Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(1): 2697 – 2716 (2025)
www.ejabf.journals.ekb.eg

A Brief Review of Water Quality Models: AQUASEA

Naglaa A. El-Naggar[1, 2]*

[1]Department of Chemistry, College of Science, University of Hafr Al Batin, P.O. Box 1803, Hafr Al Batin, 31991, Saudi Arabia
[2]National Institute of Oceanography and Fisheries, NIOF, Egypt
***Corresponding Author: naenaggar@uhb.edu.sa; naglaa.elnaggar@gmail.com**

ARTICLE INFO

Article History:
Received: Jan. 9, 2025
Accepted: Feb. 15, 2025
Online: Feb. 26, 2025

Keywords:
Hydrodynamic,
Water quality,
Modeling,
AQUASEA

ABSTRACT

Water has a vital role in our life and without it there is no life on earth. Water pollution is one of the world challenges and problems that face both developing and developed countries. To understand how an ecosystem is polluted or not, we need concrete and deep knowledge of models of water quality to make fruitful directions and decisions. Water quality modeling is an effective tool for solving water pollution problems, saving labor's and materials' cost for many industrial developments that helps policymakers, scholars, and water managers for water environmental management. The advancements in computer science have resulted in models' development for predicting the quality of water and simulating the fate/transport of environmental contaminants. Up to date, hundreds of computer software model, including ten model types of water quality, with 1D, 2D, or 3D simulation have been developed. This article review describes water quality modeling using AQUASEA program, which is a powerful, effective program, and easy to be used as finite element to solve rivers flow, tidal flow problems in coastal areas, estuaries, lake circulation and problems related to different water quality dispersion and transport of indicators. Various models have been implemented using AQUASEA program in different regions of the world. Although AQUASEA program is used in the most difficult models, this program is not widely used as water quality model in comparison with other programs.

INTRODUCTION

Water has a vital role in our life that is necessary for the life survival and affects the socio-economic growth **(Stolarska & Skrzypski, 2012)**. Our life depends on the availability and quality of water. Water pollution is a global problem that faces both developing and developed countries that have high rate of pollution because of economic growth, in addition to its impact on the human health and environment. The continuing urbanization, agriculture, industrialization with increased anthropogenic activities are important factors of environmental pollution that affect the aquatic ecosystem **(EIC, 2009)**. They release a large amount of inorganic and organic pollutants such as pesticides, hydrocarbons, heavy metals, phosphates, nitrates, and metals into the waterbodies. Eutrophication occurs due to the increase of nutrients that leads to an increase in algae growth and other aquatic plants in ecosystem **(Hussein *et al*., 2017)**. This results in a reduction of dissolved oxygen in aquatic environment **(Yang *et al*., 2008; Conley *et al*., 2009)**.

Marine pollution is leading to major environmental changes, dangerous losses of biodiversity and decreased commercial yields. There are three parameters to measure water quality: physical, chemical, and biological parameters. The first one, physical parameters involve odor, taste, color, temperature, turbidity, solids, and electrical conductivity. The second type, chemical parameters include hardness, alkalinity, pH, nutrients, dissolved oxygen, and biological oxygen demand. The last one, biological parameters, involve algae, bacteria **(Ott, 1978; Canter, 1985)**. To understand how an ecosystem is polluted or not, we need concrete and deep knowledge of models of water quality to make fruitful directions and decisions. Models allow policy makers and decision to select from among alternative possibilities, stronger and better solutions for water quality management. Water quality is modeled with different water characteristics. The co-relations between these characteristics are related to the processes that occur in the environment. Water systems managers should evolve the key processes and parameters affecting the water quality of local ecosystem to give improved and correct management decisions **(Liu, 2018)**. Pollutants and their distributions are affected by immobilization and certain dynamic processes, like dispersion, advection, and diffusion. These processes are relevant to characteristics of water flow, effluent, inflows and outflows, stratification of temperature, ecosystem body, and wind stress.

In the recent times, different models were used for simulating the quality of coastal waters, bays, lakes, estuaries, and other marine ecosystems **(Loucks & Van Beek, 2017)**. However, water quality modeling represents a challenge in the scientific community because of different limitations such as lack of expert user, site specific information, parameters, shortcomings in model calibration as well as errors in data reporting. However, up to date, hundreds of computer software model, including ten types of water quality, with 1D, 2D, and 3D simulation have developed and successfully applied practically in many countries. This article review represents a review of water quality modeling using AQUASEA program, which is a powerful and easy to use as finite element to solve rivers flow, tidal flow problems in coastal areas, estuaries, lake circulation and problems involving dispersion and transport of different water quality indicators such as temperature, salinity, DO, COD, BOD, nutrients and other parameters in aquatic environment.

OVERVIEW OF WATER QUALITY MODELING

1. Why model?

Water quality management is an essential component of comprehensive environmental management of water resources to track water quality changes and solve environmental pollution problems **(UNESCO, 2005)**. Water quality modeling is used to compute and predict the changes in the aquatic environment, analyze any existing phenomena, identify the sources of pollution, know the history of contaminant transport, determine when an incident could begin, or when contaminants could reach a certain level in a specific ecosystem and reasons of environmental deterioration of water quality in a particular ecosystem, as well as selecting better methods for sustainable development **(Zheng & Gordon, 1995; Chapra, 2008; Stolarska & Skrzypski, 2012)**. Models are tools to support decision for simulating pollutants dispersion in waterbodies and assess their hazards **(Chapra, 2008; Wang *et al.*, 2013)**. To control the source of pollution or change the flow pattern, the distribution of contaminants in the future must be calculated either under current circumstances or with engineering interference.

2. Development of water quality modeling

Since its invention in the early years of the twentieth century, water quality models have developed significantly. As shown in Fig. (1), this development can be broken down into four main stages. These stages relate to the computational abilities that were available during each stage and to societal concerns.

