

Assessment of improvement scenario for water quality in Mogan Lake by using the AQUATOX Model

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Abstract In this study, the improvement scenarios for water quality in Mogan Lake were investigated using the AQUATOX Model. The ecosystem model AQUATOX simulates conventional pollutants, such as nutrients and sediments, and considers several trophic levels, including attached and planktonic algae, submerged aquatic vegetation, several types of invertebrates, and several types of fish. In this study, all data measured at both lakes and creeks was loaded into the AQUATOX Model including both initial concentration and dynamic loading for the year 2002. Then, the AQUATOX Model was calibrated and verified for the years 2004 and 2005. Accordingly, the Aquatox Model was utilized for the analysis of future scenarios as to improve water quality in terms of conventional parameters such as dissolved oxygen, temperature, total suspended solids, pH, total nitrogen, total phosphorus, and labile and refractory organic matters in water colon and sediment. During the development of future scenarios, some plans regarding measures were taken into account the modeling periods. In one of the scenarios, constructed wetlands located in big creeks' mouths were used for improving the water quality in Mogan Lake. The results indicated that Mogan Lake would improve its hypertrophic situation towards eutrophic situation. It would be anticipated that if the situation goes on like this, Mogan Lake would improve eutrophic situation towards mezotrophic situation.

Keywords Water quality · Eutrophication · Simulation · Modeling · AQUATOX Model

Introduction

Eutrophication is a pollution process which results from an increase in planktonic algae or production of more complex aquatic plants or extraordinary change of species. Thus, deterioration of water quality, increasing nutrients, and decreasing oxygen level in the bottom layers of water bodies in lakes and estuaries media occur. The determination of eutrophication and prevention of pollution that causes ecological deterioration are possible by conducting a detailed search, by monitoring water sources, and implementing water quality and eutrophication models. These models are based on monitored results in order to receive media and to put forward scenarios based on loading change.

Some water quality models are used in order to determine the effect of nitrogen and phosphorus to aquatic environments. The first mass balance equation approach has been developed by Vollenweider (1975). Lots of models have been developed since 1960. Their comparison with AQUATOX Model used in this study is presented in “Materials and methods” section.

There are strong relations between the algae biomass and nutrient loading in all eutrophic lakes. Eutrophic lakes are generally characterized by blue-green algae (cyanobacteria). They produce toxic compounds, and some of them are more toxic than the cobra.

Developing an approach in terms of water resources management is realized on the basin level and other natural resources as they are integrated. The main goal of integrated basin management is that the basin defines not only water quantity but also all aspects and its resources; thus, more consistent decisions can be made.

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Models, which expose biota to effects, are expressed with mathematical equipment. They contribute to solving the environmental problems and accelerating the work to solve these problems. It is possible that pressures of aquatic environment make the solving plans and the most suitable solving plans by taking into account sustainable development. Thus, models are used as important tools for decision makers.

Improvement in the water quality of the constructed wetlands was made in TUBITAK-MAM Research Center using Iris and Canna plants. These wetlands showed excellent performance for removing chemical oxygen demands (COD) and total nitrogen (TN). Average removing performance of these wetlands are COD 88 %, suspended solids (SS) 97 %, total kjeldahl nitrogen (TKN) 85 %, TN 85 %, and phosphate (PO₄-P) 60 % (Ayaz and Akca. 2001). The removal performance for NH₄-N and NO₃-N have been found as 73, 57, 37, and 58 %, respectively, by using subsurface flow and free surface flow wetlands in the same place (Tunçsiper and Akça 2006).

The removal performance for SS: 99, 48, 42, and 87 %; COD: 96, 62, 75, and 87 %; NH₄-N: 89, 42, 72, and 45 %; NO₃-N: 30, 82, and 29 %; and PO₄-P: 22, 52, 17, and 35 % have been found using wetlands consisting of reeds in four regions of Italy (Conte et al. 2001).

The most important instrument for decision makers is modeling system in lake management. The ecosystem model AQUATOX is one of the few general ecological risk models that represents the combined environmental fate and effects of toxic organic chemicals. The model also represents conventional pollutants, such as nutrients and sediments, and considers several trophic levels, including attached and planktonic algae, submerged aquatic vegetation, several types of invertebrates, and several types of fish. It has been implemented for streams, small rivers, ponds, lakes, and reservoirs.

In this study, the improvement scenarios for water quality in Mogan Lake using the AQUATOX Model were investigated. Constructed wetlands located at big creeks' mouth were taken into account as measures to improve the water quality in Mogan Lake. The simulations between 2009 and 2010 for dissolved oxygen, temperature, total suspended solids, pH, total nitrogen, total phosphorus, and labile and refractory organic matters in water column and sediment in the normal and good operational conditions for wetlands were carried out with the AQUATOX Model.

