	0.0004	0.0005	mgChl.a/L
Zooplankton	0.0935	0.0867	mgDW/L
Detritus	0.9197	0.9197	mgDW/L
Dissolved Organics	0.4841	0.4841	mgCOD/L
DO	10.3489	6.7787	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

STATE VARIABLES, final values

	Epilimnion	Hypolimnion	
Nitrogen	0.1507	0.2239	mgN/L
Phosphorus	0.0003	0.0101	mgP/L
Diatom	0.0030	0.0006	mgChl.a/L
Blue-green algae	0.0000	0.0000	mgChl.a/L
Other phytoplankton	0.0000	0.0000	mgChl.a/L
Zooplankton	0.0151	0.0202	mgDW/L
Detritus	0.4263	0.5006	mgDW/L
Dissolved Organics	0.1872	0.3197	mgCOD/L
DO	13.3806	11.5089	mgO2/L
Nitrogen in Sediment	0.0000	50.0000	mgN/L-sed
Phosphorus in Sediment	0.0000	10.0000	mgP/L-sed
Dissolved Organics in Sediment	0.0000	70.0000	mgC/L-sed

Depth	20.6	32.7	m
Area	37200000	13800000	m^2
Volume	767.1	451.0	million m^3

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