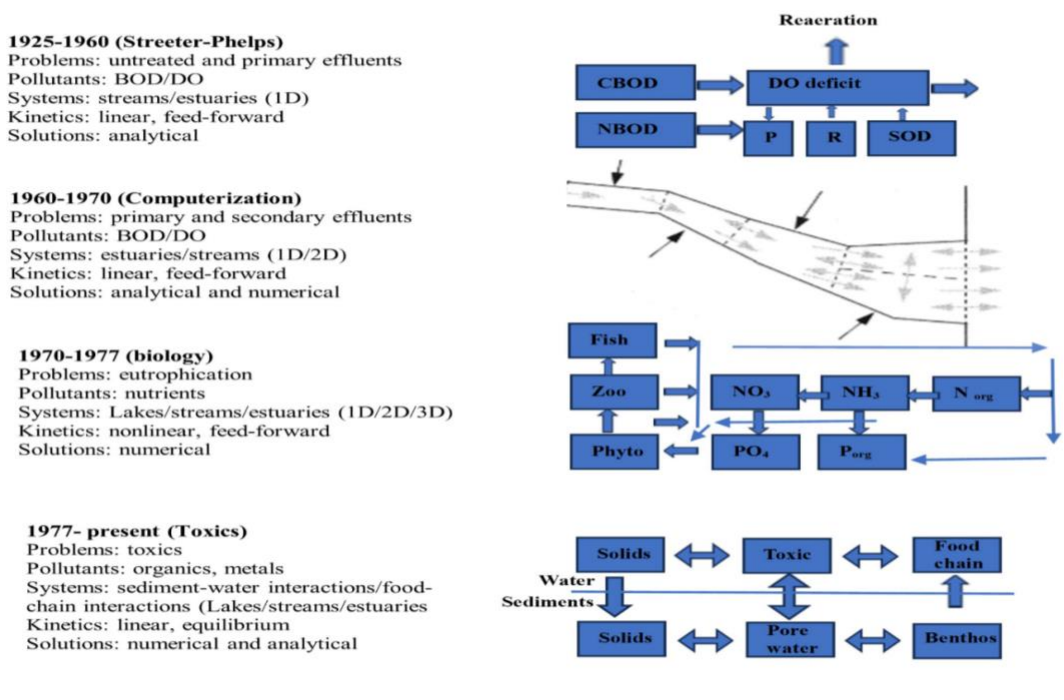

Fig. 1. Development of water quality modeling **(Chapra, 2008)**

This innovation began in Streeter and Phelps' 1925 work on the Ohio River. This and subsequent phases were conducted to determine DO levels in estuaries and streams **(O'Connor, 1967)**. Moreover, models of bacteria were also applied. No availability of computers in this era led to close model solutions. This means that computer applications were only limited to simple geometries of areas, linear kinetics and steady state water receiving conditions. In the 1960s, the first stage of development of modern practices began with the discovery mainframe computers. In the late 1980s, successful development stages were evolved by the availability of computer desktop. Additionally, in the mid to late 1990s to the present, Windows operating systems improved, and the internet have been driven. Water quality models made great progress from single parameter to multi-parameter water quality, from point source model to coupling point and non-point sources, from steady state to dynamic model, and from zero-dimensional mode to ID, 3D and 3D models **(Xu & Lu, 2003; Wang *et al.*, 2011)** (Table 1).

Table 1. The versions and characteristics of water quality models **(Ejigu, 2021)**

Models	Model version	Characteristics
Streeter-Phelps models	S-P model (Streeter and Phelps, 1925); Thomas BOD-DO model (Thomas, 1948); O'Connor BOD-DO model (O'Connor, 1967); Dobbins-Camp BOD-DO model (Camp, 1963; Dobbins, 1964)	Streeter and Phelps established the first S-P model in 1925. S-P models focus on oxygen balance and one-order decay of BOD and they are one-dimensional steady-state models.
QUAL models	QUAL I (Cao and Zhang, 2006) QUAL II (Grenney et al., 1978) QUAL2E (Brown and Barnwell, 1987) QUAL2E UNCAS (Brown and Barnwell, 1987) QUAL 2K (Esterby, 1996; Grizzetti, 2003)	The USEPA developed QUAL I in 1970. QUAL models are suitable for dendritic river and non-point source pollution, including one-dimensional steady-state or dynamic models.
WASP models	WASP1-7 models (DHI, 1993; Ambrose, 1988)	The USEPA developed WASP model in 1983. WASP models are suitable for water quality simulation in rivers, lakes, estuaries, coastal wetlands, and reservoirs, including one-, two-, or three-dimensional models.
QUASAR model	QUASAR model (Cao and Zhang, 2006; Artioli, 2005; Whitehead, 1997)	Whitehead established this model in 1997. QUASAR model is suitable for dissolved oxygen simulation in larger rivers, and it is a one-dimensional dynamic model including PC_QUA SAR, HERMES, and QUESTOR modes.
MIKE models	MIKE11 (DHI, 1993) MIKE 21 (DHI, 1996) MIKE 31 (DHI, 1996)	Denmark Hydrology Institute developed these MIKE models, which are suitable for water quality simulation in rivers, estuaries, and tidal wetlands, including one-, two-, or three-dimensional models.
BASINS models	BASINS 1 (Cao and Zhang, 2006; EPA, 2010) BASINS 2 (Cao and Zhang, 2006; EPA, 2010) BASINS 3 (Cao and Zhang, 2006; EPA, 2010) BASINS 4 (EPA, 2010)	The USEPA developed these models in 1996. BASINS models are multipurpose environmental analysis systems, and they integrate point and nonpoint source pollution. BASINS models are suitable for water quality analysis at watershed scale.
EFDC model	EFDC model (EPA, 1997; Wang, 2011)	Virginia Institute of Marine Science developed this model. The USEPA has listed the EFDC model as a tool for water quality management in 1997. EFDC model is suitable for water quality simulation in rivers, lakes, reservoirs, estuaries, and wetlands, including one-, two-, or three-dimensional models.

3. Types of water quality modeling

Water quality models are divided into optimization and simulation models (Fig. 2).