Materials and methods

Mogan Lake Basin and its characteristics

Mogan Lake is a small alluvial sediment lake, and it is one of the most important wetlands of Turkey located between 39° 44' 40"–39° 47' 45" north latitude and 32° 46' 30"–32° 49' 30"

east longitude at 972 m above sea level near the city of Ankara (Fig. 1). It is fed by small creeks, most of which are dry in the summer season. The lake has a surface area of 750 ha with huge reed beds around it. The length and width of Mogan Lake is 6 km and 900 m, respectively. The average depth is 3.5–4 m. The volume is 13–14 million m³. The precipitation area is 941 km². The average precipitation is 403 mm, and the average evaporation is 1485 mm. The total basin area is 971 km² for Mogan and Eymir Lakes, and the length of the basin is 150 km. The highest altitude is 1650 m, and the lowest altitude is 950 m.

Mogan and Eymir Lakes and their river basins are declared as special protection areas (SPA) by the Cabinet's Decree No. 90/1117 on 22.10.1990. This area covers 245 km² of the total precipitation area of the lakes.

The wetland of 750 ha at the south of the lake serves as a habitat for a lot of species, especially birds. The main stream is Çölova, which does not flow continuously, is lost in the middle of the basin and then appears from the wetland and is located to the south of Mogan Lake. Sukesen, Başpınar, Yavrucak, and Çölova generally flow, except for very dry years.

Mogan Lake has been used for hunting, swimming, and sporting purposes and recreation for many years. The most densely populated settlement is Gölbaşı district, which is located on the northern coast of Mogan Lake. Besides Gölbaşı District, there are administrative areas for Çankaya, Bala, and Haymana districts in the Mogan Lake Basin. There are 31 settlements in the Mogan Lake Basin, and the total population is 62,602. Since Gölbaşı district is 20 km far from Ankara and accessibility is quite easy, population growth and rapid urbanization are the main threats.

Generally, dry agriculture is carried out in the basin. Production pattern is heavily cereal, and in irrigated areas (in the valley of Sukesen creek), it is vegetable. There are pastures in that portion of the basin.

There are very few machinery and mining industries in the basin, and they are connected to the sewage system. However, they sometimes discharge into the lake without any control system.

According to the report, which was prepared by the Environmental Protection Agency for Special Areas in 2000, agriculture was carried out in wider areas located in the south of Mogan Lake (Environmental Protection Agency for Special Areas 2000). These areas affect Mogan Lake depending on the used fertilizer and pesticides. Therefore, the reeds have been growing in Çölova creek, eventually reaching Mogan Lake. It is anticipated that extensive use of pesticides in the basin will damage aquatic compounds.

Substances which flow into Mogan Lake through erosion, snow melting, and drainage cause accumulation of sediment and a decrease in the depth and volume of the lake as well. The biological activities continue for years and have been

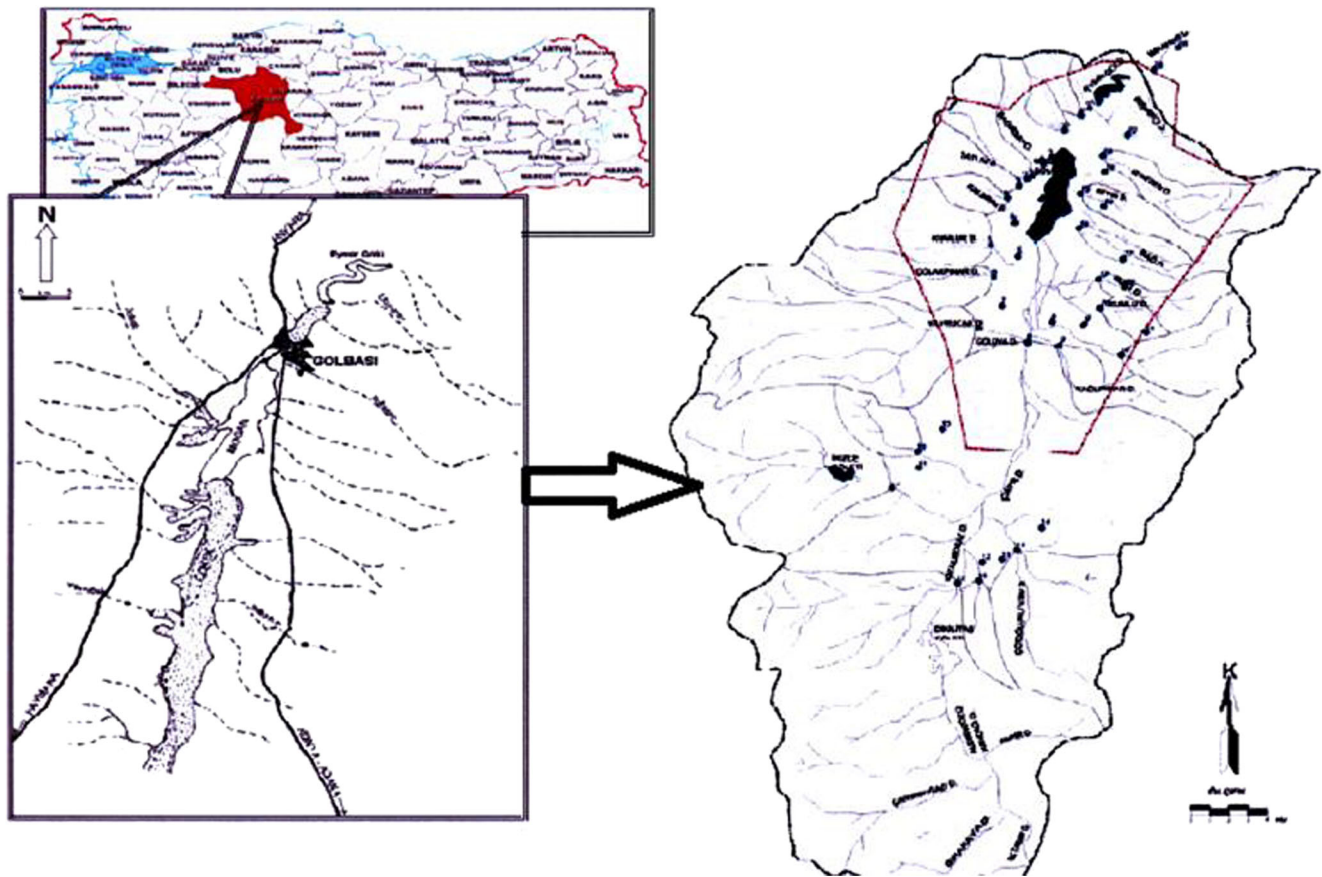


Fig. 1 Geographical location of Mogan Lake

accelerated by accumulating sediment and discharging of wastewater and nutrients which go into the lake through rainwater. Therefore, the wetlands in patches, increasing and spreading plants in water and shallow parts, have been observed in the lake. The wetlands and eutrophication have been prevalent because of the increasing sediments and nutrients. Another reason for the pollution in the lake is the diffuse pollution from agricultural lands.

When pollution loads into Mogan Lake are evaluated, Gölovası, Yavrucak, Kumluk, Başpınar, Yağlıpınar, Kurt, Çolakpınar, and Yayla creeks in the south, Kaldırım, Tatlım, Göçlük creeks in the west, and Sukesen Creek in the east carry an important amount of nitrogen, phosphate, and total dissolved solids and sediments into the lake. Furthermore, instability of water level of the lake affects the conditions in the lake. Aquatic plants' growth is accelerated because of shallowness (Yerli 2002). According to Yerli (2002), Mogan Lake is hypertrophic.

With the coordination of Environmental Protection Agency for Special Areas, the Environmental Reference Laboratory conducted analyses in the Lake in the years 2001, 2002, 2004, and 2006. Similar results were also obtained in 2003 and 2005. As a result of these analyses, especially in summer months, Mogan Lake is hypertrophic in terms of total

Table 1

Sample No	Station No	Coordinates
1	Gölcük Dere	N39° 46,303' E32° 46,407'
3	Tatlım Dere	N39° 46,058' E32° 46,163'
6	Çolakpınar Dere	N39° 44,288' E32° 45,196'
7	Yavrucak Dere	N39° 41,687' E32° 44,520'
8	Çölova Dere	N39° 41,151' E32° 46,469'
11	İközce Gölet	N39° 36,572' E32° 40,814'
12	Dikilitaş Gölet	N39° 34,034' E32° 44,118'
15	Başpınar Dere	N39° 40,943' E32° 49,040'
16	Kumlu Dere	N39° 42,388' E32° 48,959'
19	Kepir Dere	N39° 46,102' E32° 48,283'
20	Sukesen Dere	N39° 47,445' E32° 48,190'
21	Mogan Çıkış	N39° 47,671' E32° 48,013'
25	Kışlak Dere	N39°49,670' E32°50,820'
MG1	Dere Giriş Mansap	N39°47, 414' E32° 47,855'
MG2	Mansap	N39° 47,219' E32° 47,919'
MG3	Orta	N39° 46,411' E32° 47,683'
MG5	Menba	N39° 45,476' E32° 47,032'

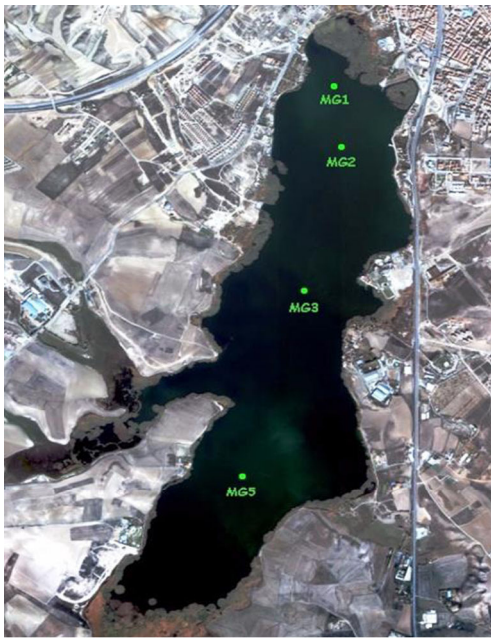


Fig. 2 Mogan Lake sampling points

phosphorus and chlorophyll, according to OECD trophic state classification (Yerli 2002).