3.1 The optimization models

The optimization model is a mathematical method and a powerful tool, used in various fields to find the best solutions to problems from a set of possible choices, considering certain limitations and objectives and divided into linear, non-linear, and dynamic programming model **(Bowen & Young 1985; Kirchner *et al.*, 1993; Lee & Howitt, 1996; Zoppou, 2001)**.

3.2 The simulation models

Simulation models were used to design general changes in water quality due to pollution and divided into a physical and mathematical model. A physical model is designed to get results that is related to the real system, while a mathematical model is a set of equations that can be solved numerically **(Ji, 2008)**. Mathematical models are divided into statistical/empirical or mechanistic models, depending on the process; but depending on the type of data such as deterministic or stochastic, as well as the level of presentation as aggregated or distributed. The types of solutions are numerical or analytical.

Furthermore, models can be classified into (1D) one-dimensional models, (2D) two-dimensional models, and (3D) three-dimensional models. The first is the simplest and most widely used in river water quality analysis, which determines only water quality indicators along the longitudinal profile of the stream and based on measuring the inflow and outflow load concentrations of water parameters but cannot take into account the variation of concentrations over time. Therefore, these models cannot give monthly, weekly, hourly and daily information about specific water parameters and do not describe the complex physical, chemical and biological interactions that are an important factor in the aquatic environment. The advantage of these models is that they can be quickly used in other aquatic environments using a small available database and without validation. **(Balcerzak, 2000)**. 2D models, which designated to analyze water quality at various depths and determine changes in the longitudinal profile of a stream, require more data and extensive experience of the user than one-dimensional models. These models are used in coastal areas, bays, rivers, and lakes, which require precise calibration and sensitivity and can provide annual, monthly, weekly, hourly and daily information on specific water quality parameters. 3D models require extensive experience from the user and huge amounts of data and can be used for predicting the changes such as coastal water, sea, bays, lakes, deep rivers, and dams.

Fig. 2. Classifications of water quality model **(Sharma & Kansal, 2013)**

4. Modelling fundamentals and basic equations

The modelling fundamentals and basic equations for flow- water quality model are:

- Thermodynamic first law (energy states conservation)
- Models of Mass balance (mass states conservation)
- First law of motion for Newton (conservation of momentum states)

5. Used techniques for solving basic equations

The techniques used to solve the differential equations are:

- The analytical solution, which is reached after simplifying the mathematical equations.

  The simplifications which depend on numerical techniques used to solve the equations.

- The numerical solution: depends on the kind of system. Differential equations are converted to algebraic equations using difference estimations - Runge-Kutta method and others.

6. Data and parameters for water quality modeling

Modeling requires data and information to predict the current and future water quality of environment **(Grimsrud *et al.*, 1976)**. The required input data can be obtained from the literature, directly determined in the field, organizations, or measured through calibration method **(Liu, 2018)**. Data should be available and accurate to be used for the management of water quality **(Loucks & Van Beek, 2017)**. Input data that may be relevant to water quality modeling include bathymetric, flow data, initial concentrations, baseline and boundary conditions, pollution source, the geometry of the waterbodies, flow characteristics, kinetic parameters, time, calibration **(Kayode & Muthukrishna, 2018)**. Moreover, the input data depends on ecosystems (river, bays, lake, coastal area etc.), the expected objectives, available data and models applied for simulation. The water quality of ecosystem can be characterized by different physical, chemical, and biological indicators like turbidity, temperature, dissolved minerals, PH, Mg, Na, K, Ca, bicarbonates, salinity, suspended solids, COD, nutrients, chloride, DO, BOD, heavy metals, bacteria/ coliforms, algae concentration, suspended sediment, sulfates, and others **(Liu, 2018)**. The outcomes of modeling will be compared with the measured data. If there is the best match between predicted parameters and measured ones, the values of model parameter may be selected for advanced modeling.

7. Water quality models creation

Modeling framework of water quality in marine coastal water, lake, river, stream, or reservoir involves two main steps:

- Water flow simulation is performed to generate clear picture of movement of water while validating the model. This includes hydrological simulation of water, stream flow surface runoff, average depths, average velocities, wind speed and wind directions, etc.
- Water quality simulation of the ecosystem with validation method involves simulating pollutants, taking into account the mechanism of transformations and reactions, self-purification capability, mass exchange between the atmosphere and water, mass exchange between water and benthos are also considered.

8. Model selection and overview of modeling process

Selection of water quality models depends on various criteria like availability of data, complexity of model, simulation abilities, type of waterbody, ease of access to the software source code, good certification of the model, applicability of the model, familiarity, support, and cost that are also used for selection appropriate models **(Kayode & Muthukrishna, 2018)**. A lot of high-quality water models are not updated to include the modern technology and are not widely used. It is important to evaluate the quality of water to determine the most suitable models. Around the world, various models are widely used and have limitations and advantages. In general, overview of modeling process are shown in Fig. (3).

Fig. 3. Overview of modeling process

The process of modelling should always begin with a planning phase where the model and information availabile should answer the questions (Fig. 4). Assumptions are made if the data are not sufficient into the model. Calibration process occurs and is repeated.

Model outputs typically answer questions about data gaps that allow researchers to focus their interest on specific data, as well as testing possible future scenarios by following calibration. Model results should be carefully analyzed and accurately reported.