The AQUATOX is a process-based model for ecological risk assessment that can represent the effects of toxic chemicals and conventional pollutants on the aquatic ecosystem (Park and Clough 2004a, b). The model uses a daily timescale to simulate the physical environment (e.g., flow, light, and sediment) and chemical environment (e.g., nutrients, oxygen and carbon dioxide, and pH). The dynamics of biotic components of detritus, algae, benthic invertebrates, and fish can be simulated.

The AQUATOX can simulate organic chemicals, but not metals or organometals, and it is the most useful organic chemical with high octanol-water partition coefficients (e.g., $>10^4$) that can be expected to bioaccumulate. For a new chemical, data are required for molecular weight, octanol-water partition coefficient, and Henry Law transformation rates as appropriate. The AQUATOX predicts the partitioning of a toxicant among water, sediment, and biota and includes processes of microbial

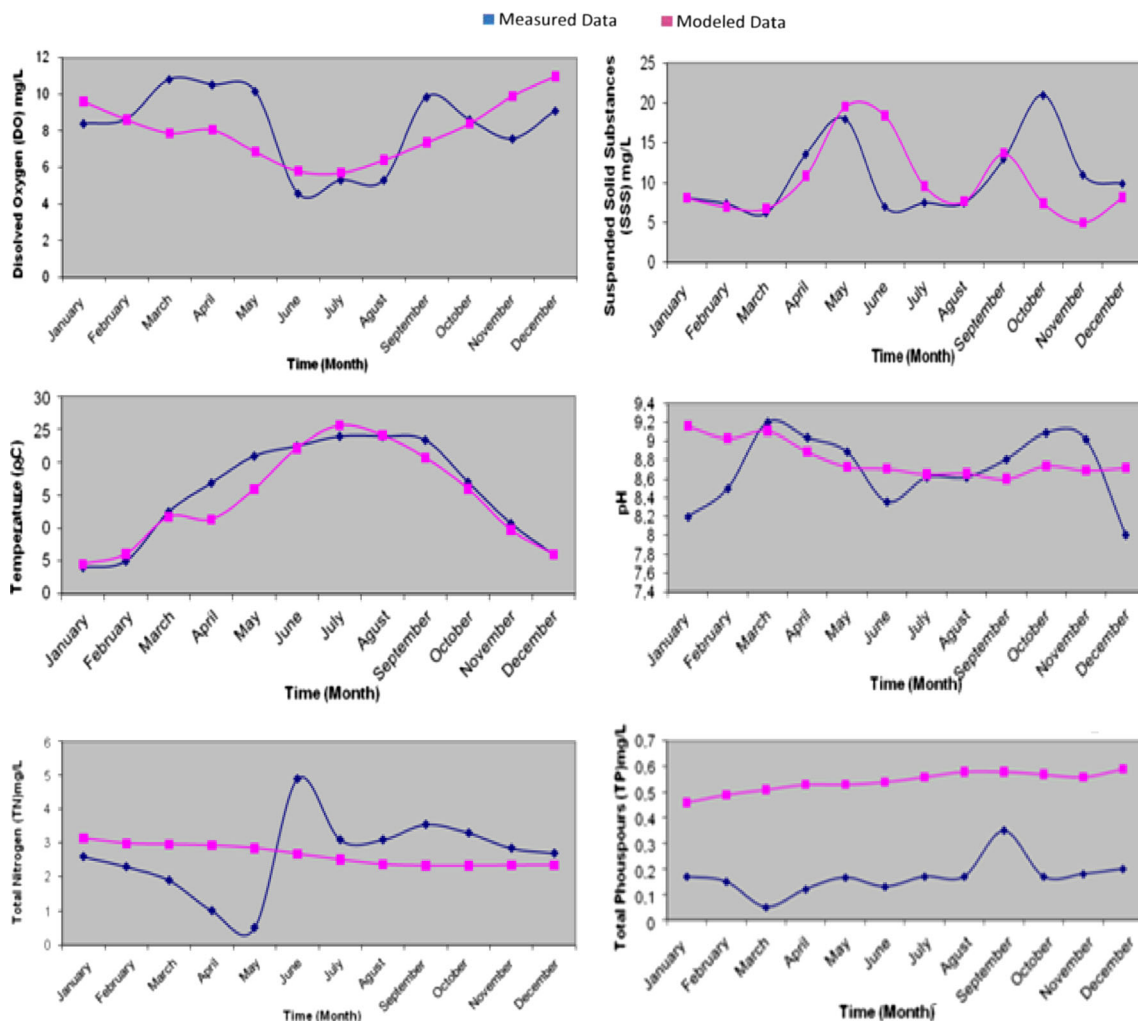
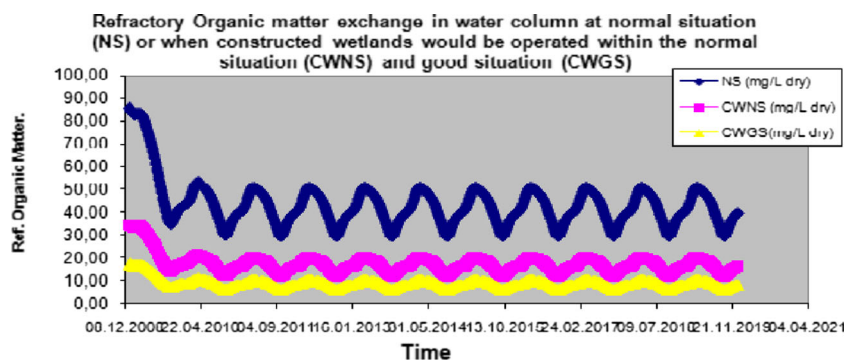


Fig. 3 Comparisons of the modeled data and measured data

Fig. 4 Refractory organic matter exchange in water column at normal situations (NS) or when constructed wetlands would be operated within the normal situation (CWNS) and good situation (CWGS) (mg/L dry)



degradation, biotransformation, photolysis, hydrolysis, and volatilization (Gonenc et al. 2007).

The AQUATOX Model simulates the following parameters: (i) concentration of nutrients and toxic substances, (ii) biomass, (iii) plants, invertebrates and fish, (iv) chlorophyll a, (v) phytoplankton, periphyton and algae, (vi) total suspended solids and secchi depth, (vii) dissolved oxygen, (viii) biological oxygen demand, (ix) bioaccumulation factor, and (x) half-lives of toxic organic.

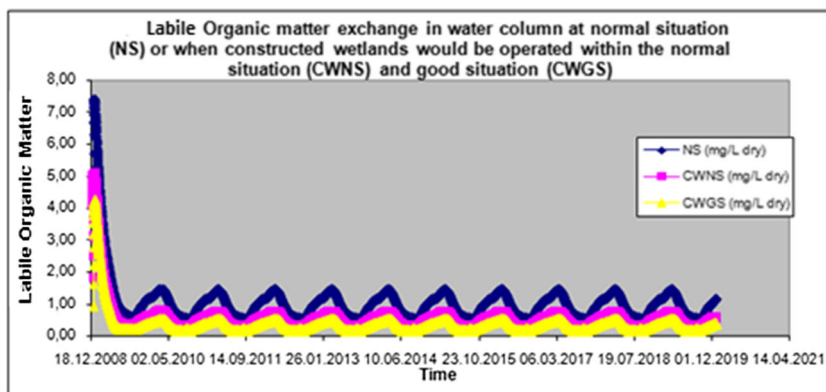
The AQUATOX Model is implemented for artificial lakes, dams, rivers, and territorial surface water. Completely mixed thermal water or salty saturated water is modeled easily (Park and Clough 2004b). The calculation, which is based on mass-balance calculation, is carried out in the AQUATOX Model. In this framework, all aquatic components are considered. The differential equation regarding toxic substances and algae is given below.

$$\frac{d\text{Toxicant}_{\text{Alga}}}{dt} = \text{Loading} + \text{AlgalUptake} - \text{Depuration} - \text{TurbDiff} - (\text{Excretion} + \text{Washout} + \sum_{\text{Pred}} \text{Predation}_{\text{Pred,Alga}} + \text{Mortality} + \text{Sink} + \text{SinkToHypo}) * \text{PPB}_{\text{Alga}} * 1e^{-6} - \text{Biotransform}_{\text{Alga}}$$

where

- Toxicant alga Algae given for water in unit volume related to toxicant mass (g/L)
- PPB alga Concentration of toxic substances in algae (g/kg)
- $1e^{-6}$ Unit conversion (kg/mg)

Fig. 5 Labile organic matter exchange in water column at normal situations (NS) or when constructed wetlands would be operated within the normal situation (CWNS) and good situation (CWGS) (mg/L dry)