Fig. 4. Steps of modeling process **(IWRMD, 2010)**

3. OVERVIEW OF THE AQUASEA PROGRAM

AQUASEA is a software designated in 1982 to solve two-dimensional water flow-transport equations utilizing the method of Galerkin finite element. Since 1992, this software has been continuously updated and applied worldwide to various challenging modeling problems. Latest version of AQUASEA runs in Windows 95/98/2000/NT and has been compiled and configured to give maximum efficiency in model set up. AQUASEA windows environment provides a multi-platform capability and interface compatible with an industrial standard for future developments **(VCE, 1998)**. There are two types of models in AQUASEA; first: hydrodynamic flow model that predicts water flows and water levels as response as forcing function in estuaries, bays, lakes, coastal ecosystems. The flow and water levels are calculated from bathymetry information, coefficients, bed resistance, boundary conditions, wind speed and direction. The equations controlling water flow model are called equation of continuity and the momentum equations. Second model is the Transport-Dispersion Model that predicts the dispersion of a substance in the ecosystem. Substance may be non-conservative or conservative, organic or inorganic salt, dissolved oxygen, heat suspended sediment, nitrogen, phosphorus, TDS, TSS, and others. The equation of transport given by **Kolar *et al.* (1994)** was used as follows:

$$\frac{\partial}{\partial x}(HD_x\frac{\partial c}{\partial x}) + \frac{\partial}{\partial y}(HD_y\frac{\partial c}{\partial y}) - Hu\frac{\partial c}{\partial x} = H\frac{\partial c}{\partial t} + S - Q(c_o - c)$$

$$\frac{\partial}{\partial x}(HD_x\frac{\partial c}{\partial x}) + \frac{\partial}{\partial y}(HD_y\frac{\partial c}{\partial y}) - \frac{\partial}{\partial x}(Hcu) = \frac{\partial}{\partial t}(Hc) + S - Qc_o$$

c is concentration, excess sediment suspended or temperature.
u is velocity within each element taken from the solution of the flow problem, m/s
D_x is longitudinal dispersion coefficient, m^2/s
D_y is transversal dispersion coefficient, m^2/s
H is total water depth, m, S is the mass flux term in kg/m^3
Q is injected water, m^3/s
c_o is concentration, excess sediment concentration/ temperature of the injected water.

1 AQUASEA features

- Mesh is automatically generated.
- Condensation of local and global mesh and creating an independent nested model from the main model domain using the sub-mesh facility
- Variable depth, wind speed, wind direction, bottom friction mixing depth, and dispersion coefficients.
- All important information like boundary conditions, sources are transformed to the nested model automatically.
- The model transport of contaminant is fully integrated with the model flow using the same input and output data.
- Time varying tidal boundary conditions and wind, also sources varying time are accepted.

- At any time, a model can be changed. Boundaries of the model can be contracted or expanded, by removing or adding the nodes also sub-models can be generated easily within the model.
- Output of all results, flow arrows, contours, and time series can be represented graphically.
- Without further knowledge of output and input data, AQUASEA can be used.
- Time step is automatically refined during calculation.
- Result can be directly transferred to Excel, Grapher and Surfer (CSV-format).

2. Examples and applications of AQUASEA

- Circulation in lakes
- Water quality model such as temperature, salinity, DO, COD, BOD, nutrients, Turb, TH, TN, EC, As, TP, FC, Ca, Mg, Cl^-, SO_4^{--}
- Tidal flow in coastal areas and estuaries
- Transport of sediment, TDS, TSS
- Heat transport from nuclear power plants
- Tidal inlets flow
- Wastewater outlet's location (decay of bacteria)
- Flow through bridges

3. Model setup using AQUASEA program

The steps of hydrodynamic-water quality model developing are shown in Fig. (5). The model consists of input, simulation, output, validation, and application of different scenarios. Input data involve geometry, bathymetry of ecosystem, (inlets and outlets) source point of discharge, physical, chemical, and biological water quality parameters, open boundary etc.

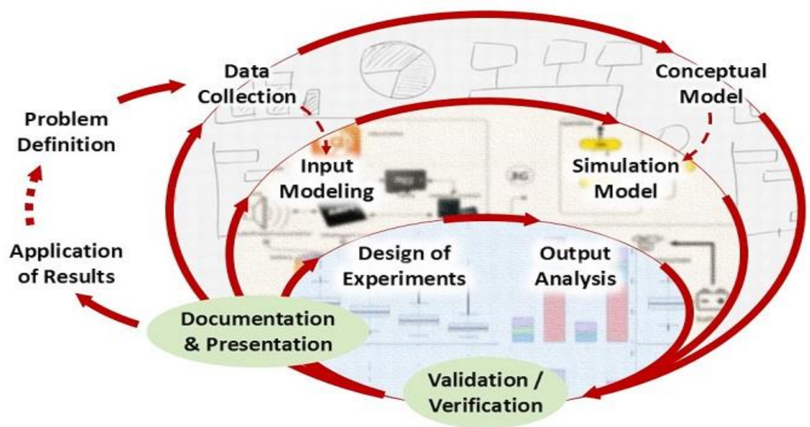

Fig. 5. General modeling and simulation

Next steps
represent model development using AQUASEA software.

3.1. Grid development

Aquatic environment bathymetry as DXF files (UTM) was generated by GEBCO Digital Atlas or Surfer program (Fig. 6). The ecosystem is classified into small regions as finite elements containing different nodes (Fig. 7b). The mesh was designed by inserting nodes manually on different triangular structure. The mesh consists of different triangles (Fig. 7c). Triangles in the mesh are elements that calculations have carried out. Boundary and closed internal boundaries are generated by inserting nodes. The inner parts of the area in the mesh should be denser than open external boundary with nodes. The external boundaries are defined as ‘no slip’u = v = 0 for solid surfaces (Fig. 7a). Nodes at the boundary can be set as sinewave/fixed values, indicating flow discharge and a source/sink at nodes in boundary area indicates flow boundary conditions **(Kolar, 1994)**.