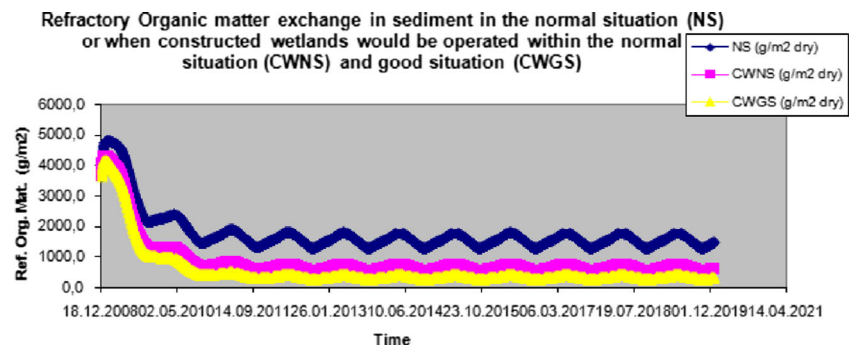


Loading	Loading of outsourced toxicants (g/ dry)
Turb diff	Average turbulence coefficient between Epilimnion and hypolimnion (g/L dry)
Depuration	Elimination rate of toxicants depending on cleaning (g/L dry)
Sink	Phytoplankton loss rate of lower sediment (mg/L dry)
Sink To Hypo	Transfer rate of phytoplanktons to hypolimnion (mg/L dry).
Algal uptake	Sorption rate of algae (g/L dry)
Excretion	Excretion (g/m ² dry)
Mortality	Death of living organisms which are not predators (g/m ² dry)
Washout	Loss due to drift and flow (g/m ² dry)
Predation	Herbivorous animals (g/m ² dry)
Biotransform alga	Biotransformation in algae

Degradation of chemicals and degradation rate have been predicted among water, sediment, and biota in the AQUATOX Model. While the AQUATOX models the effects of each chemical on aquatic environment, all features are considered. The reasons to use the AQUATOX Model in Mogan Lake are listed below.

- Since Mogan Lake is eutrophic, it can be modeled in the AQUATOX for both nutrients which are the source of eutrophication and toxic organic chemicals at the same time.

Fig. 6 Refractory organic matter exchange in water column at normal situations (*NS*) or when constructed wetlands would be operated within the normal situation (*CWNS*) and good situation (*CWGS*) (mg/m^2 dry)



- The AQUATOX, together with toxic chemicals, models the biological quality elements and shows the effect of toxic chemicals on them.
- The AQUATOX Model is more sensitive than other water quality models, which means it can work with less data.
- Moreover, the AQUATOX Model simulates the organic substances as eight fractions. So, it gives more proper results.
- The AQUATOX model can supply input to the model for some parameters which are difficult to measure via empirical equations.

The AQUATOX Model is perhaps the most comprehensive model available, as can be seen by comparison with other representative dynamic models used for risk assessment (De Laender et al. 2008; Park et al. 2008). All the models, with the exception of QSim and CASM, are public domain. The closest to the AQUATOX in terms of scope is the family of CATS models developed by Traas and others. These ecotoxicology models have simple representations of growth and are not as suitable as the AQUATOX for detailed analyses of eutrophication effects (Traas and Aldenberg 1992). CASM is similar to CATS with simplified growth terms, but it lacks a toxicant fate component. QUAL2K and WASP are water quality models that share many functions with the AQUATOX, including benthic algae. WASP is also a model of toxicants. The hydraulic and water quality models EFDC and HEM3D are often combined; EFDC has also been used to provide the flow field for linked segments in the AQUATOX, resulting in a

similar representation. The AQUATOX, QUAL2K, WASP, and EFDC include the sediment diagenesis model for remineralization (Park et al. 2008).

Among the total of 17 selected sampling points, 10 sampling points are from creeks feeding to Mogan Lake, 3 sampling points are from Eymir Lake, 4 sampling points are in Mogan Lake, and 2 sampling points are from outlets of those lakes. The coordinates of sampling points are given in Table 1, and sampling points are presented in Fig. 2 for Mogan Lake. While sampling points for creeks are selected on the mouth of the river just before discharging into the lake to be able to see the pollution from each creek, points in the lake are determined both to observe pollution from creeks and pollution from the bottom sediment.

All chemical parameters are in the unit of mg/L . Chemical parameters are loaded to the AQUATOX Model as mg/L . Biological parameters have been analyzed as species or individual/ m^3 . Therefore, it is necessary for biological parameters to be converted into g/m^3 (g/m^2). In this study, the formulation developed by Mullin et al. (1966) has been used for converting phytoplankton to g/m^3 as follows:

$$\text{Phytoplankton (mg/L)} = (\text{individual})/\text{mL} * 2\text{E}-4$$

Phytoplankton has been converted to mg/l with the help of this equation in Mogan Lake. For developing Zooplankton and Daphnia to mg/L , the formulation developed by the AQUATOX has been used, which is

$$\text{Daphnia or zooplankton (mg/L)} = 0.0006 * (\text{individual})/5$$

Fig. 7 Labile organic matter exchange in water column at normal situations (*NS*) or when constructed wetlands would be operated within the normal situation (*CWNS*) and good situation (*CWGS*) (mg/m^2 dry)