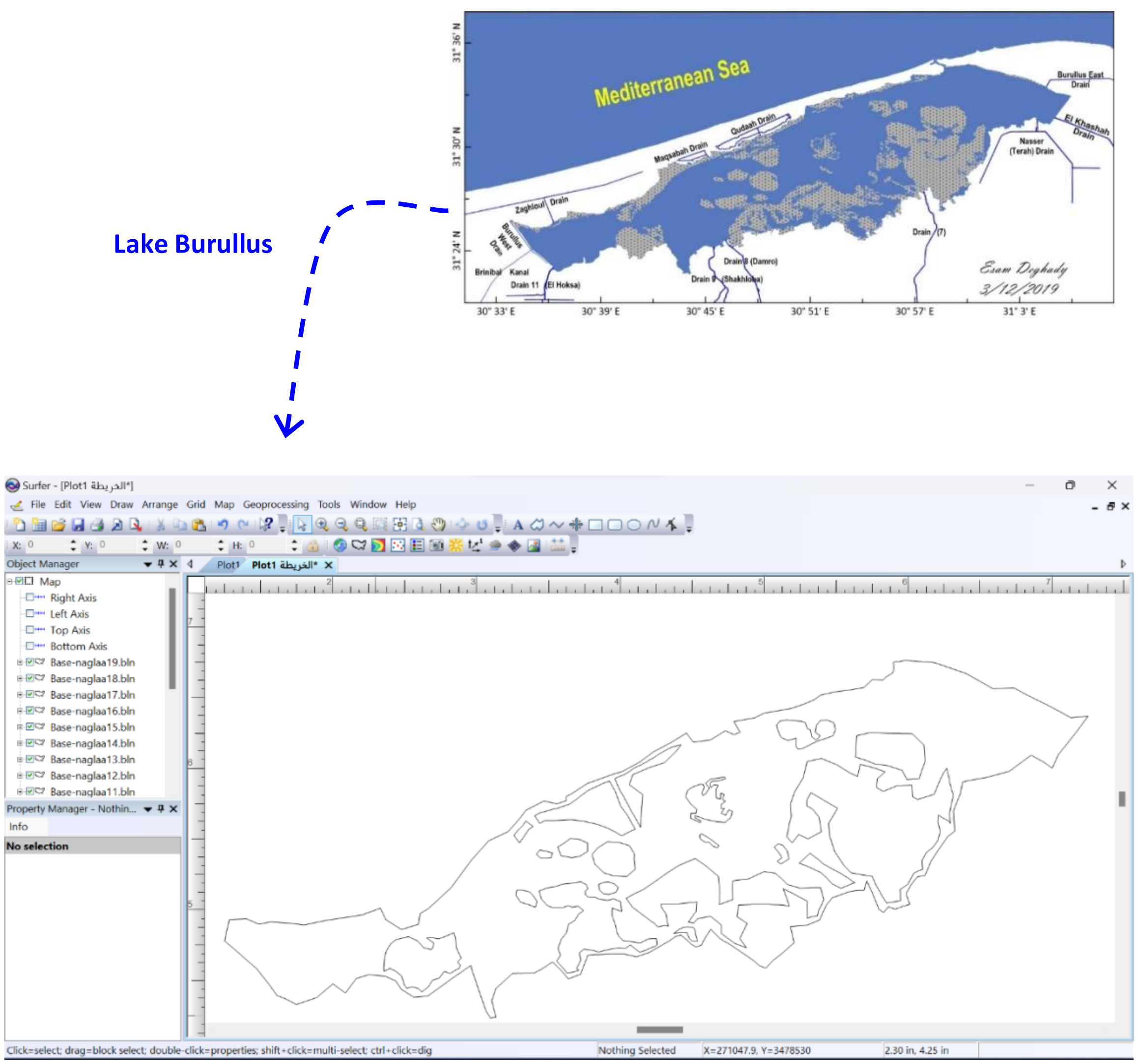

Fig. 6. Designation of bathymetry of water body (for example Lake Burullus) using contouring surfer 12 program

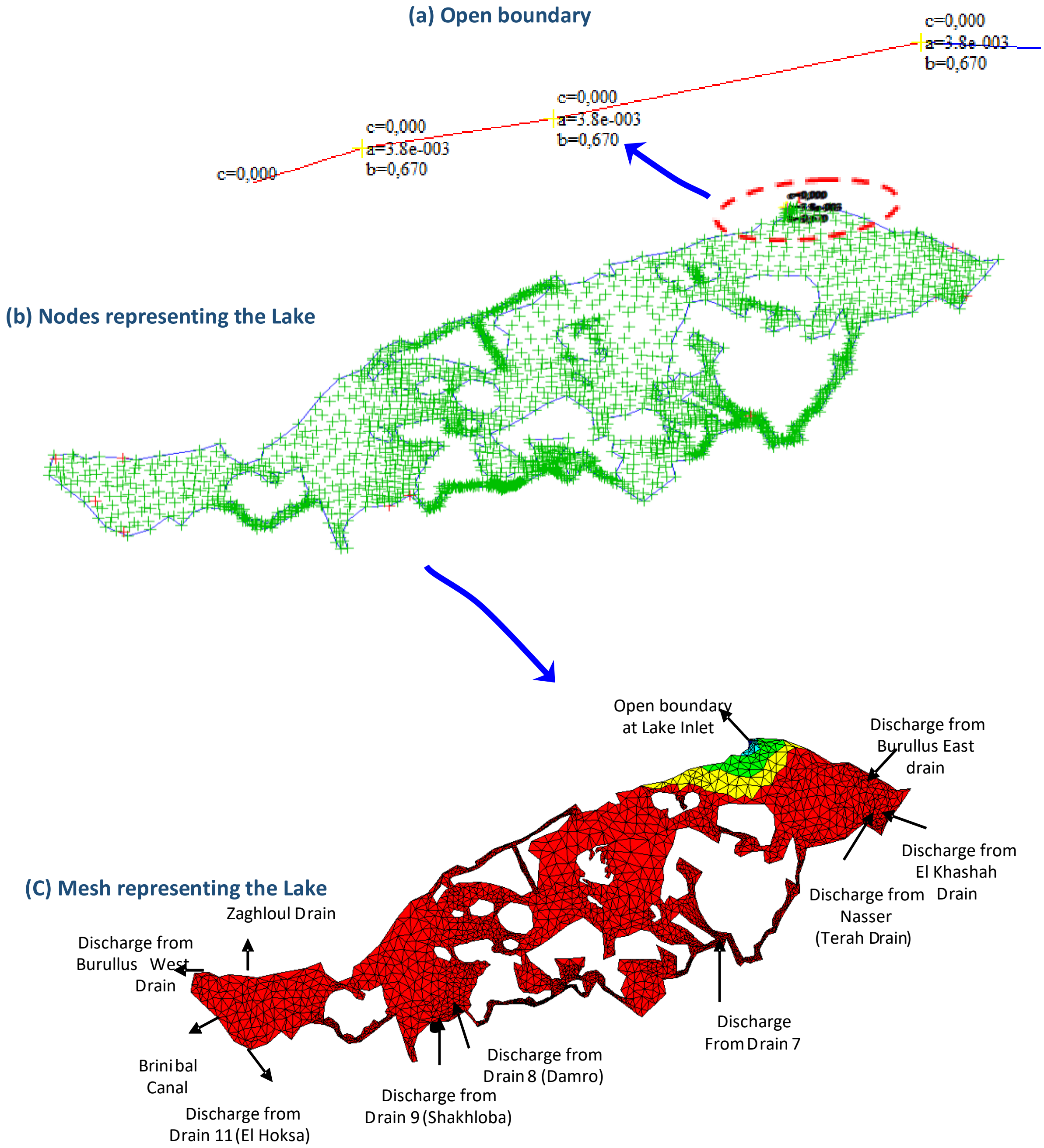

Fig. 7. Water environment grid with locations of discharges (a: open boundary, b: nodes, c: mesh **(El-Naggar & Rifaat, 2022)**

3.2 Defining parameters and substances

Model setups require various data and information to determine input or boundary conditions and are required for validation. The measurements include:

- Flow discharges (m^3/s) that specify the water outflow and inflow in the aquatic environment.
- Flow direction, cross section area (m^2), water depth; wind speed and direction, Chezy coefficient, period of sinusoidal forcing
- Basic physical parameters: such as temperature and salinity
- Chemical Parameters: such as DO, pH, nutrients, etc.

The time step must be selected, and Surfer Golden Software was used to represent AQUASEA model output.

3.3 Model validation

Various monitoring data are necessary to set up and validate the model to simulate hydrodynamic-water quality modeling in accurate. By trial and error, all constants must be calibrated according to these data. Monitoring data were plotted against model data output for comparison during the validation process.

3.4 Application of scenarios to control pollution

Testing different scenarios to control pollutions and asses different engineering solutions in aquatic environment is the final step of the model.

SURVEY OF WATER QUALITY MODEL USING AQUASEA PROGRAM

From the literature survey, different models have been implemented using AQUASEA software in various area of the world and summarized, as shown in Table (5). Although the latest version of AQUASEA runs in Windows 95/98/2000/NT, processor 166 MHz, hard disk 250 MB and RAM 32 MB, AQUASEA program has been applied worldwide in the most difficult models and was a powerful and easy to use finite element method to solve flow tidal flow problems in estuaries and coastal areas, lakes circulation and problems related to dispersion and transport of mass, heat, suspended sediments, salinity, temperature, DO, COD, etc.

In the AQUASEA models, data from flow model are fed into transport model and are run dependently of one another. This is especially the common of models for water environments. Although AQUASEA includes hydrodynamic flow and transport-dispersion models which predicts the spreading and transport of a material in ecosystem under the effect of water flow and transport processes, previous studies indicated that water quality models by AQUASEA software is little in comparison with other programs **(Lee-Lee & Hock-Lye, 2003; Kjaran *et al.*, 2004; Al-Rabai'ah, 2008, 2010; Touchinski, 2010; Irtem *et al.*, 2011; Rifaat & El-Naggar, 2013; El-Naggar *et al.*,**

2016; El-Naggar & Rifaat, 2017; El-Naggar & Rifaat, 2022), as shown in survey in Table (2).

Table 2. Some survey of water quality model using AQUASEA program

Model	Model Description
El-Naggar and Rifaat (2022)	This study investigated the hydrodynamic and transport simulation model in Burullus Lake using the AQUASEA program, considering different boundary conditions. The model showed the flow circulation therein and that the velocity is maximum at the drain's outfall and inlet locations. Self-purification capacity of the Lake occurred after about 27 days and Al-Khashah Drain sometimes pours water with salinity 30 ‰ and is responsible for increasing the salinity in the Lake to about 11 ‰. The verification and calibration of the model are based on salinity and dissolved oxygen measurements and results agreed with the actual observations but was needed more measurements to verify the model.
El-Naggar and Rifaat (2017)	Applicable a hydrodynamic and water quality model for Lake Mariout, Egypt, to show the status of the lake which is subject to pollution from the agricultural drains and the point sources discharging directly to it. This was achieved through simulating the flow circulation inside the main basin of the lake and the transport and advection of the pollutants and then identifies and develops the most critical surface drainage water quality indicators to simulate and predict the temporal and spatial variation of pollution. The model proved to be an effective tool for the water dynamics, water quality simulation, and evaluating different scenarios of such shallow lake.
El-Naggar et al. (2016)	Developed a model on El-Manzala Lake, Egypt using the AQUASEA program to show the effects of hydrodynamics on pollutant dispersion from drains and examine a potential mitigation alternative by decreasing the pollutant loads that enter the Lake. The simulation results revealed that the main driving forces that were responsible for the circulation patterns inside the Lake was wind and drains' discharges. The direction of flow is from the Lake to the sea and vice versa and pollutants coming from Bahr El-Baqar drain affect the whole area of the Lake.
Rifaat and El-Naggar (2013)	This study predicted the sediment transport model in El-Max Bay, Alexandria, Egypt and classify the flow type. The equations of continuity and momentum were used to calculate the model parameters and the output was displayed using sophisticated computer programs. The computed sediment transport model of El- Umoum Drain flow into El-Max Bay showed that the flow type changes from wall jet following a southwestern path to shoreline attached jet moving northwestward then turns to be a free jet flowing northward. The model showed that complete dispersion of the sediment flow was achieved in four hours and that its impact on El Dekhila Harbour was pronounced. As time passes, the accumulation of sediments near the harbour's entrance might cause a siltation problem unless regular dredging is carried out.
Irtem et al. (2011)	Studied the hydrodynamic characteristics of the water body movements in Ayvalık Bay, Turkey and the effect of the landfill road (between Ayvalık and Dolap Island) on these movements. Model verification and various scenarios tests were carried out. The results of this study were an important input in the contamination prevention efforts for the sustainable use of the Ayvalık Bay.
Touchinski, 2010	Studied surface water quality model in the pit lake, Montana, U.S.A, by modelling the vertical TDS profile in the lake over time based on groundwater inflow and molecular diffusion. The model indicated that no mixing would occur between fresh and saline water due to density stability under average and extreme wind.
Al-Rabai'ah (2010)	Simulated the transportation of suspended solids in Dammam, Saudi Arabia using AQUASEA, by studying the effect of dredging and in particular the suspended sediments concentrations in the region that coastal areas were developed in which the mechanisms of advection, diffusion, flocculation settling of particles, scouring, and silting of the seabed and the carrying capacity of wave and tide were involved. The model was run for 10 executive days to simulate sediment transportation and was verified with normal field data, keeping flushing the fresh sea water in and out with good water quality parameters. The results showed that the modeled contents of suspended solids matched well with the existing readings. Modeled distributions of suspended reflected basically the overall behaviors of sediment transportation.