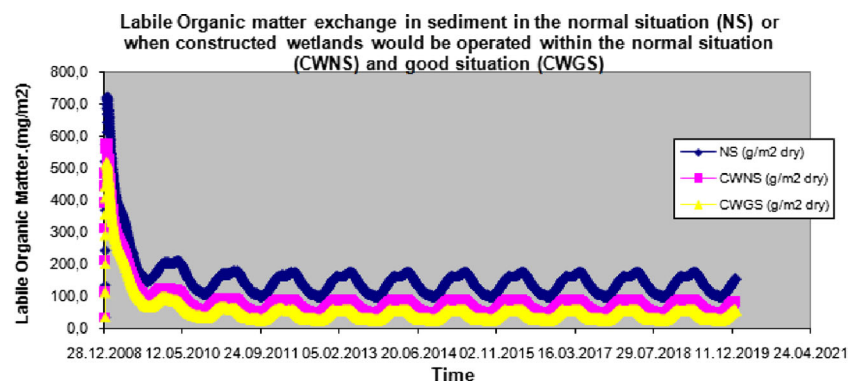
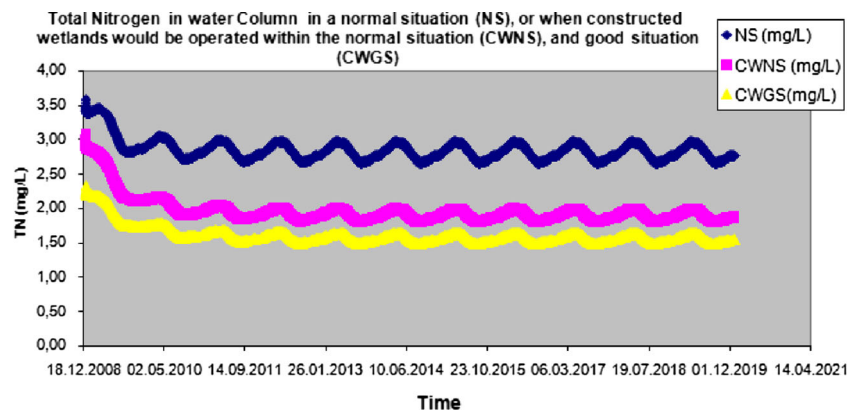


Fig. 8 Total nitrogen in water column in a normal situation (NS) or when constructed wetlands would be operated within the normal situation (CWNS) and good situation (CWGS) (mg/L)



After all those conversions, all existing data were loaded into the AQUATOX Model. All data measured at both lakes and creeks were loaded as both initial concentration and dynamic loading. Since the average concentration of some parameters in creeks were bigger than in the Lake, average concentrations of some parameters such as total nitrogen, nitrate, total soluble phosphorus, and total suspended solids have been taken as initial values. The total concentration of organic substances in creeks was taken as initial loading. The values of temperature, dissolved oxygen, pH, and biological parameters measured in Mogan Lake were loaded as both initial concentration and dynamic loading. The values of the hydrological parameters measured in the creeks were taken as both initial concentration and dynamic loading. All data were measured in 2002. At the beginning of this study, before calibration and verification, degradation coefficients and ratios determined for Clear Lake (USA), which were eutrophically similar to Mogan Lake, were used in the AQUATOX Model. Clear Lake is the largest, natural freshwater lake in California with 68 mile² of surface area. After establishing input values to the AQUATOX Model, calibration and verification stages started. While calibration and verification were carried out, the simulation results of the AQUATOX Model were compared with 2004 measured data. Those comparisons are shown in Fig. 3. As seen in Fig. 3, there is no need for calibration of temperature, pH, and suspended solids parameters in the AQUATOX Model since simulation results and measured results are very close. The calibration and verification were carried out for

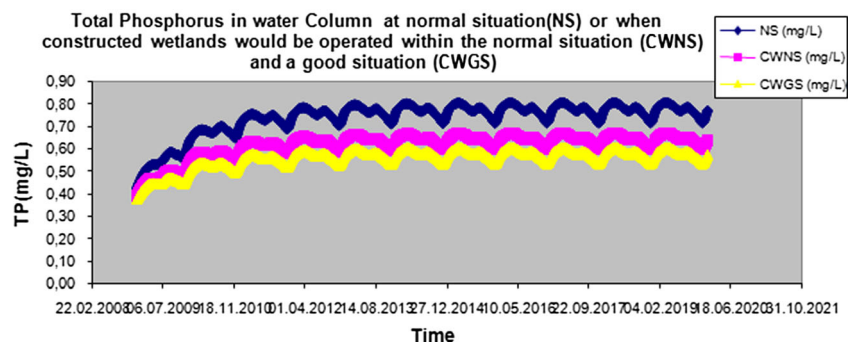
dissolved oxygen, total nitrogen, and total phosphorus. Whether trials were determined for a suitable interval or not, relative error has been used.