Model	Model Description
Al-Rabai'ah (2008)	Applied numerical modelling of water flow in a dead-end tidal inlet at Dammam coastal areas, Saudi Arabia, by simulating flow water in the channel that water went in and out inside the inlet freely, obtaining renewed water suitable for biota in the area and found that increasing channel length might reduce water quality in the channel and, hence, the decorative purposes cannot be reached.
Kjaran et al. (2004)	Lake circulation and sediment transport in Lake Myvatn have been calculated using AQUASEA. The goal of the modelling was to calculate changes in sediment transport within the lake due to changes in lake bathymetry caused by diatomite mining. The model uses the Galerkin finite element method and consists of a hydrodynamic flow model and a transport-dispersion model. The flow model is based on the shallow water equations and the wave equation. The transport model is based on the conservation of mass for suspended sediment. The model was calibrated against measurements performed during the summer of 1992. These included measurements of water elevation, current velocity, wave height, and concentration of suspended sediment. After calibration, the model was run for different mining scenarios to determine their impact on the sediment transport in the lake.
Lee-Lee and Hock-Lye (2003)	Coastal reclamation and artificial island: hydrodynamic and water quality modelling is applied, a two-dimensional depth-averaged numerical model AQUASEA, which incorporates a hydrodynamic flow model, and a transport-dispersion model is used. Changes to tidal currents and water quality subject to tidal conditions and boundary parameters due to the land reclamation will be assessed.

Water quality models are constantly in development. The primary interest is giving a correct reality picture in practical applications by improvement of the models and making their applications more and more efficient and helping experts in managerial decisions. Therefore, numerous efforts have been done for developing the equations related to pollutant transport to give accurate easy methods to handle by computer facilities. It is expected that significant progress in the use of the finite element method will help better represent the difficulty of the geometry of water environment and the development of 2D and 3D models which 1D model cannot give a sufficient answer to several problems of large water environment that is affected by pollutant concentration and surface plumes. Although AQUASEA has not been updated since 2000, it is expected that results of flow and water quality modeling using AQUASEA program support different physical and biological assessments like flood control, sediment transport, terrestrial and aquatic species, and support economic analyses on the expected costs of project for new plan alternatives. However, some water quality models are siloed and not adapted with computer technologies like interfaces and programming languages etc. Therefore, it is expected that these programs will become promising and reliable in the future if they are developed. Therefore, there are effective water quality programs such as Delft3D which is adapting with computer technologies and can be used to study the water quality dynamics of the marine environment.

CONCLUSION

Water quality modeling is of scientific value and great environmental interest for scholars, beachgoers, designers, stakeholders, and coastal managers. It is the best tool for keeping the quality of water and simulating the dispersion of contaminants that are one of the essential matters of the current problems for environment. The advancements in computer science have resulted in advanced models for predicting and simulating water quality and the fate/transport of environmental contaminants. This review features evaluating water quality models using AQUASEA program. Different models have been implemented using AQUASEA program in different regions of the world. AQUASEA model is an effective tool for the simulation of hydrodynamic-water quality to find solutions for pollution problems in marine environment. Although AQUASEA program is used in the most difficult modeling, this program is not widely used as water quality model in comparison with other programs. We recommend, in order of priority:

1. AQUASEA program should be periodically upgraded. The latest version of AQUASEA runs in Windows 95/98/2000/NT, with a processor 166 MHz, hard disk 250 MB, RAM 32 MB.
2. Automatic calibration of numerical model in most water quality programs should be recommended because they do not have this feature, and the calibration method is often performed manually.
3. AQUASEA software should be widely used as water quality model, as previous studies indicate that water quality models by AQUASEA software is little in comparison with other programs.
4. There are other effective water quality programs that are adapting with computer technologies and these should be used instead of AQUASEA program. These programs are simpler and more easily understood, applied, and their results are expected to influence the future such as Delft3D that is the same as AQUASEA, but is more developed and modified.

REFERENCES

Al-Rabai'ah, A.H. (2008). Numerical Modelling of Water Flow in a Dead-End Tidal Inlet at Dammam Coastal Areas, Saudi Arabia, Journal of Applied Science and Environmental Sanitation, Vol. 3, No. 3, pp. 127-136.

Balcerzak, W. (2000). Application of selected mathematical models to evaluate changes in water quality. In: International Conference on Water Supply, Water Quality and Protection. Kraków; 14-15 December.

Canter, W.L. (1985). Environmental impact of water resources projects [Internet]. Boca Raton (FL): CRC Press; 1985 **[cited 2020 Oct 8].** 368 p.

Chapman,V.D. (1996). Water quality assessments: A guide to the use of biota, sediments, and water in environmental monitoring-second edition. CRC Press. Retrieved September 02, 2019.

Chapra, C.S. (2008). Surface water-quality modeling. Waveland press.

Conley, D.J.; Paerl, H.W.; Howarth, R.W.; Boesch, D.F.; Seitzinger, S.P.; Havens, K.E.; Lancelot, C. and Likens, G.E. (2009). Controlling eutrophication: Nitrogen and phosphorus. Science, 323(5917),1014–1015.