Results and discussions

In the first step of this study, the scenarios were made with the AQUATOX Model for the improvement of water quality in Mogan Lake as long as there is no change regarding Mogan Lake. The simulation showed us what would happen in Mogan Lake between 2009 and 2020.

In the second step of this study, it was supposed that the wetlands were constructed on the mouth of the creek flowing into Mogan Lake. The scenarios regarding the wetland effect to water quality were devised. In this direction, when free surface flow wetlands were operated normally, which means that everything such as pressures to Mogan Lake, etc. is the same, and good conditions, which means that some measures would be taken to improve the water quality in Mogan Lake, the improving period on water quality was shown. The pollution loading, which removed performance supposedly in the normal operational condition (NOP) as biological oxygen demand (BOD) 60 %, SS 50 %, NH₄-N 30 %, NO₃-N 25 %, PO₄-P 20 %, was adjusted. The pollution loading, which removed performance supposedly in the good operational condition (GOP) as biological oxygen demand (BOD) 80 %, SS

Fig. 9 Total phosphorus in water column in a normal situation (NS) or when constructed wetlands would be operated within the normal situation (CWNS) and good situation (CWGS) (mg/L)



70 %, NH₄-N 40 %, NO₃-N 35 %, PO₄-P 30 %, was adjusted. Then, Mogan Lake would have been simulated till 2020, and simulation results are given in Figs. 4, 5, 6, 7, 8, and 9.

Conclusions

In this study, the improvement scenarios for water quality in Mogan Lake using the AQUATOX Model were investigated. The ecosystem model AQUATOX simulates conventional pollutants, such as nutrients and sediments, and considers several trophic levels, including attached and planktonic algae, submerged aquatic vegetation, several types of invertebrates, and several types of fish. It has been implemented for streams, small rivers, ponds, lakes, and reservoirs.

The most important instrument for decision makers is modeling systems in lake management. In this study, the AQUATOX Model, which was calibrated and verified for Mogan Lake, was used in future scenarios for the improvement of the water quality. Depending on these scenarios, the measures regarding water quality improvement were determined. Moreover, in these scenarios, some plans regarding the measures take into account the modeling periods.

In this study, constructed wetlands located in big creek mouths were taken into account as well as the measures for improving the water quality in Mogan Lake. The simulations between 2009 and 2020 for dissolved oxygen, temperature, total suspended solids, pH, total nitrogen, total phosphorus, and labile and refractory organic matters in water column and sediment in normal and good operational conditions for wetlands were carried out with the AQUATOX Model.

According to investigated results, Mogan Lake was hypertrophic. In this direction, scenarios created with the AQUATOX Model for nutrients which cause eutrophication, as well as some alternatives regarding water quality improvement duration, appeared. The simulation results were shown for dissolved oxygen, suspended solids and pH, total nitrogen, total phosphorus, temperature, and refractory and labile organic substances in water column and sediments from 2009 to 2020 when all conditions were normal. This means that there are not any extra measures, and constructed wetlands around this lake would be operated under normal and good conditions.

It was seen in all simulation results that there were more refractory organic matter than labile organic matter in water column and sediment for Mogan Lake. It has been understood from the simulation results that most probably, the sources of refractory organic matter have come from pesticides and sediments. All results have shown that there has not been any domestic pollution in recent years. Despite a decrease in labile organic matter, they keep their availability in sediment. All simulation results have shown that Mogan Lake was exposed to intensive organic pollution.

If the improvement measures were not taken into consideration, total nitrogen concentration would have changed between 2.65 and 2.85 mg/L in 2020. According to simulation results, when the constructed wetlands were built around Mogan Lake, total nitrogen concentration would have decreased to 1.45–1.6 mg/L, if the free flow constructed wetlands were built and operated in good conditions. The status of Mogan Lake would be converted to eutrophic from hypertrophic. When the condition went on like this, which means there are no extra pressures, it would be anticipated that the Mogan Lake would be improved to be first eutrophic, then mesotrophic.

Even if the artificial wetlands were built around the Mogan Lake, it was seen that total phosphorus would be increasing up to 2020. All these results are evidence that the sludge have been accumulating for a long time at the bottom of Mogan Lake. Besides these, results have shown that the limiting element is phosphorus in Mogan Lake.

Consequently, water quality models help to solve environmental problems and accelerate the work to solve the problems. Pressures of aquatic environment may enable solving plans and the most suitable solving plans by taking into account sustainable development. Thus, models are used as important tools for decision makers. On the other hand, decision makers can use the water quality models to improve the eutrophic and hypertrophic water body.

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