EIC (Environmental International Consultant). (2009). Environmental impact assessment for Jabel Ali power and desalination station. Retrieved August 14, 2019.

Ejigu, M.T. (2021). Overview of water quality modeling. Cogent Engineering, 8(1).

El-Naggar, N.A. and Rifaat, A.E. (2017). Hydrodynamic and Water Quality Modeling of Lake Mariout, (Nile Delta, Northern Egypt). In: Negm A., Bek M., Abdel-Fattah S. (eds) Egyptian Coastal Lakes and Wetlands: Part I. The Handbook of Environmental Chemistry, vol 71. Springer, Cham., 241-263.

El-Naggar, N.A. and Rifaat, A.E. (2022). AQUASEA hydrodynamic and transport model: Salinity and dissolved oxygen simulation in El-Burullus Lake (Nile Delta, Egypt) considering different boundary conditions, Egyptian Journal of Aquatic Research, *48* (2), 107-113.

El-Naggar, N.A.; Rifaat, A.E. and Khalil, M.K. (2016). Numerical modelling on water flow in Manzala Lake, Nile Delta, Northern Egypt, International Journal of Contemporary Applied Sciences, *3*(4), 28-44.

Grimsrud, P.G.; Finnemore, E.J. and Owen, H.J. (1976). Evaluation of water quality models: A management guide for planners, office of air, land, and water use. USEPA, Research, and Development. Retrieved August 6, 2019.

Hussein, H.; Atabay, S.; Mortula, M.M. and Ali, T. (2017). Investigation of water quality parameters for coastal lagoon. Pollution. Res, 37, 25-31.

Irtem, E.; Kabdasli, M.S.; Bagci, T. and Oguz, E. (2011). Numerical Modeling and Site Investigation on Water Body Movements in Ayvalık Bay, Turkey, Journal of Coastal Research, Special Issue 64, 1053 – 1057.

James, A. (1993). An Introduction to Water Quality Modelling, 2nd edition. John Wiley and Sons Ltd, New York.

Ji, Z.G. (2008). Hydrodynamics and water quality: modelling rivers, lakes, and estuaries. Wiley-Interscience, pp 704.

Kayode, O.O. and Muthukrishna, V.K. (2018). Assessment of some existing water quality models. Nature Environment and Pollution Technology, 17(3), 939–948.

Kirchner, J.W; Dillon P.J. and Lazerte B.D (1993). Separating hydrological and geochemical influences on runoff acidification in spatially heterogeneous catchments. Water Resource Research, 29(12):3903–3916.

Kjaran, S.P.; Hólm, S.L. and Myer, E.M. (2004). Lake circulation and sediment transport in Lake Myvatn. Aquatic Ecology 38, 145–162.

Kolar, L.R.; Westerink, J.J; Cantekin M.E. and Blain, C.A. (1994). Aspects of Nonlinear Simulations Using Shallow Water Models Based on the Wave Continuity Equation, Computers and Fluids, 23, No. 3, pp. 523-538.

Krysanova, V.; Bronstert A. and Mûller-Wohlfeil, D.I. (1999). Modelling River discharge for large drainage basins: from lumped to distributed approach, Hydrological Sciences Journal 44:2.

Lee-Lee, N. and Hock-Lye, K. (2003). Coastal reclamation and artificial island: hydrodynamic and water quality modelling, Ecological and Environmental Modelling (ECOMOD 2001): Proceedings of the National Workshop, Penerbit University Sains Malaysia, p. 218-225.

Lee, D.J. and Howitt, R.E. (1996). Modelling regional agricultural production and salinity control alternatives for water quality policy analysis. Am J Agric Econ 78(1):41–53.

Liu, L. (2018). Application of a hydrodynamic and water quality model for inland surface water systems. In Applications in water systems management and modeling (pp. 87–109).

Loucks, D.P.; Van Beek, E.; Loucks, D.P. and Van Beek, E. (2017). Water quality modeling and prediction. Water resource systems planning and management: An introduction to methods, models, and applications, 417-467.

Obropta, C.C.; Niazi, M. and Kardos, J. S. (2008). Application of an environmental decision support system to a water quality trading program affected by surface water diversions. Environmental management, 42, 946-956.

O'Connor, D.J. (1967). "The temporal and spatial distribution of dissolved oxygen in streams," Water Resource Research, vol. 3, no. 1, pp. 65–79.

Ott, W.R. (1978). Water quality indices: a survey of indices used in the United States [Internet]. Washington, DC: United States Environmental Protection Agency; 1978 Jan [cited 2020 Oct 8]. Report No.: EPA/600/4-78 005. 138 p. Available from:

Rifaat, E.A. and El-Naggar, A.N. (2013). Computation and Classification of the Sediment Transport Model in El-Max Bay, Alexandria, Egypt, JKAU: Mar. Sci., Vol. 24, No.2.

Stolarska, A.Z. and Skrzypski, J. (2012). Review of mathematical models of water quality. Ecol Chem Eng S, 19 (2), 197-211.

Tsakiris, G. and Alexakis, D. (2012). Water quality models: An overview. European Water, 37, 33–46.

UNESCO (2005). Water resources systems planning and management. Retrieved August 5, 2019.

VCE (VATNASKIL CONSULTING ENGINEERS), 1998. AQUASEA User Manual.

Wang, Q.G.; Zhao, X.H; Yang, M.S.; Zhao, Y.; Liu, K. and Ma, Q. (2011). Water quality model establishment for middle and lower reaches of Hanshui river, China," Chinese Geographical Sciences, vol. 21, no. 6, pp. 647–655.

Xu, Z.X. and Lu, S.Q., (2003). Research on hydrodynamic and water quality model for tidal river networks," Journal of Hydrodynamics, vol. 15, no. 2, pp. 64–70.

Yang, X. E.; Wu, X.; Hao, H. L. and He, Z. L. (2008). Mechanisms and assessment of water eutrophication. Journal of Zhejiang University Science B, 9 (3): 197–209.

Zoppou, C. (2001). Review of urban storm water models. Environmental Model Software 16(3):195–23.